Whose Woods Are These? State Forest and Land Use in Indonesia

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Abstract

Deforestation is the second largest source of greenhouse gas emissions after direct fossil fuel combustion, and is also responsible for significant biodiversity loss, particularly in tropical regions. Countries often attempt to limit deforestation through the imposition of protected areas, but the effectiveness of this protection appears highly variable. In this paper, I use a geographic regression discontinuity design to assess the effectiveness of Indonesia's Maintained Forest area, an area covering the majority of Indonesia's land area where it is officially illegal to permanently deforest the land. Using a variety of remote sensing data to assess differences in land use across geographically balanced sections of the boundary, I find that Maintained Forest designation leads to the emergence of small but meaningful differences in forest cover in the range of 6-7.5 percentage points of land area across these boundaries. Differences appear to operate through constraints on conversion to tree crops such as oil palm, a major driver of deforestation in Indonesia. Future work aims to assess the aggregate impact of this boundary by applying a spatial land use model calibrated with these and other estimates.

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1 Introduction

Forest loss is a significant source of greenhouse gases worldwide, accounting for roughly 12% of total GHG emissions van der Werf et al. (2009). Indonesia is a significant source of these emissions, and has lost roughly 19% of its initial forest cover so far in the 21st century (Hansen and Song, 2018). Deforestation also poses a significant threat of habitat loss, particularly in Indonesia, one of the most biologically diverse countries in the world. And deforestation can have direct and significant immediate health externalities through its effects on the risk of large-scale fires, which have caused significant health damages in recent years (Marlier et al., 2021).

For these and other reasons, Indonesia like many other countries has attempted to limit deforestation through a variety of policies. Arguably the most widespread legal restriction on deforestation is that imposed by Indonesian forest law, which divides the State Forest (Kawasan Hutan) that covers more than 60% of Indonesia's land area into categories that govern legal land use in those areas. Not all of the State Forest is intended to be permanently protected; large areas of Conversion Forest are designated for deforestation and conversion to agricultural use, and are slowly released from the State Forest over time. However, deforestation is legally prohibited in the other categories of State Forest, which I refer to collectively as the Maintained Forest.

Is the legal protection of Maintained Forest effective? Ex ante the answer is unclear. There is some evidence that the effectiveness of forest protection is particularly low in Indonesia. For example, a report by the NGO Eyes on the Forest in 2021 found that nearly half of all oil palm areas in Riau Province were located (illegally) within the State Forest, and roughly 60% of that land was within the Maintained Forest (noa, 2021). Prior research has found that the economic incentives faced by regional heads of government influence deforestation even within the Maintained Forest (Burgess et al., 2012), indicating significant local violations of national policy protecting those areas.

Assessing the effectiveness of Maintained Forest designation is difficult because the outcome of interest, deforestation, is likely impacted by a range of geographical features in ways that would be difficult to fully measure or control for even with a highly flexible parametric specification. In this paper, I assess the impact of Maintained Forest designation in the Outer Islands of Indonesia[1] using a geographic regression discontinuity

[1]The area outside the densely populated islands of Java and Bali where most of Indonesia's remain-

design. A geographic RD has the advantage of requiring only the plausible assumption of continuity of potential outcomes (and controls) across the treatment boundary. It also has the attractive feature of returning an estimate of the impact of Maintained Forest protection on the margin, which corresponds closely to a realistic potential policy of marginally expanding or reducing the Maintained Forest area at its edges.

A relevant critique of geographic regression discontinuity estimates is that they do not capture additionality (Balboni et al., 2023). Since the policy may relocate some deforestation across the boundary, net differences in forest cover thus do not correspond to the gross impact of the policy. Thus these estimates provide evidence of whether national policy is effective in maintaining higher forest cover in Maintained Forest areas, and the channels through which this impact operates, but cannot be used as a measure of gross increase in forested area at the margin or aggregated to find the overall effect of the policy. In order to assess those aggregate tradeoffs, future work will attempt to develop a spatial land use model with an additional cost of converting Maintained Forest land, and to calibrate it to match available land use data and my empirical estimates of the discontinuity at the boundary.

Separate from questions of identification are issues of measurement. The Ministry of Environment and Forestry maintains land use maps that include different categories of forest cover, but the MEF may have incentives to misreport the amount of forest cover loss within areas it is legally charged with protecting, or may be unaware of significant areas of unlicensed land conversion, which is widespread in Indonesia. For that reason I compare effects on MEF-reported forested areas with independent estimates taken from a variety of remote-sensed forest cover and land use measures, which will be discussed as they are introduced.

Identification in a geographic regression discontinuity with covariates requires that the potential outcomes and control variables are continuous at the discontinuity. This is not the case everywhere; in some regions the boundary of Maintained Forest clearly coincides with natural discontinuities such as the edges of alluvial plains. I adopt the common approach (used e.g. by Dell (2010), Asher et al. (2021)) of restricting to a subset of sample boundaries that do not correspond to sudden changes in elevation or extremely steep slopes. This does not substantially reduce the sample size, and I show below that geographical covariates appear well balanced across the Maintained Forest

ing forest is located.

boundary for these segments.

