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Does certification change the trajectory of tree cover in working forests in the tropics?

An application of the synthetic control method of impact evaluation

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Does certification change the trajectory of tree cover in working forests in the tropics? An application of the synthetic control method of impact evaluation

Pushpendra Rana[1] and Erin Sills[2]

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Abstract:
As one of the oldest systems for certifying sustainable production practices, the Forest Stewardship Council (FSC) can offer important lessons about this approach to conservation. In particular, the nearly 25 year history of FSC makes it possible to evaluate how the impacts of certification evolve over time. We estimate causal effects on deforestation from the year of certification to 2012 in ten certified tropical forest management units (FMUs) in Brazil, Gabon, and Indonesia. In the process, we demonstrate the use of open-access pan-tropical datasets and the synthetic control method (SCM) to evaluate impacts on land use and land cover change. Across the ten FMUs, our point estimates suggest that certification reduces deforestation in most years, but placebo tests show that the estimated effects are generally not significantly different from zero. In the three FMUs for which SCM is most plausible (because the synthetic controls are good matches for the certified FMUs in the pre-certification period), we find that certification reduces deforestation in the year immediately after certification and in the most recent year in our dataset (2012), with statistically significant effects on the FMUs in Brazil and Indonesia. However, looking across all years and FMUs, results are more variable. One possible reason is that our measure of "deforestation" captures a range of disturbances that result in tree cover loss. In Brazil, we test a spatial filtering method for separating small patches that may be related to logging from large patches that more likely represent conversion to agriculture. We find that FSC certification of a FMU reduces small-scale loss of tree cover in the FMU in all years since certification, which is consistent with adoption of the reduced impact logging practices required by FSC.

Keywords: Forest certification, impact evaluation, tropical deforestation, synthetic control method
JEL Codes: Q23, Q56

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Executive summary

In the quarter century since forest certification was launched with the creation of the Forest Stewardship Council (FSC), certification has been widely adopted in temperate and boreal forests, as well as tropical plantations, but there has been relatively little uptake in natural tropical forests (FSC 2015, FSC 2010; Gullison, 2003). While there have been various efforts to encourage certification of natural forests in the tropics (Ros-Tonen, 2004; Bowling, 2003; Guillery, 2007, Cashore et al. 2006), the barriers remain high and therefore participation remains low particularly by communities (Been, 2011; Segura, 2004) and small-scale private owners (Purbawiyatna and Simula, 2008). This raises the question of whether more effective efforts to increase participation in FSC – by firms, private landowners, and communities - would lead to the desired outcomes of reduced deforestation and forest degradation. To help address this question, we evaluate the causal impact of certification on tropical deforestation, and specifically, the impact of certifying forest management units (FMUs) on tree cover loss in those FMUs, allowing for heterogeneous impacts across years and FMUs.

Our focus on deforestation is motivated in part by the increased availability of annual data on forest cover across the tropics. Recent developments in satellite-based spatial data collection offer new opportunities for understanding the spatial patterns and impacts of policies and programs such as certification (Blackman 2012). Specifically, the release of images from advanced satellites with good spatial resolution (≤ 30 x 30 m) over long time periods, in combination with cutting-edge time-series analysis of those images, has enabled the construction of global time series data on tree cover loss (Hansen et al. 2013). These data can be combined with other global-scale, uniform, consistent and open-access data sets to control for site selection and other confounders in evaluations of interventions such as forest certification. We review and illustrate the use of some of these data sources. While reduced forest degradation may be the more likely outcome of certification (Shapiro et al. 2016), it is not well measured in existing pan-tropical spatial datasets. Further, certification was originally proposed and promoted as a way to slow tropical deforestation (Merry and Carter 1997), which we proxy with tree cover loss.

Studies have shown that the forests selected for certification are systematically different from other forests in many dimensions. Forest management decisions – such as whether to seek certification - depend on contextual factors that operate at the regional to international levels, including legal frameworks, market realities, alternative opportunities and investments (Romero et al. 2015a; Romero et al. 2015b). Size and ownership of forest operations, market and product characteristics, export orientation, degree of vertical integration, pressure from NGOs, and support from government have all been found to influence company decisions about whether to seek forest certification (Auld et al. 2008). In particular, certification may be more appealing to companies that already have superior environmental performance (Thornber et al. 1999) or that are proactive about meeting regulatory requirements (Blackman et al. 2014, 2015). Because these factors can also directly affect deforestation, they potentially confound estimates of the impact of forest certification itself. Thus, a key analytical challenge is to separate the effect of certification from the effects of confounding factors that led to certification of a FMU in the first place.

In our study countries (Brazil, Gabon and Indonesia), the small number of certified FMUs, and even smaller number of companies involved, presents a significant methodological challenge. First, unobserved idiosyncratic characteristics of these few companies may be important confounders. Second, statistical inference with such a small N is problematic. Third, these companies and the FMUs that they manage are quite heterogeneous, suggesting that the impacts of certification may also vary across them. Finally, the FMUs were certified in different years, so the impacts of certification may differ as a function of other time-varying factors (e.g., timber markets and regulations). To address these issues, we employ the synthetic control method (SCM) (Sills et al. 2015; Abadie et al. 2010a). SCM allows us to exploit time series data on tree cover to compensate for the small number of certified FMUs and to estimate the effect of certification separate from self-selection and other confounders.

In order to estimate the impact of certification on deforestation, we must (1) measure deforestation with certification and (2) estimate how much deforestation would have occurred without certification (the counterfactual). The first step indicates whether certification is consistent with 'zero deforestation' commitments (Wolosin 2016; Mallet et al. 2016; Beckham et al. 2014; Smith et al. 2015; Rautner et al. 2015). We find annual deforestation below 0.25% (but not zero) in all certified FMUs, except in one zone in Brazil (*estuário*). The second step allows us to estimate the impact (or causal effect) of FSC as the difference between deforestation with and without FSC certification. FSC certification appears to reduce deforestation in most certified FMUs (based on the point estimates), but these estimated effects are rarely significantly different from zero (based on confidence intervals constructed with placebo tests). The effect of certification also varies across years, which could plausibly be due to either exogenous or endogenous factors, i.e. moderators or mechanisms (Ferraro and Hanauer 2015). In the three FMUs for which SCM is most plausible (because the synthetic controls are good matches for the certified FMUs in the pre-certification period), we find that certification reduces deforestation in the year immediately after certification and in the most recent year in our dataset (2012), with statistically significant effects on the FMUs in Brazil and Indonesia.

Comparing across countries, we most often estimate statistically significant effects in Brazil. However, the sign of the estimated effect varies across years and FMUs. We identify two possible explanations. First, the FMUs that were certified had both more tree cover loss and more tree cover gain during the full period of data availability (2000 - 2012), suggesting that they may be more actively managed, with logging followed by reforestation. Because we only have annual data on tree cover loss, our synthetic controls may not match patterns of tree cover gain in the certified FMUs. Second, we illustrate a spatial filtering method for separating small patches that may be related to logging from large patches that more likely represent conversion to agriculture. We find that in Brazil, FSC certification of a FMU does not have a consistent effect on large-scale loss of tree cover, which is likely due to deforestation by external agents. Certification does consistently reduces small-scale loss of tree cover in that FMU in all years after certification, which may reflect adoption of the reduced impact logging practices required by FSC.

Contents

1. Introduction

Tropical forests have attained new significance in the context of climate change. High rates of tropical deforestation threaten not only the ability of these forests to act as carbon sinks but also endanger their biodiversity and the livelihoods of millions of forest-dependent people around the world. Deforestation often reflects the higher income potential of alternative land uses, such as commodity crops and ranching (Börner and Wunder 2012; Butler et al. 2009; Pacheco 2012). One reason that the income potential of forests is lower than these alternatives is that the profitability of sustainable management and harvest of timber is undercut by low timber prices due to rampant illegal logging in the tropics (De Koning, 2008; Schepers, 2010). Forest certification aims to increase the value of responsibly managed forests, by encouraging the market to recognize verified sustainable management of forest management units (FMUs) including compliance with regulatory frameworks, adoption of reduced-impact logging, forest stock enhancement, and respect for the rights of both workers and local people (FSC, 1999; May, 2006; Cashore, 2002; Romero et al. 2013). The costs incurred in the certification process (for adoption of new practices and for audits) are supposed to be defrayed by consumers and translated into benefits for firms through price premiums or improved market access (and therefore lower marketing costs). The costs of certification could also be compensated by improved management effectiveness or reputational and other indirect benefits. Yet these private benefits have proved elusive, raising the question of whether civil society and overseas development assistance should continue to help pay the costs of certification in order to encourage certification of more FMUs.

The answer to this question depends in part on the effectiveness of certification at achieving its stated environmental and socio-economic goals. One of the original aspirations of the non-governmental organizations that founded the Forest Stewardship Council (FSC) was to reduce tropical deforestation (Auld et al. 2008; FSC, 1999; Merry and Carter 1997; Rametsteiner, 2003). While certification may contribute to this goal through multiple channels, e.g. by raising consumer awareness and influencing government regulatory frameworks (Brack and Bailey 2013), the advocates of certification clearly expected that certification of a FMU would help protect it from deforestation.

This raises two questions. First, do FSC certified native tropical forests remain forests, i.e. does certification guarantee “zero deforestation”? This calls for an "adequacy evaluation" in the terminology of epidemiology (Habicht et al. 1999). In adequacy evaluations, the aim is to compare performance with previously established adequacy criteria, or “zero deforestation” in our case. Second, does FSC actually reduce the probability of deforestation, i.e. are certified forests more likely to have been deforested if they had not been certified? To answer this question, we must control for confounding factors through a robust counterfactual-based analysis (Ferraro, 2009; Ferraro and Pattanayak, 2006; Rubin, 2011). In this working paper, we address these questions in three tropical landscapes, and in the process, illustrate the use of open-access pan-tropical datasets and the synthetic control method (SCM; Abadie et al 2010 a,b; Sills et al. 2015) to evaluate policy impacts on land use and land cover change.

To address both of our questions, we need a measure of forest cover in forest management units. The best choice for globally consistent time series data is the dataset released by Hansen, UMD, Google, USGS and NASA on “Global Forest Change 2000-2012” (Hansen et al. 2013). Because the dataset measures tree cover rather than forest cover, we also check for any evidence that native forests are being replaced with plantations, using data from Global Forest Watch for Brazil and Indonesia.

To estimate the causal effect of FSC certification on deforestation, we must make several more critical methodological decisions. These include: (1) choosing a unit of analysis, (2) selecting a method to quantify the counterfactual outcome (i.e., how deforestation would have evolved in that unit in the absence of certification), and (3) identifying confounders that affect both forest cover change and the adoption of certification in that unit. Decisions about certification are typically made at the level of the FMU: either an entire FMU is certified or it is not. Thus, FMUs are the logical unit of analysis. This means that we have a "small N" because there were only a few certified FMUs in each of our three landscapes prior to 2010, which we established as the cut-off in order to have sufficient data on tree cover post-certification. We therefore adopt the synthetic control method, which was developed for "small N" evaluations and which is made possible by the long time series on tree cover from Hansen et al. (2013). From a large set of potential confounders, the SCM selects and assigns weights to covariates such that a synthetic control constructed to match their values in the certified unit also has the same history of tree cover change as that unit (prior to certification). This is accomplished through a nested optimization process.

While SCM applied to time series remote sensing data has great potential for evaluating the causal effects of small-N interventions like certification, such data cannot be used to address all of the questions (and perhaps not even the most important questions) about forest certification, such as its impacts on forest quality and local communities. Answers to these questions require field work (Romero et al. 2017). The sampling design for data collection could potentially be informed by SCM and specifically by the weights placed on different FMUs in the synthetic control. However, in this study, we focus on the impact of forest certification on tree cover change, which has become an important proxy for deforestation (e.g. for monitoring zero deforestation commitments).

In the next section, we describe the forest sector in each of our study regions (Brazilian Amazon, Gabon, and Kalimantan, Indonesia), focusing on how FMUs are defined and managed and referencing accompanying studies that present typologies of FMUs and identify factors influencing adoption of certification in each region. In this section, we also define our sample: we evaluate the impact of certification on FMUs certified between 2004 and 2010 (ensuring sufficient observations on tree cover change both before and after certification in our panel data from 2001 to 2012) by comparing to FMUs that have never been certified, excluding FMUs that obtained certification after 2010, that obtained and then lost certification, or have unsuccessfully sought certification. Next, we describe the data used to represent the units of analysis (FMUs under a single legal authorization or single managing entity) and the outcome (tree cover change). This allows us to address the first question about whether FSC certified FMUs have remained forested (i.e. have they retained tree cover since they became certified).

In the following section, we describe data sources for the potential confounding factors that influence both the probability of certification and deforestation. Next, we explain the synthetic control method and its application to forest certification. This is followed by presentation and discussion of our findings regarding our second question: the impact of FSC certification on deforestation in FMUs. One potential concern with our analysis is the use of tree cover loss to represent deforestation. To address this issue, we (1) examine patterns of tree cover gain as well as loss in the ten FMUs that were certified as compared to other FMUs in the same regions, (2) check for plantation development in Brazil and Indonesia, and (3) illustrate the use of spatial filtering techniques to distinguish tree cover loss associated with logging from tree cover loss associated with conversion of forest to other land uses, or deforestation in Brazil.

2. Study area

We evaluate the impact of FSC certification in three regions: the Brazilian Amazon, Gabon and Kalimantan (Indonesian Borneo). Brazil and Indonesia have historically had high deforestation rates, contributing substantially to global carbon emissions. For example, Margono et al. (2014) report that over 6 million hectares of primary forests in Indonesia were lost from 2000 to 2012. In the Brazilian Amazon, deforestation rates declined more than 75% from their peak in 2004 to 2014, but Brazil still lost an estimated 9422 km^2 of forest per year in the Amazon during the decade from 2005 to 2014, and the annual deforestation rate increased by more than 50% from 2014 to 2016 (INPE 2016). The Congo Basin contains the largest area of tropical forest after the Brazilian Amazon (WRI, UNDP and WB, 1998). In that region, Gabon is one of the leading exporters of tropical hardwoods. In all three regions, strategies to combat deforestation include expansion of protected area systems, stricter enforcement of laws that regulate the use of forest land, 'zero deforestation' supply chain initiatives that reduce demand for agricultural commodities produced on recently deforested land, and increasing returns to standing forest through payments for ecosystem services and certification of sustainable forest management.

Brazilian Amazon

As of 2010, Brazil had an estimated total forest cover of 519 million hectares, out of which 354 million hectares were in the Amazon (FAO, 2010b; Government of Brazil, 2010). Most statistics on the Brazilian Amazon refer to a region called the "Legal Amazon," established by the Brazilian government in 1966 (as amended in 1977) for planning and administrative purposes. The Legal Amazon includes over 5 million km^2 in ten states, accounting for nearly 60% of Brazilian territory. In 2009, the Brazilian Legal Amazon produced 5.8 million m^3 of processed logs (ITTO, 2010), while Brazil as a whole produced 15.5 million m^3, much from plantations, out of which only 1.06 million m^3 were exported. Nationally, the forestry sector employed 512,505 people in the year 2010 (IBGE, Diretoria de Pesquisas, Cadastro Central de Empresas, 2010).

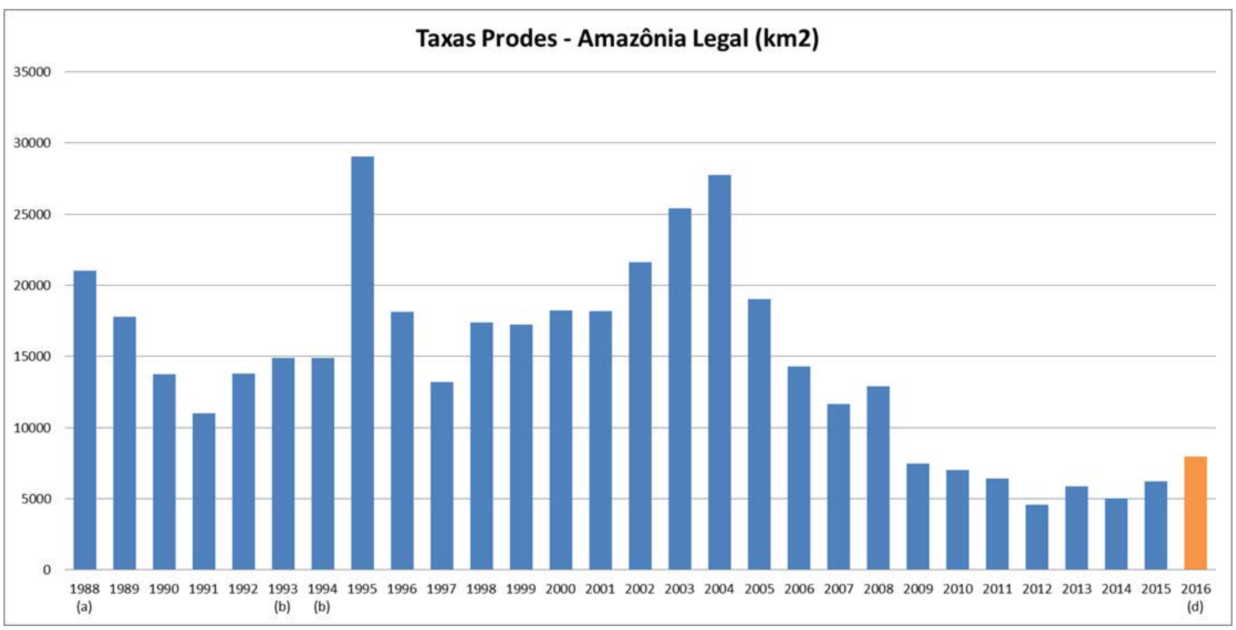


Figure 1: Annual deforestation of mature tropical Amazon forest, as reported by the Brazilian government (Source: INPE (http://www.obt.inpe.br/prodes/index.php))

The Brazilian Legal Amazon has experienced high rates of deforestation during the last 50 years, having lost 14% of its original forested area by 2012 (Souza et al. 2013; INPE 2014). As shown in figure 1 from INPE, deforestation rates fell from 2004 to 2012: annual deforestation averaged 1.56% between 2000 and 2004, falling to 1.28% between 2005 and 2009. However, since 2014, deforestation rates have been rising.

Forest certification has expanded rapidly in Brazil since 2000, mainly in response to consumer interest in sustainability (May, 2006). Brazil had 940,000 hectares under certification in 2000, increasing to 6,479,540 hectares in 2012 (Figure 2). For our analysis, we consider only natural tropical forest certified as of 2010. About 2.70 million hectares of natural tropical forests, 2.13 million hectares of planted tropical forests and 1.33 million hectares of non-tropical plantations were certified under FSC as of October 2010 (FSC, 2010).

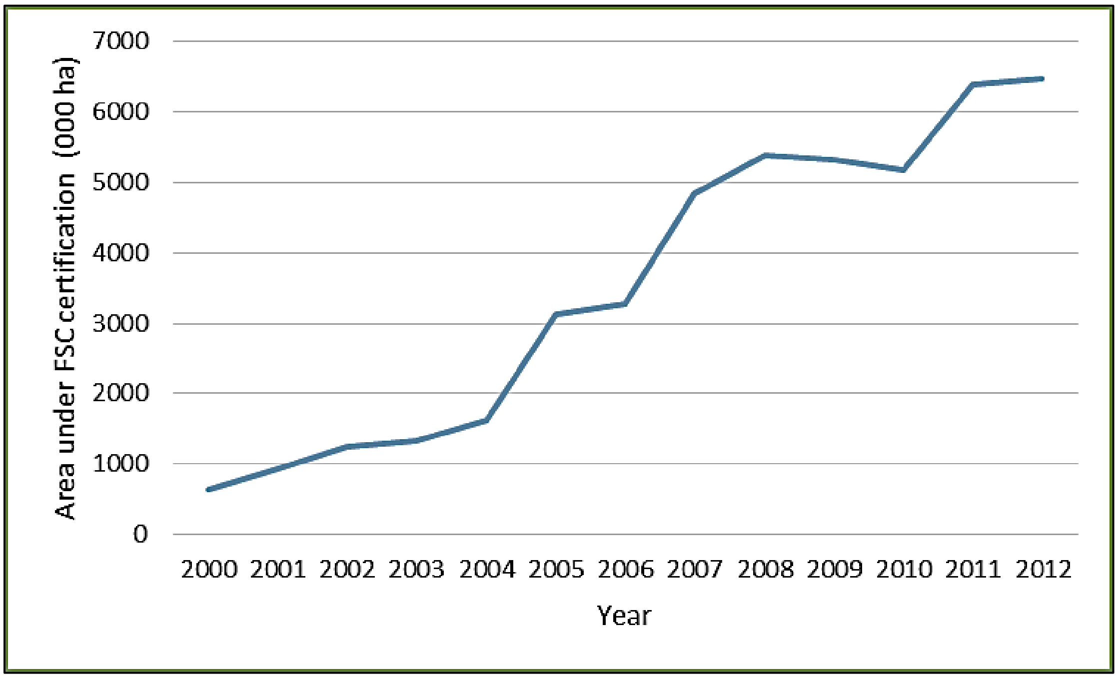


Figure 2: Forest area, including plantations, under FSC certification in Brazil (FAO, 2015)

In the Brazilian Amazon, timber can be legally harvested only from native forest that (1) has been approved for clearing and conversion to some other land use or (2) has an approved PMFS, or sustainable forest management plan (*plano de manejo florestal sustentável*)[3]. According to Sabogal et al. (2006), IBAMA (the responsible government agency) authorized harvest of 9.4 million m^3 of timber from forest with PMFSs in 2005, which constituted 38% of the total volume harvested in the Amazon. The rest of the timber originated from areas of authorized deforestation (19%) and from illegal harvest (43%). Companies or landowners interested in obtaining a PMFS must contract a professional forester, who develops the plan and is also responsible for monitoring compliance with it, e.g. through forest inventory; delimitation of harvest and high conservation value areas; and advance planning of roads,

[3] For further information, see: http://www.ibama.gov.br/areas-tematicas/manejo-florestal-sustentavel

skid trails, and harvest (Sabogal et al. 2006). Because one of the most basic requirements of FSC is compliance with national laws, any company interested in obtaining FSC certification must first obtain a PMFS, either on their private land or through a concession in a national or state forest. We therefore use "PMFS" (referring to the forest area that falls under a PMFS) as the unit of analysis.

There are only a few certified PMFSs in the Brazilian Amazon (Table 1). We evaluate the impact of FSC certification on tree cover change in the three that were first certified between 2004 and 2010 and have maintained certification since then: (1) Cikel – Rio Capim, (2) Cikel Brasil Verde Madeiras Ltda - Fazenda Jutaituba, and (3) Orsa Florestal S.A. Lentini et al. (2005) defined supply sheds or market zones for timber (or *zonas madeireiras*) in the Amazon based on forest type, age of the logging frontier, and accessibility and type of transport (road vs. river). The three PMFSs that we evaluate are located in the *zonas madeireiras* called *Estuário* and *Belém-Brasília*. To identify good comparisons to those certified PMFSs, we consider only PMFSs that have never been certified and that are located in the same *zonas madeireiras*. Table 2 shows the total area of each *zonas madeireira*, the area and percent in the three studied certified PMFSs, and the area and percent in non-certified PMFSs.

Table 1: FSC Certified PMFSs (FMUs) in the Brazilian Amazon

#	Name of Company – PMFS	State	Date of Certification	Area (HA)
1	Amata S.A.	Rondônia	11/30/2012	50044
2	Cikel - Rio Capim *****	Pará	09/01/2006	199168
3	Cikel Brasil Verde Madeiras Ltda - Fazenda Jutaituba *****	Pará	07/01/2006	120467
4	LN Guerra Indústria e Comércio de Madeiras Ltda.	Pará	10/01/2012	45567
5	Mil Madeiras S.A.	Amazonas	06/01/1997	166030
6	Orsa Florestal S.A. *****	Pará	12/07/2004	545335
7	Rohden Ind. Lignea Ltda	Mato Grosso	10/11/2003	25100
8	Rondobel Indústria e Comércio de Madeiras Ltda.	Pará	06/05/2012	5265

***** Companies certified in our defined time window (2004-2010) and therefore included in our analysis.

Table 2: Area of *zonas madeireiras*

Zona madeireira	Total area	Area in studied PMFSs (percent)	Area in other PMFSs (percent)
Estuário	98,771.5 KM^2	10,709.9 KM^2 (11%)	3,245.4 KM^2 (3%)
Belém-Brasília	83,120.0 KM^2	2,062.0 KM^2 (2%)	4,679.9 KM^2 (6%)

Gabon

The timber industry plays an important role in the economy of Gabon, in terms of its contribution to GDP, foreign exchange, and employment. There has been a log export ban since 2010 (Hance, 2010; WRI, 2017). Prior to that ban, in 2009, Gabon produced an estimated 3.4 million m^3 of industrial logs, out of which 1.87 million m^3 of logs and 157,000 m^3 (roundwood equivalent) of sawnwood were exported (Blaser et al. 2011). This made Gabon the world's second largest exporter of tropical hardwoods in 2009 (Blaser et al. 2011). However, Gabon had been a major timber exporter long before that. In the early 2000s, Gabon exported about 4 million cubic meters of industrial round logs per year (OIBT, 2002), out of which 70% was in the form of raw round logs (Fomete, 2003). In that same time period, the average annual deforestation rate for the country was 0.12% according to the Government of Gabon (2008).

Partly because of their heavy orientation towards exports, timber companies in Gabon have been interested in forest certification (Atyi, 2006). After an initial FSC certificate was issued in 1996 but later revoked (Yadav, 2016), the first FSC certificates in Gabon were issued in 2009, with a total area of about 1.87 million hectares certified as of June 2010 (Blaser et al. 2011; FAO 2015). As of 2015, 2.062 million hectares of forest in Gabon were certified (FSC 2015, https://africa.fsc.org/en-cd/notre-impact/quelques-chiffres, Figure 3). All certified areas are public forests operated under concessions awarded to private companies.

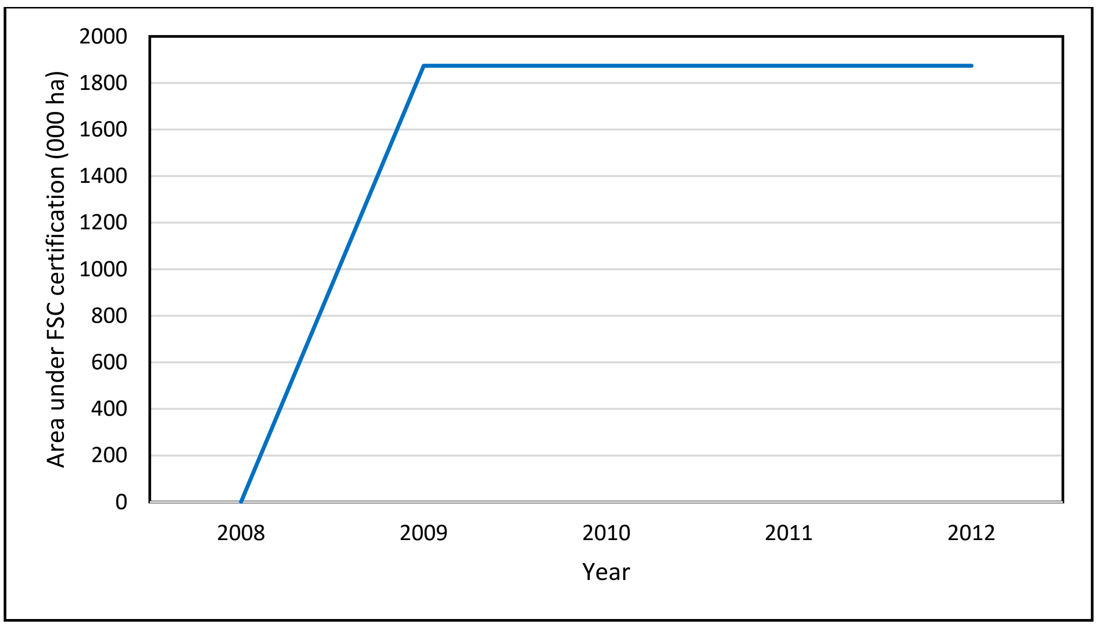


Figure 3: Forest area under FSC certification in Gabon (FAO, 2015)

In Gabon, forest certification has been promoted both as a way to increase financial returns to timber companies and as an alternative to state management that has failed to produce social and ecological benefits. Timber companies have adopted certification because they see it as an opportunity to improve their market position (Atyi, 2006). However, there have also been negative experiences with forest certification (e.g. reversal of early FSC certification of Leroy) that seem to have limited adoption (Bayami, 1997; Elad, 2001).

To evaluate the impact of forest certification on deforestation in FMUs in Gabon, we first group concessions by their holding company (i.e., concessionaire). Three companies hold FSC certificates in Gabon (Table 3). These all have multiple concessions, which are not necessarily contiguous. To understand what would have happened to the forest under their management if they had not been certified, we search for similar but uncertified FMUs (concessions managed by other companies) anywhere in the country.

Table 3: FSC Certified Companies in Gabon

#	Name of company	Date of certification	Area (HA)
1	Precious Wood	10/1/2008	616700
2	Rougier	10/1/2008	688262
3	CBG (Compagnie des Bois du Gabon)	6/1/2009	568543

Indonesian Borneo (Kalimantan)

As of 2015, Indonesia had about 91 million hectares (Mha) of forest, including 46 Mha of mature natural forests (FAO, 2015) and 4.9 Mha of plantations. About 57 Mha of forest has been designated for production. According to the Forest Resources Assessment (2015), 74,700 persons were employed full-time in the forestry sector in Indonesia in 2010.

In the period between 1990 and 2015, Indonesia experienced an annual loss of about 1.1 Mha of natural forest according to FAO (2015). Part of the deforested area has been converted to pulp and oil palm plantations. Pulp plantations (mostly of Acacia spp.) have expanded rapidly over the past decade with support from the Ministry of Forestry. An independent government commission calculated that from 2003 to 2014, 630.1 million m^3 of timber were harvested from natural forests in Indonesia, including a declining annual amount from selective logging and an increasing annual amount from land clearing or deforestation (KPK 2015). Kalimantan accounted for 40% of that total (KPK 2015). Following government efforts to rein in or downscale logging of native forests, 292 concessions remained operational in Indonesia in 2015 (MoF, 2012, Maryudi 2015; Ruslandi and Romero 2015).

Previous research has reached widely varying conclusions about the effect of logging concessions on deforestation in Indonesia, ranging from reductions in deforestation (Gaveau et al. 2013), to increases in deforestation (Brockhaus et al. 2012), to no effect (Indarto et al. 2015). These varying conclusions may be at least partly due to heterogeneity across concessions, including their certification status.

The early development of forest certification in Indonesia in the 1990s came in response to growing environmental activism against logging of native forests, and calls for sustainable forest management by multilateral organizations and agreements. Rainforest Alliance (an NGO) started the SmartWood Certification Program in Java in 1990. A Certification Working Group of the Indonesia Ecolabel Institute (LEI) was established in 1993, in the same year that the Forest Stewardship Council (FSC) was founded. In 1998, LEI became an independent accreditation body, cooperating with FSC under a Joint Certification Protocol (Muhtaman and Prasetyo, 2006).

The area certified by FSC has grown steadily over time in Indonesia. As of 2015, there were 14 FSC-certified FMUs active in Indonesia (Table 3), managing a total area of about 1.7 million hectares (Romero et al. 2015). Figure 4 shows that the increase in FSC certified hectares was particularly rapid between 2005 and 2009 (FAO, 2015).

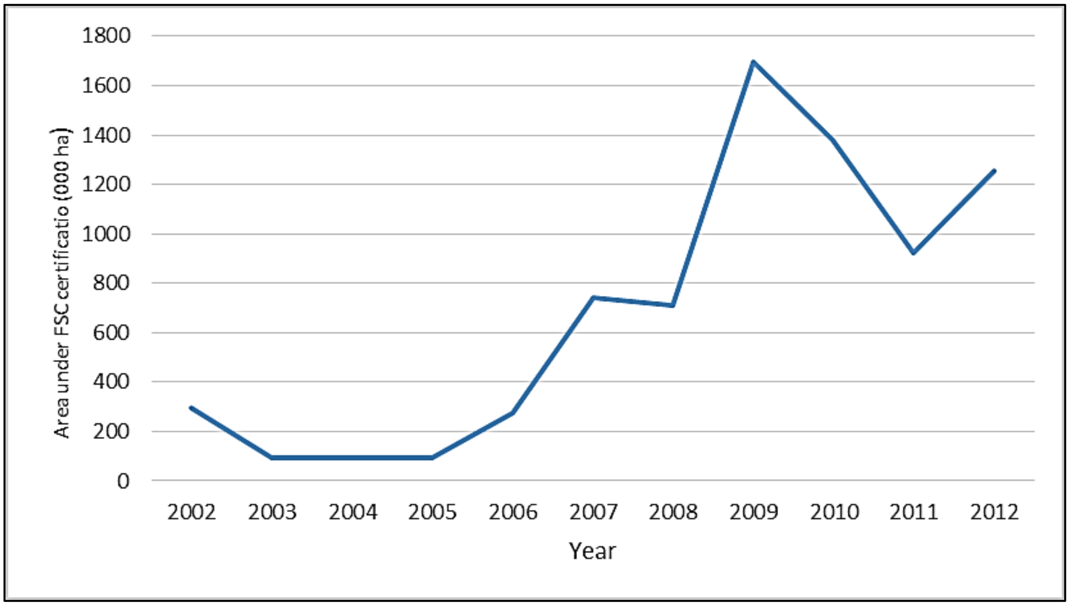


Figure 4: Forest area under FSC certification in Indonesia (FAO, 2015)

For our analysis, we consider only forest concessions in Kalimantan certified between 2004 and 2010. Specifically, we evaluate the impact of FSC certification on the tree cover of four "FMUs," or the concession areas managed by four companies (Suka Jaya Makmur, Sari Bhumi Kusuma, Erna Djuliawati, and Intracawood Manufacturing). All of these companies manage public forest lands under concessions. As noted in the last column of Table 4, all four received certification for contiguous blocks, although a more recent certificate was issued for several disjoint areas.

Table 4: FSC Certification of Companies in Kalimantan, Indonesia

Name of company	Province	Size (HA)	Date certified	Spatial arrangement
PT Diamond Raya Timber	Riau	90956	3/27/2001	Contiguous
PT Erna Djuliawati*	Central Kalimantan	184206	9/6/2005	Contiguous
PT. Intracawood Manufacturing*	East Kalimantan	195110	4/6/2006	Contiguous
PT Sari Bumi Kusuma*	Central Kalimantan	147600	9/26/2007	Contiguous. (Another half of the concession area, a separate FMU under the same concession permit, is excised from FSC certification.)
PT Suka Jaya Makmur*	West Kalimantan	171340	9/30/2010	Contiguous

PT Narkata Rimba	East Kalimantan	41540	8/16/2011	Contiguous
PT Sarmiento Parakantja Timber	Central Kalimantan	216580	12/20/2011	Contiguous
PT Belayan River Timber	East Kalimantan	97500	12/22/2011	Contiguous
PT Roda Mas Timber Kalimantan	East Kalimantan	69620	4/29/2012	Three blocks (one FMU), separated by another FSC certified concession (Kemakmuran Berkah Timber)
PT Kemakmuran Berkah Timber	East Kalimantan	82810	5/22/2012	Contiguous
PT Dwimajaya Utama	Central Kalimantan	127300	12/7/2012	Contiguous

* Companies certified in our defined time window (2004-2010) and therefore included in our analysis.

3. Deforestation in certified FMUs: data and findings

In order to evaluate whether FSC certification has been "adequate" to ensure zero deforestation, we must decide how to measure deforestation, i.e. at what scale and using what data. In this section, we address these two issues and present our findings on tree cover loss in certified FMUs.

3a. Defining the unit of analysis

A forest management unit (FMU) is a clearly delineated forest area operated by one manager under one management regime. In our study, the managers are firms. These firms decide whether to seek certification, as well as managing the forest and relations with workers and local people. We therefore define FMUs as areas managed by single firms, allowing them to include several disjoint forest areas. In the case of Brazil, firms must obtain legal authorization (a PMFS) from the government in order to harvest timber from a forest area, and they often create different legal entities to manage each PMFS. Thus, in Brazil, we consider all forest areas under a single PMFS to be a FMU. In the cases of Gabon and Indonesia (Kalimantan), we define a FMU as all of the forests under concession to a single timber company.

Increased availability of remote-sensing data has made it possible to generate huge pixel-level datasets for statistical analysis. However, it has also increased the danger of inappropriate statistical analysis at scales that are not really relevant to decision-making and of units that are highly spatially correlated. For example, to evaluate the effects of certification, we could compare pixels (30x30 m) inside and outside certified FMUs. While this would avoid the problems associated with small datasets (and increase the chances of finding statistically significant effects), it would raise other concerns. Neither certification nor deforestation decisions are made at the pixel level, making it difficult to model the selection process and to control for any related biases at that level.

3b. Defining the outcome

Perhaps the most widely used global dataset on forests was released by Hansen, UMD, Google, USGS and NASA (Hansen et al. 2013). Version 1 of the "Global Forest Change 2000-2012" dataset includes tree cover in 2000, tree cover change between 2000 and 2012, tree cover loss in each year from 2000 to 2012, and tree cover gain between 2000 and 2012, based on time-series analysis of Landsat Satellite images. The spatial data come in tiles of 10 x 10 degrees, each consisting of seven files. Each of these files contains unsigned 8-bit values with spatial resolution of approximately 30 x 30 meters at the equator.

The advantages of this dataset include that it is global, fine-resolution and consistently available for all countries of the world, initially for 13 years and now for 15 years (through 2015, in version 1.3 of the data). The data are pre-processed, calibrated and improved based on quality assessment models. Moreover, the database is continuously being updated, and new versions with improved features are made freely available.