I find that Maintained Forest protection leads to small but meaningful differences in forest cover on the order of 6-7.5 percentage points of land area (roughly 12% of mean forest cover). This difference in forest cover appears to be driven by meaningful reductions in land used for tree crops such as oil palm; across the boundary the share of land used for tree crops and for oil palm drops approximately in half. Consistent with this, impacts on remote-sensed tree cover are smaller, on the order of 2.5 percentage points, due to the widespread presence of non-forest (crop) trees along the boundary. Using administrative data on official forest concessions, I examine whether Maintained Forest designation changes the share of land within an official oil palm concession, finding differences of 4-5 percentage points across the boundary, though only significant in some specifications.

This paper contributes to the empirical literature on the economics of tropical deforestation, recently surveyed in Balboni et al. (2023). They emphasize that classical theories of optimal resource use, even with externalities, likely do not apply in the developing regions that are home to most tropical forests, given (among other frictions) the lack of clearly defined property rights in many areas. Rather, political economy concerns are first-order drivers of deforestation. This work is similar in its methodology to Burgess et al. (2019), who use a regression discontinuity across the border of Brazil to study the effect of changes in Brazilian forest policy. I contribute to the literature using regression discontinuities to study the effectiveness of forest policy by providing the first estimates of the effectiveness of a highly biodiverse protected area roughly the size of Bolivia.

In terms of context, the project relates to Burgess et al. (2012), who study the political economy of deforestation in Indonesia and show that increased competition between districts within a province (caused by district splitting) appears to increase deforestation and lower wood prices, which they attribute to increased Cournot competition between district heads with de facto control over State Forest. My project is in a sense orthogonal; I study the overall medium-term impact of a maintained national policy using variation across local boundaries, while they study how changes in subnational administration affect changes in rates of extraction over time across large areas (provinces). Together, the picture that emerges is one of enforcement that is impactful but highly imperfect, with effectiveness that is subject to erosion at lower administrative levels. Future work will aim to examine the larger-scale tradeoffs inherent in the Maintained Forest policy.

Relative to the existing economics literature on evaluating the effectiveness of protected areas, this paper innovates by using data on multiple land use categories to carefully differentiate between tree cover, forest cover, and natural forest cover and to examine the mechanisms through which protection appears to operate. Prior work on Indonesia typically measures deforestation through changes in remote-sensed tree cover. This measure includes natural forests, lumber forests, and tree crops, and so cannot detect the replacement of natural forests with tree crops such as oil palm, a major driver of forest loss in Indonesia. Consistent with this, I find effects on forest cover (not including tree crops) that are roughly three times as large as the effect on total tree cover, the measure used in earlier studies. In contrast to the focus in earlier work on the market for lumber as a driver of deforestation, I show that a significant factor in the effectiveness of the Maintained Forest boundary is its effectiveness in reducing the intrusion of tree crops such as oil palm (a major driver of deforestation in Indonesia) into the Maintained Forest.

2 Background

Of Indonesia's 190 million hectares of land area, roughly 124 million hectares are classified as State Forest (Kawasan Hutan), deemed to be property of the state under the administration of the Ministry of Environment and Forestry (MEF, previously the Ministry of Forestry) (Siscawati et al., 2017). A large proportion of this land, up to 84 million hectares, has been managed by communities living within the forest since before the establishment of the modern Indonesian state, but prior to 2013 there was no legal recognition these claims of traditional ("adat") community ownership of lands within the State Forest (Bennet et al., 2019).[2]

Within the State Forest, land is operated under varying levels of control on use, ranging from Protected Forest (with a complete ban on resource extraction) to Production Forest (which can legally be logged by concessionaires but not permanently deforested i.e. converted to non-forest use) to Conversion Forest, which can be converted permanently to non-forest uses such as urban land or agriculture. The remainder of Indonesia's land area outside the State Forest is classified as "Other Use Area" ("Areal Penggunaan Lain", area outside the control of the MEF). These areas may or may not be forested de

[2]In fact even today the de jure recognition of *adat* land claims is not widely applied in practice.

facto, but they are not considered State Forest de jure by the MEF; they are administered by the National Land Agency (BPN) and may be privately owned. Roughly 30% of Other Use Area land is formally titled as privately owned; the same is true of only 3% of State Forest (Siscawati et al., 2017).

Table 1: Land Classifications in Indonesia

Category	Agency	Maintained Forest
Protected Forest	MEF	Yes
Production Forest	MEF	Yes
Conversion Forest	MEF	No
Other Use Area	BPN	No

The official process for conversion of forest land to other uses involves a company applying to the government for a release of land from the Conversion Forest area of the State Forest. If approved, this area of land then becomes Other Use Area (outside MEF control) and a concession (granting control of the land for a fixed period of time, usually 35 years) is issued for the petitioning company. Such concessions can also be issued by BPN on land already in the Other Use Area.[3] In this sense, both Conservation Forest and the Other Use Area are areas legally available for conversion to oil palm or other non-forest uses, while the Protected and Production Forest are legally off-limits to conversion. It is not obvious ex ante how firmly this legal distinction actually binds on the ground. Thus it is an empirical question whether the legal distinction embodied by the boundary of the Maintained Forest has force in practice.

2.1 Delineation of State Forest

Despite the name "State Forest", it is not the case that State Forest necessarily coincides with natural forest boundaries, or indeed with actual forest. By 2000, a report by the International Council for Research in Agroforestry noted that "Ministry [of Forestry] data itself reveals that large areas of the forest estate [... are] actually covered by imperata grasslands, agroforests such as rubber and mixed fruit gardens, rice fields and villages"

[3] In theory concessions in Other Use Area can only be granted if they are not in conflict with existing private land ownership; in practice both de facto and de jure ownership by smallholders is widely ignored.

(Fay et al., 2000). Similarly, a 2005 report notes that "According to the Department of Forestry data, 33 million hectares [roughly 25%] of Kawasan Hutan [State Forest] have no trees at all. On the other hand, some 8 million hectares of forests are not included as parts of the Kawasan Hutan" (Contreras-Hermosilla and Fay, 2005). This is not simply due to later encroachment upon land that was initially forest when the delineation was initially made. Rather, there is good reason to believe that the delination of State Forest did not closely follow the boundaries of actual forests extant at the time the boundaries were drawn.

The process of delineating forest areas by category in the Outer Islands, called (euphemistically) "Forest Land Use by Consensus" ("Tata Guna Hutan Kesepakatan", TGHK) began in 1984 (Nawir, 2007) but the actual delineations were promulgated slowly, province by province, beginning in the early 1980s (Directorate of Forest Area Conservation and Management, 2024). The production of the TGHK State Forest maps was done with little or no input from ministries outside the MEF or data on existing community claims to forest areas (Santoso, 2003). The MEF may have had bureaucratic incentives to make the area under their control as expansive as possible, especially since the diversion of revenues from logging concessions on State Forest land was a major form of patronage under the dictatorship of Suharto (Smith et al., 2003). In the province of South Sumatra, the MEF forest area designation promulgated in 1984 included three times as much land under "Forest" as had been found by the Dutch colonial government (which had ended 35 years earlier). In Lampung Province, where the designation was promulgated in 1991, the State Forest boundaries set by the Ministry of Forestry included not only all of the forest delineated by the Dutch colonial government, but also an additional 44,000 ha that the Dutch had considered to be owned by local communities. This was despite significant conversion of forest into non-forest land in the intervening decades (Fay et al., 2000).

Throughout the 1990s, negotiations went on between the MEF, BPN, and the provinces to attempt to square MEF forest designations with the provincial land use plans. The main impact of these was to correct the MEF maps for five provinces which had included Other Use Area land as Conversion Forest, and to update the limits of Conversion Forest that had since been converted to other land categories. The area of the Maintained Forest in the shapefile I use is within 4% of the corresponding figure that emerged at the end of the reconciliation process in 1999, as reported in Santoso (2003). Thus it appears that the demarcation of the Maintained Forest has been fairly static at least between 1999 and

2017, the year in which I observe the boundaries.[4]

Within the State Forest, the division of lands into categories does not appear to follow a natural border in the area of study. In the Outer Islands, the division between protected or production forests and conversion forests was made on the basis of a score that aggregated together slope, soil type, and climate.[5] Land with an accumulated score above 125 was placed into the "protected" or "production" forest types (becoming Maintained Forest), while land with a score below 125 inside the State Forest became Conversion Forest (Fay et al., 2000).

Thus it is not clear that the boundary of the State Forest reflects natural forest boundaries, or even actual forest boundaries at its inception. It also appears that the division of land within the State Forest (at least in the Outer Islands) was made on the basis of an arbitrary threshold that need not coincide with any fundamental geographical boundary. Taken together, it seems plausible that the boundaries of the Maintained Forest Area reflect an administrative but not a geophysical boundary, and that emergent discontinuities in outcomes across this boundary reflect the impact of policy rather than geography. I investigate this possibility empirically in subsequent sections, before turning to impacts that I attribute to the impact of the Maintained Forest delineation.

3 Data

I derive the boundaries of the Maintained Forest area from a shapefile produced by the Indonesian Ministry of Environment and Forestry (MEF) and made available by Global Forest Watch. The boundaries are those current in 2017.[6] I classify as "Maintained Forest" all areas that are in wilderness preserves, Protected Forest, Production Forest, and Limited Production Forest. The latter two categories cover areas that can be logged by concessionaires but not permanently converted to non-forest use. The remaining land area consists of Other Use Area (land outside the State Forest and under the remit of the National Land Agency, which may be privately owned) and Conversion Forest (State Forest that may be permanently converted to other uses by approved concessionaires). I

[4] I have recently obtained data on the dates at which particular areas became State Forest, and plan to more fully investigate whether and where boundaries may have changed in the intervening time period.

[5] Other socioeconomic variables were intended to be included but were not in fact considered.

[6] I am attempting to locate earlier versions of this boundary delineation.

ignore small (< 1 km^2) isolated areas of Conversion Forest or Other Use Area inside the Maintained Forest, and similarly small isolated areas of Maintained Forest within the those land classifications.

The boundary of the Maintained Forest is long and undulating; two villages can both be near the boundary and yet nowhere near each other. To prevent comparisons being made between villages which are extremely remote from each other despite both being near the boundary, I divide the length of the Maintained Forest boundary into sections no more than 20km in length and within the same kabupaten (district).[7] To aid precision, I also control for several geophysical variables (discussed in the following section) in some specifications (this does not meaningfully change the estimates).