The tree cover loss layer in the Hansen dataset includes clearing of any forest type (whether young or old forest, natural or plantations), but for our analysis, we only consider loss in pixels that were forested in 2000. Specifically, we identify the pixels that remained forested at the beginning of each year (i.e. pixels that were forested in 2000 and that had never undergone tree cover loss), and then calculate the percent of those pixels where tree cover was lost in the year. We label this measure of annual percent tree cover loss as "deforestation." Specifically, our outcome variable is calculated as follows:

$$\textit{Rate of deforestation in a FMU in year } t = \frac{\textit{Tree cover loss observed in FMU during year } t \textit{ (ha)}}{\textit{Total tree cover in FMU at the beginning of year } t \textit{ (ha)}} \times 100$$

While this results in a dependent variable that is a close proxy for the deforestation rate, it may (i) exclude deforestation followed by establishment of plantations, (ii) include deforestation of plantations that existed in 2000, and (iii) include forest management that results in temporary tree cover loss, e.g. due to large tree fall gaps associated with selective logging.

In order to assess the extent to which the first two concerns could affect our analysis, we use maps from Global Forest Watch (2015) to identify any plantations in the FMUs in our sample in Brazil and Indonesia (data not available for Gabon, Global Forest Watch - http://www.globalforestwatch.org/). We find no plantations in FSC certified FMUs in Indonesia in 2013. In Brazil, plantations covered 6.55% of the PMFS managed by one of the certified companies. Orsa Florestal Ltd. is part of the Orsa Group, which has extensive plantations and a large pulp and paper mill. Without a field visit, it is difficult to verify whether plantations have been established inside the PMFS, or whether there are errors in the shape files designating the PMFS and the plantations. Turning to non-certified FMUs, 0.46% of their area in Indonesia was in plantations (primarily oil palm), and 0.42% of their area in Brazil was in plantations (primarily for wood fiber) in 2013. While these are very small fractions of the total area, they are substantial relative to the annual deforestation rate. Thus, for Brazil and Indonesia, we conclude that the classification of plantations as tree cover generally does not affect our measure of deforestation in certified FMUs (except in one FMU in Brazil), but could result in either an under-estimate of deforestation (missing conversion of native forest to plantation) or an over-estimate of deforestation (including harvest of plantations) in our counterfactual scenarios.

A second limitation of the Hansen dataset is that tree cover loss could represent timber harvest as well as deforestation. Skid trails, logging roads, and loading zones may all result in canopy gaps (Fearnside 2005, Carlson et al. 2012, Margono et al. 2012). Temporary loss of tree cover in these gaps is a necessary result of active timber management. Poor forest management may also result in more permanent loss of tree cover, representing fragmentation and degradation of forests (Skole and Tucker 1993, Abdullah and Nakagoshi 2007, Fitzherbert et al. 2008, Arbainsyah et al. 2014, Margono et al. 2014). To assess whether tree cover loss in FMUs is temporary, we compare tree cover loss to tree cover gain over the entire time period from 2000 to 2012 (since annual data on tree cover gain are not available). FSC certified companies have been found to build narrower roads and cause less damage when felling trees compared to conventional logging operations (Medjibe et al. 2013). To explore whether certification influences tree cover loss through this mechanism, we implement a spatial filtering method to distinguish tree cover loss that may be due to logging from tree cover loss that represents deforestation and estimate the impact of certification on both types of tree cover loss in Brazil.

3c. Fate of the forests in FSC certified FMUs

Our first question is whether tree cover has been maintained in the FMUs that have been certified. That is, we ask whether FSC certification has been consistent with “zero deforestation” in these three landscapes.

While recognizing that active forest management often entails temporary loss followed by re-establishment of tree cover, we begin with our measure of deforestation. This would be consistent with a scenario in which the Hansen data on tree cover loss were used to monitor compliance with a “zero deforestation” commitment. Tables 5 to 7 report percent deforestation in the certified FMUs in our sample, limited to the years in which all of the study FMUs in a given country were certified. In all three landscapes, the average rate of deforestation was similar to the average rate of deforestation in the region, with the highest rate in Estuário in Brazil (0.41%) and a very low rate (< 0.025% per year) in Gabon. This demonstrates that certified FMUs have neither been subject to rapid deforestation nor exactly complied with zero deforestation. However, it does not provide any evidence on whether certification has reduced – or increased – deforestation relative to what would have happened without certification.

Table 5: Percent deforestation in certified FMUs in Brazil

	Certified FMUs in:	
Year	Estuário	Belém-Brasília
2006	0.25	0.03
2007	0.27	0.13
2008	0.38	0.24
2009	0.86	0.02
2010	0.47	0.02
2011	0.40	0.05
2012	0.24	0.004
Average	0.41	0.07

Table 6: Percent deforestation in certified FMUs in Gabon

	All Certified FMUs
2010	0.02
2011	0.02
2012	0.01

Table 7: Percent deforestation in certified FMUs in Indonesia

	All Certified FMUs
2011	0.10
2012	0.18

4. Impact of FSC Certification on Deforestation: Data and Methods

Moving beyond adequacy evaluation to impact evaluation, we describe our data and methods for evaluating the impact of FSC on deforestation in this section. This requires that we control for any other possible influences on tree cover that may be confounded with FSC certification. Thus, we first review data sources on potential confounders and then present the synthetic control method (SCM) as a way to account for these confounders and estimate the causal effects of an intervention that has been applied to only a few units.

4a. Sources of data

Analysts have increasingly turned to global, open-access spatial data sets, often obtained via remote sensing, to evaluate the impacts of policies and programs on tropical forests (Blackman 2012). To the extent possible, we draw our variables from these datasets, so that we can model impacts using the same covariates in each region. In this section, we review these datasets, which we combine with country-specific data described in section 5.

Global Forest Watch (http://www.globalforestwatch.org/)

Global Forest Watch (GFW) is an interactive online global forest monitoring and alert system that aims to improve forest information by merging the latest technologies with on-the-ground partnerships, convened by the World Resources Institute and its partners. Global Forest Watch aggregates (1) Hansen's Global Forest Change spatial data layers (as described above), (2) near real-time forest alerts and active fire data, (3) maps of primary forests, intact forest landscapes, mangroves and carbon stocks, (4) data on forest use including concessions for agriculture, logging, mining, and oil palm, (5) data on biodiversity and natural resources, and (6) data on indigenous peoples and reserves.

For evaluating certification, GFW is a rich source of spatial data on the ownership, location and other attributes of logging concessions. GFW shapefiles of logging concessions have been used for analysis in the case of Gabon and Indonesia in the ArcMap environment. Each concession can be categorized as certified or non-certified, and secondary socio-economic and other non-spatial data can be joined to this shape file, based either on overlap of polygons or Euclidean distances from polygons representing logging concessions to other features such as roads and protected areas

WorldClim – Global Climate Data (http://www.worldclim.org/**)**

This spatial dataset contains global data on temperature, rainfall and other bioclimatic variables derived from monthly temperature and rainfall values with a spatial resolution of about 1 square kilometer.

SRTM (Shuttle Radar Topography Mission) (http://www2.jpl.nasa.gov/srtm/)

NASA provides global elevation data with a resolution of about 1 km.

FIRMS (Fire Information for Resource Management System) (https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms)

NASA maintains a repository of MODIS fire data. The number of fire events as well as the extent of burned areas can be downloaded in shapefiles for further processing in ArcMap.

WDPA (World Database on Protected Areas) (http://www.protectedplanet.net/)

WDPA is a joint project of IUCN and UNEP providing comprehensive data on terrestrial and marine protected areas. The spatial boundaries of protected areas – national parks, wildlife sanctuaries, biosphere reserves etc. - can be downloaded.

Global Rural-Urban Mapping Project (http://sedac.ciesin.columbia.edu/data/collection/grump-v1)
The Global Rural-Urban Mapping Project Version 1 (GRUMPv1) provides estimates of human population for the years 1990, 1995 and 2000 by 1 km grid cells. The spatial dataset is produced by the Columbia University Center for International Earth Science Information Network (CIESIN) in collaboration with the International Food Policy Research Institute (IFPRI), The World Bank, and Centro Internacional de Agricultura Tropical (CIAT). The dataset also has spatial information on population density, settlement points, coastlines, national boundaries and urban settlements.

LandScan (http://web.ornl.gov/sci/landscan/)
LandScan provides estimates of daytime 'ambient' human population at approximately 1 km resolution on an annual basis from 2000 to 2012. The LandScan algorithm uses a multi-layered, dasymetric and spatial modeling approach for reallocating census counts within administrative boundaries (LandScan). The spatial data layers that are used include administrative boundaries, census information, slope, elevation, landcover, nighttime lights, and transportation networks. The resulting population estimates are made available through Oak Ridge National Laboratory.

LandScan data provide a long time-series on population, which can be used to model deforestation trajectories. However, special care is needed while downloading and using the LandScan data in the ArcMap environment as the projection can result in data loss. Moreover, while using the data in ArcMap, analysis cell size should be set to match the LandScan data with corresponding analysis window snapped to cell interval extent.

Global Poverty Estimates (http://www.ngdc.noaa.gov/eog/dmsp.html)

Spatial data on the percent of the population in poverty at a resolution of about 1 km for the year 2004 are available from National Geophysical Data Center (NGDC). The poverty estimates are constructed on the basis of LandScan Gridded Population (2004) and NOAA-NGDC Nighttime Lights of the World (2003) data (for details – visit http://www.ngdc.noaa.gov/eog/dmsp/download_poverty.html).

Other spatial variables

In addition to the spatial datasets described above, additional covariates can be derived from the shape files of certified and non-certified FMUs. Specifically, the spatial boundaries of FMUs can be used to construct a variable that represents the compactness of the FMUs. The more compact a FMU, the less monitoring effort required to oversee harvesting and prevent incursions that may lead to deforestation. We measure compactness as the perimeter of a FMU divided by the perimeter of a circle of same area. The larger this ratio, the more highly fragmented is the FMU, potentially increasing the cost of monitoring and controlling forest use.

4b. Synthetic control method (SCM)

We use the Synthetic Control Method (SCM) to evaluate the effect of certification of a FMU (our treatment) on deforestation in that FMU (our outcome). SCM is based on Mill's Method of Difference and thus simulates the counterfactual of a treated case in the absence of treatment. SCM was introduced by Abadie and Gardeazabal (2003) and further developed by Abadie et al. (2010 a). It has been used to construct the counterfactual for single jurisdictions affected by anti-smoking legislation, minimum wages, terrorist conflict, and immigration controls (Abadie et al. 2010 a, b; Sabia et al. 2012; Abadie and Gardeazabal 2003; Bohn, Lofstrom and Raphael 2013). Sills et al. (2015) illustrate the use of SCM for evaluating policy impacts on land use. SCM has also been suggested as a way to systematically choose comparison units for comparative case studies, thus bridging the quantitative/qualitative methodological divide (Abadie et al. 2012). We adopted SCM as a rigorous and robust method, which is appropriate for the very small and heterogeneous pool of certified FMUs in our three study regions and which is feasible due to the long time-series of data on the outcome available in the Hansen dataset.

Motivation for the approach

When analyzing aggregated units (which by definition means a smaller sample size), it is often difficult to find control units exactly like treated units in terms of all potentially confounding factors. Because of the small sample size, it is neither possible nor sufficient to identify sub-sets of treated and control units that are similar in expectation (on average). The alternative offered by SCM is to create a "synthetic control," or weighted combination of comparison units, that has the same (or similar) characteristics as the unit under investigation. Thus, the objective of SCM is to determine a set of weights on all potential comparison units that results in the synthetic unit that most closely resembles the unit of interest before that unit was treated (certified, in our case). The method makes unambiguously clear how much a particular comparison unit contributes to the construction of the counterfactual (i.e., the relative weight of each control unit). The explicit weights help quantitatively and qualitatively explore the plausibility of the synthetic control as the counterfactual of the unit of interest.

SCM is preferred to other quasi-experimental approaches when there are only a few treated units, which is often the case when analyzing aggregate units like countries or states. In such cases, it is difficult to identify treatment effects using traditional matching, because the law of large numbers does not help produce treated and control groups that are similar on average. To compensate for the small number of units, however, SCM requires a long time-series of data on the outcome variable. This is because SCM uses a nested optimization process that identifies a set of weights on potential covariates such that matching on those weighted covariates results in the closest possible match on the outcome over the full time series available prior to treatment.

Construction of synthetic controls

To explain how synthetic controls are constructed, we first present a concrete example and then introduce notation. For the example, assume there are 6 Forest Management Units: FMUs A to F (J=1..6). Out of these 6 FMUs, one FMU, say A (j=1), is FSC certified. The remaining 5 non-certified FMUs (B to F, j=2 to 5) become the “donor pool” (or potential controls) because they are thought to have similar structural drivers of deforestation as the certified FMU (A). As shown in Table 8, assume that there is a measure of deforestation in each FMU in each of the past 14 years, from t_1 to t_{14}.

The data for all FMUs are observed for each time period. Therefore, t=1,….,T is the total number of studied years (t_1 to t_{14} in our example), T_0 is the number of pre-intervention years (t_1 to t_8), and T_1 is the number of post-intervention years (t_9 to t_{14}).

Table 8: Deforestation in FMUs A - F in past 14 years (t_1 to t_{14})

FMUs	t1	t2	t3	t4	t5	t6	t7	**t8**	t9	t10	t11	t12	t13	t14
A	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14
B	b1	b2	b3	b4	b5	b6	b7	b8	b9	b10	b11	b12	b13	b14
C	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12	c13	c14
D	d1	d2	d3	d4	d5	d6	d7	d8	d9	d10	d11	d12	d13	d14
E	e1	e2	e3	e4	e5	e6	e7	e8	e9	e10	e11	e12	e13	e14
F	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11	f12	f13	f14

Assume that the treatment or intervention (i.e., certification of FMU (A)) happened in t_8 soon after deforestation outcomes for t_8 were observed. If we further assume that certification was not anticipated, or that the expectation of certification did not affect the outcome, we can define the years t_1 to t_8 as the pre-intervention period and the years t_9 to t_{14} as the post-intervention period. Our aim is to estimate the impact of the intervention (i.e., certification of FMU (A) in year t_8) on deforestation in FMU (A) in years t_9 to t_{14}.

We compare the pre-intervention characteristics of the donor pool (FMUs B – F) with the treated unit (FMU A) to decide which FMUs should be included in the synthetic control. SCM seeks to match the structural drivers of deforestation to create a synthetic control in which deforestation follows the same path across the entire time period (t_1 to t_{14}) as it would have followed in FMU (A), were it not for certification. In addition to those structural drivers, synthetic controls typically are constructed by matching on the average pre-treatment level of the outcome, i.e. historical rates of deforestation.

Here, we adopt the standard notation for the synthetic control method as established by Abadie and Gardeazabal (2003), Abadie et al. (2010), and Abadie et al. (2012) and implemented in the SYNTH package for Matlab, R and Stata available from Jens Hainmueller’s website: https://web.stanford.edu/~jhain/synthpage.html . The SCM optimization routine weights characteristics such that matching on the weighted characteristics results in a close match between the historical outcomes in the treated unit (a_1 to a_8) and in the synthetic control. Thus, the SCM procedure creates two sets of weights, one on the characteristics (V) and the other on the units in the donor pool (W). The weights on the donor pool (W, here W*j(2 to 5)* where *j* is an index of FMUs B to F) should add to one and should all fall between 0 and 1. In practice, many of the weights may be close to zero. This results in a synthetic control that is an average of the FMUs in the donor pool, weighted based on observable characteristics to most closely approximate the deforestation trends in FMU (A) in the pre-intervention period.

Let us assume that

Xt: (n x 1) vector of n pre-intervention characteristics of the certified FMU;

Xc: (n x J) matrix that contains the n pre-intervention characteristics of the J1 FMU in the donor pool.

The vector Xt - XcW is the difference between the pre-intervention structural characteristics (i.e. observable characteristics of the units that are drivers of deforestation) of the certified FMU and the synthetic control. The SCM optimization routine selects the W that minimizes this difference, subject to the constraint $0<W_j<1$. Specifically, the SYNTH() function chooses W* , which is a vector value of W that minimizes:

$$\sum_{u=0}^{n} V_u (Xt_u - Xc_u W)^2 \qquad \text{Eq.1}$$

Where

Xt_u is the pre-intervention value of the u-th variable of the treated unit (u is indexed 1,….,n)

Xc_u is 1 x j vector containing the n pre-intervention variables of the FMUs in the donor pool

V_u is the weight (relative importance) assigned to the u-th variable in calculating the difference between Xt and XcW.

V_u is a (*k x 1*) symmetric and positive semi-definite matrix chosen such that the synthetic control generated by matching the weighted characteristics also matches pre-intervention levels of deforestation. In effect, this means that the characteristics with the highest predictive power for the outcome are assigned the largest V_u weights.

The SYNTH package for R includes various optimization algorithms for picking W and V, including Nelder-mead, BFGS (Broyden–Fletcher–Goldfarb–Shanno algorithm), CG (conjugate gradient), and L-BFGS-B (limited memory version of BFGS that handles simple box constraints). The default option is a data-driven process to choose V in such a way that mean squared prediction error (MSPE) of the outcome variable (deforestation in our case) is minimized over the pre-intervention period (Abadie et al. 2011; Abadie et al. 2010). MSPE is the squared deviation between the deforestation outcome for the certified (treated) FMU and the synthetic control FMU summed over all pre-intervention years under study.

In our example:
Let Y_1* be the (T_0 X 1) vector of pre-intervention values of deforestation for the treated unit, i.e. a_1 to a_8; and Y_0* be the (T_0 X J) matrix containing the pre-intervention values of deforestation in the FMUs in the donor pool in the pre-intervention period (T_0).

V_u is chosen to minimize the difference between deforestation in the treated unit (Y_1*) and deforestation in the synthetic control (Y_0*W*) in the pre-intervention period. That is, V_u minimizes

$$\underset{V \in \upsilon}{\arg\min}\, (Y_1^* - Y_0^* W(V_u))' (Y_1^* - Y_0^* W(V_u)) \qquad \text{Eq. 2}$$

Where ʋ is the set of available positive (diagonal) definite matrices of weights for the synthetic control. The function synth () solves a nested optimization problem to minimize eq. 2, for W* (V_u) given by Eq. (1), to find the convex combination of the control FMU units with the lowest MSPE.

Once the synthetic control is defined, the effect of forest certification on deforestation is estimated as follows. First, define Y_1 as the (T_1 x1) vector of post-intervention deforestation in the certified unit, i.e. a_9 to a_{14}, and Y_0 is the (T_1 X J) matrix containing the post-intervention values of deforestation in the donor pool. For any given year, the synthetic control estimator of the effect of forest certification on deforestation is:

$$= Y_1 - Y_0 W^*$$

Thus, SCM estimates the impact for each treated unit and for each year of the post-treatment period as the difference between the outcome for the treated unit (the certified FMU) and the outcome for the synthetic control in that year. This is shown in graphical form in Figure 5.

As shown in Figure 5, deforestation in the synthetic control (Y_0*W*) should be similar to deforestation in the treated unit (Y_1*) over the pre-intervention time period from 1990 to 2008, although typically these are not perfectly matched. Any difference between the deforestation trajectories of the certified FMU and the synthetic control in the post-treatment period is attributed to the certification intervention. It is important to note that this figure shows an ideal application of SCM, which is difficult to achieve in reality. When the pre-treatment match and post-treatment divergence of outcomes are not as obvious, it becomes important to assess the uncertainty associated with the annual outcomes in the synthetic control in order to establish whether they are statistically different from the annual outcomes in the treated unit.

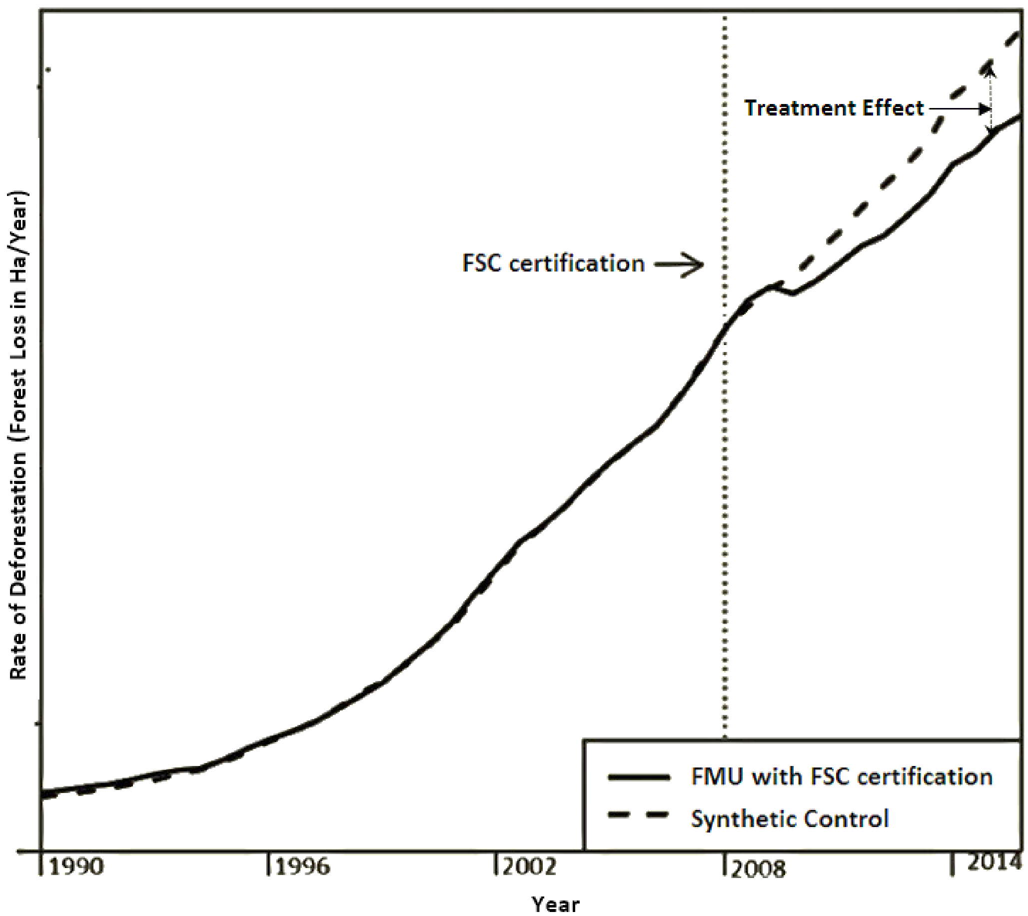


Figure 5: Hypothetical synthetic control estimator of the impact of FSC certification on deforestation (adapted from Abadie et al. 2013). The difference between the dark line (unit with certification) and the dashed line (synthetic unit) is interpreted as the impact of FSC Certification on deforestation post 2008.

In standard matching, the analyst must assume conditional independence, or selection-on-observables – that is, it must be possible to measure all of the confounders that influence both treatment and outcomes (certification and deforestation, in our case). For SCM, the analyst should collect data on as many of the structural factors driving deforestation as possible. However, the method also controls for confounding by unobservables by matching on both observed factors and observed outcomes in the pre-treatment period. Intuitively, this is because the difference between the outcome predicted by the observed factors and the actual observed outcome reflects potentially confounding unobservables.

4c. Application of SCM to evaluate impacts of forest certification

In our application of SCM, we sought to standardize data and methods across Brazil, Gabon, and Indonesia to the degree possible, while also considering the units, time frame and covariates relevant and available for each case. Specifically, the following must be decided before implementing SCM:

(i) *The unit of the analysis:* SCM was originally developed to evaluate events or policies in single jurisdictions such as states or countries (e.g., anti-smoking legislation, minimum wages, terrorist conflict, and immigration controls). When the intervention area is comprised of multiple units, such as parks in a protected area system, either the system or the individual units can be defined as the treated unit, depending on the precise question of interest.

(ii) *Time of intervention:* SCM is used to estimate the impact of an intervention on a specific treated unit (rather than the average impact on treated units, or ATT, as estimated with conventional matching). Thus, with SCM, the analyst can account for variation in the timing of treatment across units. In our case, FMUs have been certified in different years. We define treatment as occurring in the year when the certificate was issued. To capture any anticipatory effects, the year of treatment could instead be defined based on the preliminary FSC audit (conditional on data availability).

(iii) *Covariate selection*: Covariate selection is informed by existing literature on drivers of the outcome, the theory of change for the intervention, the availability of data from the pre-treatment period, and the feasibility of merging those data at the scale of the chosen unit of analysis. In our application, we choose the years of our covariates based on the year of certification of each treated FMU. For example, consider two FMUs certified in 2005 and 2008. To create a synthetic control for the first certified FMU, we only use covariates for which we have values before 2005. For the second FMU, there may be additional covariates measured 2005 – 2007. Selection of covariates is also necessarily a function of data availability. To facilitate comparison of our results across the three landscapes, we selected variables that are consistently available across the tropics. In particular, we use a consistent set of bio-physical factors that affect both forests and demand for agricultural land, as summarized in Table 9.

Table 9 Bio-physical factors considered in construction of synthetic controls

Variable	Description	Units	Spatial resolution	Time frame	Source	Rationale
Tree cover 2000	Tree cover in FMU	Hectares	30 m	2000	Hansen et al. 2013, “High-Resolution Global Maps of 21st-Century Forest Cover Change.” Science 342 (15 November): 850–53 http://www.earthenginepartners.appspot.com/science-2013-global-forest/download.html	Higher initial tree cover may be associated with greater timber stocks, potentially leading to greater legal and illegal logging, which can result in temporary deforestation or provide access for agents of deforestation (Foley et al. 2007; Asner et al. 2004).
Altitude	Mean elevation from sea level	Meter	1 km	Represen-tative of 1950-2000 (Average)	SRTM elevation database (http://www2.jpl.nasa.gov/srtm/) accessed through WorldClim (Global Climate Data portal) –aggregated to 30 arc-seconds, “1 km” http://www.worldclim.org/current	Higher elevations typically have more varied topography, which increases difficulty of both deforestation and monitoring.
Climate Mean temperature	Annual mean temperature	Centigra de	1 km	Represent-ative of 1950-2000 (Average)	WorldClim (Global Climate Data portal) – aggregated to 30 arc-seconds, “1 km” http://www.worldclim.org/current (for detail – see Hijmans et al. (2005)	Higher temperature may be associated with higher probability of wildfire damage, resulting in higher chances of deforestation (Kirilenko and Sedjo 2007).

Mean precipitation	Mean annual precipitation	Cm	1 km	Represent-ative of 1950-2000 (Average)	WorldClim (Global Climate Data portal) – aggregated to 30 arc-seconds, "1 km" http://www.worldclim.org/current (for detail – see Hijmans et al. (2005))	Areas with higher precipitation are less likely to be profitable for agriculture, possibly leading to less deforestation (Chomitz and Thomas, 2003).
FMU Area	Area of the FMU (Based on official shape file.)	km^2	Polygon	2004	FMU shape files (source varies by country)	The larger a FMU, the harder to monitor and to prevent illegal activity.
Monitoring cost	Shape of FMU, indexed by the perimeter of the FMU divided by perimeter of a circle of the same area	1 = perfectly compact >1 = fragmen ted	Polygon	2004	FMU shape files (source varies by country)	The shape of a FMU affects the cost of monitoring and supervision, thereby influencing the probability of deforestation.

(iv) *Dependent/outcome variable*: The availability, consistency, and robustness of the outcome data influence the results irrespective of the methods used. For SCM, a long time series of data on the outcome variable (deforestation in our case) is a prime requirement. We demonstrate the use of Hansen et al. (2013) global forest change data, as described below, while acknowledging that like all datasets, it has limitations (e.g., problematic definition of forest and classification errors).

Outcome evaluated using SCM					
Variable	Description	Measurement	Spatial resolution	Time frame	Source
Deforest ation	Annual percent tree cover loss in each FMU	Tree cover loss observed in FMU during the year (ha) * 100/Total tree cover (ha) in the FMU at the beginning of year	30 m	2001-2012 (Annual)	Hansen et al. 2013, "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850–53 http://www.earthenginepartners.appspot.com/science-2013-global-forest/download.html

(v) *Pre-treatment and post-treatment periods*: These periods should be long enough to create synthetic controls that match pre-treatment trends (the calibration period) and show any differences in post-treatment trends (the results period), but not so long as to be affected by structural breaks unrelated to treatment. In our case, structural breaks could be caused by changes in forestland ownership, expansion or contraction of regional timber markets, natural disasters, or local changes in labor supply. These are problematic when they affect only the treated unit or only part of the donor pool of potential control units, in which case either the time period or the donor pool should be defined to exclude them.

4d. Assessing plausibility and statistical significance in the context of SCM

Once the above have been defined and the synthetic controls (W*) constructed for each treated unit, the quality of those synthetic controls must be assessed. Of course, it is not possible to observe whether the outcome in the synthetic control follows the same path as would have occurred in the treated unit had it not been treated. Instead, synthetic controls are evaluated based on how well they match the characteristics and the levels and trends of the outcome in the treated units before treatment. Specifically, we use the following criteria to assess the quality of the synthetic control constructed for each treated unit:

(i) Mean square prediction error (MSPE), with low values indicating good fit.
(ii) Coincidence of the turning points in the pre-treatment deforestation trajectories of the certified unit and its synthetic control, assessed by visual inspection of these turning points.
(iii) Difference in the level of deforestation between the treated FMU and the synthetic control in the last year before treatment, which should be small.

Based on these three criteria, we categorize the quality of each synthetic control or the plausibility[4] that it represents the counterfactual for a certified FMU as follows: 1) **High Plausibility** – the synthetic control does well in terms of the above three criteria; 2) **Medium Plausibility** – the synthetic control has reasonably low MSPE, and at least a fair match of turning points and of the level of deforestation in the year before certification, and 3) **Low Plausibility** – the synthetic control fails to meet at least two of the three criteria and is therefore unlikely to represent the counterfactual.

Placebo tests are used to assess the robustness of estimates by exploring the likelihood that they would have been observed merely by chance (Abadie and Gardeazabal, 2003; Bertrand, Duflo, and Mullainathan, 2004, Abadie and Gardeazabal, 2010). For these tests, we estimate the "impact" of placebo (or fictitious) certification treatments on each FMU in the donor pool (and therefore not actually certified), i.e. we run the SYNTH optimization routine for each unit in the donor pool. We are interested in whether the estimated impact of actual certification is larger than the "impacts" of placebo treatments of FMUs that were not actually certified. If the estimated impact of certification on the certified FMU is larger (in absolute value) than almost all of the placebo effects on non-certified FMUs, that increases our confidence that the estimated impact is significantly different from zero, because it falls outside the range of statistical noise as represented by the placebo effects.

Placebo impacts are the difference in deforestation between fictitiously-certified FMUs and their synthetic controls. However, these estimated impacts are not all comparable. If a synthetic control fails to reproduce the deforestation outcome before the fictitious intervention, then the placebo impact is not a reasonable basis for comparison. Thus, we only consider placebo impacts based on synthetic controls with MSPE lower or equal to the MSPE of the synthetic control for the unit that was actually treated. We trim off the high MSPE placebo cases in order to focus on the range of estimated effects possible when there is no treatment and the method works well. In this trimmed sample, we identify the 10^{th} and 90^{th} percentiles of the placebo effects in order to assess statistical significance at the 80% confidence interval.

[4] Plausibility is understood as a reasonable credence or subjective degree of belief (Bartha, 2010).

4e. Benchmarking

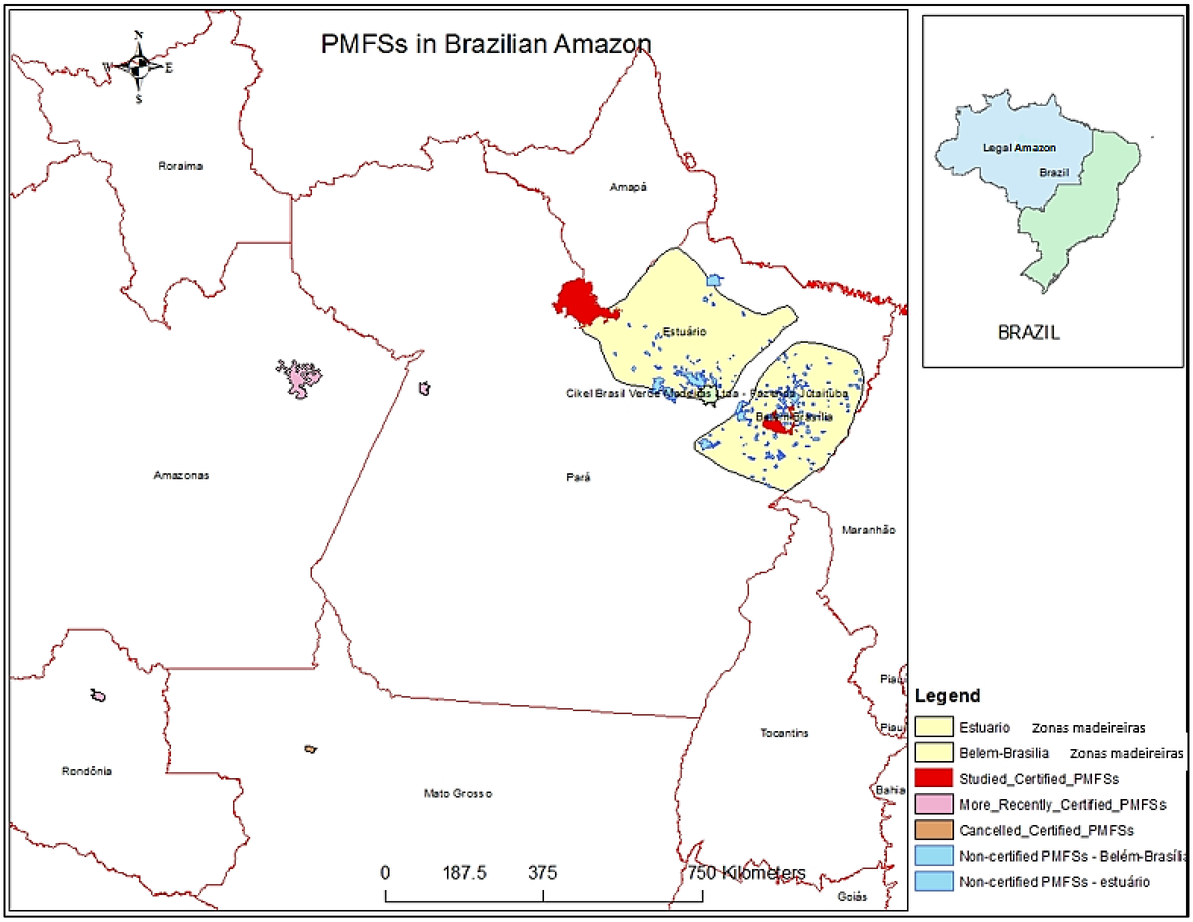
The most naïve approach to estimating the impact of FSC certification would be to compare average deforestation in certified FMUs to average deforestation in non-certified FMUs. This comparison is a useful benchmark for impact estimates, and it should be possible to relate differences in the sign and size of this comparison and the effect estimated through SCM to the selection process or participation decision.

Many evaluations of policies that target particular places or territories (like protected areas or payments for ecosystem services) have used pixels as their unit of analysis (Jayachandran et al. 2016; Chen et al. 2014; Curran et al. 2016; Tuanmu et al. 2016). We do not adopt this approach, because it does not reflect the structure of decision-making about certification: firms rather than pixels decide whether to obtain FSC certification, and it is not possible to certify individual pixels. However, as a robustness check and to facilitate comparison to other impact evaluations, we compare random samples of pixels in certified and non-certified FMUs in Appendix E.

5. Impact of FSC on Tree Cover Change: Results

5a. Brazilian Amazon

In this landscape, we evaluate the impact of FSC certification of three PMFSs (Cikel – Rio Capim, Cikel Brasil Verde Madeiras Ltda - Fazenda Jutaituba, and Orsa Florestal S.A.) by constructing synthetic controls from donor pools of non-certified PMFSs (i.e. PMFSs that have never been certified) in the same *zonas madeireiras* (estuário or Belém-Brasília). This ensures similarity of contextual conditions such as forest type and qualifications of local labor force among certified and comparison PMFSs (henceforth, FMUs). Map 1 shows the locations of the three study FMUs and their donor pools, as well as other FMUs in the Brazilian Amazon that were certified outside of our time frame for the analysis.



Map 1: Locations of PMFSs certified prior to 2010, PMFSs certified in 2010 - 2016, cancelled FSC certificates (in the Brazilian Amazon); and non-certified PMFSs (in the two zones with PMFS certified prior to 2010)

Trends in deforestation

The boxplots in Figures 6 and 7 show how percent tree cover loss (deforestation) was distributed across the years from 2001 to 2012 in each FMU in the two zones of interest. In Estuário, most (74%) of FMUs have a mean annual percent deforestation below 0.20%. In Belém-Brasília, fewer than half (44%) of the FMUs have a mean annual percent deforestation below 0.20%.