4 Sample and Methodology

To assess the impact of Maintained Forest delination, I need a sample of locations at which to measure forest cover. I generate a 1km equispaced grid of points that spans Indonesia and restrict it to points within 20km of the Maintained Forest boundary in the Outer Islands. Because I am primarily interested in effects on deforestation, I limit the sample to areas that were initially forested according to two different sources.

The first source is from Sayer et al. (1991).[8] The underlying source is a map produced between 1984 and 1989 (Poniman et al., 2004) by a collaboration between the National Coordination Agency for Surveys and Mapping (BAPPENAS), the Regional Physical Planning Programme for Transmigration (RePPProT) and the UK government, based on a combination of satellite imagery, aerial photography, and existing field surveys (Sayer et al. (1991) p. 143). The data "are from various years but are generally taken to describe the situation in 1985," (around the time the earliest State Forest delineation maps for the Outer Islands were produced) and are used as the 1985 baseline forest map in FWI/GFW (2002). The credibility of this map is bolstered by the fact that it was created by groups separate from the Ministry of Forestry (which may have had incentives to overstate forest area, as discussed above) and that its forest totals agree closely (within 4%) with

[7] A kabupaten is a second-level administrative division, of which there are slightly under 500 in Indonesia.

[8] My sincere thanks to Bex Gottlieb at UNEP-WCMC for locating this shapefile in a legacy database and making it available.

independently derived FAO estimates of total forest cover (Sayer et al. (1991) p. 143). The second is the Ministry of Environment and Forestry's 1990 land use category map, which was produced by the MEF from a variety of contemporaneous sources. I deem land which is demarcated as forested on both maps to be initially forested prior to the delineation of the Maintained Forest in the mid to late 1980s.

I split the Maintained Forest boundary at the boundaries of kabupatens (districts) and into segments of no more than 20km in length. Points from my sample are assigned to the nearest boundary segment in the same kabupaten, and my specification includes segment fixed effects. Thus, any differences detected in the specification are not due to differences in kabupaten-level policies or economic conditions that affect deforestation smoothly across the boundary, and are based on comparisons within the same local area. To ensure that I am using boundary segments where geography is approximately balanced across the discontinuity, I omit areas with mean elevation above 500m or where the approximate slope in the sample across the boundary is greater than 2%.

My treatment is determined by a boundary originally digitized from paper maps, which by their nature have finite precision; points extremely close to the digitized line may therefore be mis-categorized relative to the true on-the-ground boundary maintained by the MEF. Similarly, most outcome variables come from either remote sensing data with values assigned at the pixel level. These datasets also have finite precision; sufficiently local comparisons will always detect zero difference in outcomes (whether or not true differences exist on the ground) because the comparison points will be located within the same data pixel and thus have the same value. To avoid basing my estimates on uninformative comparisons such as these, I drop points within 500m of the digitized boundary, so that the sample consists only of points with unambiguous treatment status and in separate pixels.

I estimate the following specification:

$$Y_i = \alpha_{k(i)} + \gamma_1(Dist_i \cdot \mathbb{1}_{Dist_i>0}) + \gamma_2(Dist_i \cdot \mathbb{1}_{Dist_i<0}) + \beta \cdot \mathbb{1}_{Dist_i>0} + X_i\mu + \epsilon_i \qquad (1)$$

Here, $\alpha_k(i)$ is a boundary segment fixed effect capturing the average level of forest cover in the area adjoining a boundary segment, while γ_1 and γ_2 capture the locallinear relationship between distance and the outcome on either side of the boundary. The coefficient μ captures the effect of a vector of exogenous geophysical characteristics: elevation, slope, ruggedness, mean temperature and precipitation, distance to the nearest river, coastline, and city, and FAO estimates of potential yields of rice, soy, oil palm, cassava, coffee, and cocoa (the main crops in the Outer Islands). These controls are present to potentially aid precision. Standard errors are clustered at the kabupaten level.

The coefficient of interest is β. Under the standard regression discontinuity assumptions that the expectation functions of the outcome are continuous at the cutoff, that there is no perfect manipulation (points on the ground cannot sort themselves relative to the boundary), and that treatment does not shift the means of the covariates (which are fixed geographical features), the coefficient captures the local (net) treatment effect of Maintained Forest designation along the boundary.

5 Balance

In order to satisfy the RD assumptions, potential outcomes should be continuous across the discontinuity. While counterfactual outcomes cannot be observed, I make two demonstrations that this continuity assumption is plausible.

5.1 Geophysical Covariate Balance

First, I estimate Equation 1 (without geophysical controls) for each of the geophysical variables, and demonstrate that there are no significant jumps in any of these potential drivers of deforestation suitability across the boundary. Results for the main variables are displayed in Table 2. There are no statistically significant jumps in any of these geophysical variables across the boundary using the robust estimator, while differences that are significant in the "conventional" estimator are economically too small to drive meaningful differences in forest cover.