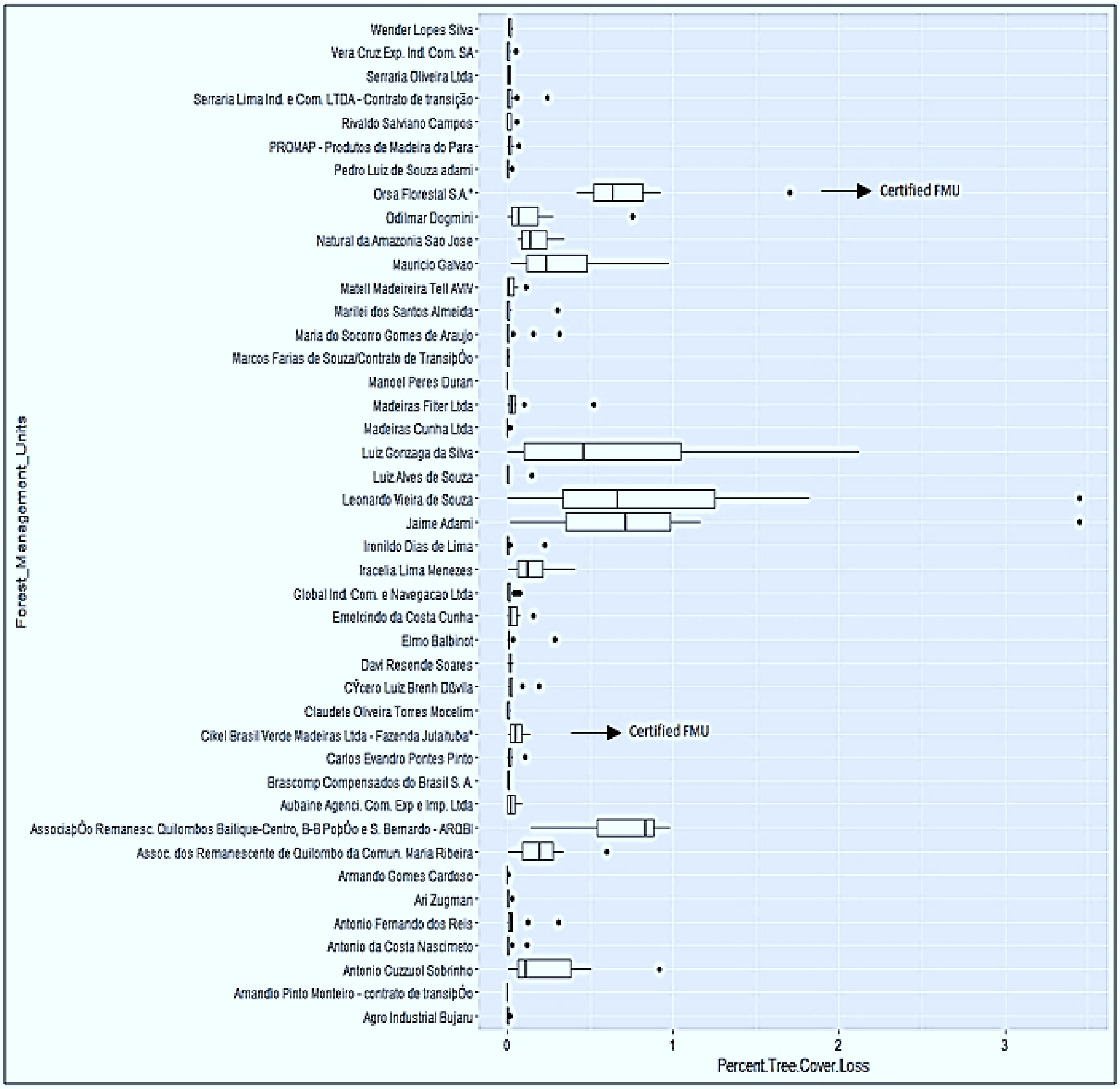


Figure 6: Distribution of percent deforestation across the years 2001-2012 for each FMU in Estuário (omitting outliers to improve presentation[5]). The box is the interquartile range (IQR, from Q1 to Q3), and the line across the box is the median value (Q2). Whiskers represent values that are no more than 1.5 times the length of the box from the end of the box. Values less than 1.5*IQR below Q1 or greater than 1.5*IQR above Q3 are shown as dots. The two certified FMUs are indicated with arrows.

[5] Omitting four outlier FMUs: Antonio Marcos Quadro Cunha, Gerson Cei Souza, Silvio Florestal Abaete Ltda and Antonia Maciel dos Santos.

Figure 7: The distribution of percent deforestation across the years 2001-2012 for each FMU in Belém-Brasília (omitting outlier FMU to improve presentation[6]). The box is the interquartile range (from Q1 to Q3), and the line across the box is the median value (Q2). Whiskers represent values that are no more than 1.5 times the length of the box from the end of the box. Values less than 1.5*IQR below Q1 or greater than 1.5*IQR above Q3 are shown as dots. The certified FMU is indicated with an arrow.

[6] Omitted FMU is Noila Araldi Balbinot.

Naïve comparison of deforestation

We start by comparing deforestation in the certified FMUs to average deforestation in non-certified FMUs (omitting FMUs certified outside of our time range). This naïve approach to estimating the impact of FSC certification provides a useful benchmark for estimates of the causal effects. As shown in Table 10, in Estuário, in the time period before certification, the rate of deforestation was higher in FMUs that later became certified. After certification, the rate of deforestation was lower in certified FMUs in four out of seven years and on average. On the other hand, in Belém-Brasília, the rate of deforestation was higher in non-certified FMUs in every year, both before and after certification. (See Appendix (E) for alternative method of comparing randomly selected pixels inside and outside certified FMUs.) This suggests both that certification may attract FMUs with lower rates of deforestation (in Belem-Brasília), and that certification may lower deforestation (in Estuário).

Table 10: Annual percent deforestation in certified and never-certified FMUs in Estuário and Belém-Brasília (excluding any FMUs that were certified before 2004 or after 2010).

Year	Estuário		Belém-Brasília	
	Certified FMUs	Never-certified FMUs	Certified FMU	Never-certified FMUs
2001	0.29	0.10	0.01	0.72
2002	0.40	0.19	0.03	0.65
2003	0.35	0.05	0.02	0.58
2004	0.49	0.48	0.07	1.00
2005	0.29	0.20	0.27	1.17
2006	0.25	0.30	0.03	0.98
2007	0.27	0.99	0.13	0.87
2008	0.38	0.52	0.24	0.76
2009	0.86	0.35	0.02	0.79
2010	0.47	0.68	0.02	1.89
2011	0.40	0.16	0.05	1.17
2012	0.24	0.13	0.004	1.33
Average	0.39	0.35	0.07	0.99
Average in years after certification[7]	0.41	0.45	0.07	1.12

[7] In Estuário, one FMU was certified in 2004 and another in 2006. We report average percent deforestation from 2006 to 2012. Shaded area corresponds to years when all FMUs in certified columns were certified.

Impact evaluation using SCM

Covariates used to construct synthetic controls

The spatio-temporal distribution of deforestation in Brazil is shaped by a range of socio-economic, political, and bio-physical factors (Pfaff et al. 2007; Voigtlaender 2015). Table 11 lists the factors considered as potential covariates in the Synthetic Control Matching (SCM), in addition to the bio-physical covariates listed in Table 9. We identified factors from previous literature on the Brazilian Amazon and then defined proxy measures based on available data, focusing on measures that are available across the tropics for consistency with the analyses in Gabon and Indonesia.[8] Many of these factors are confounders in the sense that they influence both the decision whether to certify and deforestation. For example, the probability of certification is likely related to the timber stock in the FMU, which in turn depends on both its size and its prior tree cover. Larger FMUs are more likely to remain certified over a longer period (Zerbini, 2014; Voigtlaender, 2015). Of course, a larger timber stock may also make a FMU more attractive to illegal loggers and therefore more susceptible to deforestation. Likewise, the accessibility of a FMU, which we represent by distances to nearest settlement and timber pole, may influence the probabilities of certification and deforestation. These potential causal mechanisms are also described in Table 11.

Table 11. Description of covariates

Variable	Description	Units	Spatial unit	Year	Source	Plausible causal mechanism
Distance from settlement	Distance from closest settlement	Km	Point	2000	Global rural-urban mapping project (GRUMP), v1 (2000) - http://sedac.ciesin.columbia.edu/data/set/grump-v1-settlement-points (CIESIN)	Von Thunen theory and a large body of empirical evidence suggest higher probability of deforestation closer to settlements.
Distance from timber pole, or wood processing center	Distance from closest "Polo madeireiro"	Km	Point	2004	Location of polos madeireiros from Pereira et al., 2010 "Fatos Florestais da Amazonia 2010" http://imazon.org.br/publicacoes/fatos-florestais-da-amazonia-2010/	Better access to wood processing centers is likely to encourage both legal and illegal logging, which can result in temporary deforestation, finance deforestation, or provide access for agents of deforestation (Foley et al. 2007; Asner et al. 2004).

[8] In addition to the pan-tropical datasets described above, we draw on country-specific data from the Instituto Brasileiro de Geografia e Estatística (IBGE, Brazilian Institute of Geography and Statistics) and ImazonGeo. ImazonGeo (http://www.imazongeo.org.br/doc/downloads.php) compiles and makes available for download spatial information on the Amazon including: (1) timber routes - locations of the principal axes along which logs are moved, (2) Meat-packing plants – location and slaughter capacity of plants, (3) Logging frontiers – locations of major logging frontiers, classified according to forest type, age of the frontier and access conditions, (4) "Timber poles" – clusters of wood processing industries that process >100,000 m^3 / year of roundwood, and (5) polygons of deforestation and degradation identified by a deforestation alert system (DPS). ImazonGeo also contains spatial data on geo-physical factors like vegetation, soil, land use capacity, geology, biodiversity, and ecological zonation.

Distance from protected area	Distance from closest protected area	Km	Polygon	2014	UNEP-WCMC, UNEP, and IUCN. "World Database on Protected Areas." Accessed in April, 2014. www.protectedplanet.net.	Spill-over of monitoring and supervision from protected areas may decrease the probability of deforestation in nearby FMUs.
Poverty count	Poverty count	Number	1 Km (approx.)	2004	Global poverty estimates. National Geophysical Data Center (NGDC) data products http://www.ngdc.noaa.gov/eog/dmsp.html	Poverty may affect relations between FMUs and local communities, and may drive deforestation, depending on the context (Atmadja and Sills 2016).

Clearly, our covariates do not include all potential confounders. For example, unclear and conflicting land tenure and associated illegal logging and logging roads are important determinants of the extent and patterns of deforestation (Romero et al. 2015; Carneiro, 2007; Lentini et al. 2012, Marquesini and Edwards, 2001), and also affect the desirability and uptake of FSC certification (Lentini et al. 2012). Likewise, social conflicts over land and related NGO involvement may present a barrier to certification (Voigtlaender, 2015) and encourage deforestation as a way to stake a claim to the disputed land. To the extent that these missing covariates are long-standing influences on deforestation, they are represented by historical trends in the outcome variable (deforestation) in the nested optimization process.

Table 12 (a, b) presents descriptive statistics for the outcome and covariates that we do have available for FMUs in the Estuário zone, and Table 13 (a, b) for the Belém-Brasília zone.

Table 12(a): Descriptive statistics for non-certified FMUs in the Estuário Zone (Donor pool)

(i) Deforestation

	N	Mean	Standard Deviation	Median	Minimum	Maximum	Range
Annual percent deforestation (2001 to 2012, average)	44	0.25	1.16	0.01	0	18.09	18.09

(ii) Covariates

Covariates							
Tree cover 2000	44	6788.91	15600.71	2260.71	74.88	66671.64	66596.76
Altitude	44	39.21	16.52	34.95	9.51	78.11	68.6
Mean temperature	44	26.64	0.66	26.74	22.72	27.09	4.37
Mean precipitation	44	250.79	17.45	249.66	216.01	302.51	86.5
Area of FMU	44	73.76	170.74	24.37	0.93	716.91	715.98

Monitoring cost	44	1.45	0.4	1.32	1.11	3.11	1.99
Poverty count	44	118.38	285.88	25.21	0	1725.96	1725.96
Distance from settlement	44	77.28	31.93	77.17	8.06	134.41	126.36
Distance from timber pole	44	55.97	23.32	56.36	6.14	102.62	96.48
Distance from protected area	44	24.31	19.62	20.05	0	67.61	67.61

Table 12 (b): Characteristics of the certified FMUs: **Cikel Brasil Verde Madeiras Ltda - Fazenda Jutaituba (Cikel) and Orsa Florestal S.A. (Orsa)**

(i) Deforestation

	Cikel	Orsa
Annual percent deforestation (2001 to 2012, average)	0.055	0.73

(ii) Covariates

Tree Cover	147481.9	747538.78
Altitude	57.18	107.81
Mean Temperature	26.9	26.64
Mean precipitation	246.14	209.9
Distance from settlement	53.38	31.68
Distance from timber pole	61.48	29.26
Distance from protected area	0	0
Poverty count	7775.38	3179.95
Area of the FMU	1604.81	9105.08
Monitoring cost	1.89	2.79

Table 13(a): Descriptive statistics for non-certified FMUs in Belém-Brasília (Donor pool)

(i) Deforestation

	n	Mean	Standard Deviation	Median	Range	Standard Error
Percent deforestation (2001 to 2012, average)	106	0.81	1.14	0.33	7.20	0.11

(ii) Covariates

Tree cover 2000	106	3827.34	5597.12	2167.01	35648.9	543.64
Altitude	106	102.66	49.58	86.73	227.62	4.82
Mean temperature	106	26.64	0.51	26.73	4.55	0.05
Mean precipitation	106	218.14	23.92	224.04	107.3	2.32
Distance from settlement	106	51.93	21.92	52.12	101.62	2.13
Distance from timber pole	106	42	18.57	42.71	84.62	1.8
Distance from protected area	106	25.32	20.83	20.29	91.14	2.02
Poverty count	106	103	217.32	37.11	1418.5	21.11
Area of the FMU	106	44.15	61.99	25.33	401.49	6.02
Monitoring cost	106	1.8	1.68	1.36	14.46	0.16

Table 13(b): Characteristics of the certified FMU - Cikel Rio Capim

(i) Deforestation

Percent deforestation (2001 to 2012, average)	0.08

(ii) Covariates

Tree cover 2000	189,005
Altitude	117.22
Mean temperature	26.76

Mean precipitation	214.14
Distance from settlement	55.7
Distance from timber pole	32.85
Distance from protected area	4.03
Poverty count	1414.4
Area of the FMU	2062.02
Monitoring cost	3.86

Implementation of synthetic control method

Covariates selected to construct synthetic controls

For each certified FMU, we implemented the nested optimization process to construct synthetic controls using the SYNTH package.

Orsa Florestal S.A.: Four covariates contribute the most (sum of weights > 74%) to construction of the synthetic control for Orsa (Appendix B (a)). These are listed below in order of their contribution:

(i) *Percent deforestation (2001-2005).* This covariate has the highest weight (36%) in the construction of synthetic control. This means that the average historical rate of deforestation is among the best predictors of the deforestation rate in any given year. This suggests some inertia or path dependence in forest loss.

(ii) *Distance from protected area.* This variable is allocated a weight of 17% by the nested optimization process. Possible explanations for this large weight include that proximity to protected areas increases enforcement of forest laws in nearby FMUs or that deforestation pressures are displaced from protected areas to those nearby FMUs.

(iii) *Distance from timber pole*. The distance from a FMU to the nearest wood-processing center has a weight of 11% in the construction of the synthetic control. This distance is likely inversely related to logging activity (both legal and illegal) and both temporary loss of tree cover in tree-fall gaps and permanent loss of tree cover due to the entry of deforestation agents along logging roads.

(iv) *Distance from settlement*. This covariate has a weight of 10%, confirming the large body of literature on deforestation that links the probability of forest conversion to proximity to market.

Cikel Rio Capim: In the case of this FMU, we find that two covariates contribute about 94% of the total weight used to construct the synthetic control (Appendix B (b)).

(i) *Area:* We expected larger FMUs to experience higher rates of deforestation due to the difficulty of monitoring all parts of the FMU, and the resultant higher likelihood of illegal activity. We find that this covariate contributes the most (47%) to the construction of the synthetic control for Cikel Rio Capim.

(ii) *Tree cover (2000).* This covariate also has a weight of 47% in the construction of synthetic control. This indicates that FMUs with similar initial tree cover are likely to have similar rates of deforestation.

<u>Cikel Brasil Verde Madeiras Ltda – Fazenda Jutaituba</u>: The synthetic control for this FMU is based largely on the following two covariates (Appendix B (c)).

(i) *Mean annual precipitation*: This covariate has a weight of 37%. One possible explanation is that excessive precipitation limits the profitability of agriculture, thereby reducing pressure demand for cleared land.

(ii) *Distance from protected area*: This variable has the second largest weight (28%). The distance of FMUs from protected areas could influence long-term trajectories of forest loss through spillover of protection efforts or deforestation pressures.

Plausibility of synthetic controls

While the nested optimization routine in SYNTH always identifies a weighted combination of control units that is more similar to the treated unit than the simple average of all units in the donor pool, it is not always possible to identify a weighted combination that closely replicates the outcome of the treated unit in the pre-treatment or calibration period. Thus, before examining results, we first assess the plausibility of the synthetic controls as estimators of what would have happened in the certified FMU without certification.

Among the certified FMUs in Brazil, the best quality – or most plausible – synthetic control is for Orsa Florestal (column 2 of Table 14). Two caveats are: (1) there is a very small window of pre-treatment years to judge the similarity between the past deforestation behavior (trajectory) of the certified FMU and its synthetic control, and (2) visual assessment of turning points is always subjective.

Table 14: Plausibility of the synthetic control as the counterfactual

Forest Management Unit (PMFS)	Plausibility of Synthetic Control
Orsa Florestal S.A.	Medium Plausibility 1) MSPE = 0.029 2) All turning points in deforestation trends matched between certified FMU and Synthetic Control (Figure 8). 3) Deforestation in year before treatment in synthetic control is almost equal to that of the treated unit.

Cikel Rio Capim	Low Plausibility 1) MSPE = 0.054 2) Most turning points in deforestation trends matched between certified FMU and Synthetic Control (Figure 9). 3) Deforestation in year before treatment in synthetic control six times higher than in treated unit.
Cikel Brasil Verde Madeiras Ltda - Fazenda Jutaituba	Low Plausibility 1) MSPE = 0.001 2) Half of the turning points in deforestation trends mis-matched between certified FMU and Synthetic Control (Figure 10). 3) Deforestation in year before treatment in synthetic control is 75% of the level in treated unit.

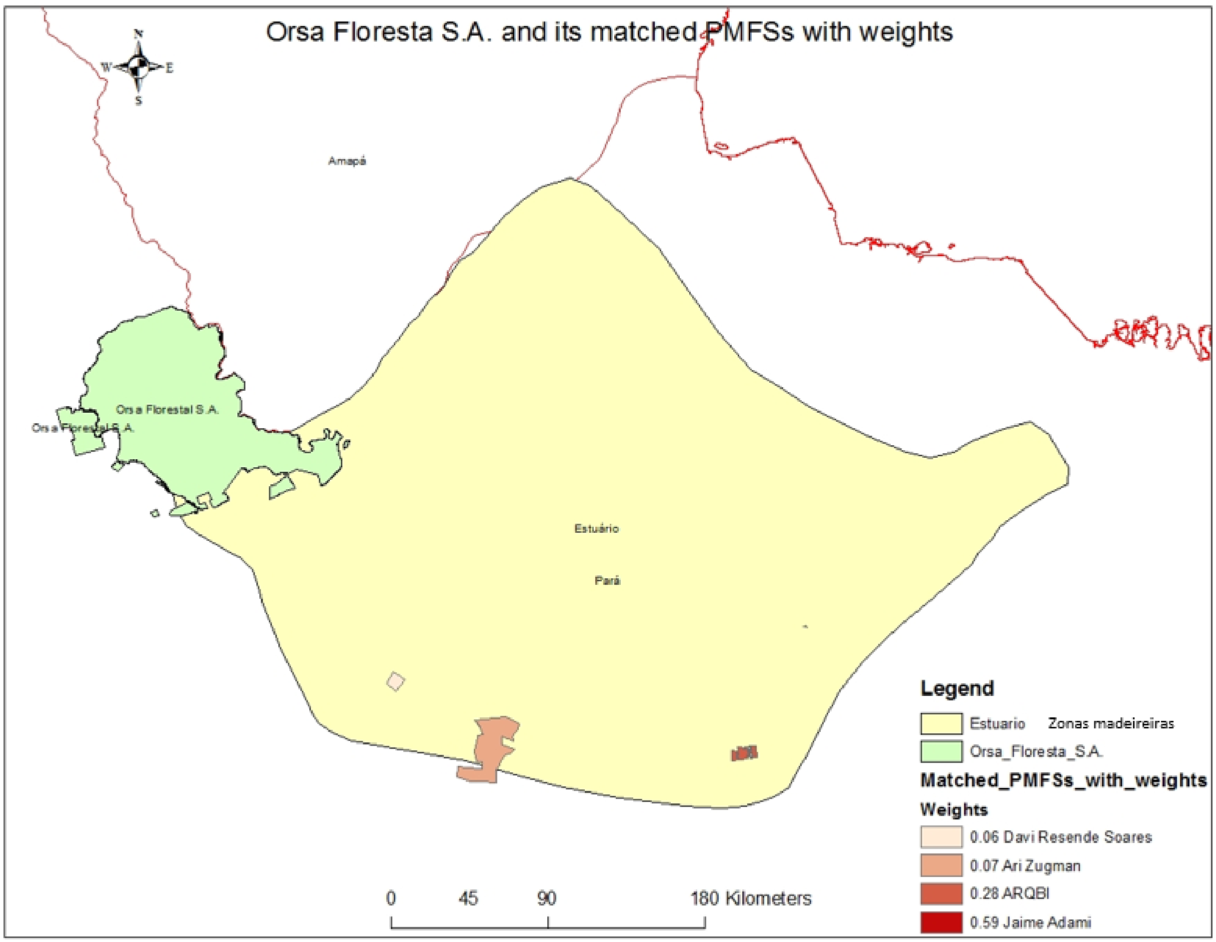
Results

For each of the three certified FMUs, we first present a map showing the non-certified FMUs with substantial (>5%) weights in their synthetic control, then a figure showing deforestation rates in the certified unit and its synthetic control both prior to certification (the calibration period) and after certification (the results period). In these figures, deforestation (loss of tree cover that existed in 2000), increases down the Y axis (i.e. the Y axis is the negative of deforestation). Thus, the desired outcome is for the certified unit to be higher than the synthetic control. The next table compares deforestation rates in the certified FMU, the average of all non-certified FMUs, and the synthetic control. The final table presents the estimated treatment effects, or the difference in deforestation rate between the certified unit and its synthetic control, along with confidence intervals reflecting the 10th and 90th percentiles of the placebo tests.

Summarizing across the three certified FMUs, the point estimates consistently show that certification reduced deforestation in the year immediately after certification and in the most recent year in our data (2012). These impacts are statistically significant only at the 80% level in Orsa Florestal, but not in Cikel Brasil Verde Madeiras Ltda – Fazenda Jutaituba and Cikel-Rio Capim. In all three, the apparent effect of certification varies over the years between certification and 2012. This highlights a key advantage of SCM: rather than evaluating results for just one year or just one metric, the SCM automatically generates results for all years post-treatment included in the dataset. SCM also allows results to vary across units, as we describe next.

Orsa Florestal S.A (Estuario Zone)

Map 2 shows the weights assigned to control FMUs in the synthetic control for Orsa Florestal. Only FMUs with substantial (> 0.05) weights are depicted in the map. Figure 8 compares deforestation in Orsa Florestal and its synthetic control. The deforestation trajectories are similar but not a perfect match in the pre-certification period (MSPE = 0.029). After certification, there is no consistent difference, with deforestation rate higher in the synthetic control in some years and lower in others (see Appendix A (1) for percent deforestation in Orsa Florestal and synthetic control in each year).



Map 2: Orsa Floresta S.A. and its matched PMFSs with weights

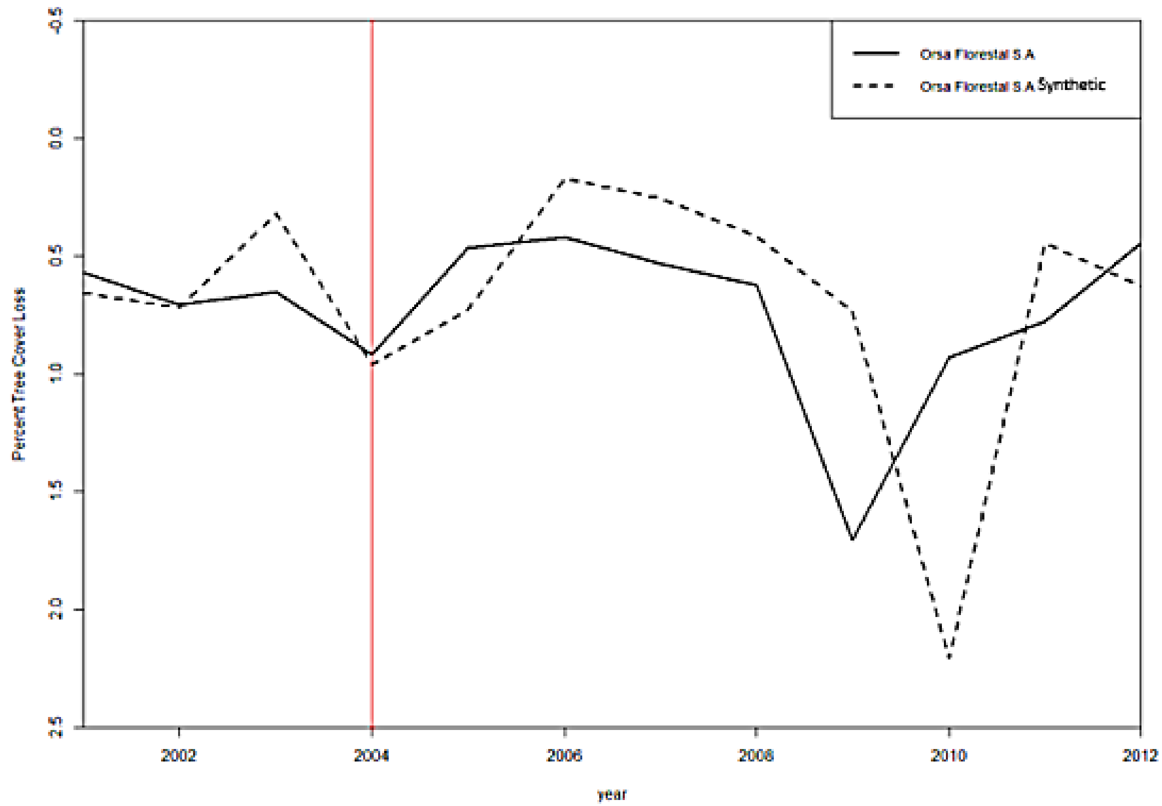


Figure 8: Comparison of Orsa Florestal and its synthetic control, 2001-2012. Deforestation decreases as move up the Y-axis, i.e. more forest is conserved as move up the Y-axis.

Placebo tests

Table 15 lists percent deforestation in Orsa Florestal, the difference with percent deforestation in the synthetic control, and the 10th and 90th percentiles of placebo treatment effects for all FMUs in the donor pool. The estimated effects of certification on deforestation in Orsa Florestal are statistically different from zero, that is, they fall outside of the 10th to 90th percentiles (also outside of the 5th to 95th percentiles, although not reported in table). Thus, certification of Orsa Florestal does appear to impact deforestation, but not always in the expected direction. In the first year after certification, it appears to reduce deforestation. But after that, certification appears to increase deforestation for the next four years followed by a reduction in deforestation in the sixth year.

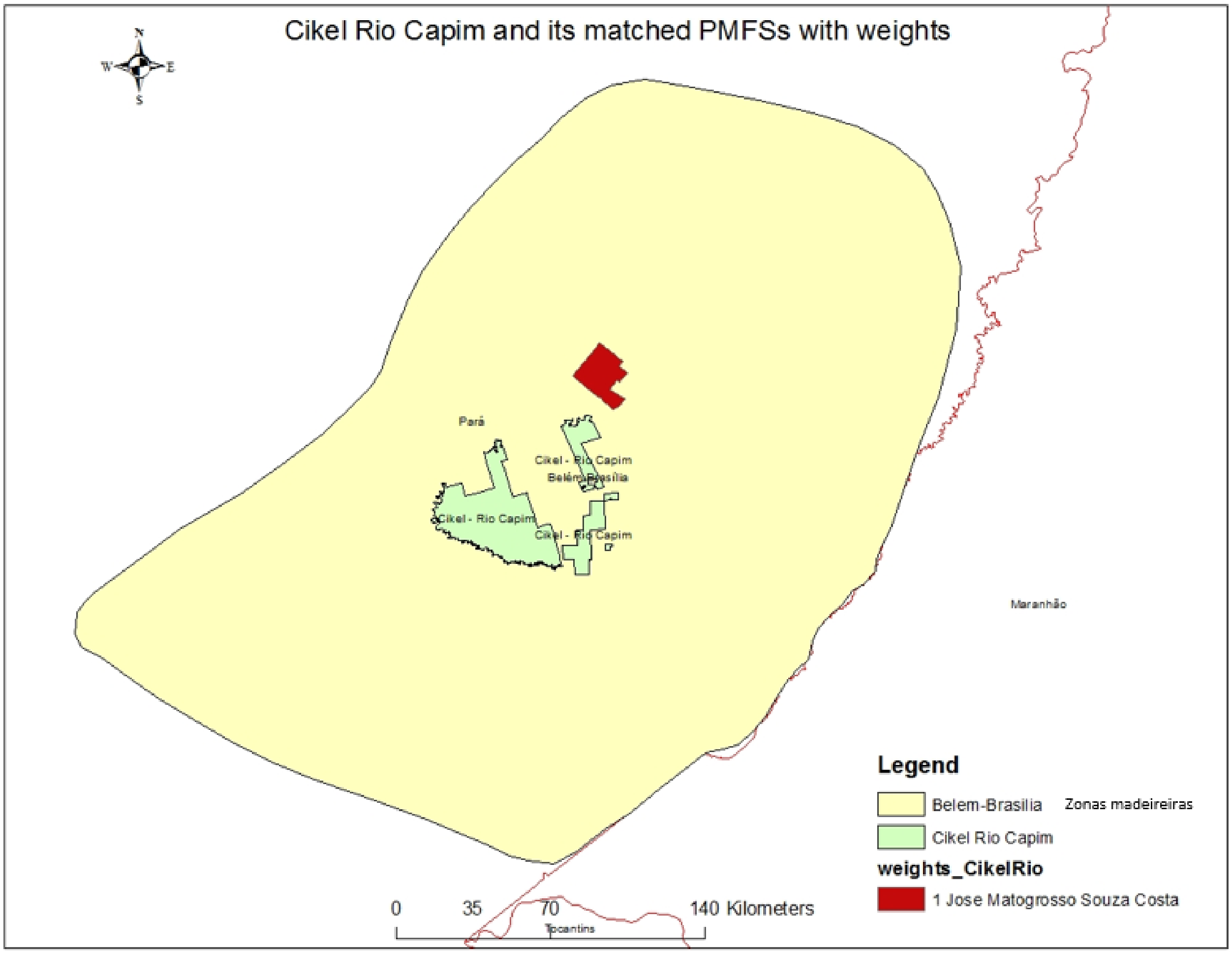
Table 15: Significance of the estimated effects of certification on deforestation in Orsa Florestal (10th and 90th percentiles of the placebos treatment effects, 80% confidence interval)

Year	Actual percent deforestation in Orsa Florestal, S.A. (Observed)	Treatment effect of certification on deforestation in Orsa Florestal, S.A.	10th and 90th percentiles of the placebo treatment effects‡
2005	0.47	-0.26*	-0.03 to 0.03
2006	0.42	0.25*	-0.25 to 0.03
2007	0.53	0.28*	-0.22 to 0.02
2008	0.62	0.20*	-0.19 to 0.02
2009	1.70	0.97*	-0.03 to 0.13
2010	0.93	-1.28*	-0.12 to 0.20
2011	0.78	0.33*	-0.30 to 0.21
2012	0.44	-0.18*	-0.09 to 0.08

* Significant at 80% level, as determined by whether the estimated effects fall within or outside of the 10^{th} to 90^{th} percentiles of the placebo treatment effects (80% confidence interval). All treatment effects also fall outside 5^{th} to 95^{th} percentiles of placebo treatment effects (90% confidence interval).
‡ Confidence intervals based on estimated treatment effects of placebos with MSPE less than the MSPE of Orsa Florestal (the treated unit).

Cikel Rio Capim (Belem-Brasilia Zone)

Figure 9 suggests that the synthetic control for Cikel is not a plausible representation of its counterfactual, as the deforestation trajectories are poorly matched prior to certification (MSPE= 0.053). We present the estimation results here in order to demonstrate the method, but we have little confidence that they accurately represent the impact of certification on Cikel. Map 3 shows that only one non-certified FMU received any significant weight in the synthetic control. Figure 9 shows that deforestation in the synthetic control was always higher than deforestation in Cikel in the period prior to certification. Appendix (A (2)) confirms that Cikel had lower deforestation than both the average of the donor pool and the synthetic control for the entire study period (before and after the certification).



Map 3: Cikel Rio Capim and the single PMFS included in the synthetic control

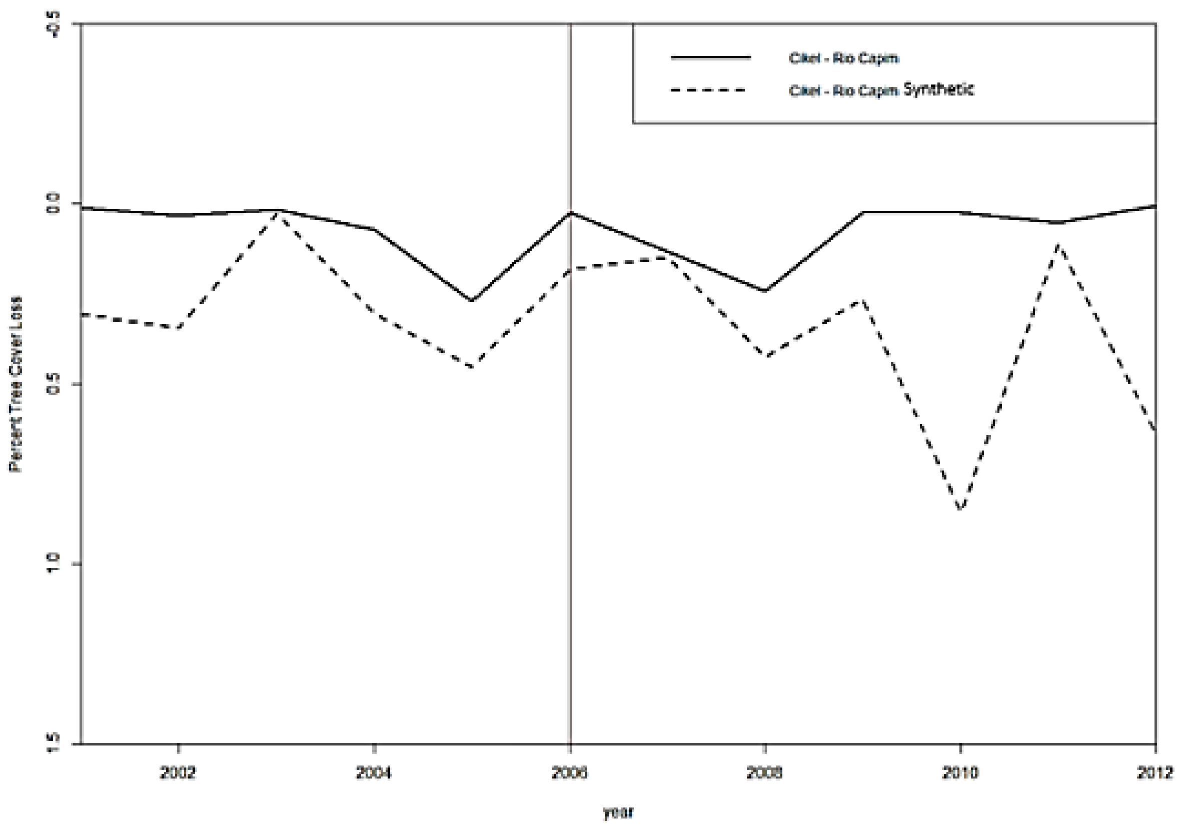


Figure 9: Comparison of certified PMFS and its synthetic control from 2001-2012. The y-axis shows percent deforestation, with less deforestation as move up the y-axis.

Placebo tests

As shown in Table 16, none of the effects are statistically different from zero. This may be because certification did not affect the deforestation trajectory in this FMU, or it may be because the true effect is not revealed by the poor quality synthetic control.