Figure 1: Geographical Covariate Balance

	(1) Elev.	(2) Slope	(3) Rugg.	(4) Rain	(5) Temp	(6) RiverDist	(7) CoastDist	(8) CityDist
Conventional	-2.80***	0.02	-0.03	-0.23	0.01***	0.06	0.01	-0.08
	(1.06)	(0.07)	(0.28)	(0.46)	(0.00)	(0.05)	(0.06)	(0.06)
Robust	-2.23	0.13	0.58	0.99	0.01	0.24	0.19	-0.25
	(3.35)	(0.23)	(0.91)	(1.84)	(0.01)	(0.18)	(0.24)	(0.23)
Bandwidth (km)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Geog. Controls								
Clustering	Kab.	Kab.	Kab.	Kab.	Kab.	Kab.	Kab.	Kab.
Samp. Mean	184.21	5.69	27.29	2,964.35	26.19	29.82	83.07	212.39
Samp. SD	313.49	7.21	32.02	604.29	1.61	65.72	69.57	140.13
N	62,358	62,358	62,358	62,358	62,358	62,358	62,358	62,358

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

5.2 Pre-Treatment Outcome Balance

Second, I run Equation 1 on outcome data from the years just after the initial delineation of the Maintained Forest boundary. If the boundary followed a pre-existing boundary between more and less forested areas, these differences should be apparent in these pre-period estimates.[9]

Forest cover is measured as the binary outcome of whether a point is covered with tropical moist forest. The classification is based on remote sensing data from Vancutsem et al. (2021), who detect forest pixels based on Landsat imagery with 30m $\times$ 30m resolution.

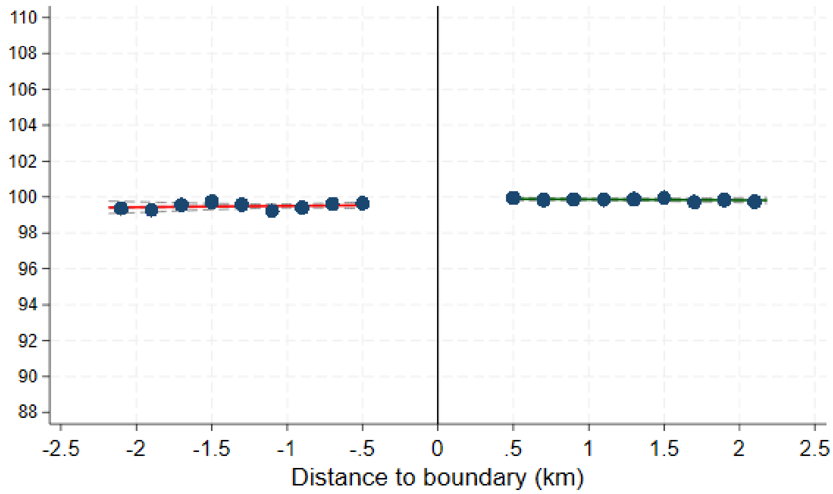
As can be seen in Figure 2, which displays the estimates from Equation 1 using the conventional RD estimator, the remote sensed forest cover data from Vancutsem et al. (2021) confirm that the sample consists of areas that were initially completely forested and without any meaningful difference in forest cover across the Maintained Forest boundary.[10]

Table 3 displays the estimated differences in forest cover in 1990 across the disconti-

[9]Note that the remote sensing outcomes used here are separate from the forest maps used to limit the sample to initially forested areas, so that treatment and control are not equally forested by construction.

[10]The RD estimator identifies a difference across the boundary but not the mean at the discontinuity, due to the presence of segment fixed effects. For presentation purposes I add the sample mean to the outcome values to display differences in the context of typical levels.

Figure 2: Tree Cover (0-100)



nuity. All subsequent tables describing additional outcome variables follow this format.

Column 1 shows the results of estimating Equation 1, without the controls X, using the optimal bandwidth of Calonico et al. (2020) and a triangular kernel. Column 2 shows the same regression but including the geophysical controls. Column 3 shows the same specification as Column 1 but using a 2km bandwidth. Column 4 echoes Column 2 but with a 2km bandwidth. The first row of coefficients in the table are those returned by the "conventional" weighted least squares estimator of Equation 1, while those in the second row are those of the "robust" estimator of Calonico et al. (2014).

Differences in 1990 forest cover across the boundary are all negative and insignificant with the robust estimator, and economically tiny (a third of a percentage point of land area) with the conventional estimator. Thus it appears that differences in forest cover across the boundary when it was initially drawn, if any, were extremely small.

Figure 3: Vancutsem et al. Tropical Moist Forest, 1990 (0-100)

	(1)	(2)	(3)	(4)
Conventional	0.338**	0.349**	0.323	0.323
	(0.172)	(0.176)	(0.200)	(0.200)
Robust	-0.053	-0.233	-0.413	-0.433
	(0.552)	(0.665)	(0.817)	(0.808)
Bandwidth (km)	2.31	2.18	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	99.67	99.68	99.69	99.69
Samp. SD	5.77	5.62	5.53	5.54
N	24,534	23,024	20,846	20,825

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6 Results

Having demonstrated that geophysical variables and initial forest cover appear to be well-balanced across the boundary in my sample, I investigate the differences in forest cover that emerge over time. Before discussing the results, a brief discussion of land use categories is called for.

6.1 A Note on Terminology

In the following results, it will be important to keep in mind the distinction between tree cover, forests, planted forests (also known as forestry land), and tree crop land (also known as estate crop land). Each of these describes an area of land on which trees are growing, but the distinctions between them are important for understanding agriculture in Indonesia, which is both a major source of harvested wood and tree crops such as palm oil, as well as home to some of the world's largest remaining and most biodiverse natural forests.