Table 16: Significance of the effects of certification on deforestation in the certified FMU (10th and 90th percentiles of the placebo treatment effects, 80% confidence interval)

Year	Actual deforestation in Cikel Rio Capim (Observed)	Treatment effect of certification on deforestation in Cikel Rio Capim[9]	10th and 90th percentiles of the placebo treatment effects[‡]
2007	0.13	-0.02	-1.58 to 0.74
2008	0.24	-0.18	-1.12 to 0.79

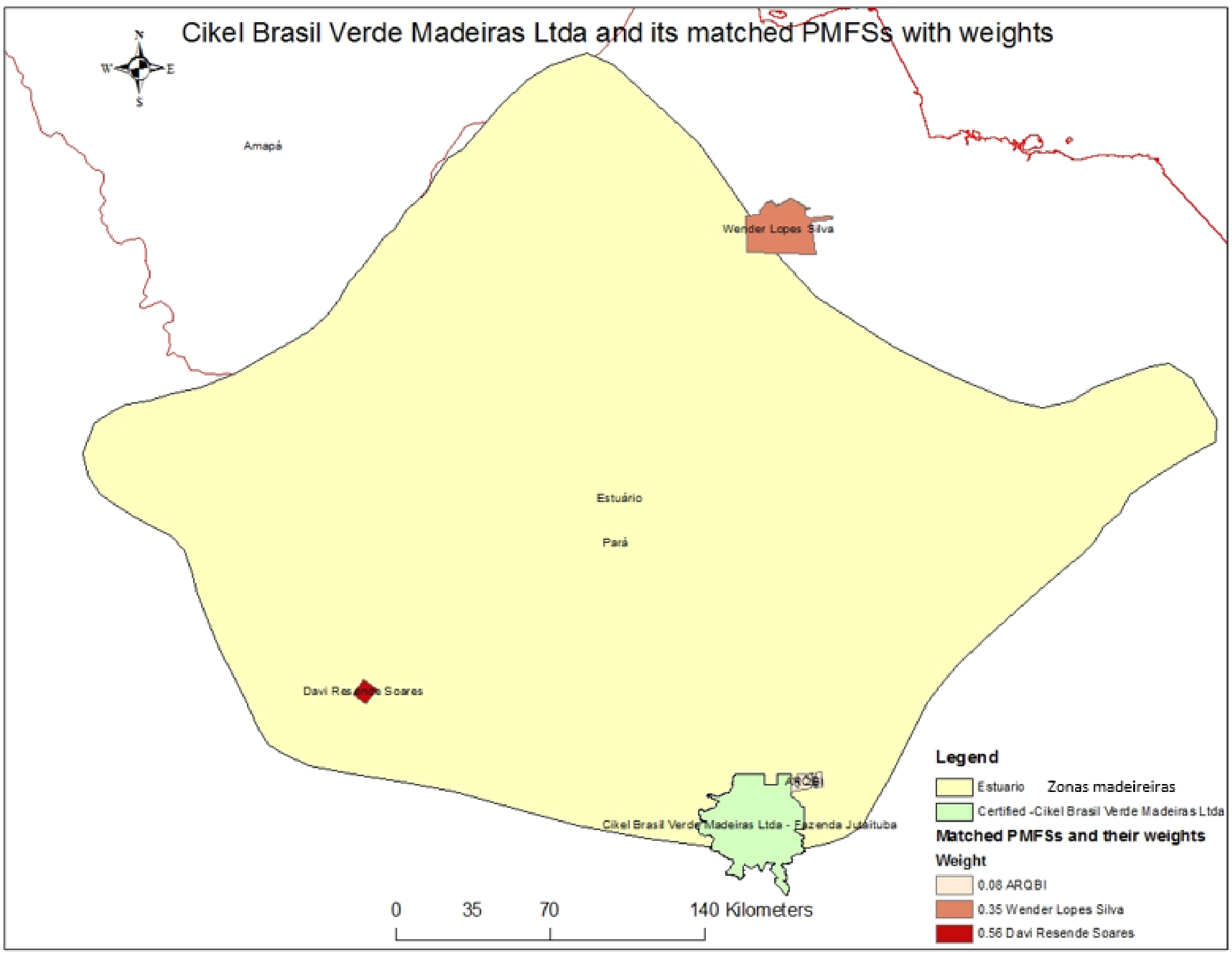
[9] All estimated treatment effects are insignificant as they fall within the 10th and 90th percentiles of the placebo treatment effects and therefore, are not statistically different from zero.

2009	0.02	-0.24	-1.49 to 0.33
2010	0.02	-0.83	-4.38 to 0.65
2011	0.05	-0.06	-2.52 to 0.54
2012	0.004	-0.63	-3.50 to 0.69

‡ Confidence intervals based on estimated treatment effects on placebos with MSPE less than the MSPE of Cikel Rio Capim (the treated unit).

Cikel Brasil Verde Madeiras Ltda - Fazenda Jutaituba (Estuario zone)

The synthetic control for Cikel Brasil Verde Madeiras Ltda – Fazenda Jutaituba (CBVM) places significant weights on the four FMUs shown in Map 4.



Map 4: CBVM and matched PMFSs included in synthetic control with colors indicating weights

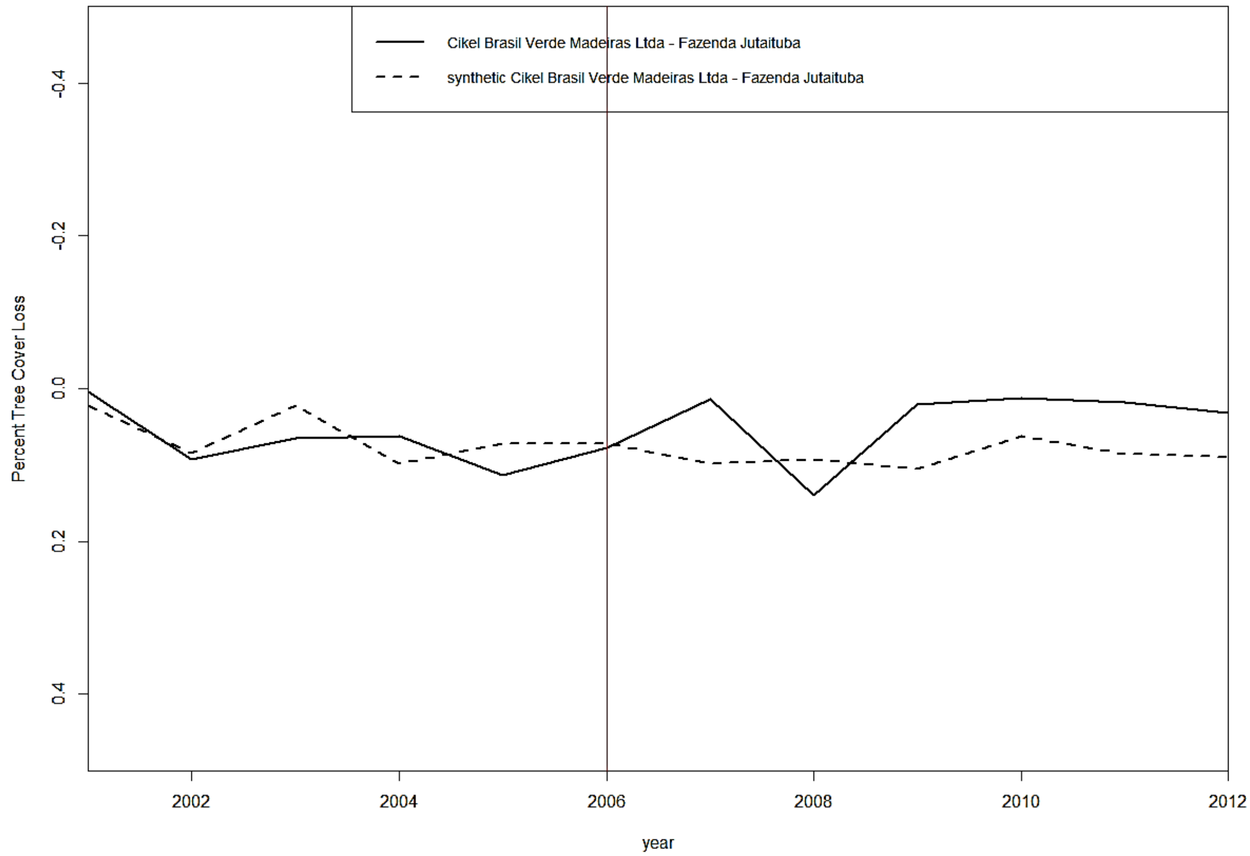


Figure 10: Comparison of treated FMU (CBVM) and its synthetic control 2001-2012

In Figure 10, the solid line shows the actual percent deforestation in CBVM (which became certified in 2010), while the dotted line shows the percent deforestation in the synthetic control. After 2008 (two years after certification), there is less deforestation in CBVM compared to its synthetic control. (See Appendix (A (3)) for percent deforestation in CBVM and its synthetic control.)

Placebo tests

Table 17 shows that, in the six years after the certification of CBVM, there were significant treatment effects at the 80% confidence level (falling outside of the 10th to 90th percentiles of the placebo treatment effects) in four years. Immediately after the introduction of certification, it reduces deforestation in CBVM. This reduction is followed by an increase in deforestation in the second year. Thereafter, deforestation declines in the certified FMU, to levels significantly below the synthetic control in 2009 and 2012.

Table 17: Effect of certification (10th and 90th percentiles of the placebo treatment effects)

Year	Actual percent deforestation in CBVM (observed)	Treatment effect of certification on deforestation in CBVM	10th and 90th percentiles of the placebo treatment effects‡
2007	0.015	-0.08*	-0.02 to 0.03
2008	0.140	0.05*	-0.02 to 0.02
2009	0.021	-0.08*	-0.005 to 0.01
2010	0.013	-0.05	-0.2 to 0.03
2011	0.018	-0.07	-0.13 to 0.20
2012	0.032	-0.06*	-0.01 to 0.03

* Significant at 80% level, as determined by whether the estimated effects fall within or outside of the 10th to 90th percentiles of the placebo treatment effects (80% confidence interval).
‡ Confidence intervals based on estimated treatment effects of placebos with MSPE less than the MSPE of CBVM (the treated unit).

The statistical significance of the effects of certification on deforestation in the three certified FMUs that we evaluated are summarized in Table 18.

Table 18: Certification effects on deforestation based on placebo tests

FMU (PMFS)	**Existence and direction of significant effects on deforestation based on placebo tests**
ORSA FLORESTA S.A.	In the first year after certification, it reduced deforestation, i.e. deforestation in Orsa was significantly lower (at the 90% level) than deforestation in its synthetic control. However, in the next four years (2006 to 2009), deforestation was lower in the synthetic control than in the certified PMFS. Certification again appears to reduce deforestation in the years 2010 and 2012, but not the intervening year 2011. Thus, SCM reveals that certification has a mixed effect on deforestation, although the raw comparison of deforestation in Orsa and all non-certified PMFS shows higher deforestation in Orsa.
CIKEL RIO CAPIM	No significant effect of certification in any year after introduction of forest certification.
CBVM (Cikel Brasil Verde Madeiras Ltda - Fazenda Jutaituba)	In the first year after certification, it reduced deforestation, i.e. deforestation in Fazenda Jutaituba was significantly lower (at the 80% level) than deforestation in its synthetic control. However, in 2008 and 2009, deforestation in Fazenda Jutaituba was significantly greater than in its synthetic control. In 2012, certification again has a significant negative impact on deforestation.

Spatial filtering to distinguish tree cover loss due to logging and to deforestation

Tree cover loss may result from either (i) forest management activities, especially conventional selective logging, including construction of logging roads and decks, or (ii) deforestation, i.e. permanent conversion of forest to another land use. Certification seeks to reduce both types of tree cover loss, by requiring adoption of reduced impact logging practices that limit damage to the residual stand through careful planning, felling, and extraction of logs, and by requiring long-term management and protection of the FMU, including prevention of competing land uses. In this section, we apply spatial filtering to distinguish these two types of tree cover loss. Recognizing that tree cover loss due to logging it likely to occur in small patches (e.g., tree fall gaps) or thin lines (e.g., skid trails), we assume that any pixel of tree cover loss surrounded by other pixels of tree cover loss in the same year represents deforestation, rather than logging. On the other hand, smaller patches of tree cover loss pixels may be the result of logging or other forest management operations.

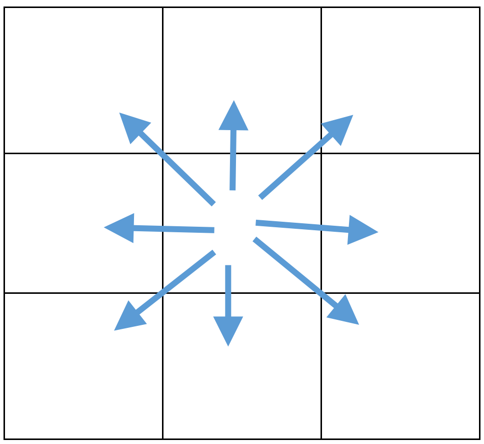


Figure 11: Illustration of the queen-continuity neighborhood window

Specifically, we identified clusters of tree cover loss pixels in each year using a queen-continuity search window, as shown in figure 11. Clusters of 5 or more pixels are interpreted as deforestation, while clusters of 4 or fewer pixels of tree cover loss may be the result of active forest management or timber harvest. Thus, we identity the following two types of tree cover loss in each FMU in each year from 2001 to 2012:

I) **Tree cover loss that may be due to logging:** Any individual pixel or any group of 4 or fewer pixels of tree cover loss in a given year. The limit of 4 pixels (3600 sq.m.) means that no tree cover loss pixel is surrounded by other tree cover loss pixels (on all four sides). This pattern therefore represents either highly fragmented or linear forest disturbances, which could be associated with felling and extraction of trees.

II) **Tree cover loss that likely represents deforestation:** Clusters of more than 4 pixels of tree cover loss in a given year are likely to represent deforestation for agriculture, plantation crops, or pasture.

To verify that this is a reasonable classification and interpretation, we visually interpreted the distribution of clusters of tree cover loss pixels using Google Earth. Selective logging and associated logging roads and landings do appear to be associated with isolated clusters of tree cover loss (with 4 or fewer pixels). Of course, more carefully planned reduced impact logging may be significantly less likely to result in detectable tree cover loss, and conventional logging could result in larger clusters of tree cover loss. Thus, we do not claim that our spatial filtering results in an exact measure, but rather an indication of which tree cover loss pixels are more likely to represent deforestation and which are more likely to represent logging.

We then apply the same methods as above to estimate the impact of certification on each type of tree cover loss (possibly associated with logging and likely to represent deforestation) in each of the three certified FMUs. We use the same covariates, the same criteria to judge the plausibility of the synthetic controls, and the same approach to calculating the causal effects of certification:

Treatment effect = Y1 – Yo W*

Where

Y1 is the (T1 x1) vector containing the post-intervention values of tree cover loss (in either small or large clusters) in the certified FMU

Yo is the (T1 X J) matrix containing the post-intervention values of tree cover loss (in either small or large clusters) in the donor pool of FMUs in the same zone.

W = SCM generated weights for the units in the donor pool (W). These weights add to one and all fall between 0 and 1.

Results are presented in Tables 19 - 21. Summarizing, we consistently find that certification reduces small clusters of tree cover loss that may be due to logging. This is consistent with adoption of reduced-impact logging practices, including careful planning of harvests in order to reduce damage to future crop trees, other vegetation and soils. The estimated effects are small in absolute terms, but large relative to the total amount of tree cover loss in this category and relative to the MSPE. Turning to tree cover loss that is more likely associated with deforestation, we do not find any consistent effect across the certified FMUs. In all cases, the sign of the effect switches during the post-certification period, and the magnitude of the effect is also variable. This suggests that large-scale deforestation in FMUs is driven by factors other than certification. One possible explanation is that the managers of all FMUs intend to keep them under forest cover, and thus, any forest cover loss is a result of actions by other agents. Certification in and of itself does not affect the probability of deforestation by those other agents coming from outside the FMU. Note that we have not estimated placebo tests for these effects, and some may fall within the range of statistical noise around zero.

Orsa Florestal

The results for Orsa Florestal (Table 19) show that immediately after the introduction of FSC, there is a reduction in the tree cover loss due to large-scale tree cover loss events, likely representing deforestation, compared to the synthetic control. But in the following years, there are more large clusters of tree cover loss in the certified FMU in all years except 2010 and 2012. In contrast, the percent tree cover loss in small clusters is lower in Orsa Florestal than in its synthetic control in almost all years after the introduction of FSC certification (except 2009).

Table 19: Extent of tree cover loss that is more likely deforestation and more likely logging in Orsa Florestal and its synthetic control

	Year	Y	Y0*W	Effect =Y-Y0*W
DEFORESTATION (clusters >4 pixels or 3600 sq.m.)				
MSPE = 0.04	2001	0.54	0.60	-0.06
	2002	0.45	0.56	-0.11
	2003	0.45	0.31	0.14
	2004	0.81	0.86	-0.05
	2005	0.44	0.78	-0.34
	2006	0.39	0.14	0.25
	2007	0.43	0.22	0.21
	2008	0.59	0.32	0.28
	2009	1.45	0.72	0.73
	2010	0.79	2.38	-1.58
	2011	0.65	0.36	0.29
	2012	0.39	0.54	-0.15
POSSIBLE LOGGING (clusters <=4 pixels)				
MSPE = 0.007	2001	0.03	0.05	-0.02
	2002	0.02	0.14	-0.11
	2003	0.02	0.02	0.00
	2004	0.03	0.09	-0.06
	2005	0.03	0.04	-0.01
	2006	0.02	0.04	-0.01
	2007	0.03	0.04	-0.01
	2008	0.03	0.07	-0.04
	2009	0.06	0.05	0.00
	2010	0.04	0.08	-0.04
	2011	0.03	0.07	-0.03
	2012	0.05	0.10	-0.05

Grey-shaded rows are years with FSC-certification

Cikel Rio Capim

Table 20: Extent of tree cover loss that is more likely deforestation and more likely logging in Cikel Rio Capim and its synthetic control

	Year	Y	Y0*W	ATE =Y-Y0*W
DEFORESTATION (clusters >4 pixels or 3600 sq.m.)				
MSPE = 0.05	2001	0.01	0.26	-0.26
	2002	0.02	0.24	-0.22
	2003	0.01	0.02	-0.01
	2004	0.07	0.27	-0.21
	2005	0.26	0.39	-0.13
	2006	0.02	0.15	-0.13
	2007	0.13	0.08	0.05
	2008	0.23	0.38	-0.15
	2009	0.02	0.24	-0.22
	2010	0.02	0.84	-0.82
	2011	0.05	0.09	-0.05
	2012	0.00	0.65	-0.65
POSSIBLE LOGGING (clusters <=4 pixels)				
MSPE = 0.002	2001	0.01	0.04	-0.04
	2002	0.01	0.06	-0.05
	2003	0.01	0.01	0.00
	2004	0.01	0.03	-0.02
	2005	0.02	0.06	-0.05
	2006	0.00	0.03	-0.03
	2007	0.01	0.07	-0.07
	2008	0.01	0.03	-0.02
	2009	0.00	0.02	-0.01
	2010	0.01	0.03	-0.02
	2011	0.01	0.02	-0.02
	2012	0.00	0.01	-0.01

Grey-shaded rows are years with FSC-certification

The results for Cikel Rio Capim (Table 20) show that immediately after the introduction of the FSC certification, tree cover loss in large clusters (more likely deforestation) is greater than in the matched synthetic control. However, such large loss events decline in Rio Capim in comparison to the synthetic control after the first year, suggesting that certification reduces deforestation over the long run. An important caveat is that the MSPE for this synthetic control is among the largest for any of our synthetic controls (0.05).

Similar to Orsa Florestal, there are fewer small-sized tree cover loss events in Rio Capim compared to its synthetic control after certification, for all years after certification, consistent with better forest management including reduced impact logging practices.

Cikel Brasil Verde Madeiras Ltda –Fazenda Jutaituba

Table 21: Extent of tree cover loss that is more likely deforestation and more likely logging in CBVM and its synthetic control

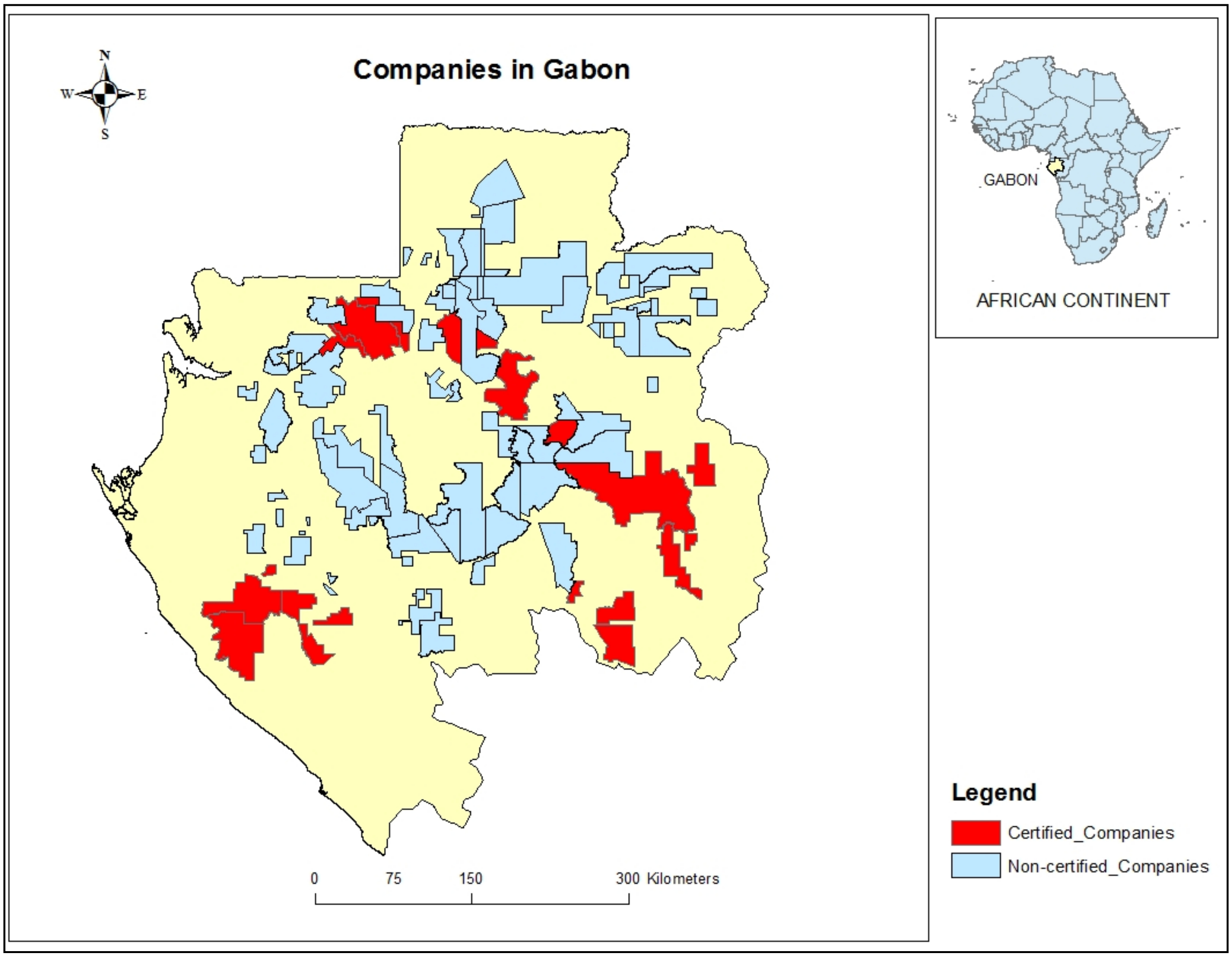
	Year	Y	Y0*W	ATE =Y-Y0*W
DEFORESTATION (clusters >4 pixels or 3600 sq.m.)				
MSPE = 0.002	2001	0.00	0.01	-0.01
	2002	0.08	0.06	0.02
	2003	0.06	0.01	0.04
	2004	0.05	0.07	-0.03
	2005	0.10	0.04	0.06
	2006	0.06	0.04	0.02
	2007	0.01	0.06	-0.05
	2008	0.12	0.06	0.06
	2009	0.01	0.08	-0.07
	2010	0.01	0.04	-0.03
	2011	0.01	0.06	-0.05
	2012	0.01	0.06	-0.05
POSSIBLE LOGGING (clusters <=4 pixels)				
MSPE = 0.0003	2001	0.00	0.01	-0.01
	2002	0.01	0.02	-0.01
	2003	0.01	0.01	0.00
	2004	0.02	0.02	0.00
	2005	0.02	0.03	-0.01
	2006	0.01	0.03	-0.01
	2007	0.00	0.03	-0.02
	2008	0.02	0.02	-0.01
	2009	0.01	0.01	-0.01
	2010	0.01	0.01	-0.01
	2011	0.01	0.02	-0.01
	2012	0.02	0.03	-0.01

Grey-shaded rows show the years with FSC-certification

The results show that after the introduction of FSC-certification, CBVM (Table 21) experienced less large-sized deforestation events than its synthetic control for almost all years (except 2008). Similarly, there were fewer small-sized tree loss events in Fazenda Jutaituba compared to its synthetic control in all years after the introduction of certification. The effect sizes are small, but the MSPE of this synthetic control is also the smallest, suggesting that it is a highly plausible representation of the counterfactual.

5b. Gabon

We evaluate the impact of FSC certification of three companies – Rougier, Precious Wood and Compagnie des Bois du Gabon – on deforestation in their concessions by constructing synthetic controls from non-certified companies that hold timber concessions in Gabon. None of the non-certified companies have ever been certified for forest management. Map 5 shows the concessions held by the three certified companies that we analyzed and by the non-certified companies in the donor pool.



Map 5: Timber concessions in Gabon held by certified companies[10] and non-certified companies

Trends in deforestation

The boxplots (Figure 12) shows the distribution of percent tree cover loss across years (2001-2012) for each FMU. All companies except Hua Jia have median annual percent tree cover loss less than 0.1%.

[10] Each company holds concessions to multiple spatial units. All spatial units under concession to certified companies are included in their certificates. In the general terminology of our report, a "FMU" in Gabon is comprised of all forest areas under concession to a single company.

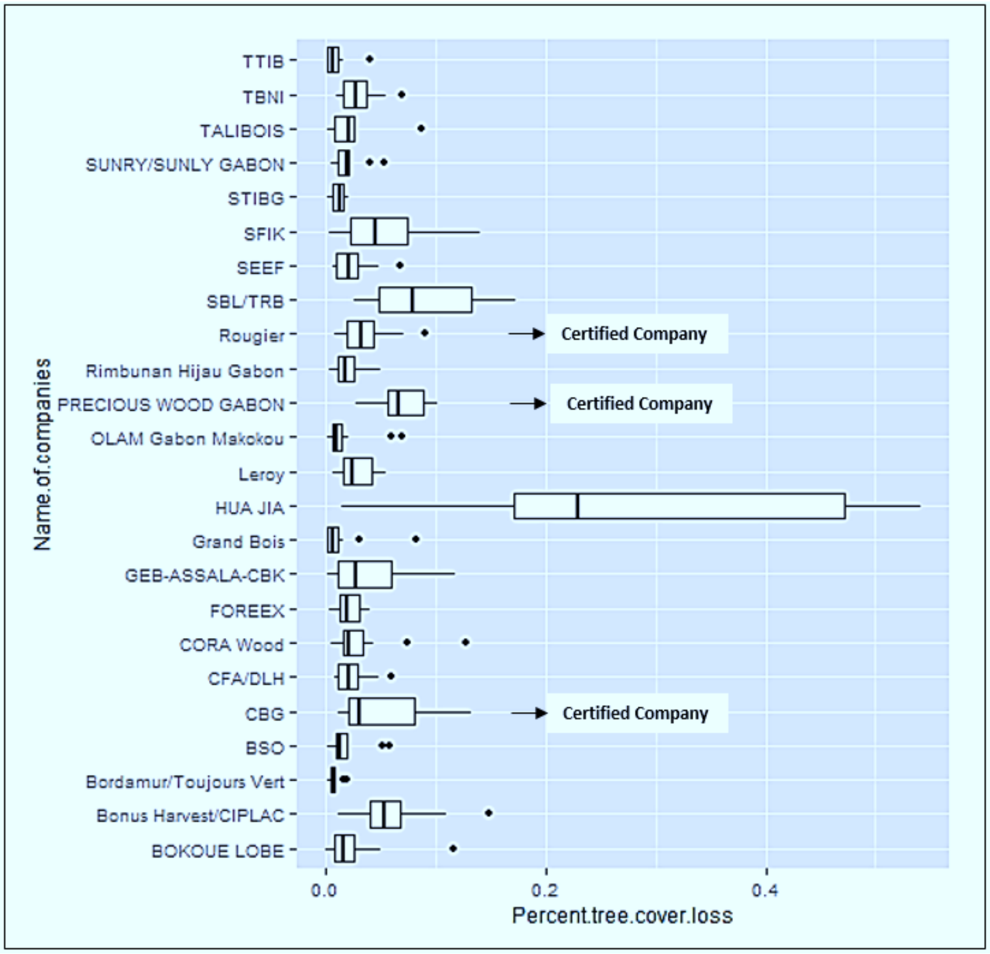


Figure 12: The distribution of the values of percent tree cover loss across years (2001-2012) for each FMU in Gabon. The box of the plot is the interquartile range (IQR) and the line across the box is the median value. Whiskers are 1.5 times the IQR from the end of the box. Values less than 1.5 times the IQR from Q1 or greater than 1.5 times the IQR from Q3 are represented as dots. The certified FMUs are identified with arrows.

Naïve comparison of deforestation

We compare tree cover loss in the certified companies (selected for this study) to average tree cover loss in non-certified companies, as a benchmark for estimates of the impact of FSC certification. As shown in Table 22, before certification in Gabon, the average rate of tree cover loss in companies that later became certified (0.056) was higher than in FMUs that have not gained certification (0.043) and higher than in the certified FMUs after certification (0.048). For non-certified companies, the rate of tree cover loss remained stable, increasing only slightly after certification. See Appendix E for comparison to alternative method of randomly selected points.

Table 22: Annual percent tree cover loss in all FMUs in Gabon. Shaded area of table corresponds to years when all companies in certified columns were certified.

Year	Certified FMUs	Never-certified FMUs
2001	0.03	0.04
2002	0.06	0.05
2003	0.07	0.05
2004	0.04	0.02
2005	0.06	0.04
2006	0.07	0.05
2007	0.06	0.05
2008	0.06	0.04
2009	0.05	0.06
2010	0.05	0.02
2011	0.05	0.04
2012	0.04	0.02
Cumulative average	0.05	0.04
After certification average	0.04	0.04

Impact evaluation using SCM

Variables used in Synthetic Control Matching

The covariates for synthetic control matching should include the observable structural determinants of deforestation. The literature on tropical deforestation suggests that determinants include biophysical conditions, population pressure, governance, and market access.

The timber economy in Gabon relies heavily on a single tree species: Okoume (*Aucoumea klaineana*). The species commands a high price due to its desirable properties for rotary peeling and slicing (Atyi, 2006). Thus, the proportion of a FMU's land area that has Okoume may influence both its proneness to illegal logging or interest in certification. As described in the methods, we include average elevation, precipitation, and temperature to represent the local climate, which affects agricultural productivity, thereby shaping incentives for deforestation.

Gabon's relatively low population density (4.6 persons per sq.km) and high per capita income (USD 9,200 GNI per person) suggest limited pressure to clear forests for agriculture (ITTO, 2003). However, people do have customary subsistence rights over forests and thus we include population density as a possible factor explaining the spatial variation in deforestation. Higher population density could also encourage uptake of certification as a way to demonstrate social responsibility.

There are significant concerns about poor governance capacity in the forestry sector in Gabon (Atyi, 2006, Kaplinsky et al. 2011). We capture this factor with two types of variables: distance from FMU to the nearest city, where the government forest office would normally be located; and size and shape of concession. The size and shape of concessions matters because monitoring and enforcement of is more expensive in large and fragmented FMUs. We consider total area under management by a company, the shape of those areas, and the maximum distance between any two spatial units managed by a company as predictors of the efficacy of monitoring and hence of deforestation outcomes. A larger total area under management may also encourage certification by spreading the transactions costs of obtaining certification over more hectares (Atyi, 2006).

Both von Thünen theory and a large body of empirical evidence suggest that the probability of deforestation is linked to market access. Market access is influenced by timber companies in Gabon, because they construct roads to transfer harvested timber or to fulfill their social responsibilities by connecting villages (Atyi, 2006). We use road density and number of villages to represent market access.

While there are clearly many other factors that affect deforestation, we are limited to variables available from secondary sources. Although we do not know the exact causal mechanisms through which these variables influence the trajectories of the forest deforestation, we suggest some plausible mechanisms in table 23 below.

Table 23. Description of covariates

Covariates

Variable	Description	Measure ment	Spatial Resolution	Year	Source	Plausible causal mechanism
Distance from city	Euclidian distance from nearest city (km)	km	Company	2008	WRI – http://www.wri.org/our-work/project/congo-basin-forests/gabon	Von Thunen theory and a large body of empirical evidence suggest higher probability of deforestation in FMUs closer to settlements.
Quota 2008	Quotas for FMUs in 2008 (halved when a joint quota was shown in the list)	m^3	Company	2008	Statistiques SEPBG (Société d'exploitation des parcs à bois du Gabon).	Higher quotas are likely to be associated with more intensive harvest, which can result in temporary tree cover loss or provide access for agents of deforestation
Exchange rate 2008	Ratio of the CFA Franc (XAF) to the currency of the home country of the company	Ratio	Company	2008	Oanda - http://www.oanda.com/currency/converter/	Higher ratio means exports become more competitive in global market.

Okoume presence	Total area in which okoume is present (Sq.Km)	Sq.Km	Company	2005	Brunck F., Grison F, and Maitre HF, 1990: L'Okoumé (Aucoumea klaineana Pierre), Monographie. Centre Technique Forestier Tropical, Nogent-sur-Marne, 102 p.	Logging in areas with okoume is more profitable.
Number of villages	Number of villages within and in 10KM buffer around FMUs	Number	FMU	2008	WRI – http://www.wri.org/our-work/project/congo-basin-forests/gabon	Number of villages within and in the neighborhood of a company is likely associated with forest loss due to the higher demand for agricultural land and possibly forest products (e.g. fuelwood)..
Population density	Population density within the FMU (2001-2012)	Inhabitants/area	FMU	2001-2012	LandScan 2000-2012, http://web.ornl.gov/sci/landscan/ Based on the LandScan 2006™ High Resolution Global Population Data Set copyrighted by UT-Battelle, LLC, operator of Oak Ridge National Laboratory	Population density in FMU is likely associated with forest loss due to demand for agricultural land and possibly forest products (e.g. fuelwood).
Road density	Density of roads in the FMU	Km per Sq.Km	FMU	2008	WRI – http://www.wri.org/our-work/project/congo-basin-forests/gabon	Greater road density is likely to cause more deforestation mainly due to improved access.
Maximum distance between any two spatial units under concession to the same company	Maximum of the Euclidean distances between each pair of spatial units	Km	FMU	2005	Shapefiles of FMUs – from "Logging." World Resources Institute. Accessed through Global Forest Watch in April, 2014. www.globalforestwatch.org.	The greater the distance between any two spatial units in a FMU, the greater the difficulty of monitoring and protecting the forest.

Descriptive statistics

Table 24(a) Descriptive statistics of non-certified FMUs (donor pool)

(i) Deforestation

	N	Mean	Standard Deviation	Median	Range
Percent tree cover loss (2001 to 2012, average)	21	0.04	0.06	0.02	0.26

(ii) Covariates

	n	mean	standard deviation	median	range
Tree cover 2000	21	230216	145901.7	195159.8	479469.3
Altitude	21	431.3	155.54	482.83	577.59
Mean Temperature	21	24.4	0.76	24.16	2.63
Mean precipitation	21	1830.77	205.93	1776.81	738.89
Distance from cities	21	42.57	11.25	40.99	43.31

Quota 2008	21	34296.1	33052.69	22800	117600
Exchange rate 2008	21	0.43	1.03	0.01	3.38
Area with okoume (sq.km.)	21	1896.32	1491.51	1543.25	5512.83
Number of villages	21	56.24	48.79	42	207
Population Density	21	1.49	1.15	1.07	4.69
Road Density	21	0.04	0.02	0.04	0.08
Area in sq.km.	21	2455.16	1554.62	2084.65	5112.61
Maximum distance between units of a company	21	80.26	119.32	49.18	407.05
Shape metric	21	1.67	0.25	1.55	0.74

Table 24 (b): Descriptive statistics of the certified FMUs:

(i) Deforestation

	n	Mean	Standard Deviation	Median	Range
Percent tree cover loss (2001 to 2012, average)	3	0.05	0.01	0.05	0.03

(ii) Covariates

Covariates	n	Mean	Standard Deviation	Median	Range
Tree cover 2000	3	648035.9	129534	613068.8	293260.9
Altitude	3	327.45	191.86	377.22	373.92
Mean Temperature	3	24.78	0.76	24.76	1.51
Mean precipitation	3	1824.06	140.23	1819.66	280.36
Distance from cities	3	40.31	9.44	40.06	18.88
Quota 2008	3	123800	39346.16	132000	77400
Exchange rate 2008	3	0.002	0.0005	0.0015	0.0009
Area under okoume presence in sq.km.	3	6921.51	1701.35	6181.77	3152.25
Number of villages	3	127	34.64	107	60
Population Density	3	1.63	0.95	1.43	2.23
Road Density	3	0.04	0.01	0.04	0.01
Area in sq.km.	3	6921.51	1701.35	6181.77	3152.25
Maximum distance between units of a company	3	183.71	181.13	100.28	332.19
Shape metric	3	1.78	0.03	1.79	0.06

Implementation of synthetic control method

Covariates used to construct synthetic controls

<u>Rougier</u>: Seven covariates contribute the most (sum of weights = 0.84%) to construction of the synthetic control, which is then compared with the certified Rougier to determine the effects of certification (Appendix B (d)). These four covariates are listed below in order of their contribution:

(v) *Maximum distance between spatial units of the FMU* (weight of 24%). This covariate has the greatest weight in the construction of synthetic control, suggesting that it is among the best predictors of deforestation in FMUs. This may be because more disperse units are more susceptible to illegal logging and invasion.

(vi) *Number of villages* (weight of 18%). This variable may proxy for population pressure or market access.

(vii) *Mean annual temperature, altitude and mean annual precipitation* (weights of 8-9% each). Higher temperature may lead to higher incidence of wildfire (Kirilenko and Sedjo, 2007). Higher elevations may be less accessible, and thus both more difficult to monitor and less desirable for agriculture. Precipitation also affects the profitability of agriculture.

(viii) *Road density* (weight of 9%). The construction of roads directly results in tree cover loss, may be associated with more intensive harvest of timber resulting in temporary tree cover loss, and may provide better access to farmers and other agents of deforestation.

<u>Precious Wood Gabon</u>: In the case of this company, we find that five covariates contribute about 80% of the total weight used to construct the synthetic control (Appendix B (e)).

(iii) *Percent Tree Cover Loss (2001 to 2008)* (weight of 25%). The average historical rate of percent tree cover loss appears to be one of the best predictors of the rate of tree cover loss in any given year. This suggests inertia or path dependence in forest loss.

(iv) *Road density* (weight of 23%).

(v) *Number of villages* (weight of 14%).

(vi) *Timber harvest quota* (weight of 12%). Higher quotas are likely associated with higher logging intensity.

(vii) *Exchange rate* (weight of 7%). This exchange rate proxies for the profitability of exporting to the primary international market, which is assumed to be the home country of the company managing the FMU.