Table 2: Tree Land Categories

Land Type	Forest?	Tree Cover?
Natural forest	Yes	Yes
Planted forest (forestry land)	Yes	Yes
Planted tree crops (estate crops)	No	Yes
Non-forest non-tree crop land	No	No

In this paper, "forest" refers to a stand of trees which are not being used to grow crops. This is similar to the FAO definition (FAO, 2018), which defines forests as areas with trees capable of reaching 5m in height and 10% canopy cover and not being used for agriculture or urban uses. Note that by this definition naturally occurring forests and land planted with lumber or pulpwood trees (such as eucalyptus and acacia) for later harvest are both "forest"[11], while land planted with trees bearing fruits (such as banana or oil palm) or producing other harvested outputs (such as rubber trees) is tree crop land but not forest land. All three categories (natural forests, planted tree forests, and planted tree crops) contribute to tree cover, which is thus an imperfect proxy for forests in areas where planted tree crops are common. "Deforestation" refers to permanent[12] conversion of previously forested land to a non-forest land use, including tree crops. Logging of areas which later re-grow is not deforestation under this definition. Change in tree cover is not the same as deforestation because tree crops replacing natural forest create deforestation but not a change in tree cover.

6.2 Effects on Tree Cover

I measure tree cover using remote sensed data from DiMiceli et al. (2022), a 250m gridded data product giving the share of land within the pixel that is estimated to be tree cover (as opposed to non-tree vegetation or vegetation-free ground) in 2015. As discussed above, this measure will include all detected trees, including tree crops.

Estimates suggest that the Maintained Forest boundary creates a small increase in total tree cover at the discontinuity, on the order of 2.5 percentage points of land.

[11] This aspect of the FAO definition has attracted criticism from conservationists.
[12] In practice, up to the point of the most recent available observation.

Figure 4: 2015 Tree Cover (DiMiceli et al. 2022) (0-100)

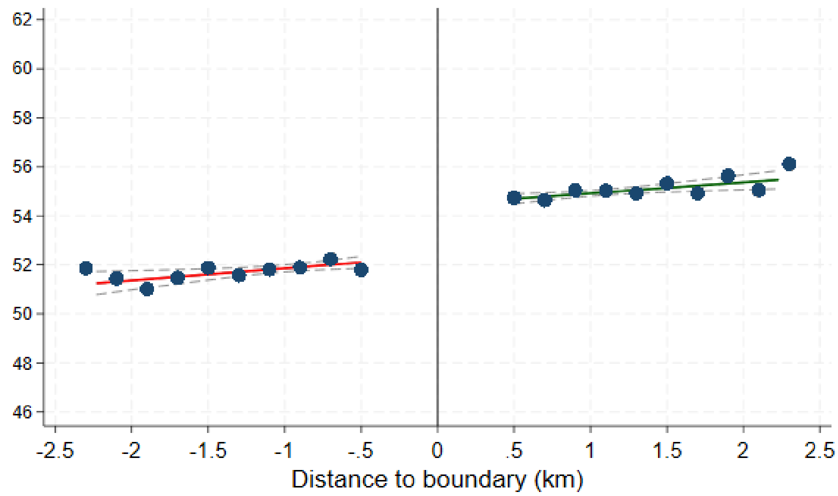


Table 3: Tree Cover (0-100)

	(1)	(2)	(3)	(4)
Conventional	2.138***	2.135***	2.202***	2.197***
	(0.464)	(0.464)	(0.492)	(0.492)
Robust	2.601***	2.603***	2.674**	2.684**
	(1.000)	(1.001)	(1.188)	(1.189)
Bandwidth (km)	2.23	2.23	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	53.61	53.61	53.56	53.56
Samp. SD	23.30	23.31	23.33	23.33
N	70,446	70,488	62,323	62,320

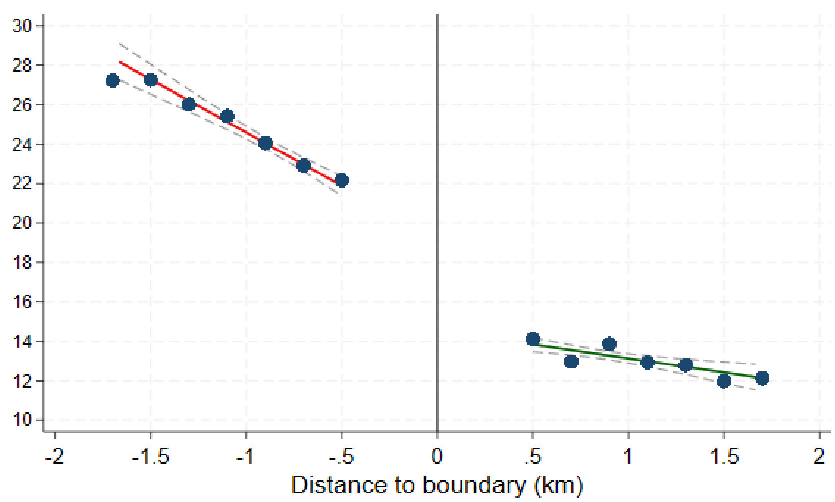
Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.3 Oil Palm Concessions

De jure, concessions allowing companies to operate oil palm plantations can only be issued outside the Maintained Forest. In practice, due to conflicts between local and national administration and imperfect enforcement of this rule, meaningful amounts of oil palm production do appear to take place within the Maintained Forest. Here I evaluate whether the boundary creates a change in the fraction of land that falls within an oil palm concession, using MEF data made available by Global Forest Watch and corresponding approximately to the year 2015.