<u>CBG (Compagnie des Bois du Gabon)</u>: The synthetic control for this company is based largely on the following six covariates (Appendix B (f)), which contribute about 91% to the construction of the synthetic control:

(iii) *Percent Tree Cover Loss* (2001 to 2008) (weight of 18%)

(iv) *Monitoring cost (Shape metric)* (weight of 17%). The shape of a FMU affects the cost of monitoring and supervision, thereby influencing probability of deforestation. For example, a circular FMU around a head office lowers the cost of monitoring and supervision of all areas on the boundary of the FMU, compared to a highly irregular or fragmented FMU.

(v) *Tree Cover* (weight of 15%). Higher initial tree cover may be associated with greater timber stocks, potentially leading to greater legal and illegal logging, which can result in temporary tree cover loss or provide access for agents of deforestation (Foley et al. 2007; Asner et al. 2004).

(vi) *Area* (weight of 15%). The larger a FMU, the greater the difficulty of monitoring and preventing illegal activity in the FMU.

(vii) *Number of villages* (weight of 13%).

(viii) *Altitude* (weight of 13%).

Plausibility of the synthetic controls

After the nested optimization process in SYNTH uses the covariates listed above to construct synthetic controls, we assess their plausibility as representations of the counterfactual. As described in Table 25, we conclude that the synthetic control for Rougier has medium plausibility, whereas the other two are not very plausible (based on MSPE, turning points, and level of deforestation in year before certification). One caveat is that there is a very small window of pre-treatment years to judge the similarity between the past deforestation behavior (trajectory) of a certified FMU and its synthetic control.

Table 25: Plausibility of synthetic controls as the counterfactual

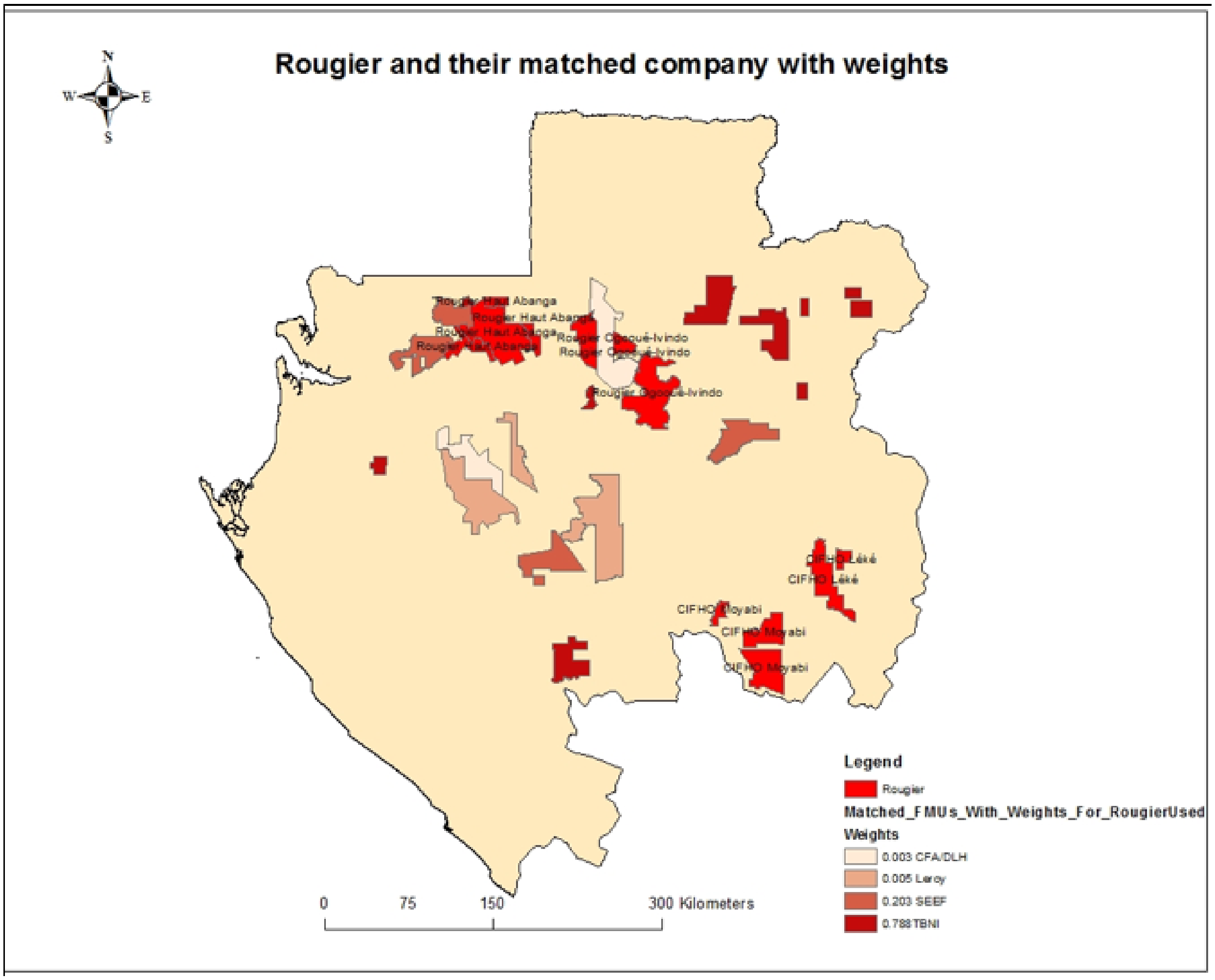
Company	Whether and why the synthetic control is plausible
ROUGIER	***Medium Plausibility*** 1) MSPE = 0.0005 2) All turning points in deforestation trends matched between certified FMU and Synthetic Control (Figure 13). 3) Deforestation in year before treatment in synthetic control is almost equal to that of the treated unit
PRECIOUS WOOD	***Low Plausibility*** 1) MSPE = 0.0007 2) Few turning points in deforestation trends matched between certified FMU and Synthetic Control (Figure 14). 3) Deforestation in year before treatment in synthetic control is about 37% more than the level in treated unit.
CBG (Compagnie des Bois du Gabon)	***Low Plausibility*** 1) MSPE = 0.001 2) Few turning points in deforestation trends matched between certified FMU and Synthetic Control (Figure 15). 3) Deforestation in year before treatment in synthetic control is six times more than the level in treated unit.

Results

Medium Plausibility

Rougier

Map 6 shows the weights that matched companies were assigned by SYNTH for the treated company (excluding companies assigned very small weights). Figure 13 shows similar deforestation trajectories in the certified company and its synthetic control in both the pre-certification and post-certification periods. Annual deforestation rates in Rougier and its synthetic control are presented in Appendix A (4).



Map 6: Rougier and companies included in its synthetic control

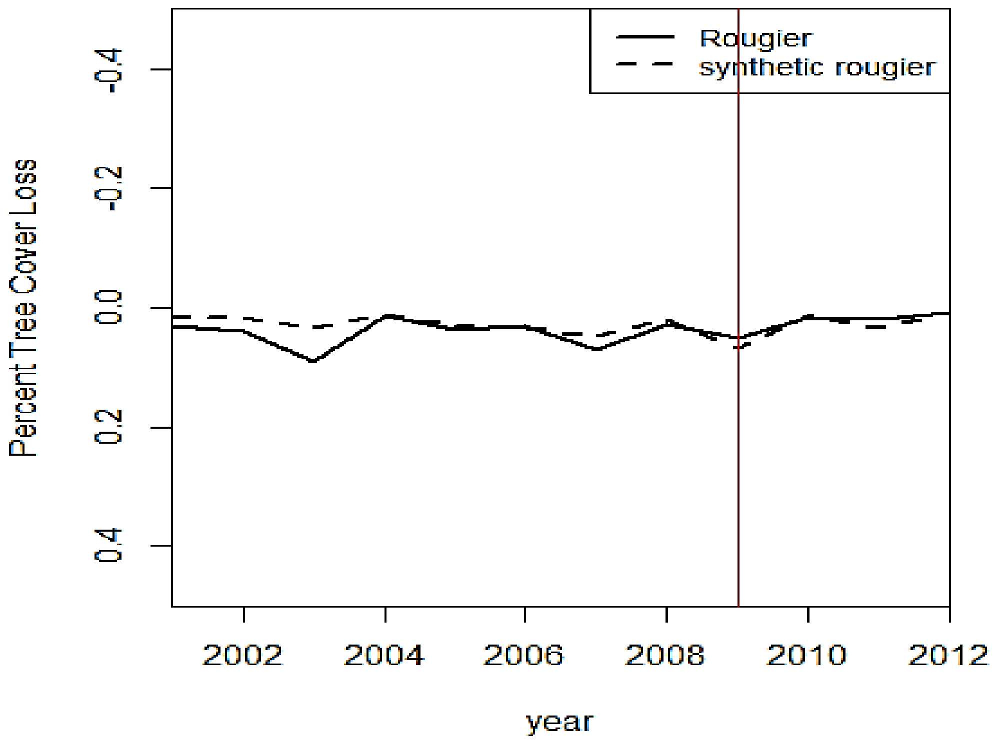


Figure 13: Comparison of treated company (ROUGIER) and its synthetic control from 2001-2012

Placebo effects

Table 26: Significance of the effects of certification on deforestation in the Rougier FMU, based on 10th and 90th percentiles of placebo treatment effects

Year	Observed percent tree cover loss in Rougier	Treatment effect of certification on Rougier*	10th and 90th percentiles of the placebo treatment effects‡
2009	0.05	-0.02	-0.04 to 0.05
2010	0.02	0.004	-0.01 to 0.007
2011	0.02	-0.01	-0.02 to 0.03
2012	0.008	-0.001	-0.009 to 0.01

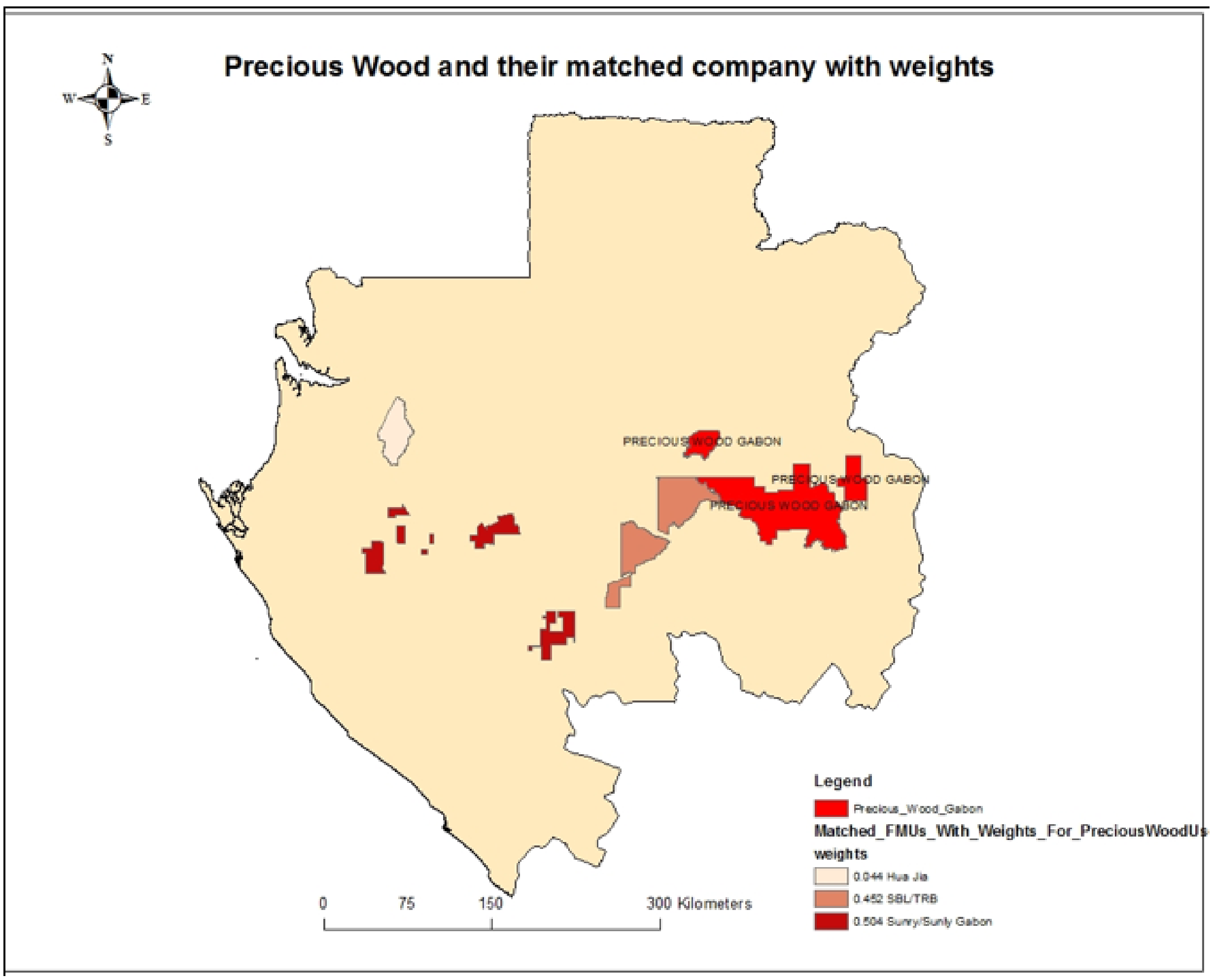
* None of the treatment effects are significant at 80% level, because they all fall within the 10th to 90th percentiles of the placebo treatment effects.
‡ Confidence intervals based on estimated treatment effects of placebos with MSPE less than the MSPE of Rougier (the treated unit).

The placebo tests confirm our visual interpretation of Figure 13: certification has no effect on tree cover loss in Rougier.

Low Plausibility

Precious Wood

Map 7 shows the weights assigned by SYNTH to construct the synthetic control for Precious wood. However, Figure 14 shows that this synthetic control is not very informative about the counterfactual because it was a poor match in the pre-certification period in terms of turning points and the level of deforestation in the year before certification, even though its MSPE is quite low (0.0007). (See Appendix A (5) for deforestation rates)



Map 7: Precious wood with its matched companies with weights

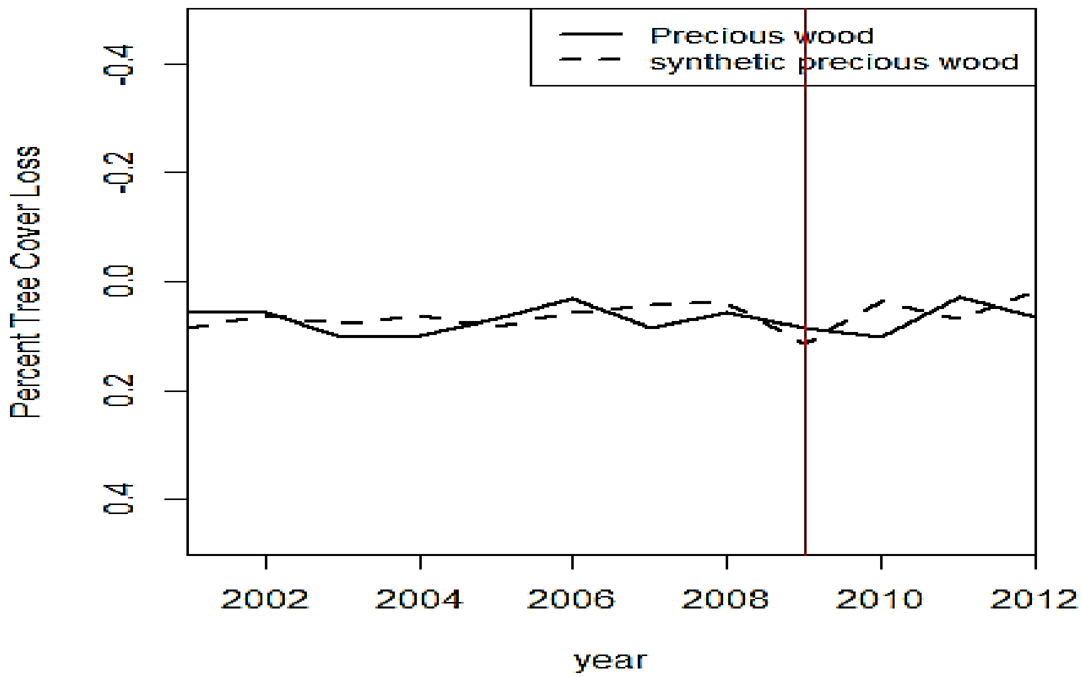


Figure 14: Comparison of treated company (PRECIOUS WOOD) and its synthetic control from 2001-2012

Placebo effects

For completeness, we present placebo tests of the statistical significance of the effects of certification on deforestation in the Precious Wood FMU. However, we do not place much stock in these, because of the low plausibility of the synthetic control.

Table 27: Significance of the effects of certification on deforestation in the Precious Wood FMU, based on 10th and 90th percentiles of placebo treatment effects

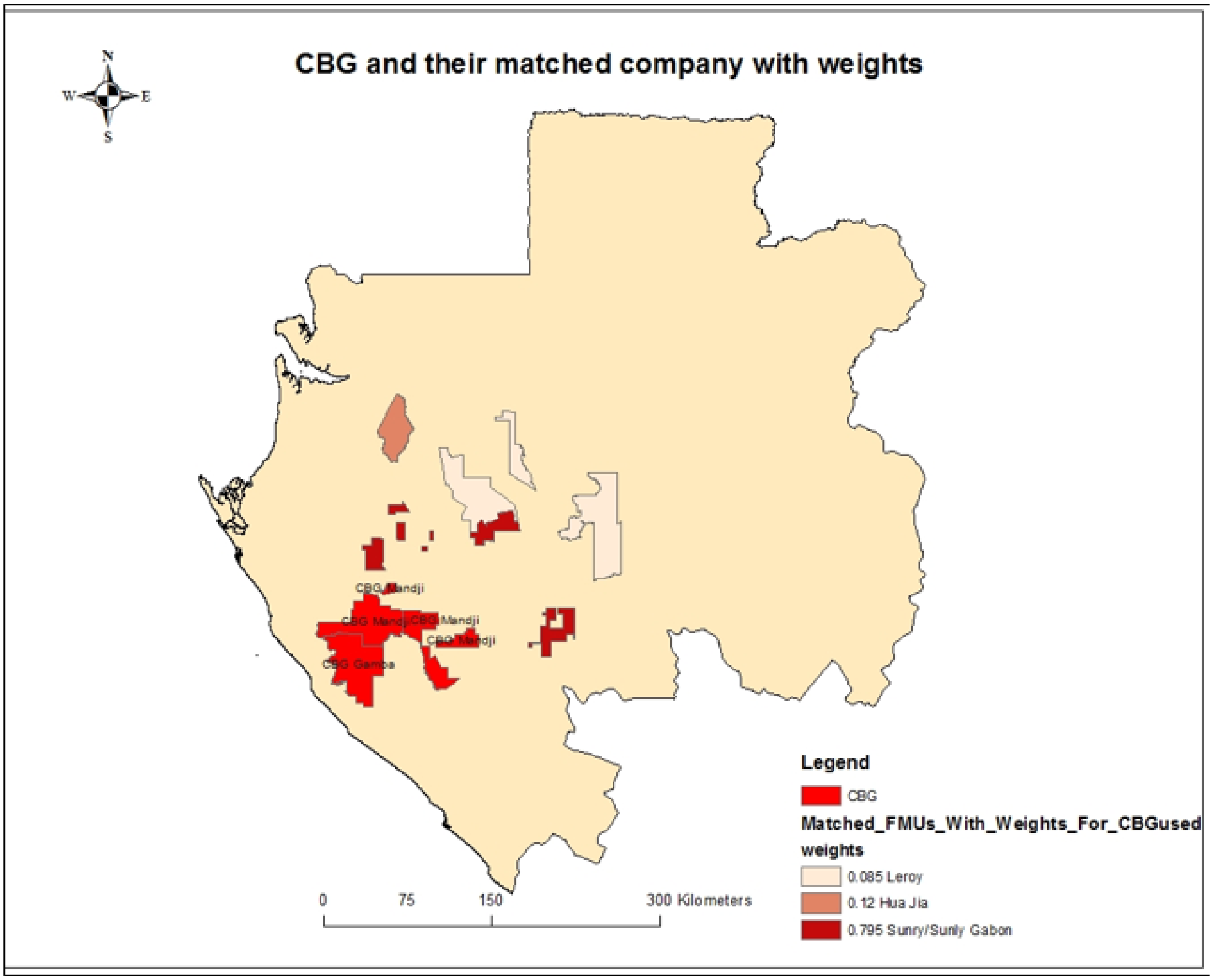
Year	Observed percent tree cover loss in Precious Wood	Treatment effect of certification on Precious Wood	10th and 90th percentiles of the placebo treatment effects‡
2009	0.08	-0.03*	-0.02 to 0.03
2010	0.10	0.06*	-0.01 to 0.02
2011	0.03	-0.04*	-0.01 to 0.02
2012	0.07	0.05*	-0.01 to 0.02

* All treatment effects are significant at 80% level, because they fall outside the 10^{th} to 90^{th} percentiles of the placebo treatment effects.

‡ Confidence intervals based on estimated treatment effects of placebos with MSPE less than the MSPE of Precious Wood (the treated unit).

CBG (Compagnie des Bois du Gabon)

As for the other companies, we present a map of the weights assigned by SYNTH to construct the synthetic control (Map 8) and a graph of deforestation in CBG and its synthetic control (Figure 15). This figures clearly demonstrates that the synthetic control lacks plausibility as a representation of the counterfactual (also see Appendix A (6)).



Map 8: CBG and its matched companies with weights

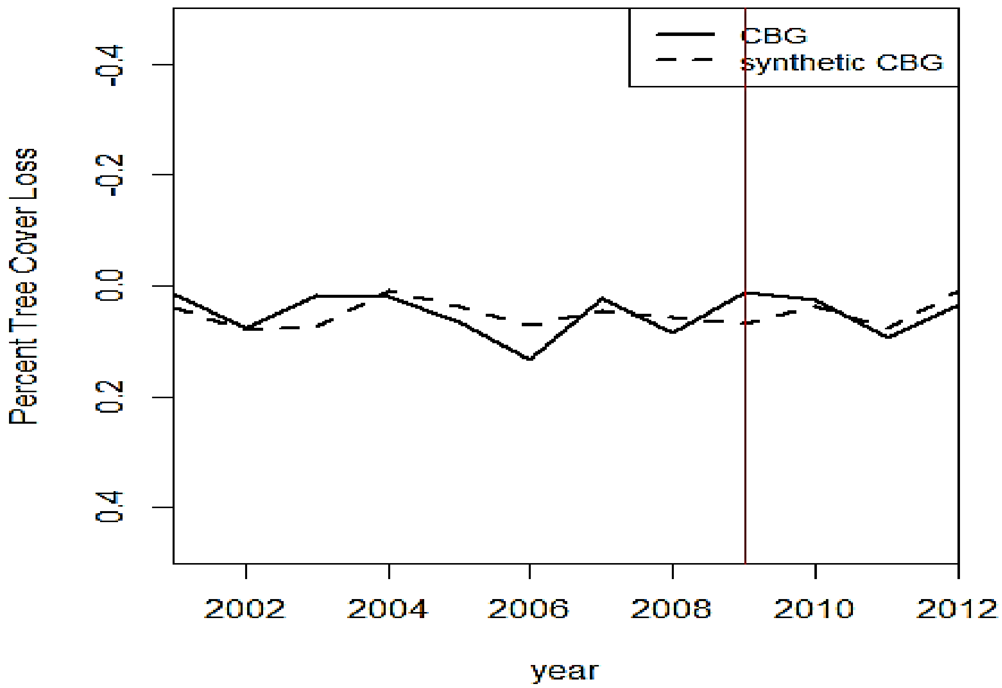


Figure 15: Comparison of treated company (CBG) and its synthetic control from 2001-2012

Placebo effects

Placebo tests suggest that certification immediately reduced tree cover loss in CBG, but this apparent effect may be due to poor quality of the synthetic control.

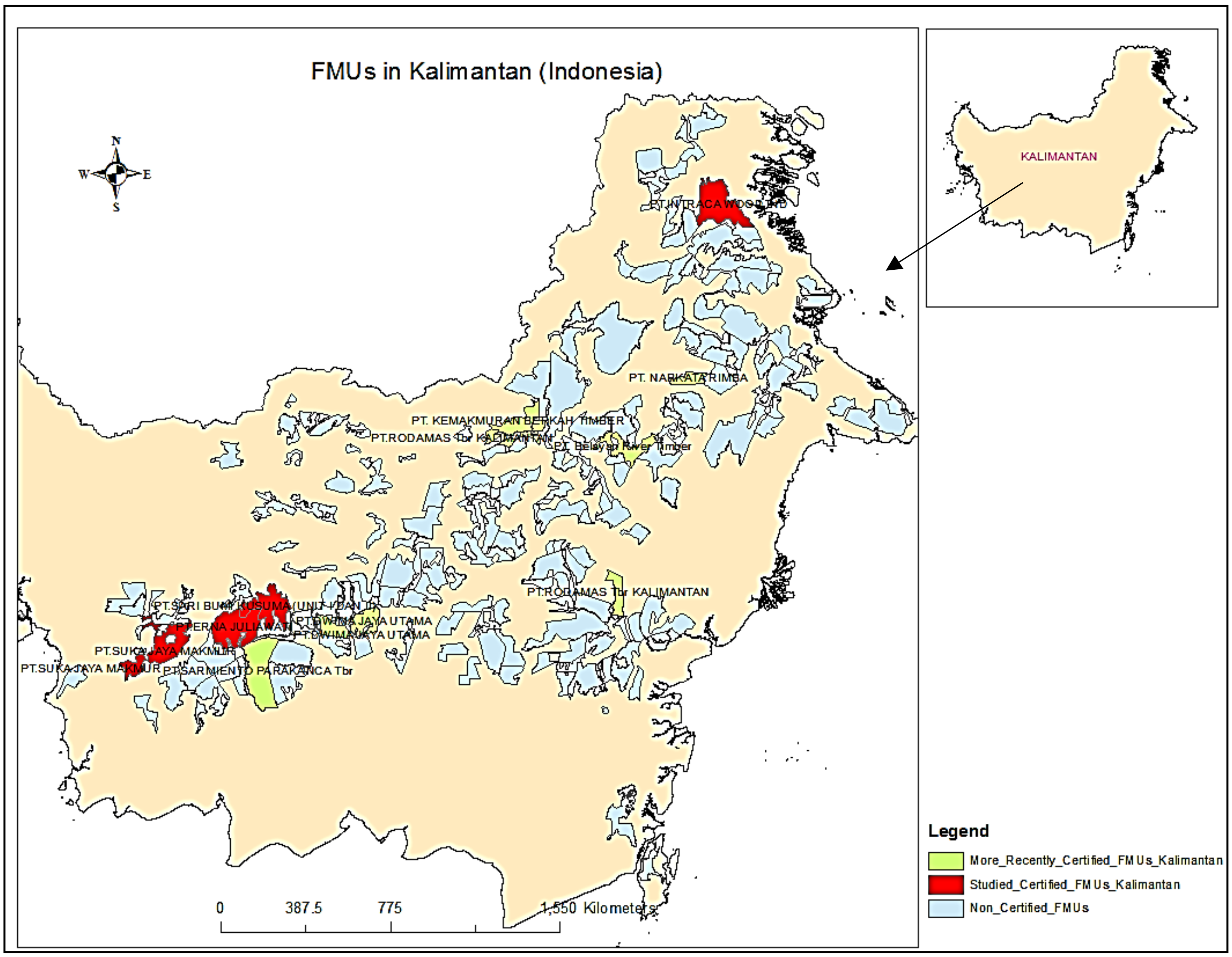
Table 28: Significance of the certified effects for certified FMU/company (10th and 90th percentiles of the placebos treatment effects)

Year	Actual percent tree cover loss in CBG (observed)	Treatment effect of certification on CBG	10th and 90th percentiles of the placebo treatment effects‡
2009	0.01	-0.06*	-0.05 to 0.04
2010	0.03	-0.01	-0.01 to 0.01
2011	0.09	0.02	-0.01 to 0.03
2012	0.03	0.02	-0.01 to 0.02

* Treatment effect significant at 80% level, because falls outside the 10^{th} to 90^{th} percentiles of the placebo treatment effects.
‡ Confidence intervals based on estimated treatment effects of placebos with MSPE less than the MSPE of CBG (the treated unit).

5c. Kalimantan (Indonesia)

In Kalimantan, we evaluate the impact of FSC certification on four FMUs, defined as the forests managed by the following four companies: Erna Djuliawati, Intracawood Manufacturing, Sari Bhumi Kusuma and Suka Jaya Makmur. We compare tree cover loss in these FMUs to synthetic controls constructed from a donor pool of non-certified FMUs, or companies that have never sought certification. Map 9 shows the locations of certified FMUs, more recently certified FMUs that we excluded from the analysis, and non-certified FMUs in the donor pool. We first examine patterns in tree cover loss in these FMUs, then consider covariates that may explain differences in tree cover loss, and finally construct synthetic controls to estimate the impacts of certification on tree cover loss.



Map 9: Certified FMUs evaluated in this study, more recently certified FMUs excluded from the study, and non-certified FMUs in the donor pool in Kalimantan (Indonesia)

Trends in deforestation

The boxplots in Figure 16 show the distribution of percent tree cover loss across years (2001-2012) for each FMU. There is substantial variation, both within and across FMUs.

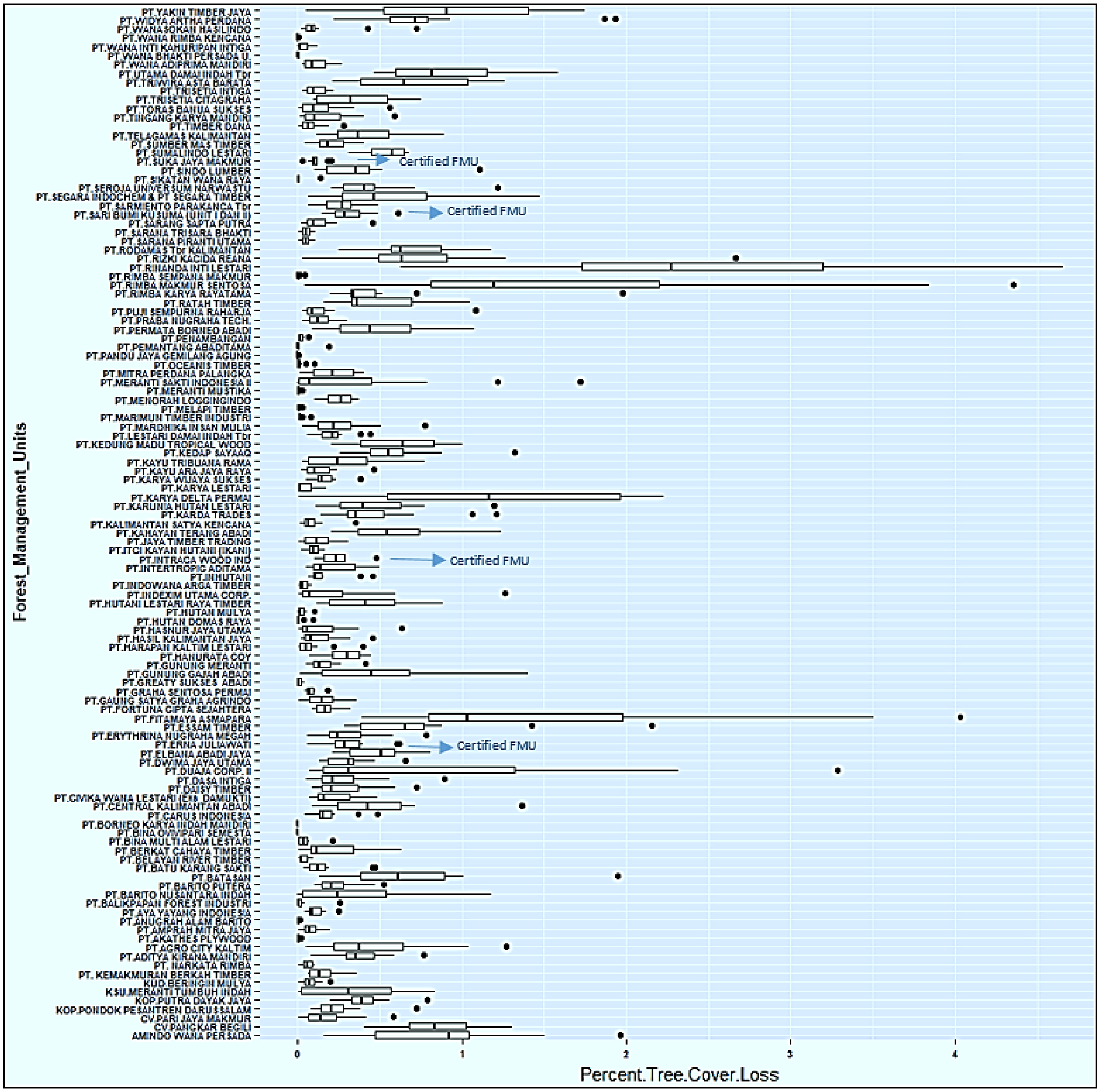


Figure 16: The distribution of percent tree cover loss across years (2001-2012) for each FMU in Kalimantan (excluding one outlier: Kayu Waja, a non-certified FMU).

Naïve comparison of deforestation

Here we compare tree cover loss in the certified FMUs (selected for this study) to average tree cover loss in non-certified FMUs (the donor pool), which is perhaps the most naïve approach to estimating the impact of FSC certification (Table 29). Certified FMUs had on average for the entire period (before and after the certification) less deforestation compared to non-certified FMUs. Also, when only the post-certification period is considered, the deforestation in the certified FMU is considerably lower compared to that of the non-certified FMUs.

As shown in Table 30, the cumulative average percent tree cover loss (2001-2012) is much higher for non-certified FMUs compared to certified ones. (See Appendix E for comparison to alternative method of randomly selected points.) However, certified FMUs were certified in different years. We find that after certification, the average rate of annual tree cover loss was 0.37% in Erna Djuliawati (2006 to 2012); 0.29% in Intracawood Manufacturing (2007 to 2012); 0.38% in Sari Bhumi Kusuma (2008 to 2012); and 0.14% in Suka Jaya Makmur (2011 to 2012). Compared to the annual rate of tree cover loss in non-certified FMUs over the entire period from 2001 to 2012, Intracawood Manufacturing and Suka Jaya Makmur had lower average percent tree cover loss during the years that they were certified, while Erna Djuliawati and Sari Bhumi Kusuma had higher average percent tree cover loss. However, this naïve comparison does not consider other differences between certified and non-certified FMUs.

Table 29: Percent tree cover loss (Average, 2001-2012) for all studied FMUs in Kalimantan. Certified FMUs are Suka Jaya Makmur: certified in 2010; Erna Djuliawati: Certified in 2005; Intracawood Manufacturing: certified in 2006; and Sari Bhumi Kusuma: certified in 2007.

	Certified FMUs (certified 2005 – 2010)	Non-certified FMUs (never certified during the study period)
2001	0.28	0.25
2002	0.19	0.26
2003	0.13	0.21
2004	0.27	0.35
2005	0.14	0.36
2006	0.20	0.44
2007	0.21	0.31
2008	0.21	0.31
2009	0.40	0.40
2010	0.18	0.25
2011	0.23	0.34
2012	0.47	0.57
Cumulative average	0.24	0.34

Impact evaluation using SCM

Variables used in Synthetic Control Matching

Table 30 lists the variables used to construct the synthetic controls, in addition to the bio-physical factors listed in Table 9. These were selected based on previous literature about the determinants of deforestation and operationalized using data available from across the tropics, to ensure consistency of our pan-tropical analyses. Factors that have been found to influence deforestation outcomes in

Indonesia include forest fires, poor governance, illegal logging, unclear property rights, social conflicts, market access and perverse incentives created by government policies (Mayers et al. 2002, Muhtaman and Prasetyo 2006, Musthofid and Witjaksana, 2002, Mir and Fraser, 2003). Poor implementation of sustainability policies has led to over-exploitation of forest resources (Muhtaman and Prasetyo, 2006).

Almost all native forests in Indonesia are publicly owned, and different levels of government allocate logging concessions, or permits to harvest timber from forests. This has often led to conflicts with communities who consider these forests as their own. These conflicts have serious implications for deforestation and the uptake of certification by timber companies (Ruwiastuti, 2000; Rowland and Simpoha, 1999; Muhtaman and Prasetyo, 2006). For example, Cerutti et al. (2014) found that local populations may feel constrained by new regulations on forest use imposed to comply with certification requirements, resulting in social conflicts that may trigger deforestation. The costs of managing these conflicts and monitoring the resource use of local people in turn may deter companies from seeking certification (Gullison, 2003; Raunetsalo et al., 2002; Teisl et al., 2001).

To capture the potential for conflict as well as the demand for cleared land, we include population density and change of population in the jurisdictions where FMUs are located. Deforestation is also a function of the area available to be deforested, which depends on the forest stock and its accessibility. Thus, we include the proportion of primary forests, past tree cover, total area logged, logging intensity, and logging road density.

The probability of deforestation inside a FMU also depends on whether that FMU is monitored and patrolled (Gullison, 2009; Bass et al, 2001 in Gullison). While the efficacy of efforts to protect FMUs depends in large part on the government's enforcement capacity (Muhtaman and Prasetyo, 2006), we represent differences in the cost and effectiveness of monitoring across FMUs by the area of the FMU and its shape (on a scale from perfectly round and compact to highly fragmented).

Following the description of the covariates, descriptive statistics are presented for the outcome (tree cover loss) as well as the physical and country-specific covariates in Tables 31 a and b.

Table 30. Description of the variables and plausible mechanisms

Covariates

Variable	Description	Measurement	Spatial resolution	Year	Source	Plausible causal mechanism
Forest management						
Area Logged	Area logged per year	Hectares	FMU (Company forest land)	2007	Forest management plans - Ministry of Forestry (MoF)	Logging creates gaps in the canopy and increases access for deforestation agents
Volume Harvested	Volume harvested per year	m3/yr	FMU (Company forest land)	2007	Forest management plans - Ministry of Forestry (MoF)	Harvest of higher volume may require more roads and skid trails that increase access
Logging Intensity	Logging intensity	m3/ha	FMU (Company forest land)	2007	Calculated as ratio of volume of timber harvested and area in ha.	Higher logging intensity may create more gaps in the canopy and increase forest access

Primary Forests	Percent of primary forests	Percent	FMU (Company forest land)	2009	Forest management plans - Ministry of Forestry (MoF)	Primary forests may be subject to more regulation and better protected by governments
Limited Production Forest Area	Percent of limited production area	Percent	FMU (Company forest land)	2009	Forest management plans - Ministry of Forestry (MoF)	Limited production areas may be subject to more regulation and better protected by governments
Previously logged forest	Percent of previously logged forest	Percent	FMU (Company forest land)	2009	MoF website at http://appgis.dephut.go.id/appgis/iuphhk.aspx.	Previously logged forests are less attractive for logging but possibly more accessible to deforestation agents.
Duration of Harvest permit	Duration of harvest permit	Years	FMU (Company forest land)	2007	Forest management plans - Ministry of Forestry (MoF)	We expect fast and intensive deforestation, if a company has limited duration to harvest trees as per their harvest permits. Companies would ignore long-term management by focusing only on short-term intensive extraction of timber rather than following sustainable harvesting.
Anthropogenic Population density	Population density of FMUs (2001-2012)	Population count/ Km^2	Resolution of 1 Km^2	2001-2012	LandScan 2000-2012, http://web.ornl.gov/sci/landscan/ Based on the LandScan 2006™ High Resolution Global Population Data Set copyrighted by UT-Battelle, LLC, operator of Oak Ridge National Laboratory	Higher population pressure is often associated with higher rates of deforestation.
Logging Road density	Density of logging roads in the FMUs of a company, year 2000 and 2010	Km per Sq.Km	FMU (Company forest land)	2000, 2010	David Gaveau	Higher road density facilitates rapid forest loss by providing access to remotely-situated forests and, thereby, leading to intensive extraction and transport of timber resources.
Population Density in surrounding areas/district	Population density in surrounding areas per district	Number/sq.km.	FMU (Company forest land)	2010	National Population Census, 2010 (http://sp2010.bps.go.id/index.php/publikasi/index)	Von Thunen theory and a large body of empirical evidence suggest higher probability of deforestation in FMUs closer to settlements.
Population Change in surrounding area/District	Population change in surrounding areas per district	Percent change/Year	FMU (Company forest land)	2010	National Population Census, 2010 (http://sp2010.bps.go.id/index.php/publikasi/index)	Von Thunen theory and a large body of empirical evidence suggest higher probability of deforestation in FMUs closer to settlements.

Descriptive statistics

Table 31(a): ***Descriptive statistics of the non-certified FMUs (Donor pool)***

(i) Deforestation

	n	Mean	Standard Deviation	Median	Maximum
Percent tree cover loss (2001 to 2012, average)	108	0.34	0.41	0.21	2.45

(ii) Covariates

	n	Mean	Standard Deviation	Median	Maximum
Tree cover 2000	108	61727.11	71274.1	41563.12	461608.8
Altitude	108	261.64	150.04	230.55	783.36
Mean Temperature	108	25.35	0.79	25.43	4.53
Mean Precipitation	108	3054.99	524.76	3085.73	2543.14
Area Logged/year (ha/year)	108	1397.01	1619.44	1000	14446.32
Volume Harvested/Yr (m3/yr)	108	51924.46	63689.64	39662.5	622874.8
Primary Forests (%)	108	20.73	25.39	9.2	92
Limited Production Forest Area (percent)	108	63.35	35.49	75	100
Previously Logged (%)	108	62.92	25.04	68.4	95
Logging Intensity (m3/ha)	108	40.22	14.28	39.54	84.91
Duration of Harvest Permit	108	25.28	13.8	15	35
Population Density Within FMU	108	7.13	8.35	4	50
Logging Road Density (2001)	108	1.33	11.3	0.16	117.53
Logging Road Density (2010)	108	0.14	0.12	0.11	0.67
Population Density in surrounding areas/district (Number/sq.km.)	108	12	12.13	8	78
Population Change in surrounding area/District (%/Year)	108	2.78	1.64	2.3	5.9
Area (Sq.Km)	108	713.98	887.49	491.64	7390.55
Shape Metric	108	1.89	0.48	1.78	2.24
Population	108	2106.76	3659.36	807.12	26757

Table 31 (b): Descriptive statistics of the certified FMUs - Erna Djuliawati, Intracawood Manufacturing, Sari Bhumi Kusuma and Suka Jaya Makmur

(i) Tree Cover

	n	Mean	Standard Deviation	Median	Maximum
Tree cover (2001 to 2012, average)	4	162282.3	21547.48	168412.1	180893.1
Percent tree cover loss (2001 to 2012, average)	4	0.24	0.10	0.27	0.32

(ii) Covariates

	n	Mean	Standard Deviation	Median	Maximum
Altitude	4	215.4	34.48	211.64	73.95
Mean Temperature	4	25.78	0.25	25.73	0.54
Mean Precipitation	4	3773.64	1342.45	3148.42	2760.67
Area Logged/year (ha/year)	4	5449.33	1084.05	5869.66	2360
Volume Harvested/Yr (m3/yr)	4	205325	82616.29	219031.5	184931.7
Primary Forests (%)	4	16.11	8.1	14.35	17.33
Limited Production Forest Area (percent)	4	61.78	40.11	64.55	75.46
Previously Logged (%)	4	72.39	7.57	73.35	18.35
Logging Intensity (m3/ha)	4	45.08	26.01	35.99	56.81
Duration of Harvest Permit	4	48.75	11.81	45	25
Population Density Within FMU	4	6.25	3.95	5	12
Logging Road Density (2001)	4	0.33	0.17	0.28	0.39
Logging Road Density (2010)	4	0.19	0.02	0.19	0.05
Population Density in surrounding areas/district (Number/sq.km.)	4	9.62	6.34	11	15.5
Population Change in surrounding area/District (%/Year)	4	2.74	1.97	2.12	5.5
Area (Sq.Km)	4	1752.98	219.1	1816.14	505.34
Shape Metric	4	2.16	0.23	2.16	0.55
Population	4	1871.02	1553.14	1406.38	4031

Implementation of synthetic control method

Covariates used to construct synthetic controls

Suka Jaya Makmur: Three covariates contribute the most (sum of weights ~85%) to construction of the synthetic control, which is then compared with certified Suka Jaya Makmur to determine the effects of certification (Appendix B (g)). These three covariates are listed below in order of their contribution:

(ix) *Percent tree cover loss (2001-2010).* This covariate is allocated a weight of 43% in the construction of the synthetic control. This indicates that the average historical rate of deforestation is one of the best predictors of the deforestation rate in any given year, suggesting that there is some inertia or path dependence in forest loss.

(x) *Altitude* (weight of 26%). More varied topography may make monitoring difficult, which may allow more illegal tree cover loss. On the other hand, it may also make agriculture less profitable, leading to less tree cover loss.

(xi) *Mean annual temperature* (weight of 15%). Extreme temperature may lead to higher probability of wildfire ignition, faster spread, and greater intensity, resulting in higher chances of tree cover loss.

Erna Djuliawati: The same three covariates contribute about 94% of the total weight used to construct the synthetic control for this FMU (Appendix B (h)).

(i) *Percent tree cover loss (2001-2010)* (weight of 85%).

(ii) *Altitude* (weight of 5%).

(iii) Mean annual temperature (weight of 5%).

Intracawood Manufacturing: In the case of this FMU, three covariates contribute about 88% of the total weight used to construct the synthetic control (Appendix B (i)).

(i) *Percent tree cover loss (2001-2010)* (weight of 30%).

(ii) *Tree cover* (weight of 29%). The original extent of tree cover clearly determines the potential for tree cover loss.

(iii) *Population density* (weight of 29%). Higher population density is likely to lead to higher demand for agricultural land.

Sari Bhumi Kusuma: The synthetic control for this FMU is based largely (79%) on the following four covariates (Appendix B (j)).

(i) *Duration of Harvest Permit* (weight of 37%). Companies that have only short-term harvest permits are likely to focus on intensive extraction of timber in the short-term, giving less emphasis to long-term sustainable management or to protecting the concession from deforestation.

(ii) *Tree cover (2001-2012)* (weight of 29%).

(iii) *Area Logged* (weight of 7%). Logged areas are more susceptible to tree cover loss both because of logging operations and because they become more accessible to deforestation agents.

(iv) *Volume Harvested/year* (weight of 5%). Higher harvesting intensity has a great impact on forest cover, both directly and by increasing accessibility to deforestation agents.

Plausibility of the synthetic controls

The next step is to construct synthetic controls, i.e. combinations of FMUs that are similar to the certified FMUs in all respects except certification. If we are successful, then the synthetic controls provide plausible estimators of the counterfactual: tree cover loss in the certified FMU without certification. This allows us to separate the influence of selection from the causal effect of certification.

As described in Table 32, we conclude that only the synthetic control for Suka Jaya Makmur is highly plausible as a measure of the counterfactual. The synthetic control for Erna Djuliawati has medium plausibility. One important caveat is that for some of the synthetic controls, there is a very small window of pre-treatment years to judge the similarity between the past deforestation behavior (trajectory) of a certified FMU and its synthetic control.

Table 32: Plausibility of the synthetic (counterfactual) control

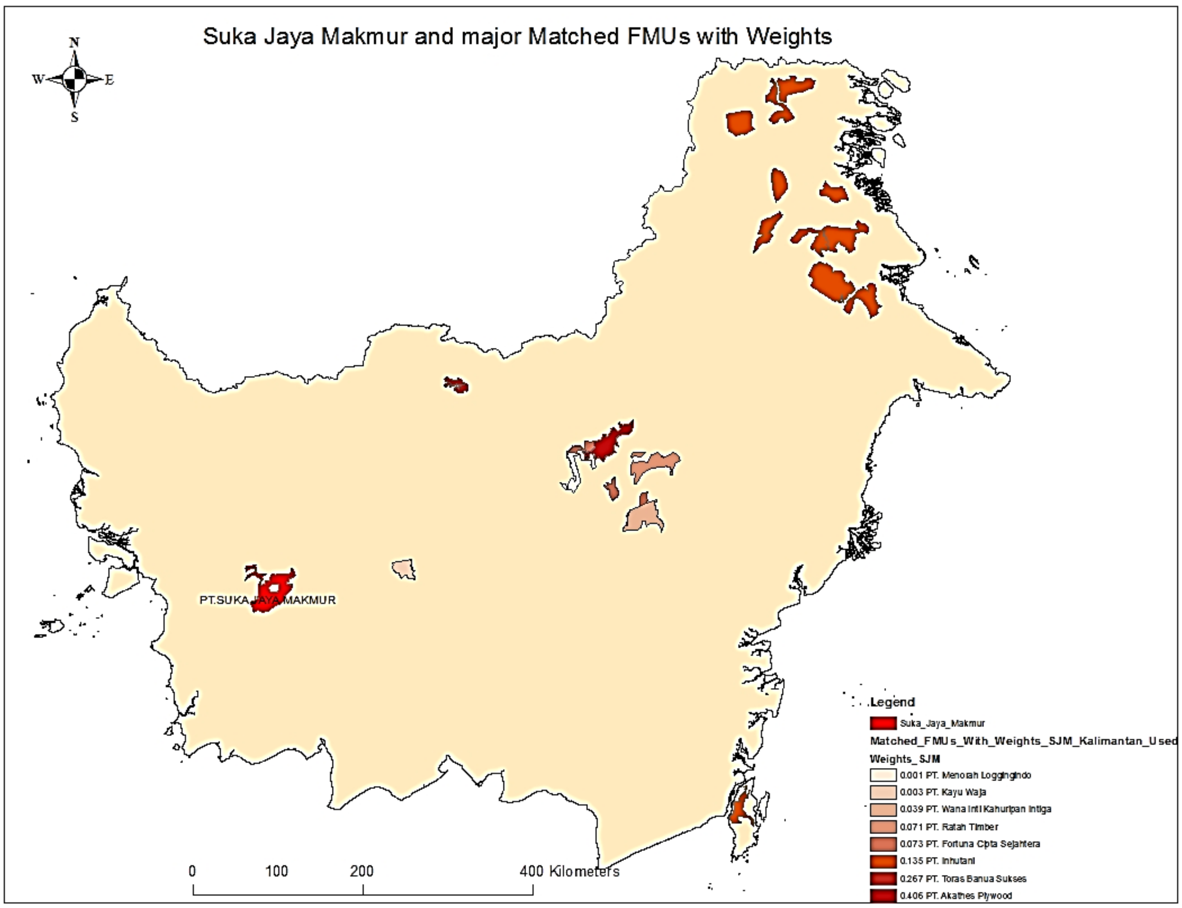
Company	Plausibility of Synthetic Control
SUKA JAYA MAKMUR	High Plausibility 4) MSPE = 0.0003 5) All turning points in deforestation trends matched between certified FMU and Synthetic Control (Figure 17). 6) Deforestation in year before treatment in synthetic control is almost equal to that of the treated unit
PT. ERNA DJULIAWATI	Medium Plausibility 4) MSPE = 0.003 5) Most turning points in deforestation trends matched between certified FMU and Synthetic Control (Figure 18). 6) Deforestation in year before treatment in synthetic control is almost equal to that of the treated unit
INTRACAWOOD MANUFACTURING	Medium Plausibility 1) MSPE = 0.0028 2) Most turning points in deforestation trends matched between certified FMU and Synthetic Control (Figure 19). ***3)*** Deforestation rate in year before treatment is 27% higher in synthetic control compared to certified unit
SARI BHUMI KUSUMA	Medium Plausibility 1) MSPE = 0.023 2) Almost all of the turning points in deforestation trends are mis-matched (Figure 20). 3) Deforestation in year before treatment in synthetic control is almost equal to that of the treated unit

Results

Highly Plausible Synthetic Control

Suka Jaya Makmur

Figure 17 illustrates the high plausibility of the synthetic control, which follows a deforestation trajectory almost identical to that of the certified company in the pre-certification period. Map 10 shows the weights assigned by SYNTH to comparison companies matched to Suka Jaya Makmur. Annual deforestation rates in Suka Jaya Makmur and its synthetic control are presented in Appendix A (7).



Map 10: Suka Jaya Makmur and its matched FMUs/Companies with weights

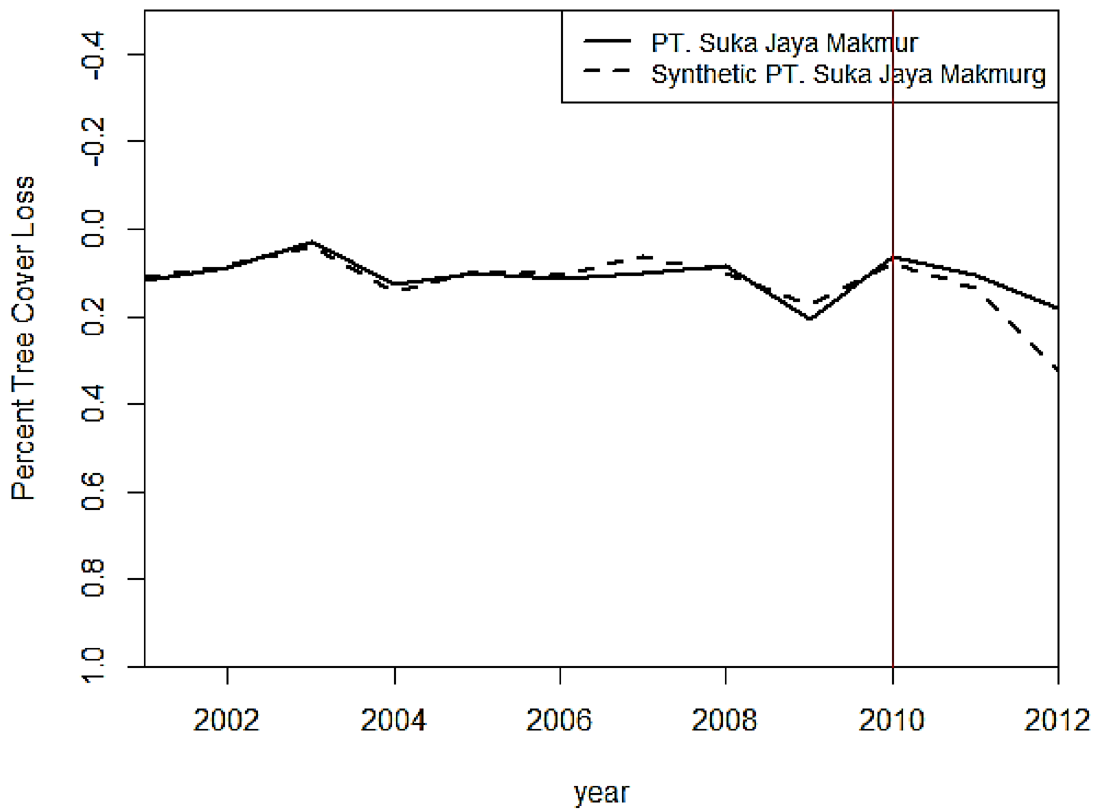


Figure 17: Comparison of treated FMU (PT Suka Jaya Makmur) and its synthetic control from 2001-2012

In figure 17, positive numbers on the y-axis indicate percent tree cover loss, and thus loss of tree cover decreases up the y-axis. The solid line shows the actual percent tree cover loss in the FMU that became certified in 2010. The dotted line shows the percent tree cover loss in the synthetic control. After 2010, there is less tree cover loss in PT. Suka Jaya Makmur compared to its synthetic control, suggesting that certification reduced tree cover loss.

Placebo tests

As shown in Table 33, the estimated treatment effects are significantly different from zero at the 80% confidence level, i.e. they fall outside the 10th and 90th percentiles of the distribution of placebo treatment effects.

Table 33: Significance of the certified effects for certified FMU (10th and 90th percentiles of the placebo treatment effects)

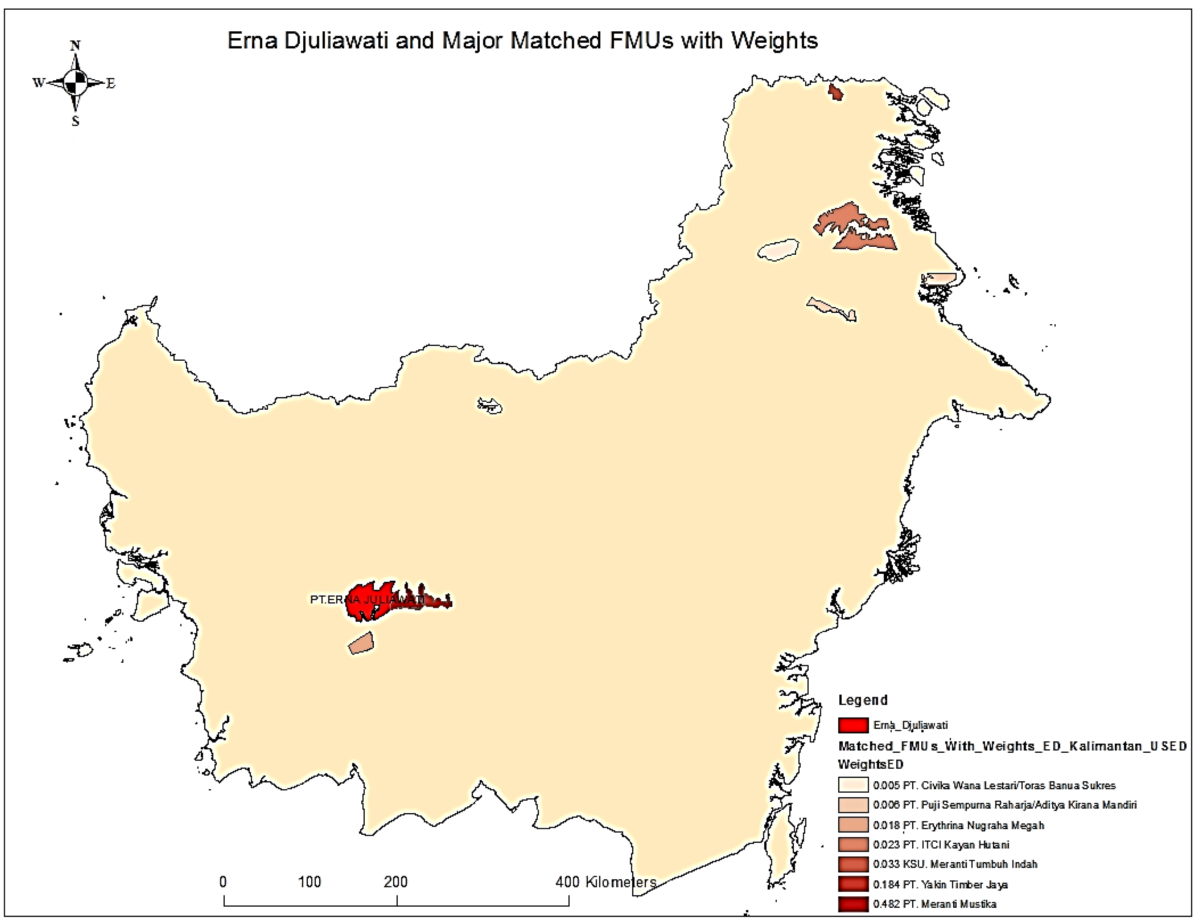
Year	Observed percent tree cover loss in PT. SJM	Treatment effect of certification on SJM	10th and 90th percentiles of the placebo treatment effects‡
2011	0.10	-0.03*	-0.01 to 0.05
2012	0.18	-0.14*	-0.04 to 0.12

* Treatment effect significant at 80% level, because falls outside the 10^{th} to 90^{th} percentiles of the placebo treatment effects.
‡ Confidence intervals based on estimated treatment effects of placebos with MSPE less than the MSPE of Suka Jaya Makmur (the treated unit).

Medium Plausibility of Synthetic Control

PT. Erna Djuliawati

The Figure 18 shows that the counterfactual (i.e. synthetic control) is plausible as there is a reasonable match between the deforestation trajectories of the certified company and its synthetic control in the pre-certification period (MSPE = 0.003)(also see Appendix A (8)). Map 11 shows the weights assigned by SYNTH to matched companies for the treated PT. Erna Djuliawati. Only FMUs with substantial weights are depicted.



Map 11: Erna Djuliawati and its matched FMUs/Companies with weights

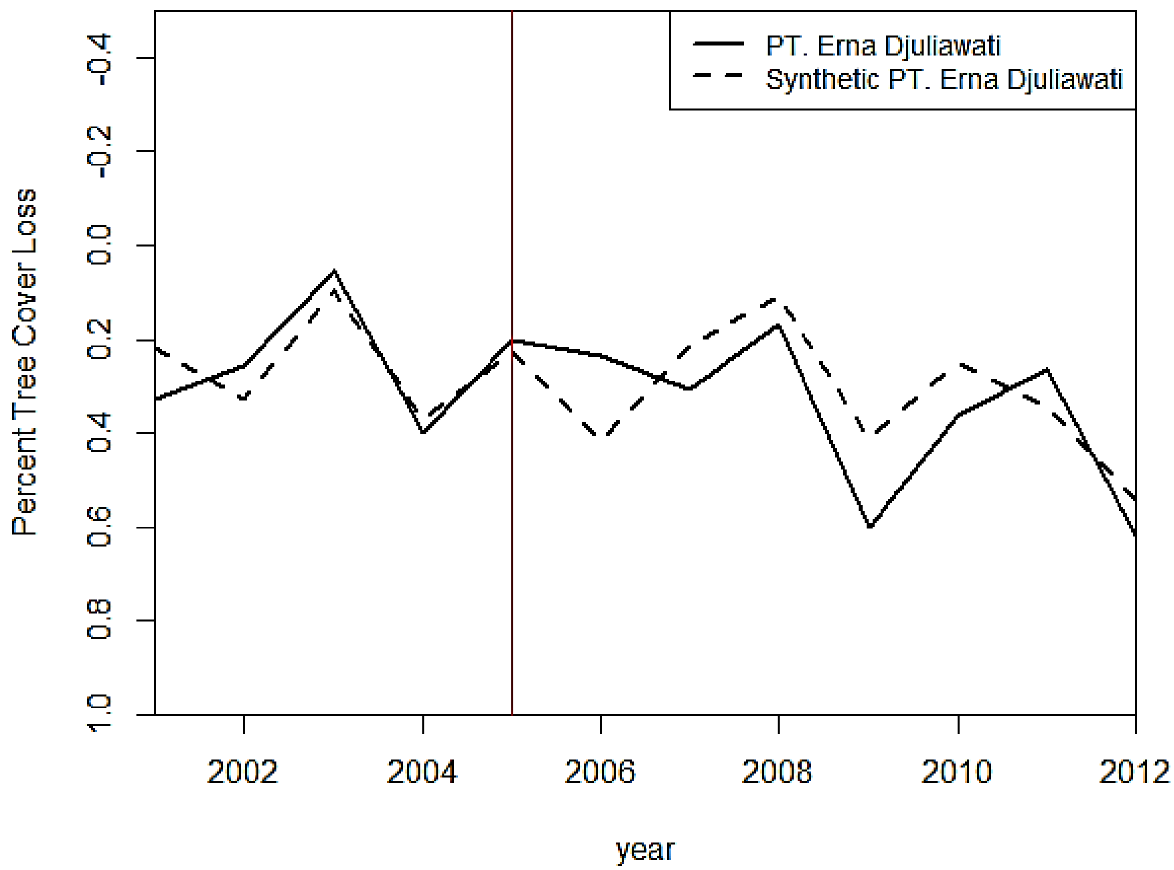


Figure 18: Comparison of treated FMU (PT Erna Djuliawati) and its synthetic control, 2001-2012

Figure 18 suggests that after certification in 2005, PT. Erna Djuliawati experienced similar or higher rates of tree cover loss than it would have under the counterfactual of no certification, in all years except 2011.

Placebo tests

As shown in Table 34, none of the effects, except for year 2011, are statistically different from zero at 80% confidence level (10th and 90th percentiles). Either there is no effect of the certification on the deforestation trajectory of Erna Duliawati, or the true effect is masked by poor quality of the synthetic control.

Table 34: Significance of the certified effects for certified FMU (10th and 90th percentiles of the placebos treatment effects)

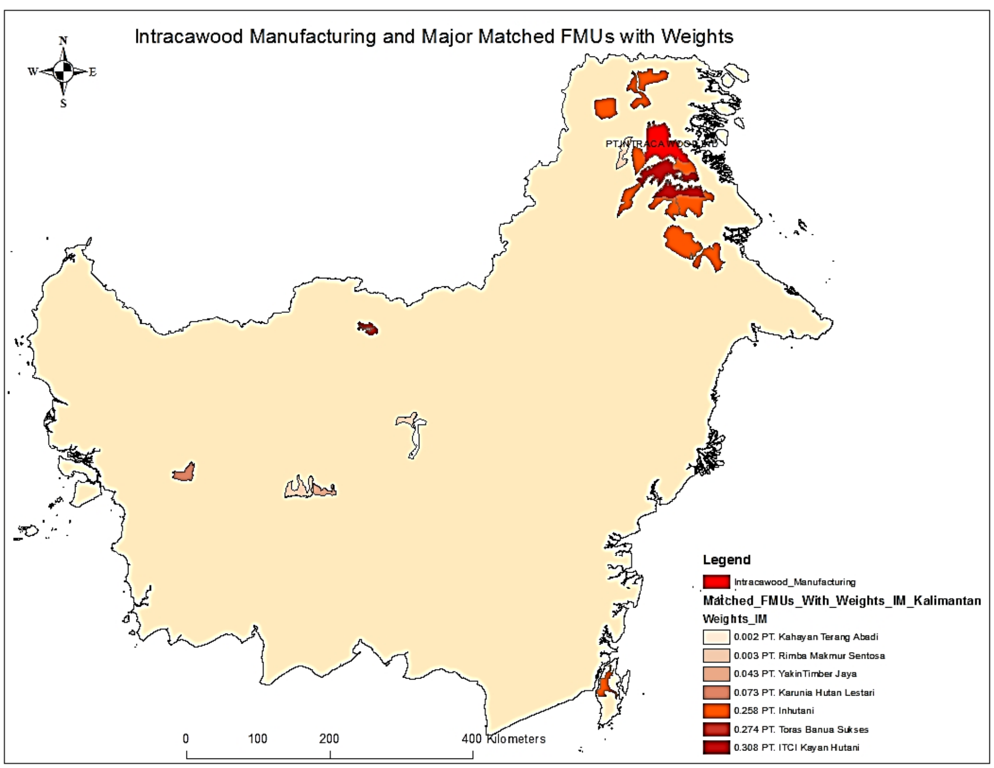
Year	Actual percent tree cover loss in PT. Erna Djuliawati (observed)	Treatment effect of certification on PT. Erna Djuliawati	10th and 90th percentiles of the placebo treatment effects‡
2006	0.24	-0.18	-0.46 to 0.12
2007	0.31	0.09	-0.61 to 0.35
2008	0.17	0.06	-0.12 to 0.33
2009	0.60	0.19	-0.39 to 0.39
2010	0.36	0.11	-0.07 to 0.15
2011	0.26	-0.08*	-0.06 to 0.33
2012	0.62	0.08	-0.32 to 0.78

* Treatment effect significant at 80% level, because falls outside the 10^{th} to 90^{th} percentiles of the placebo treatment effects.
‡ Confidence intervals based on estimated treatment effects of placebos with MSPE less than the MSPE of PT. Erna Djuliawati (the treated unit).

Intracawood manufacturing

The results (Figure 19) shows that the synthetic control for the certified company is plausible as there is reasonable match between the deforestation trajectory of the certified company and its synthetic control in the pre-certification period (MSPE = 0.0028). Annual deforestation rates in Intracawood manufacturing and its synthetic control are presented in Appendix A (9).

Map 12 shows the weights assigned by SYNTH to matched FMUs for the treated Intracawood Manufacturing. Only FMUs with substantial weights are depicted.



Map 12: Intracawood Manufacturing and its matched FMUs/Companies with weights

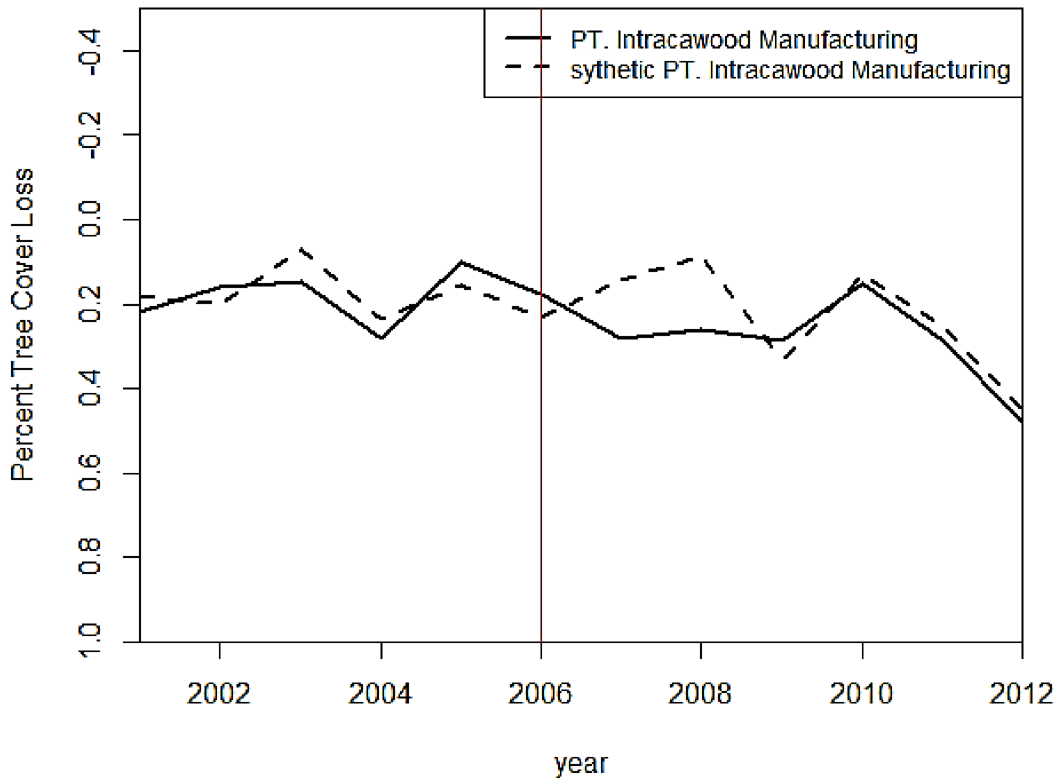


Figure 19: Comparison of treated FMU (Intracawood Manufacturing) and its synthetic control from 2001-2012. The solid line that shows the trajectory of the certified FMU (PT. Intracawood Manufacturing) clearly depicts more forest cover loss compared to its synthetic control except in 2009.

Placebo tests

Placebo tests show that none of the results, except for year 2007, are significant at the 80% confidence level (that is, they nearly all fall within the 10th to 90th percentiles of the placebo treatment effects). This again shows either no effect of the certification on the deforestation trajectory of Intracawood Manufacturing, or may be its true effected is masked by poor quality of the synthetic control.

Table 35: Significance of the certified effects for certified FMU (10th and 90th percentiles of the placebos treatment effects)

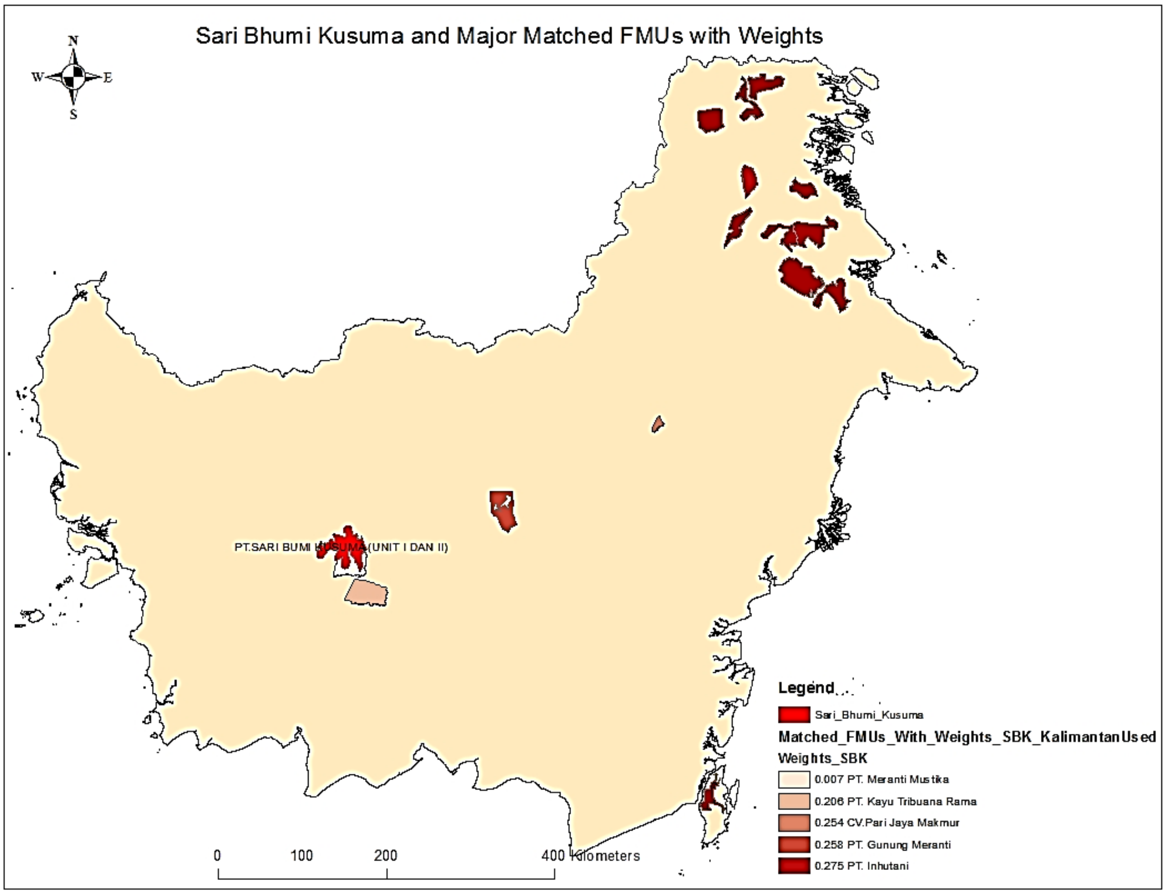
Year	Observed percent tree cover loss in PT. Intracawood Manufacturing	Treatment effect of certification on Intracawood Manufacturing	10th and 90th percentiles of the placebo treatment effects‡
2007	0.28	0.14*	-0.37 to 0.10
2008	0.26	0.17	-0.15 to 0.56
2009	0.29	-0.05	-0.10 to 0.60
2010	0.15	0.02	-0.05 to 0.28
2011	0.29	0.04	-0.25 to 0.21
2012	0.48	0.03	-0.19 to 0.40

* Treatment effect significant at 80% level, because falls outside the 10th to 90th percentiles of the placebo treatment effects.
‡ Confidence intervals based on estimated treatment effects of placebos with MSPE less than the MSPE of Intracawood (the treated unit).

Low Plausibility of Synthetic Control

Sari Bhumi Kusuma

Figure 20 suggests that little can be learned from this impact evaluation because the synthetic control or counterfactual is not plausible. The deforestation trajectory of the certified company is a poor match with the deforestation trajectory of the synthetic control (MSPE = 0.023) (also see Appendix A (10)). Map 13 shows the weights assigned by SYNTH to matched FMUs for the treated Sari Bhumi Kusuma.