Oil Palm Concession Coverage (0-100)



Point estimates suggest that there is a small but meaningful decline in the share of oil palm concession land across the boundary. The estimated gap is roughly 20% of the average share of land covered by oil palm concessions in the sample. However, these differences are not statistically significant when using the Calonico et al. (2014) robust estimator and the optimal bandwidth.

Table 4: Oil Palm Concession Coverage (0-100)

	(1)	(2)	(3)	(4)
Conventional	-4.654***	-4.665***	-4.987***	-5.017***
	(0.880)	(0.902)	(0.805)	(0.803)
Robust	-4.326	-4.478	-3.673*	-3.757*
	(3.089)	(3.278)	(2.155)	(2.140)
Bandwidth (km)	1.72	1.67	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	18.23	18.24	18.24	18.24
Samp. SD	38.61	38.62	38.62	38.62
N	51,912	49,892	62,330	62,328

Standard errors in parentheses

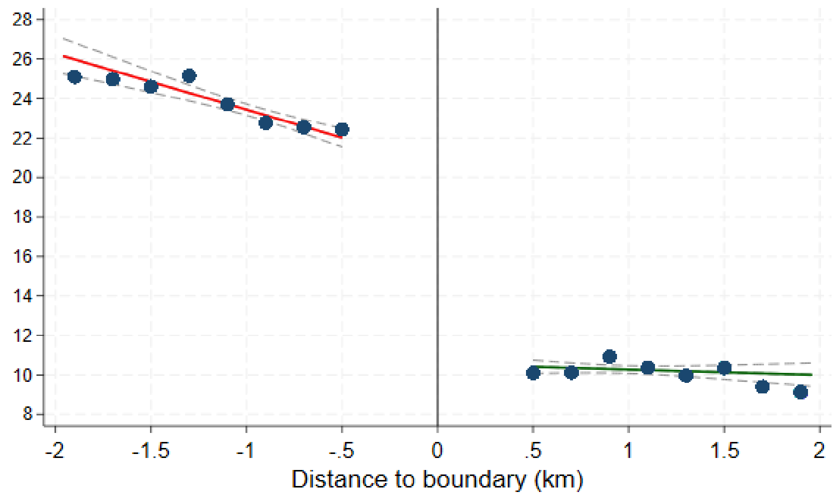
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.4 Remote Sensed Oil Palm Plantations

There are three key reasons why administrative data on oil palm concessions may not accurately capture the location of actual oil palm plantations. First, administrative data on the location of oil palm plantations may be unreliable given incentives to avoid disclosing concessions which are in violation of national forest policy. Second, not all concessions are actually used, so there is an additional margin of variation in actual oil palm cover beyond simply the variation in whether concessions are issued. Third, smallholder farmers operate a meaningful fraction of oil palm land, and the administrative boundary may be less binding on their activities.

To analyze the impact of the boundary on actual oil palm plantations, rather than official concessions, I use data from Gaveau et al. (2022), who identify both large-scale and smallholder oil palm plantations from manual interpretation of high-resolution satellite imagery. The outcome variable is a binary indicator of whether a particular point is within an oil palm plantation identified in this dataset in 2015, so the coefficient represents the gap in the share of land within detected oil palm plantations.

Oil Palm Plantation Coverage (0-100)



Here the evidence is more clear: all estimates suggest that the share of land within oil palm plantations drops by roughly 11 percentage points (roughly 70% of the sample mean or 50% of the mean value just outside the Maintained Forest). The Maintained Forest boundary does appear to constrain actual oil palm plantations to an economically meaningful extent despite evidence of imperfect enforcement (the level of oil palm coverage within the Maintained Forest is still meaningfully different from zero).

Table 5: Oil Palm Plantation Coverage (0-100)

	(1)	(2)	(3)	(4)
Conventional	-10.054***	-10.094***	-10.034***	-10.080***
	(1.077)	(1.070)	(1.072)	(1.066)
Robust	-11.741***	-11.927***	-11.555***	-11.741***
	(2.316)	(2.260)	(2.217)	(2.182)
Bandwidth (km)	1.95	1.96	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	16.11	16.10	16.08	16.08
Samp. SD	36.76	36.76	36.74	36.74
N	60,607	60,900	62,355	62,355

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.5 Remote Sensed Tree Crops

Oil palm is the most significant tree crop in this context, but there are a variety of other tree crops also being grown near the boundary of the Maintained Forest. Petersen et al. (2016) locate planted trees (including planted lumber and pulpwood monoculture forests and tree crops not limited to oil palm) in approximately the year 2014 by visual interpretation of satellite imagery, and identify the type of tree being grown. I limit the dataset to tree crops (excluding trees planted for lumber or wood pulp, such as eucalyptus and acacia, which count as forest). The outcome variable is a binary indicator of whether a point is located within an identified tree crop plantation, scaled by 100 to give the percentage of land cover.