Map 13: Sari Bhumi Kusuma and its matched FMUs/Companies with weights

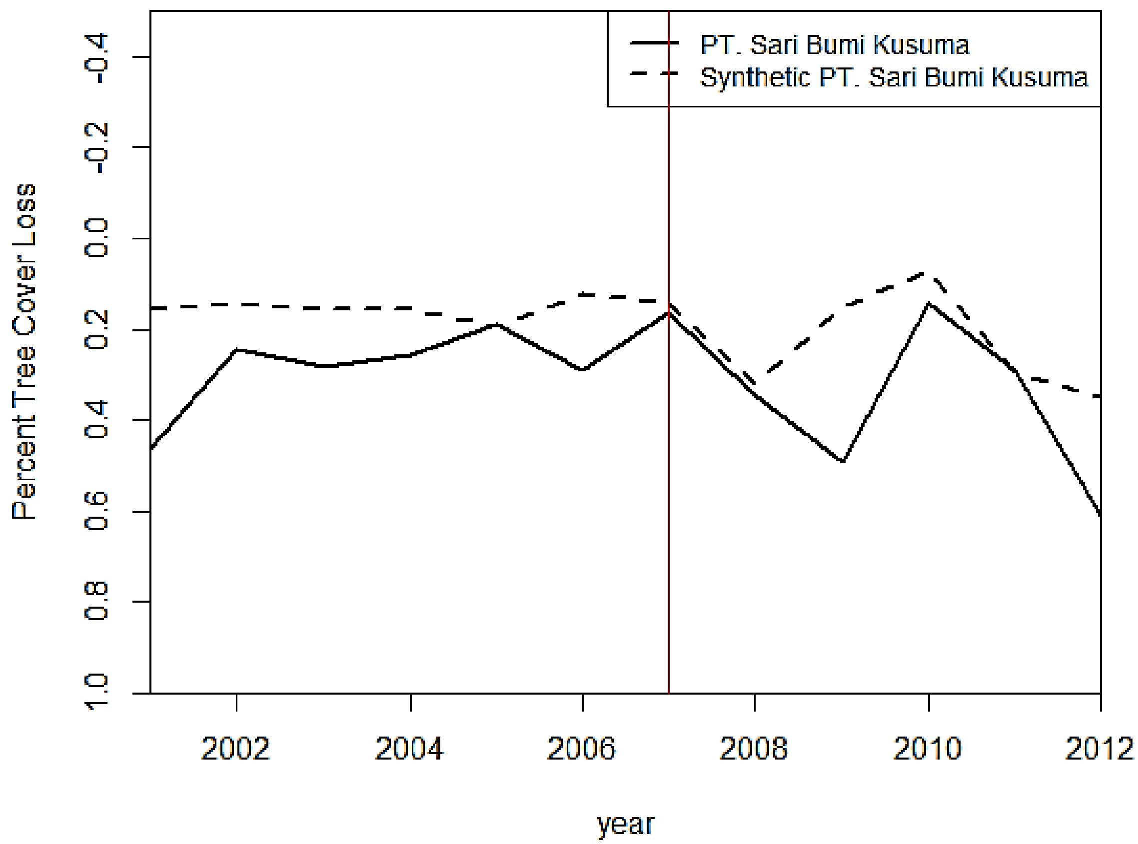


Figure 20: Comparison of treated FMU (PT Sari Bumi Kusuma) and its synthetic control from 2001-2012.

In the above figure, Y-axis is coded the opposite, with positive numbers indicating percent tree cover loss, and therefore less loss of tree cover as we move up the y-axis. The solid line that shows the trajectory of the certified company (PT. Sari Bumi Kusuma) clearly depicts more forest cover loss compared to its synthetic throughout and even after 2006, when certification was introduced. In the pre-certification period, i.e. before 2006, one can observe inadequate matching of deforestation trajectories of certified FMU and the synthetic control. Hence, it would introduce error that might lower the validity of the results obtained.

Placebo effects

Table 36 shows that none of the effects, except for the year 2009, are significantly different from zero at the 80% confidence level. However, this could be due to either lack of impact or poor quality of the synthetic control.

Table 36: Significance of the certified effects for certified FMU (10th and 90th percentiles of the placebos treatment effects)

Year	Observed percent tree cover loss in PT. SBK	Treatment effect of certification on SBK	10th and 90th percentiles of the placebo treatment effects‡
2008	0.35	0.03	-0.23 to 0.50
2009	0.49	0.34*	-0.26 to 0.31
2010	0.14	0.07	-0.15 to 0.24
2011	0.29	-0.01	-0.18 to 0.31
2012	0.61	0.26	-0.32 to 0.59

* Treatment effect significant at 80% level, because falls outside the 10th to 90th percentiles of the placebo treatment effects.
‡ Confidence intervals based on estimated treatment effects of placebos with MSPE less than the MSPE of SBK (treated unit).

5d. Summary of results for 10 certified FMUs in three countries

Table 37(a) shows the effect of certification on deforestation in each of the 10 FMUs studied in the Brazilian Amazon, Gabon, and Kalimantan (Indonesia). The desired outcome is a negative significant effect, meaning that certification of the FMU resulted in less deforestation in a given year compared to the counterfactual of no certification. Results show that certification has a mixed record with more evidence of success in Brazil than in Kalimantan and Gabon. Considering just the three FMUs with the most plausible synthetic controls, Orsa Florestal, Rougier, and Suka Jaya Makmur (SJM), the point estimates are all negative in the year immediately after certification and the last year in our dataset (2012), but the effects in the intermediate years are highly variable in terms of both sign and statistical significance.

Table 37(a): Estimated effects of certification on percent tree cover loss by calendar year for ten certified FMUs in the Brazilian Amazon, Gabon and Kalimantan (Indonesia)

	Brazilian Amazon			Gabon			Kalimantan (Indonesia)			
Year	CKV	ORSA	CRC	CBG	PW	ROUGIER	ED	IM	SBK	SJM
2005		-0.26*								
2006		0.25*					-0.18			
2007	-0.08*	0.28*	-0.02				0.09	0.14*		
2008	0.05*	0.20*	-0.18				0.06	0.17	0.03	
2009	-0.08*	0.97*	-0.24	-0.06*	-0.03*	-0.02	0.19	-0.05	0.34*	
2010	-0.05	-1.28*	-0.83	-0.01	0.06*	0.004	0.11	0.02	0.07	
2011	-0.07	0.33*	-0.06	0.02	-0.04*	-0.01	-0.08*	0.04	-0.01	-0.03*
2012	-0.06*	-0.18*	-0.63	0.02	0.05*	-0.001	0.08	0.03	0.26	-0.14*

CKV: Cikel Brasil Verde Madeiras Ltda; ORSA: Orsa Florestal S.A.; CRC : Cikel Rio Capim; PW : Precious wood; ED: Erna Djuliawati ; IM: Intracawood Manufacturing; SBK: Sari Bhumi Kusuma; SJM: Suka Jaya Makmur
Shaded columns indicate FMUs with most plausible synthetic control in each country.
Negative values of the treatment effect indicate less tree cover loss in the FMU compared to its synthetic control.
*Treatment effect is statistically significant, i.e. it lies outside the 10th and 90th percentiles of the placebo treatment effects.

Table 37(b) presents the same results by number of years since certification. In Brazil and Gabon, the treatment effects are negative in the first year after certification, and statistically significant in two out of three FMUs in each country. In the following years, there is a mix of positive, negative, and insignificant results. In the case of Orsa Florestal, which has the most plausible synthetic control in Brazil, the effects become positive after the first year and then alternate between positive and negative. In the case of Rougier in Gabon, the effects are not statistically significant in any year. Finally, in the case of SJM, which has the best quality synthetic control of any FMU, the estimated effects are negative in the two years post-certification considered in this analysis. This is a much more complex response to certification than would be identified through a more typical impact evaluation that considers just one year, such as the year after certification or the most recent year. The variation in treatment effects that we find may be due to exogenous (e.g. market demand) or endogenous factors (e.g. company leadership and human capital).

Table 37(b): Estimated effects of certification on percent tree cover loss by years since certification for ten certified FMUs in the Brazilian Amazon, Gabon and Kalimantan (Indonesia)

Year after certification	Gabon			Kalimantan (Indonesia)				Brazil		
	CBG	PW	ROUGIER	ED	IM	SBK	SJK	CKV	ORSA	CRC
First Year	-0.06*	-0.03*	-0.02	-0.18	0.14*	0.03	-0.03*	-0.08*	-0.26*	-0.02
Second Year	-0.01	0.06*	0.004	0.09	0.17	0.34*	-0.17*	0.05*	0.25*	-0.18
Third Year	0.02	-0.04*	-0.01	0.06	-0.05	0.07		-0.08*	0.28*	-0.24
Fourth Year	0.02	0.05*	-0.001	0.19	0.02	-0.01		-0.05	0.20*	-0.83
Fifth Year				0.11	0.04	0.26		-0.07	0.97*	-0.06
Sixth Year				-0.08*	0.03			-0.06*	-1.28*	-0.63
Seventh Year				0.08					0.33*	
Eighth Year									-0.18*	

See footnotes for Table 38(a)

6. Tree cover gain and loss in certified and other FMUs

In all three countries, we find evidence that certification has increased tree cover loss in some certified FMUs in some years. One possible explanation is that certification leads to both more timber harvest (which results in short-term tree cover loss) and more regeneration. To assess the plausibility of this explanation, we examine tree cover loss and gain statistics for 2000 – 2012 in the certified FMUs and all other FMUs in the eastern Brazilian Amazon, Gabon and Kalimantan (Indonesia), based on the gain and loss data layers in Hansen et al. (2013).

Specifically, we use the following two layers from Hansen et al. (2013):

1. Global tree cover loss 2000–2012 (loss): Tree cover loss during the period 2000–2012, defined as a stand-replacement disturbance, or a change from a forest to non-forest state. Encoded as either 1 (loss) or 0 (no loss).

2. Global tree cover gain 2000–2012 (gain): Tree cover gain during the period 2000–2012, defined as the inverse of loss, or a non-forest to forest change entirely within the study period. Encoded as either 1 (gain) or 0 (no gain).

Using ArcGIS, tree cover loss and gain are calculated for (i) Certified FMUs, and for (ii) Non-certified FMUs, in hectares and as a percent of the total FMU area. We first present the rates of tree cover loss and gain in FMUs that became certified vs. other FMUs in each study region. We then turn to a more granular pixel-level analysis.

Forest gain and loss summarized by country and eventual certification status

Tree cover gain and loss pixels as a percent of total pixels in certified and non-certified FMUs combined across the three study regions are presented in Figures 21 and 22.

Forest gain, as a percentage of total area, is much greater in certified FMUs compared to non-certified FMUs in Brazilian Amazon, about the same in Gabon, and much less in Kalimantan.

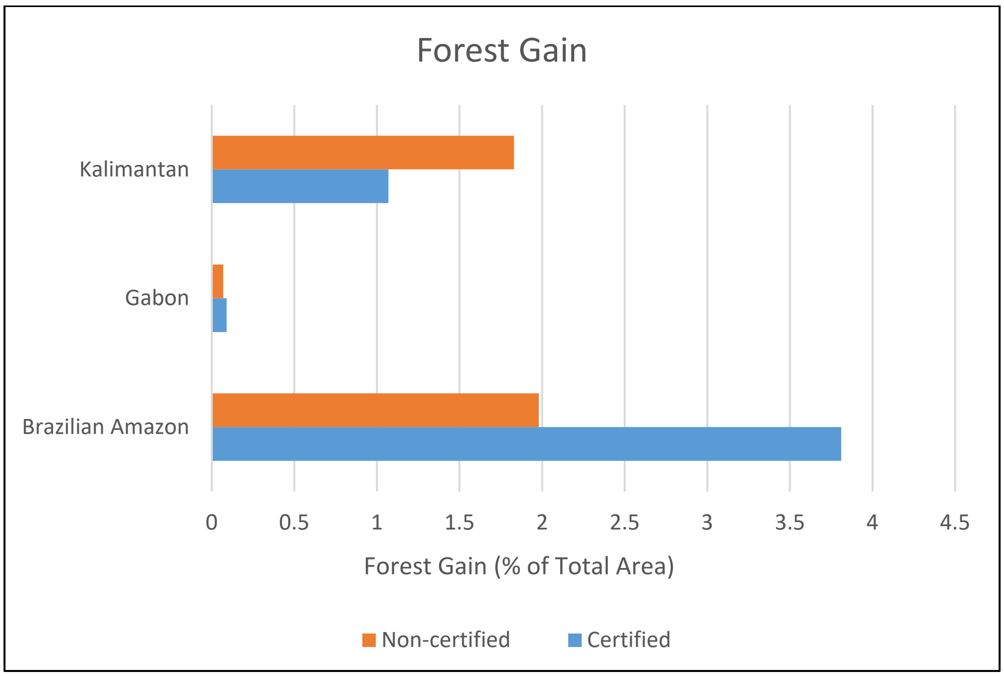


Figure 21: Comparison of Forest Gain (% of Total Area) in certified and non-certified FMUs in three landscapes.

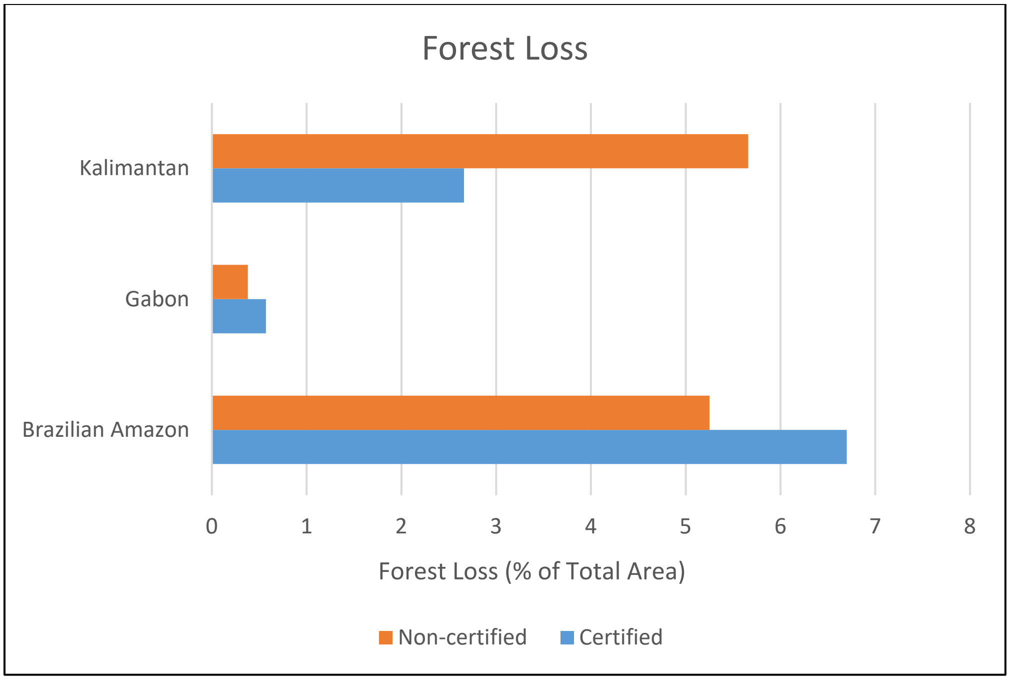


Figure 22: Comparison of Forest Loss (% of Total Area) in certified and non-certified FMUs in three landscapes.

Figure 22 shows the levels of forest loss in FMUs in our three study regions. Here, in both the Brazilian Amazon and Gabon, there is more forest loss, as a percentage of total area, in certified units compared to non-certified units. That is, certified forests in these two countries are not only experiencing higher forest gain, but are also observing more forest loss. In the case of Kalimantan, certified FMUs have lower rates of forest loss and forest gain compared to non-certified units. This suggests that certification is associated with more active forest management in Brazil and Gabon, but less active management in Kalimantan.

Forest management scenarios

By examining patterns of forest loss and gain pixel by pixel, we can categorize them into four different scenarios or pathways of forest management (Table 38).

Table 38. Forest management scenarios, based on tree cover loss and gain 2000-2012

Pathways	Gain layer (1= Gain , 0 = no gain)	Loss layer (1= Loss, 0 = no loss)	Likely mechanisms and their interpretations
I. Static Forest Management Pathway	0	0	There are two possible explanations. First, a forested pixel in 2000 remained forested through 2012. This may reflect no-harvest zones or high-value conservation areas within the FMU that are not open to harvest. Second, a non-forest area in 2000 remained non-forest through 2012. This may represent infrastructure such as sawmills.

II. Active forest management Pathway (a) Solitary deforestation-pathway	0	1	This may be due to tree cover loss anytime between 2001 and 2012, which in turn could result from timber harvest or deforestation. No compensating tree cover gain is reported.
(b) Solitary forest regeneration pathway	1	0	This may be due to tree cover gain anytime between 2001 and 2012, which in turn could result from natural regeneration or active reforestation. No tree cover loss is reported.
III. Hyper-active forest management pathway	1	1	Both tree cover loss and tree cover gain are reported for the same pixel when: (i) a non-forest area in 2000 became forested and then was deforested sometime 2002 - 2012, (ii) a forested area in 2000 was deforested 2001-2011 and then became forest again by 2012. This indicates either intensive forest management or deforestation and natural regeneration inside FMUs.

Because Hansen (2013) only reports forest gain over the entire period from 2000 to 2012, we cannot calculate forest gain just during the period when a FMU was certified. Instead we compare tree cover loss and gain over the entire period in our 10 study FMUs that became certified at some point, and in all other FMUs. In both categories, there is more tree cover loss than gain (Tables 39, 43, 47).

A. Brazilian Amazon

Table 39: Forest Gain and Loss, 2000 to 2012

Companies	Total Area (ha)	Forest Gain (Ha)	Percent of FMU with Forest Gain (%)	Forest Loss (Ha)	Percent of FMU with Forest Loss (%)	Net Change (Ha)	Net Change as % of FMU
Certified PMFSs[11]	1742091	48614.22	2.79	85522.5	4.91	-36908.3	-2.12
Non-Certified PMFSs[12]	1104283	15720.93	1.42	41607	3.77	-25886.1	-2.34

[11] Certified PMFSs include the three FMUs evaluated in this study: Cikel Brasil Verde Madeiras (Certified in 2006), Orsa Florestal S.A.(Certified in 2004), and Cikel Rio Capim (Certified in 2006).

[12] List of the non-certified FMUs in Belém-Brasilia and Estuario are given in Appendix C (a); for Forest Gain(i) and Forest Loss(ii)

Table 40: Forest Gain and Loss, 2000 to 2012 (by FMU)

Certified Companies	Total Area (ha)	Forest Gain (Ha)	Forest Gain as % of FMU	Forest Loss (Ha)	Forest Loss as % of FMU	Net Change (Ha)	Net Change as % of FMU
Cikel Brasil Verde Madeiras Ltda - Fazenda Jutaituba	160481	1130.04	0.70	1228.95	0.77	-98.91	-0.06
Orsa Florestal S.A.	910507.7	45776.61	5.03	82166.49	9.02	-36389.9	-3.99
Cikel Rio-Capim	206202.1	1707.57	0.83	2142.81	1.04	-435.24	-0.21

Forest management scenarios

Table 41. Certified and non-certified FMUs (pooled)

Certified Companies	Static Forest Management Pathway (ha)	Percent of total area	Active forest management Pathway (ha)[13]	Percent of total area	Hyper-active forest management pathway (ha)	Percent of total area
Certified PMFSs	1190896	93.24	57921.1	4.54	28368.25	2.22
Non-Certified PMFSs	932785.5	95.62	36365.61	3.73	6364.331	0.65

The results indicate that a very large percentage of the total area of both certified and non-certified FMUs experienced no change in tree cover. A pixel that was forested in 2000 was very likely to remain forested in 2012, and a pixel that was not forested in 2000 was likely to still not have tree cover in 2012. These likely include remote forests that remain untouched, as well as permanently deforested areas with transportation or other infrastructure.

Certified FMUs include more areas under active and hyper-active forest management. Both loss and gain of tree cover (hyper-active forest management) occurred in 2.2% of certified FMUs in the period 2001-2012, compared to just 0.65% of other FMUs. This suggests more intensive management (with both timber harvest and regeneration) of certified FMUs.

a) Certified companies

13

Table 42. Certified companies: Forest management scenarios

Certified Companies	Static Forest Management Pathway (ha)	Percent of total area	Active forest management Pathway (ha)	Percent of total area	Hyper-active forest management pathway (ha)	Percent of total area
Cikel Brasil Verde Madeiras Ltda - Fazenda Jutaituba	158562.2	98.80	1836.26	1.14	78.56	0.05
Orsa Florestal S.A.	828839.6	91.03	53959	5.93	27708.31	3.04
Cikel Rio-Capim	203493.68	98.69	2125.84	1.03	581.38	0.28

While all three certified FMUs that we evaluated are mostly under "static forest management," with no change in tree cover, Orsa Florestal does have a substantially greater area under active management (5.93%) and hyper-active management (3.04%). This perhaps explains the pattern of treatment effects estimated for this FMU, where certification reduces tree cover loss in the first year, then increases it in several years, followed by alternating negative and positive effects.

B. Gabon

Table 43: Forest Gain and Loss, 2000 to 2012

Companies	Total Area (ha)	Forest Gain (Ha)	Forest Gain as % of FMU	Forest Loss (Ha)	Forest Loss as % of FMU	Net Change (+/-)	Net Change (%)
Certified Companies[14] (Total)	2076454	1946.52	0.09	11739.51	0.57	-9792.99	-0.47
Non-Certified Companies[15] (Total)	5155845	3679.02	0.07	19761.48	0.38	-16082.5	-0.31

Table 44: Forest Gain and Loss, 2000 to 2012 (by FMU)

Certified Companies	Total Area (Ha)	Forest Gain (Ha)	Forest Gain as % of FMU	Forest Loss (Ha)	Forest Loss as % of FMU	Net Change (+/-)	Net Change (%)
CBG	571526.55	509.76	0.09	3243.51	0.57	-2733.75	-0.48
Precious Wood	618176.56	577.53	0.09	4834.26	0.78	-4256.73	-0.69
Rougier	886751.34	859.23	0.10	3661.74	0.41	-2802.51	-0.32

[14] Certified companies are the three evaluated in this study: CBG, Precious Wood and Rougier.
[15] Non-certified companies in Gabon are listed in Appendix C (b); Forest Gain (i) and Forest Loss(ii)

Forest management scenarios

Table 45: Certified and non-certified FMUs (pooled)

Certified Companies	Static Forest Management Pathway (ha)	Percent of total area	Active forest management Pathway (ha)	Percent of total area	Hyper-active or dynamic forest management pathway (ha)	Percent of total area
Certified companies	2062981	99.35	12353.19	0.59	1077.08	0.05
Non-Certified companies	5132299	99.54	21838.95	0.42	1527.978	0.3

The analysis suggests low levels of forest management or deforestation in all FMUs (whether certified or not) in Gabon. Areas managed by non-certified companies have undergone more hyper-active management, with both loss and gain events happening in 0.3% of the area, compared to only 0.05% of the area managed by FSC certified companies. Certified companies have higher rates of active management with 0.59% of their area on solitary regeneration or deforestation pathways.

Table 46: Certified companies: Possible pathways of deforestation or forest management

Certified Companies	Static Forest Management Pathway (ha)	Percent of total area	Active forest management Pathway (ha)	Percent of total area	Hyper-active forest management pathway (ha)	Percent of total area
CBG	567755.2	99.34	3487.00	0.61	246.93	0.04
Precious Wood	612770.1	99.13	5106.85	0.83	315.97	0.05
Rougier	882455.4	99.52	3759.34	0.42	514.18	0.06

Table 46 shows that this pattern holds in the areas managed by the three certified companies. Precious Woods has the highest proportion of its area under active forest management with 0.87% of its area experiencing solitary regeneration or deforestation events, whereas Rougier has the lowest proportion (0.42%) of its area on an active forest management pathway.

C. Kalimantan (Indonesia)

Table 47: Forest Gain and Loss, 2000 to 2012

Companies	Total Area (Ha)	Forest Gain (Ha)	Forest Gain as % of FMU	Forest Loss (Ha)	Forest Loss as % of FMU	Net Change (+/-)	Net Change (%)
Certified FMUs[16]	701192.51	7492.77	1.07	18654.48	2.66	-11161.7	-1.59
Non-Certified FMUs[17]	7710942.23	141320.52	1.83	436170.24	5.66	-294850	-3.82

Table 48: Forest Gain and Loss, 2000 to 2012 (FMU-wise)

Certified FMUs	Total Area (Ha)	Forest Gain (Ha)	Forest Gain as % of FMU	Forest Loss (Ha)	Forest Loss as % of FMU	Net Change (+/-)	Net Change (%)
Erna Djuliawati	180250.46	2988.54	1.66	6299.73	3.49	-3311.19	-1.84
Intracawood Manufacturing	194249.50	1511.73	0.78	5122.08	2.64	-3610.35	-1.86
Sari Bhumi Kusuma	143715.47	2414.34	1.68	4969.53	3.46	-2555.19	-1.78
Suka Jaya Makmur	182977.08	364.59	0.19	2263.14	1.24	-1898.55	-1.04

Forest management scenarios

Table 49: Certified and non-certified FMUs (pooled)

FMUs	Static Forest Management Pathway (ha)	Percent of total area	Active forest management Pathway (ha)	Percent of total area	Hyper-active forest management pathway (ha)	Percent of total area
Certified FMUs	675544.1	96.34	23599.86	3.37	2003.351	0.29
Non-Certified FMUs	8973830.5	94.22	491130.34	5.16	59252.913	0.62

[16] Certified FMUs included are (i) Erna Djuliawati, (ii) Intracawood Manufacturing, (iii) Sari Bhumi Kusuma and (iv) Suka Jaya Makmur.

[17] List of non-certified FMUs in Kalimantan included in the analysis are given in Appendix C (c); Forest Gain (i) and Forest Loss (ii)

In Kalimantan, less of the certified FMUs that we evaluated were on active or hyper-active management pathways compared to non-certified FMUs. Non-certified FMUs had higher proportions of their areas under active (5.16%) and hyperactive management pathways (0.62%) compared to non-certified FMUs.

Table 50: Certified FMUs: Possible pathways of deforestation or forest management

Certified Companies	Static Forest Management Pathway (ha)	Percent of total area	Active forest management Pathway (ha)	Percent of total area	Hyper-active forest management pathway (ha)	Percent of total area
Erna Djuliawati	171199.26	94.98	8308.66	4.61	743.69	0.41
Intracawood Manufacturing	187778.16	96.67	5925.52	3.05	545.63	0.28
Sari Bhumi Kusuma	136429.19	94.93	6692.23	4.66	549.52	0.38
Suka Jaya Makmur	180137.60	98.45	2673.45	1.46	164.5	0.09

Suka Jaya Makmur has the lowest percentage of its area under active forest management and also experienced the lowest amount of net forest cover loss.

Summarizing across our three study regions (Table 51), we see that although FSC certified FMUs in Brazilian Amazon are smaller, more of their area is under active and hyper-active forest management pathways compared to non-certified FMUs. This finding is consistent with other research in this region that has found a higher level of active forest management by FSC certified companies compared to non-FSC companies (Romero et al. 2015).

Table 51: Forest management scenarios suggested by patterns of tree cover loss and gain

	Brazilian Amazon			Gabon			Kalimantan		
	Static (%)	Active (%)	Hyper-active (%)	Static (%)	Active (%)	Hyper-active (%)	Static (%)	Active (%)	Hyper-active (%)
FSC Certified companies/FMUs	93.24	4.54	2.22	99.35	0.59	0.05	96.34	3.37	0.29
Non-FSC companies/FMUs	95.62	3.73	0.65	99.54	0.42	0.3	94.22	5.16	0.62

In the case of Gabon, there is little difference in the forest dynamics in areas managed by certified vs. non-certified companies, with just a slightly larger area of certified FMUs under active management, and a slightly larger area of non-certified FMUs under hyper-active management. The pattern is completely different in Kalimantan (Indonesia) where non-certified FMUs have more area under active as well as hyper-active management pathways compared to certified FMUs. We emphasize that this reflects difference between FMUs that become certified and FMUs that do not become certified, not necessarily any effect of certification on FMU management. However, even without isolating the years when FMUs were certified, we find interesting patterns. This is promising for future analyses using richer remote sensing data to quantify outcomes in FMUs across the tropics.

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Appendix A: Time trends in percent deforestation

Brazilian Amazon

A naïve comparison of deforestation (Table 1) shows that Orsa Florestal experienced higher deforestation compared to non-certified FMUs in the same zone on average and in every year except 2007. This emphasizes the importance of comparing the certified FMU to comparable non-certified FMUs in order to construct the counterfactual scenario of deforestation that would have occurred without certification (Figure 8).

Table 1: Time trends in percent deforestation. Shaded rows correspond to years after FSC certification.

	Certified FMU (Orsa Florestal)	All FMUs in the donor pool	Synthetic control (deforestation rate * weight (W*) for each donor FMU in the synthetic control)
2001	0.57	0.10	0.66
2002	0.70	0.19	0.72
2003	0.65	0.05	0.32
2004	0.92	0.48	0.96
2005	0.47	0.20	0.73
2006	0.42	0.30	0.17
2007	0.53	0.99	0.25
2008	0.62	0.52	0.42
2009	1.70	0.35	0.73
2010	0.93	0.68	2.21
2011	0.77	0.16	0.44
2012	0.44	0.13	0.62

The vectors of weights on covariates and on comparison municipalities used to construct the synthetic control are given in Appendix B.

Table 2: Time trends in percent deforestation in Cikel Rio Capim. Shaded rows correspond to years after FSC certification.

	Certified FMU (Cikel Rio Capim)	All FMUs in the donor pool	Synthetic control (deforestation rate * weight (W*) for each donor FMU in the synthetic control)
2001	0.01	0.72	0.31
2002	0.03	0.65	0.35
2003	0.02	0.58	0.03
2004	0.07	1.00	0.30
2005	0.27	1.17	0.45
2006	0.03	0.98	0.18
2007	0.13	0.87	0.15
2008	0.24	0.76	0.43
2009	0.02	0.79	0.27
2010	0.02	1.89	0.86
2011	0.05	1.17	0.11
2012	0.004	1.33	0.64

The vectors of weights on covariates and on comparison municipalities used to construct the synthetic control are given in Appendix B.

Table 3 shows time trends in deforestation in the certified FMU, all FMUs in the donor pool, and the synthetic control for CBVM. CBVM experienced lower deforestation compared to non-certified FMUs on average for the entire study period (before and after certification) except for the year 2003. In contrast, deforestation rates in CBVM were generally slightly higher than in its synthetic control prior to certification, and lower after certification (except in 2008).

Table 3: Time trends in deforestation. Shaded rows in table correspond to years after FSC certification.

	Certified FMU (Cikel Brasil Verde Madeiras Ltda - Fazenda Jutaituba)	Mean of all FMUs in the donor pool	Synthetic control (deforestation rate for each donor FMU X weight of each FMU (W*) in the synthetic control)
2001	0	0.10	0.02
2002	0.09	0.19	0.08

2003	0.07	0.05	0.02
2004	0.06	0.48	0.10
2005	0.11	0.20	0.07
2006	0.08	0.30	0.07
2007	0.01	0.99	0.09
2008	0.14	0.52	0.09
2009	0.02	0.35	0.10
2010	0.01	0.68	0.06
2011	0.02	0.16	0.09
2012	0.03	0.13	0.09

The vectors of weights on covariates and on comparison municipalities used to construct the synthetic control are given in Appendix B.

Gabon

A naïve comparison of deforestation (Table 4) shows that the certified FMU (Rougier) experienced higher deforestation compared to all non-certified FMUs on an average for the entire period (before and after certification). The deforestation on an average for the certification period is slightly less in certified FMU compared to its synthetic control.

Table 4: Time trends in the forest cover change

	Certified FMU (Rougier)	All FMUs in the donor pool	Synthetic control
2001	0.03	0.04	0.02
2002	0.04	0.05	0.02
2003	0.09	0.05	0.03
2004	0.02	0.02	0.01
2005	0.04	0.04	0.03
2006	0.03	0.05	0.03
2007	0.07	0.04	0.05
2008	0.03	0.04	0.02
2009	0.05	0.06	0.07
2010	0.017	0.02	0.013
2011	0.02	0.04	0.03
2012	0.008	0.02	0.009

A naïve comparison of the deforestation (table 5) shows that the certified FMU (Precious wood) experienced higher deforestation compared to non-certified FMUs on an average for the entire period (before and after certification) and even when only the period under certification is considered. This necessitates the use of counterfactual (synthetic control) for robust estimation of the impact of FSC certification.

Table 5: Time trends in the forest cover change

	Certified FMU/company – Precious wood	All FMUs/companies in the donor pool	Synthetic control (deforestation rate for each donor FMU in the synthetic control X weight of each FMU (W*))
2001	0.06	0.04	0.08
2002	0.06	0.05	0.06
2003	0.10	0.05	0.08
2004	0.10	0.02	0.06
2005	0.07	0.04	0.08
2006	0.03	0.05	0.06
2007	0.09	0.04	0.04
2008	0.06	0.04	0.04
2009	0.08	0.06	0.11
2010	0.10	0.02	0.04
2011	0.03	0.04	0.07
2012	0.07	0.02	0.02

Naïve comparison of the deforestation (table 6) indicates that CBG experienced higher deforestation compared to non-certified FMUs on an average for the entire period (before and after certification), and also for the post-certification period.

Table 6: Time trends in the forest cover change

	Certified FMU/company-CBG	All FMUs(companies) in the donor pool	Synthetic control
2001	0.01	0.04	0.04
2002	0.08	0.05	0.08
2003	0.02	0.05	0.07
2004	0.02	0.02	0.01
2005	0.06	0.04	0.04
2006	0.13	0.05	0.07
2007	0.02	0.04	0.05
2008	0.09	0.04	0.06
2009	0.01	0.06	0.07
2010	0.03	0.02	0.04
2011	0.09	0.04	0.07
2012	0.03	0.02	0.01

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A naïve comparison of tree cover loss (Table 7) shows that the Suka Jaya Makmur experienced much less deforestation on average over the entire period (before and after certification) compared to non-certified FMUs. This demonstrates the importance of comparing tree cover loss in Suka Jaya to tree cover loss in a matched comparison (Map 10) in order to construct the counterfactual scenario of tree cover loss that would have occurred without certification.

Table 7 Tree cover loss in the certified FMU (Suka Jaya Makmur), all non-certified FMUs in the donor pool, and the synthetic control.

	Certified FMU – Suka Jaya Makmur	All FMUs in the donor pool	Synthetic control
2001	0.12	0.25	0.11
2002	0.09	0.26	0.08
2003	0.03	0.21	0.04
2004	0.13	0.35	0.14
2005	0.10	0.36	0.10
2006	0.11	0.45	0.11
2007	0.10	0.31	0.06
2008	0.09	0.31	0.10
2009	0.21	0.39	0.17
2010	0.06	0.25	0.08
2011	0.10	0.34	0.13
2012	0.18	0.58	0.32

Table 8 shows the naïve comparison of the deforestation experienced in certified FMU (Erna Djuliawati) and non-certified FMUs. It indicates that the certified FMU has on have average for the entire period (before and after the certification) a slightly less deforestation compared to non-certified FMUs. However, when only the post-certification period is considered, the deforestation in the certified FMU is almost similar to that of the non-certified FMUs.

Table 8 indicates the time trends in the forest cover change in the certified FMU, all FMUs in the donor pool and in the synthetic control.

Table 8: Time trends in the forest cover change

	Certified FMU – Erna Djuliawati	All FMUs in the donor pool	Synthetic control
2001	0.33	0.25	0.22
2002	0.26	0.26	0.33
2003	0.05	0.21	0.10
2004	0.40	0.35	0.37
2005	0.20	0.36	0.23
2006	0.24	0.45	0.42
2007	0.31	0.31	0.22
2008	0.17	0.31	0.11
2009	0.60	0.39	0.41
2010	0.36	0.25	0.25

2011	0.26	0.34	0.34
2012	0.62	0.58	0.54

Table 9 compares tree cover loss in the certified FMU, all FMUs in the donor pool, and the synthetic control. It indicates that Intracawood Manufacturing experienced much lower deforestation on average over the entire period (before and after certification) compared to non-certified FMUs. This results holds even when only the post-certification period is considered.

Table 9: Time trends in the forest cover change

	Certified FMU – Intracawood Manufacturing	All FMUs in the donor pool	Synthetic control
2001	0.22	0.25	0.18
2002	0.16	0.26	0.20
2003	0.15	0.21	0.07
2004	0.28	0.35	0.24
2005	0.10	0.36	0.16
2006	0.18	0.45	0.23
2007	0.28	0.31	0.14
2008	0.26	0.31	0.09
2009	0.29	0.39	0.33
2010	0.15	0.25	0.13
2011	0.29	0.34	0.25
2012	0.48	0.58	0.45

As shown in Table 10, the certified FMU (Sari Bhumi Kusuma) experienced lower deforestation on an average for the entire period (before and after certification) compared to the non-certified FMUs. However, for the post-certification period, the deforestation is almost equal on an average for the certified FMU and the non-certified FMUs.

Table 10: Time trends in the forest cover change

	Certified FMU – Sari Bhumi Kusuma	All FMUs in the donor pool	Synthetic control
2001	0.46	0.25	0.16
2002	0.25	0.26	0.14
2003	0.28	0.21	0.16
2004	0.26	0.35	0.16
2005	0.19	0.36	0.19
2006	0.29	0.45	0.12
2007	0.16	0.31	0.14
2008	0.35	0.31	0.32
2009	0.49	0.39	0.15
2010	0.14	0.25	0.07
2011	0.29	0.34	0.30
2012	0.61	0.58	0.35

Appendix B: Vectors of weights on covariates used in construction of synthetic control

This appendix lists the weights on covariates used in the construction of synthetic controls for each certified FMU. High weights suggest that the covariate is an important determinant of deforestation.

Brazilian Amazon

a) Orsa Florestal

Vectors of weights on covariates used in construction of synthetic control

	v.weights
Percent tree cover loss (2001 to 2005)	0.363
Distance from Protected area (2004)	0.17
Distance from Polo (2004)	0.114
Distance from Settlement (2004)	0.106
Altitude (2001)	0.09
Mean Annual Temperature (2001)	0.078
Monitoring effort (2004)	0.046
Poverty Count (2004)	0.019
Tree Cover (2000)	0.007
Area (2004)	0.006

b) Cikel Rio Capim

Vectors of weights on covariates used in construction of synthetic control

	v.weights
Area (2004)	0.471
Tree Cover(2000)	0.469
Percent tree cover loss (2001 to 2005)	0.012
Mean Annual Temperature (2001)	0.01
Altitude (2001)	0.008
Distance from Protected area (2004)	0.008
Distance from Polo (2004)	0.007
Mean Annual Precipitation (2001)	0.007
Poverty Count (2004)	0.006
Monitoring effort (2004)	0.002

c) Cikel Brasil Verde

Vectors of weights on covariates used in construction of synthetic control (Cikel Verde)

	v.weights
Mean Annual Precipitation (2001)	0.373
Distance from Protected area (2004)	0.284
Percent tree cover loss (2001 to 2005)	0.08
Distance from Polo (2004)	0.078
Mean Annual Temperature (2001)	0.068
Altitude (2001)	0.033
Monitoring effort (2004)	0.03
Area (2004)	0.023
Distance from Settlement (2004)	0.023
Tree Cover (2000)	0.004
Poverty Count (2004)	0.002

Gabon

d) Rougier

Important drivers of deforestation and their weights

	v.weights
Maximum distance between units of a company (2005)	0.238
Number of villages (2008)	0.181
Mean Annual Temperature (2005)	0.091
Road Density (2008)	0.086
Mean Annual Precipitation (2005)	0.082
Percent tree cover loss (2001 to 2008)	0.06
Area under Okoume presence (2005)	0.032
Shape metric (2005)	0.017
Population density (2001-2012)	0.01
Tree cover (2001-2012)	0.001
Timber harvest quota (2008)	0.001
Area (2005)	0.001
Exchange rate (2008)	0.042

Distance from cities (2008)	0.071
Mean Elevation (2001)	0.087

e) Precious wood Gabon

Important drivers of deforestation and their weights

	v.weights
Percent tree cover loss (2001 to 2008)	0.246
Road Density (2008)	0.23
Number of villages (2008)	0.136
Timber harvest quota (2008)	0.12
Exchange rate (2008)	0.072
Mean Elevation (2001)	0.053
Population density	0.05
Mean Annual Temperature 2005	0.04
Distance from cities (2008)	0.027
Maximum distance between units of a company (2005)	0.022
Area under Okoume presence (2005)	0.004

f) CBG

Important drivers of deforestation and their weights

Covariates	v.weights
Percent tree cover loss (2001 to 2008)	0.188
Shape metric (2005)	0.168
Tree cover (2001-2012)	0.15
Area (2005)	0.147
Number of villages (2008)	0.134
Mean Elevation (2001)	0.126
Exchange rate (2008)	0.066
Mean Annual Temperature(2005)	0.019
Mean Annual Precipitation(2005)	0.001

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g) Suka Jaya Makmur

Important drivers of deforestation and their weights

Covariates	v.weights
Percent Tree Cover Loss (2001-2010)	0.432
Mean Elevation (2001)	0.264
Mean Temperature (2001)	0.153
Area Logged/year (ha/year) (2007)	0.041
Primary Forests (%) (2009)	0.028
Logging Intensity (m3/ha) (2007)	0.016
Duration of Harvest Permit (2007)	0.016
Mean Precipitation (2001)	0.011
Shape (2010)	0.011
Previously Logged (%) (2009)	0.011
Volume Harvested/Yr (m3/yr) (2007)	0.007
Percent of Limited Production Forest Area (2009)	0.005
Area (Sq.Km.)(2010)	0.004
Population density (2001-2012)	0.002
Density of logging roads (2010)	0.001

h) Erna Djuliawati

The drivers of deforestation and their weights

Drivers	v.weights
Percent Tree Cover Loss (2001-2005)	0.849
Mean Elevation (2001)	0.046
Mean Annual Temperature (2001)	0.042
Mean Annual Precipitation (2001)	0.026
Population density (2001-2012)	0.025
Density of logging roads (2001)	0.013

i) Intracawood Manufacturing

The drivers of deforestation and their weights

Covariates	Weights
Percent Tree Cover Loss (2001-2006)	0.297
Tree cover (2000)	0.292
Population density (2001-2012)	0.287
Mean Annual Precipitation (2001)	0.071
Mean Elevation (2001)	0.033
Mean Annual Temperature (2001)	0.019
Density of logging roads (2001)	0.002

j) Sari Bhumi Kusuma

The drivers of deforestation and their weights

Covariates	v.weights
Duration of Harvest Permit (2007)	0.374
Tree Cover (2001-2012)	0.294
Area Logged/year (ha/year) (2007)	0.071
Volume Harvested/Yr. (m3/yr)(2007)	0.052
Percent Tree Cover Loss (2001-2007)	0.04
Mean Annual Precipitation (2001)	0.037
Mean Annual Temperature (2001)	0.035
Logging Intensity (2007)	0.024
Population density (2001-2012)	0.019
Density of logging roads (2001)	0.009
Mean Elevation (2001)	0.045

Appendix C: List of non-certified FMUs included in the Forest Gain and Loss analysis

C (a) Brazilian Amazon

(i) Forest Gain

OBJECTID *	Name of the FMUs
1	Acara Industria e Comercio de Madeiras LTDA
2	Adao Ribeiro Soares
3	Ademar Bortolanza
4	Ademir Chaves Ferreira
5	Adenilson Tedesco- Lote CEAJ
6	Adriano DAgnoluzzo
7	Afrodisio Ferreira dos Santos
8	Agildo Sergio Lima
9	Agostinho Soares da Silva
10	Agro Industrial Bujaru
11	Albertino Guimaraes Silva
12	Aloisio Alves de Souza
13	Amandio Pinto Monteiro - contrato de transiþÒo
14	Amilton Caliman
15	Anaximandro da Silva Soares
16	Antonia Maciel dos Santos
17	Antonio Alves de Moura
18	Antonio Cuzzuol Sobrinho
19	Antonio da Costa Nascimeto
20	Antonio Fernando dos Reis
21	Antonio Gomes da Costa
22	Antonio Henrique da Silva Barbosa
23	Antonio Marcos Quadro Cunha
24	Ari Zugman
25	Armando de Carvalho Osorio
26	Armando Gomes Cardoso
27	Assoc. dos Remanescente de Quilombo da Comun. Maria Ribeira
28	AssociaþÒo Remanesc. Quilombos Bailique-Centro, B-B PoþÒo e S. Bernardo - ARQBI
29	Aubaine Agenci. Com. Exp e Imp. Ltda
30	Biopalma da Amazonia SA Reflorestamento Ind. e Com.
31	Brascomp Compensados do Brasil S. A.
32	Brasil Ind. e Com. de Madeiras Ltda
33	Brasil Ind. e Com. Mad. Ltda
34	Cajamil Agropecuaria Ltda
35	Carlos Alberto Tozzi Milanese

36	Carlos Alberto Tozzi Milaneze
37	Carlos Eduardo Ribeiro do Valle
38	Carlos Evandro Pontes Pinto
39	Carlos Leite Silva
40	Carlos Vinicios de Melo Oliveira
41	CCM-Madeiras Ind. e Com. LTDA
42	Celia Neuza Fonseca de Araujo
43	Celso Buzzi
44	Cikel Brasil Verde Madeiras Ltda
45	Cimatal Comercio e Industria de Madeira Tailandia Ltda
46	Claudete Oliveira Torres Mocelim
47	Cobem Madeiras
48	Codenorte
49	CVRD Fazenda Sta Maria
50	CÝcero Luiz Brenh Dßvila
51	Dalsan Madeiras Ltda
52	Davi Resende Soares
53	Dilson Silva Farias
54	Domingos da Silva Farias
55	Ederson Omori
56	Edvaldo da Silva Branco
57	Eldes Antonio Depra
58	Elier Soares Junior
59	Eliseu Francischetto
60	Elmo Balbinot
61	Eloir Tramontin
62	Elso Sadi Guidini
63	Emelcindo da Costa Cunha
64	Erismar Farias Salgado
65	Erito Aragao Exler
66	Fergumar Ferro Gusa do Maranhao
67	Firmino Guidini
68	Flavio Sufredini
69	Floraplac Industrial Ltda
70	Francisco Eudes Lopes Rodrigues
71	Genecy Egydio Donatti
72	Gerson Cei Souza
73	Gilberto Avance
74	Gilberto Miguel Sufredini
75	Gilson Antonio Moreira Machado
76	Gimasa Madeireira
77	Global Ind. Com. e Navegacao Ltda
78	IBL-Izabel Madeiras do Brasil Ltda

79	Iracelia Lima Menezes
80	Ironildo Dias de Lima
81	Isac Santos Lima
82	Jahyr Seixas Gonþalves Agroindustrial
83	Jaime Adami
84	Jaime Argolo Ferrao
85	Jefferson Cardozo Zocateli
86	Joao Francisco da Silveira Bueno
87	Joao Lopes de Angelo
88	Joao Malcher Dias
89	Jonacir Dalmaso
90	Jose Antonio Magalhaes de Almeida
91	Jose Ernesto da Silva Branco
92	Jose Matogrosso Souza Costa
93	Jurua Florestal Ltda
94	Kasuhiro Ishi
95	Laminadora Boaretto
96	Leonardo Vieira de Souza
97	Leucir Maulli
98	Lindolfo Moreira da Silva
99	Lourival Del Pupo
100	Luiz Alves de Souza
101	Luiz Fagundes
102	Luiz Gonzaga da Silva
103	Luiz Henrique Miro Rebello
104	LUMAPAL
105	Maca Aero Agricola Ltda
106	Madecap
107	Madeiras Cunha Ltda
108	Madeiras Filter Ltda
109	Madeireira Alianaa Ltda
110	Madeireira Art Ind Comercio e Servicos Ltda
111	Madeireira Rowaniel Ltda
112	Manoel Peres Duran
113	Manoel Rozio Filho
114	Marcelino Ferreira Lima
115	Marcelo Alves Pereira
116	Marcio Gomes Kalil
117	Marco Antonio Siviero
118	Marcos Antonio Fachetti Filho
119	Marcos Farias de Souza/Contrato de TransiþÒo
120	Maria de Lourdes Depolo Caliman
121	Maria do Socorro Gomes de Araujo

122	Maria Helena dos Reis Brandao
123	Marilei dos Santos Almeida
124	Mario Cesar Lombradi
125	Matell Madeireira Tell AVIV
126	Mauricio Galvao
127	Milton Barbosa Cordeiro
128	Moacir Roberto Raimam
129	Moacir Rodrigues Contreras
130	Natural da Amazonia Sao Jose
131	Noila Araldi Balbinot
132	Norteflora Empreendimentos Florestais Ltda
133	NOVACOM VI
134	Odilmar Dogmini
135	Osmar Passamani
136	Osmar Scaramussa
137	Ozeio Maria Carvalho de Moraes
138	Paulo Cesar Machado
139	Paulo Jose Leite da Silva
140	Paulo Renato Malacarne
141	Paulo Roberto Silva Farias
142	Pedro de Andrade Silva
143	Pedro Luiz de Souza adami
144	PROMAP - Produtos de Madeira do Para
145	Raimundo Nelio de Oliveira
146	Raimundo Nonato Freire Dias
147	Raimundo Nonato Nogueira da Costa
148	Renato Viegas de Souza
149	Rivaldo Salviano Campos
150	Roberto de Jesus Carvalho Renno
151	Ronaldo Cursge Mafra
152	Ronaldo Sperandio
153	Rosa Madeireira
154	Serraria Lima Ind. e Com. LTDA - Contrato de transição
155	Serraria Nova Conceicao Ltda
156	Serraria Oliveira Ltda
157	Serraria Timborana Ltda
158	Silvana Brito Santos
159	Silvano Rogerio Baldon Querubino Terra
160	Silvia Lima Batista
161	Silvio Dagnoluzzo
162	Silvio Florestal Abaete Ltda
163	Sipasa Seringa Ind. do Para Sa
164	Soc. Espirito Santense Industrializacao de Madeiras Ltda

165	Talita Piekarski Siviero
166	Tiete Agricola Ltda
167	Tramontina Belem SA
168	Ubaldino Nogueira de Oliveira
169	VALDOMIR CIPRANDI
170	Vale do Caripe AgroI Industrial Sa
171	Vera Cruz Exp. Ind. Com. SA
172	Vladimar Mezzomo
173	Wagner Fernandes de Oliveira
174	Waldemar Basilio Gomes
175	Washington Faustiono Santos Lima
176	Wellison Oliveira de Sousa
177	Wender Lopes Silva
178	Zelino Gallegari

(ii) Forest Loss

OBJECTID *	Name of the FMUs
1	Acara Industria e Comercio de Madeiras LTDA
2	Adao Ribeiro Soares
3	Ademar Bortolanza
4	Ademir Chaves Ferreira
5	Adenilson Tedesco- Lote CEAJ
6	Adriano DAgnoluzzo
7	Afrodisio Ferreira dos Santos
8	Agildo Sergio Lima
9	Agostinho Soares da Silva
10	Agro Industrial Bujaru
11	Albertino Guimaraes Silva
12	Aloisio Alves de Souza
13	Amandio Pinto Monteiro - contrato de transiþÒo
14	Amilton Caliman
15	Anaximandro da Silva Soares
16	Antonia Maciel dos Santos
17	Antonio Alves de Moura
18	Antonio Cuzzuol Sobrinho
19	Antonio da Costa Nascimeto
20	Antonio Fernando dos Reis
21	Antonio Gomes da Costa
22	Antonio Henrique da Silva Barbosa
23	Antonio Marcos Quadro Cunha
24	Ari Zugman
25	Armando de Carvalho Osorio
26	Armando Gomes Cardoso

27	Assoc. dos Remanescente de Quilombo da Comun. Maria Ribeira
28	AssociaþÒo Remanesc. Quilombos Bailique-Centro, B-B PoþÒo e S. Bernardo - ARQBI
29	Aubaine Agenci. Com. Exp e Imp. Ltda
30	Biopalma da Amazonia SA Reflorestamento Ind. e Com.
31	Brascomp Compensados do Brasil S. A.
32	Brasil Ind. e Com. de Madeiras Ltda
33	Brasil Ind. e Com. Mad. Ltda
34	Cajamil Agropecuaria Ltda
35	Carlos Alberto Tozzi Milanese
36	Carlos Alberto Tozzi Milaneze
37	Carlos Eduardo Ribeiro do Valle
38	Carlos Evandro Pontes Pinto
39	Carlos Leite Silva
40	Carlos Vinicios de Melo Oliveira
41	CCM-Madeiras Ind. e Com. LTDA
42	Celia Neuza Fonseca de Araujo
43	Celso Buzzi
44	Cikel Brasil Verde Madeiras Ltda
45	Cikel Brasil Verde Madeiras Ltda
46	Cimatal Comercio e Industria de Madeira Tailandia Ltda
47	Claudete Oliveira Torres Mocelim
48	Cobem Madeiras
49	Codenorte
50	CVRD Fazenda Sta Maria
51	CÝcero Luiz Brenh Dßvila
52	Dalsan Madeiras Ltda
53	Davi Resende Soares
54	Davi Resende Soares
55	Dilson Silva Farias
56	Domingos da Silva Farias
57	Ederson Omori
58	Edvaldo da Silva Branco
59	Eldes Antonio Depra
60	Elier Soares Junior
61	Eliseu Francischetto
62	Elmo Balbinot
63	Eloir Tramontin
64	Elso Sadi Guidini
65	Emelcindo da Costa Cunha
66	Erismar Farias Salgado
67	Erito Aragao Exler
68	Fergumar Ferro Gusa do Maranhao
69	Firmino Guidini

70	Flavio Sufredini
71	Floraplac Industrial Ltda
72	Francisco Eudes Lopes Rodrigues
73	Genecy Egydio Donatti
74	Gerson Cei Souza
75	Gilberto Avance
76	Gilberto Miguel Sufredini
77	Gilson Antonio Moreira Machado
78	Gimasa Madeireira
79	Global Ind. Com. e Navegacao Ltda
80	IBL-Izabel Madeiras do Brasil Ltda
81	Iracelia Lima Menezes
82	Ironildo Dias de Lima
83	Isac Santos Lima
84	Jahyr Seixas Gonþalves Agroindustrial
85	Jaime Adami
86	Jaime Argolo Ferrao
87	Jefferson Cardozo Zocateli
88	Joao Francisco da Silveira Bueno
89	Joao Lopes de Angelo
90	Joao Malcher Dias
91	Jonacir Dalmaso
92	Jose Antonio Magalhaes de Almeida
93	Jose Ernesto da Silva Branco
94	Jose Matogrosso Souza Costa
95	Jurua Florestal Ltda
96	Kasuhiro Ishi
97	Laminadora Boaretto
98	Leonardo Vieira de Souza
99	Leucir Maulli
100	Lindolfo Moreira da Silva
101	Lourival Del Pupo
102	Luiz Alves de Souza
103	Luiz Fagundes
104	Luiz Gonzaga da Silva
105	Luiz Henrique Miro Rebello
106	LUMAPAL
107	Maca Aero Agricola Ltda
108	Madecap
109	Madeiras Cunha Ltda
110	Madeiras Filter Ltda
111	Madeireira Alianaa Ltda
112	Madeireira Art Ind Comercio e Servicos Ltda

113	Madeireira Rowaniel Ltda
114	Manoel Peres Duran
115	Manoel Rozio Filho
116	Marcelino Ferreira Lima
117	Marcelo Alves Pereira
118	Marcio Gomes Kalil
119	Marco Antonio Siviero
120	Marcos Antonio Fachetti Filho
121	Marcos Farias de Souza/Contrato de TransiþÒo
122	Maria de Lourdes Depolo Caliman
123	Maria do Socorro Gomes de Araujo
124	Maria Helena dos Reis Brandao
125	Marilei dos Santos Almeida
126	Mario Cesar Lombradi
127	Matell Madeireira Tell AVIV
128	Mauricio Galvao
129	Milton Barbosa Cordeiro
130	Moacir Roberto Raimam
131	Moacir Rodrigues Contreras
132	Natural da Amazonia Sao Jose
133	Noila Araldi Balbinot
134	Norteflora Empreendimentos Florestais Ltda
135	NOVACOM VI
136	Odilmar Dogmini
137	Osmar Passamani
138	Osmar Scaramussa
139	Ozeio Maria Carvalho de Moraes
140	Paulo Cesar Machado
141	Paulo Jose Leite da Silva
142	Paulo Renato Malacarne
143	Paulo Roberto Silva Farias
144	Pedro de Andrade Silva
145	Pedro Luiz de Souza adami
146	PROMAP - Produtos de Madeira do Para
147	Raimundo Nelio de Oliveira
148	Raimundo Nonato Freire Dias
149	Raimundo Nonato Nogueira da Costa
150	Renato Viegas de Souza
151	Rivaldo Salviano Campos
152	Roberto de Jesus Carvalho Renno
153	Ronaldo Cursge Mafra
154	Ronaldo Sperandio
155	Rosa Madeireira

156	Serraria Lima Ind. e Com. LTDA - Contrato de transição
157	Serraria Nova Conceicao Ltda
158	Serraria Oliveira Ltda
159	Serraria Timborana Ltda
160	Silvana Brito Santos
161	Silvano Rogerio Baldon Querubino Terra
162	Silvia Lima Batista
163	Silvio Dagnoluzzo
164	Silvio Florestal Abaete Ltda
165	Sipasa Seringa Ind. do Para Sa
166	Soc. Espirito Santense Industrializacao de Madeiras Ltda
167	Talita Piekarski Siviero
168	Tiete Agricola Ltda
169	Tramontina Belem SA
170	Ubaldino Nogueira de Oliveira
171	VALDOMIR CIPRANDI
172	Vale do Caripe AgroI Industrial Sa
173	Vera Cruz Exp. Ind. Com. SA
174	Vladimar Mezzomo
175	Wagner Fernandes de Oliveira
176	Waldemar Basilio Gomes
177	Washington Faustiono Santos Lima
178	Wellison Oliveira de Sousa
179	Wender Lopes Silva
180	Zelino Gallegari

C (b) Gabon

(i) Forest Gain

OBJECTID *	Name of the company
1	HUA JIA
2	BSO Ogooué Ndjolé
3	SUNRY GABON Nord Est
4	Rimbunan Hijau Gabon
5	CFA/DLH
6	Leroy
7	SFIK
8	Grand Bois
9	TTIB
10	BSO Ogooué Mitzic
11	BOKOUE LOBE
12	CORA Wood LASSIO
13	FOREEX
14	GEB-ASSALA-CBK

15	OLAM Gabon Makokou
16	SEEF
17	STIBG
18	SBL/TRB
19	TBNI
20	TALIBOIS
21	SUNLY GABON Centre Sud
22	Bordamur/Toujours Vert
23	CORA Wood
24	Bonus Harvest/CIPLAC

(ii) Forest Loss

OBJECTID *	Name of the company
1	HUA JIA
2	BSO Ogooué Ndjolé
3	SUNRY GABON Nord Est
4	Rimbunan Hijau Gabon
5	CFA/DLH
6	Leroy
7	SFIK
8	Grand Bois
9	TTIB
10	BSO Ogooué Mitzic
11	BOKOUE LOBE
12	CORA Wood LASSIO
13	FOREEX
14	GEB-ASSALA-CBK
15	OLAM Gabon Makokou
16	SEEF
17	STIBG
18	SBL/TRB
19	TBNI
20	TALIBOIS
21	SUNLY GABON Centre Sud
22	Bordamur/Toujours Vert
23	CORA Wood
24	Bonus Harvest/CIPLAC

C (c) Kalimantan

(i) Forest Gain

OBJECTID *	NAME OF THE FMUs
1	PT. RANGGAU ABDINUSA
2	PT. BUMIMAS PERMATA ABADI
3	PT.AKATHES PLYWOOD
4	PT. AUSTRAL BYNA
5	PT.TAMAN RAJA PERSADA
6	PT. BARITO PUTERA
7	PT.FITAMAYA ASMAPARA
8	PT. AMPRAH MITRA JAYA
9	PT. HASNUR JAYA UTAMA
10	PT.HUTANI LESTARI RAYA TIMBER
11	PT.SINERGI HUTAN SEJATI
12	PT. SARANG SAPTA PUTRA
13	PT. WIDYA ARTHA PERDANA
14	PT. INTERTROPIC ADITAMA
15	PT. KIANI LESTARI (Eks PT GPI)
16	PT. RIMBA MAKMUR SENTOSA
17	PT.JAYA TIMBER TRADING
18	PT. RIMBA KARYA RAYATAMA
19	PT. SUMALINDO LESTARI JAYA II
20	PT. RIZKI KACIDA REANA
21	PT. RATAH TIMBER
22	PT. BARITO NUSANTARA INDAH
23	PT.KEDAP SAYAQ
24	PT. AQUILA SILVA
25	PT.MITRA PERDANA PALANGKA
26	PT.FORTUNA CIPTA SEJAHTERA
27	PT.MENORAH LOGGINGINDO
28	PT.KARYA DELTA PERMAI
29	PT.GUNUNG MERANTI
30	PT.KAYU WAJA
31	PT.BERKAT CAHAYA TIMBER
32	PT.SARANA PIRANTI UTAMA
33	PT.GAUNG SATYA GRAHA AGRINDO
34	PT.SIKATAN WANA RAYA
35	PT.PANDU JAYA GEMILANG AGUNG
36	PT.GRAHA SENTOSA PERMAI
37	PT.BINA MULTI ALAM LESTARI
38	PT.MERANTI MUSTIKA
39	PT.TINGANG KARYA MANDIRI
40	PT.TRISETIA INTIGA

41	PT.HUTAN DOMAS RAYA
42	PT.CARUS INDONESIA
43	PT.PRABA NUGRAHA TECH.
44	PT.ERYTHRINA NUGRAHA MEGAH
45	PT.TRISETIA CITAGRAHA
46	KOP.MANDAU TALAWANG
47	PT.HASIL KALIMANTAN JAYA
48	PT.YAKIN TIMBER JAYA
49	PT.INDEXIM UTAMA CORP.
50	PT.SINDO LUMBER
51	PT.RINANDA INTI LESTARI
52	PT.HUTAN MULYA
53	PT.KAYU TRIBUANA RAMA
54	PT.ANUGRAH ALAM BARITO
55	PT.MARAGADAYA WOOD WORK
56	PT.KAYU ARA JAYA RAYA
57	PT.PEMANTANG ABADITAMA
58	KOP.PUTRA DAYAK JAYA
59	PT.LESTARI DAMAI INDAH Tbr
60	PT.KAHAYAN TERANG ABADI
61	PT.WANA INTI KAHURIPAN INTIGA
62	PT.CENTRAL KALIMANTAN ABADI
63	PT.KARDA TRADES
64	PT.WANA AGUNG ASA UTAMA
65	PT.ELBANA ABADI JAYA
66	PT.AYA YAYANG INDONESIA
67	PT.INHUTANI I (PIMPING)
68	PT.MERANTI SAKTI INDONESIA II
69	PT.ITCI KAYAN HUTANI (IKANI)
70	PT.KODECO TIMBER
71	PT.INHUTANI I (PANGEAN)
72	PT.CIVIKA WANA LESTARI (Eks DAMUKTI)
73	PT.INHUTANI I (SAMBARATA)
74	PT.INHUTANI I (UNIT SEGAH HULU)
75	PT.GUNUNG GAJAH ABADI
76	PT.PUJI SEMPURNA RAHARJA
77	PT.ADITYA KIRANA MANDIRI
78	PT.WANA BHAKTI PERSADA U.
79	PT.MARDHIKA INSAN MULIA
80	PT. HUTANI KALIMANTAN ABADI PERMAI
81	PT.UTAMA DAMAI INDAH Tbr
82	PT.KARYA LESTARI
83	PT.KEDUNG MADU TROPICAL WOOD

84	KSU.MERANTI TUMBUH INDAH
85	PT.INHUTANI II (UNIT MALINAU)
86	PT.BORNEO KARYA INDAH MANDIRI
87	PT.WANA RIMBA KENCANA
88	PT.PENAMBANGAN
89	PT.WANGSA KARYA LESTARI
90	PT.MARIMUN TIMBER INDUSTRI
91	PT.MELAPI TIMBER
92	PT.TRIWIRA ASTA BARATA
93	PT.KEDAP SAYAAQ
94	PT.INHUTANI II (UNIT TANAH GROGOT)
95	PT. INHUTANI II
96	PT.HANURATA COY
97	PT.OCEANIS TIMBER
98	PT.DAISY TIMBER
99	PT.SUMBER MAS TIMBER
100	PT.RIMBA SEMPANA MAKMUR
101	PT.INHUTANI I (UNIT KUNYIT-SIMENDURUT)
102	PT.INHUTANI I (UNIT MERAANG)
103	PT.INHUTANI I (UNIT LABANAN)
104	PT.TIMBER DANA
105	PT. BALIKPAPAN FOREST INDUSTRI
106	PT.SUMALINDO LESTARI JAYA I (Eks HPH PT GOMPU)
107	PT.BATU KARANG SAKTI
108	PT.KARYA WIJAYA SUKSES
109	PT.TELAKAI MANDIRI SEJAHTERA
110	KUD.BERINGIN MULYA
111	CV.PARI JAYA MAKMUR
112	PT.PAKAR MULA BHAKTI
113	KOP.PONDOK PESANTREN DARUSSALAM
114	PT.AGRO CITY KALTIM
115	PT.HARAPAN KALTIM LESTARI
116	PT.INDOWANA ARGA TIMBER
117	PT.TELAGAMAS KALIMANTAN
118	PT.RIZKI KACIDA KEANA (JANGKA 15 TH)
119	PT.WANA ADIPRIMA MANDIRI
120	PT.ESSAM TIMBER
121	KSU. MAYANG PUTRI PRIMA
122	PT. GREATY SUKSES ABADI
123	PT. MAHARDIKA INSAN MULIA
124	PT. SUMALINDO LESTARI JAYA TBK
125	SUMALINDO LESTARI JAYA V

126	PT.SARANA TRISARA BHAKTI
127	PT. SEROJA UNIVERSUM NARWASTU
128	PT. PERMATA BORNEO ABADI
129	MUTIARA KALJA PERMAI
130	PT. SEGARA INDOCHEM & PT SEGARA TIMBER
131	PT.INHUTANI II (UNIT PULAU LAUT)
132	PT. DASA INTIGA
133	PT. SUMALINDO LESTARI JAYA IV
134	Amindo Wana Persada
135	PT. SEWAKA LAHAN SENTOSA
136	PT. KALIMANTAN SATYA KENCANA
137	PT. KAWEDAR WOOD INDUSTRY
138	CV. PANGKAR BEGILI
139	PT.BINA OVIVIPARI SEMESTA
140	PT.BUMI RAYA UTAMA WOOD
141	PT.LANJAK DERAS JAYA RAYA
142	PT.TORAS BANUA SUKSES
143	PT.HARAPAN KITA UTAMA
144	PT.SINERGI BUMI LESTARI
145	PT.WANASOKAN HASILINDO
146	PT.MOHAIRSON PAWAN KHATULISTIWA
147	PT.DUAJA CORP. II
148	PT.KARUNIA HUTAN LESTARI
149	CV. BAKTI DWIPA KARIZA
150	PT.KARYA REKANAN BINABERSAMA
151	PT.KUSUMA ATLAS TIMBER
152	PT.BATASAN
153	PT.SEWAKA LAHAN SENTOSA
154	PT.TAWANG MERANTI
155	PT.WANA KAYU BATU PUTIH
156	PT.BENUA INDAH

(ii) Forest Loss

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2	PT. BUMIMAS PERMATA ABADI
3	PT.AKATHES PLYWOOD
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5	PT.TAMAN RAJA PERSADA
6	PT. BARITO PUTERA
7	PT.FITAMAYA ASMAPARA
8	PT. AMPRAH MITRA JAYA
9	PT. HASNUR JAYA UTAMA

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23	PT.KEDAP SAYAQ
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25	PT.MITRA PERDANA PALANGKA
26	PT.FORTUNA CIPTA SEJAHTERA
27	PT.MENORAH LOGGINGINDO
28	PT.KARYA DELTA PERMAI
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30	PT.KAYU WAJA
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34	PT.SIKATAN WANA RAYA
35	PT.PANDU JAYA GEMILANG AGUNG
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37	PT.BINA MULTI ALAM LESTARI
38	PT.MERANTI MUSTIKA
39	PT.TINGANG KARYA MANDIRI
40	PT.TRISETIA INTIGA
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43	PT.PRABA NUGRAHA TECH.
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47	PT.HASIL KALIMANTAN JAYA
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81	PT.UTAMA DAMAI INDAH Tbr
82	PT.KARYA LESTARI
83	PT.KEDUNG MADU TROPICAL WOOD
84	KSU.MERANTI TUMBUH INDAH
85	PT.INHUTANI II (UNIT MALINAU)
86	PT.BORNEO KARYA INDAH MANDIRI
87	PT.WANA RIMBA KENCANA
88	PT.PENAMBANGAN
89	PT.WANGSA KARYA LESTARI
90	PT.MARIMUN TIMBER INDUSTRI
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96	PT.HANURATA COY
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124	PT. SUMALINDO LESTARI JAYA TBK
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154	PT.TAWANG MERANTI
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156	PT.BENUA INDAH

Appendix D: Check for plantations in FMUs in Brazil and Indonesia

Source: Transparent World. “Tree Plantations.” 2015. Accessed through Global Forest Watch on [date]. www.globalforestwatch.org

Brazilian Amazon

a) FSC certified

We found 177 plantations as per WRI (2013) plantation data in FSC certified areas in Brazil. Importantly, all these plantations are observed in only one of our studied company – Orsa Florestal Ltd. The total acreage under plantations observed is 59655.07 ha. which is 6.55% of the total area of the company. The table shows the types of plantations and its acreage observed in the area managed by Orsa Florestal:

Type of plantation	Number of plantations	Total area in ha.	Species planted and purposes
Clearing/very young plantations	7	1620.58	Eucalyptus sp. For wood fiber/timber
Large Industrial plantations	168	57794.4	Eucalyptus sp. For wood fiber/timber
Mosaic of medium-sized plantations	2	240.09	Eucalyptus sp. For wood fiber/timber

b) Non FSC

We also explored whether non-FSC companies in Brazil have some established plantations. We found 24 plantations in non-certified companies (studied) with an area of 4644.41 ha. which is 0.42% of the total area of these non-FSC companies in Brazilian Amazon (Belem Brasilia and Estuario). All these plantations are for large industrial plantations.

Kalimantan

a) FSC certified

We found no plantations inside the FSC certified FMUs.

b) Non FSC

Our analysis found 26 plantations with an area of 35626.08 ha which constitutes 0.46 % of the total acreage under non-FSC FMUs in Kalimantan. The table shows the type, number and extent of plantations in non-FSC areas in Kalimantan:

Type of plantation	Number of plantations	Total area in ha.	Species planted and purposes
Clearing/very young plantations	13	11807.49	Recently cleared
Large Industrial plantations	13	23818.59	Oil palm plantations

Appendix E: Comparison to pixel-scale analysis

For purposes of comparison with other studies that analyze the probability of deforestation in matched samples of pixels inside and outside certified FMUs, we drew a random sample of points across three states in the Brazilian Amazon (PA, RO, and MT), Gabon, and Kalimantan in Indonesia with a density of one point per square kilometer. We used ArcMap 10.2.2 to generate the random points. We defined "deforested" points as those that had experienced tree cover loss between 2000 and 2012 (i.e., a change from forest to non-forest state), according to Hansen et al. (2013). Because this is just a supplementary analysis, we do not identify matched (or balanced) sub-samples, but rather report raw statistics, calculated as follows for each country/ region:

$$\textit{Percent deforestation in FSC FMUs} = \frac{\textit{Total number of random points deforested in FSC FMUs}}{\textit{Total number of random points in FSC FMUs}}$$

$$\textit{Percent deforestation in Non-FSC FMUs} = \frac{\textit{Total number of random points deforested in Non-FSC FMUs}}{\textit{Total number of random points in Non-FSC FMUs}}$$

Pixel-scale results for the Brazilian Amazon

Table: Proportion of pixels with tree cover loss in certified and uncertified PMFSs in different regions of the Brazilian Amazon (2001-2012)

Brazilian Amazon (MT, PA, and RO)	PMFSs		Total	p-value
	FSC	NON-FSC		
Percent (and number) of randomly selected pixels deforested	4.99% (n= 697)	5.38% (n = 880)	10.3% (n = 253,910)	0.33
Total number of pixels selected	13,970	16,360	MT = 953,645 RO = 244,663 PA = 1,256,431 Total = 2,454,739	
Area in sq.km.(GIS-based)	13,966	16,323	1,967,733	
Points per sq.km.	1	1.002	1.2	
Percent (number) of points with tree cover loss in timber zones with FSC certified PMFSs				
Zonas Madeireiras				
Estuario	4.83% (676)	0.19% (26)	13,986	0.48
Belem_Brasilia	0.31% (21)	4.26 (288)	6,766	NA*

*Insufficient observations for statistical test

The percent of pixels deforested in certified FMUs was smaller than the percent deforested in other FMUs, but the difference is not statistically significant. In the Estuario timber zone, we find the opposite sign on the point estimate, still not statistically significant. In the Belém-Brasília zone, very few of the randomly sampled points fell in certified FMUs.

Pixel-scale results for Gabon
For this analysis, we started with a random sample of points all across Gabon with a density of one point per square kilometer (using ArcMap 10.2.2). We then identified points that fall inside concessions certified by FSC and concessions not certified by FSC (based on shape file of concessions from WRI).

Table: Proportion of pixels deforested in certified and uncertified concessions in Gabon (2001-2012)

Gabon	Concessions		All of Gabon	p-value
	FSC	NON-FSC		
Percent (and number) of randomly selected pixels deforested	0.50% (n= 103)	0.42% (n =213)	0.71 (n =1883)	0.60
Total number of random pixels	20591	51235	264853	
Area in sq.km.(GIS-based)	20765	51558	261689	
Points per sq. km.	0.99	0.99	1.01	

Here, 0.5% of the pixels in certified FMUs were deforested between 2001 and 2012, which is lower than the overall rate in Gabon but higher than the rate in non-certified FMUs, although the difference is not statistically significant.

Pixel-scale results for Kalimantan (Indonesia)
We started with a random sample of points all across Kalimantan with a density of one point per square kilometer (using ArcMap 10.2.2), resulting in 434,484pixels. We then identified points that fall inside concessions certified by FSC and concessions not certified by FSC.

Table: Proportion of pixels deforested in certified and uncertified concessions in Kalimantan (2001-2012)

Kalimantan	Concessions		All of Kalimantan	p-value
	FSC	NON-FSC		
Percent (and number) of randomly selected pixels deforested	2.79% (n= 314)	4.79% (n = 3711)	11.4% (n =49,698)	0.28
Total number of pixels	11,265	77,414	434,484	
Area in sq.km.(GIS-based)	13,883	95,542	535,070	
Points per sq. km.	0.81	0.81	0.81	

A smaller proportion of the randomly selected pixels have undergone deforestation in FSC certified concessions compared to non-certified concessions, but again, this difference is not statistically significant. It is notable that the proportion of pixels deforested in either certified or non-certified concessions is less than half the proportion deforested in Kalimantan as a whole.

Interpretation

The pixel-scale results presented here are descriptive statistics, which do not imply causality. Specifically, we have not controlled for differences between certified and non-certified areas that may drive differences in tree cover change. For example, it could be that managers of concessions or FMUs in areas facing deforestation risks are more likely to seek certification, which would lead to more deforestation in certified concessions. Selection bias in the opposite direction is also possible. Thus, we present these results just to provide context and facilitate comparison of descriptive statistics with other studies.