The estimated gap in total tree crop area is smaller in magnitude than the impact on oil palm, but in the same direction. Once again, all estimates suggest an economically meaningful decline in tree crops across the Maintained Forest boundary despite nonzero tree crop presence within the Maintained Forest, pointing to meaningful but imperfect enforcement of the administrative boundary.

Tree Crop Coverage (0-100)

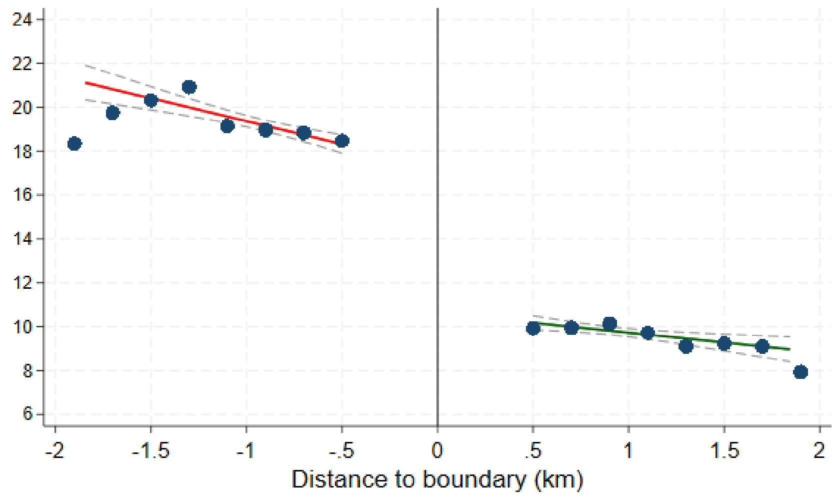


Table 6: Tree Crop Coverage (0-100)

	(1)	(2)	(3)	(4)
Conventional	-6.555***	-6.715***	-6.815***	-6.887***
	(0.883)	(0.864)	(0.847)	(0.842)
Robust	-8.085***	-7.688***	-6.462***	-6.657***
	(2.571)	(2.344)	(1.972)	(1.947)
Bandwidth (km)	1.78	1.84	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	14.01	13.90	13.78	13.78
Samp. SD	34.08	33.97	33.86	33.86
N	54,225	56,500	62,337	62,336

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.6 Forest Cover Measures

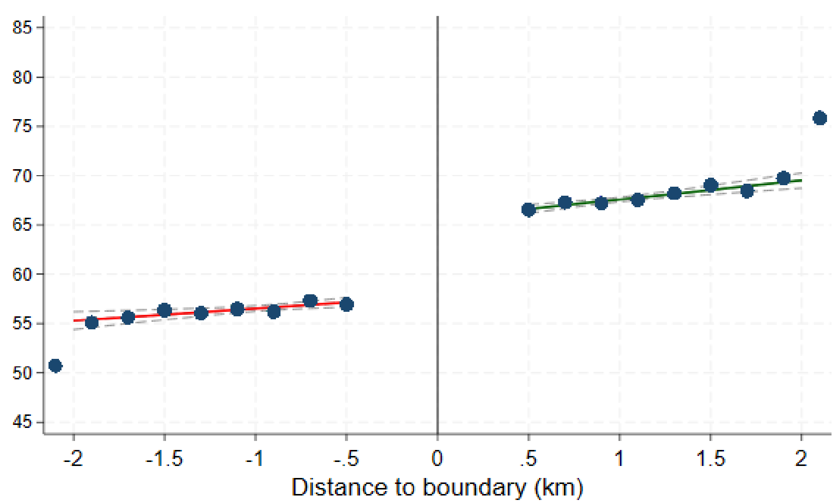
The measure of remote-sensed tree cover used above does not differentiate between forested land and tree crops, which have similar spectral signatures in satellite imagery. I adopt two different approaches to measure forest cover (as distinct from tree cover).

First, I use official land use data from the MEF, which maintains annual data on forest cover in Indonesia from a combination of sources including on-the-ground surveying, aerial imagery, and satellite data. This official land use data has separate categories for tree crops and forests, so I examine the impact of the boundary on the share of land reported by the MEF to be forest.

I also develop two proxies for forest area, by eliminating the areas detected as tree crops by Gaveau et al. (2022) and Petersen et al. (2016) from the remote sensed tree cover of DiMiceli et al. (2022). After eliminating detected tree crops, the remaining areas of remote sensed tree cover should correspond to forests.

6.6.1 MEF Forest Cover

Forest Cover (0-100)



The official data from the MEF suggest that there is a meaningful increase in forest cover across the boundary, in the range of 7-8 percentage points (relative to mean forest cover of just over 60% in the sample). Note that the MEF's own data acknowledges that a substantial share of land within the Maintained Forest is in fact not forested.

Table 7: Forest Cover (0-100)

	(1)	(2)	(3)	(4)
Conventional	7.740***	7.946***	7.755***	7.949***
	(1.017)	(1.023)	(1.026)	(1.023)
Robust	7.610***	7.820***	7.538***	7.824***
	(2.470)	(2.483)	(2.534)	(2.487)
Bandwidth (km)	2.03	2.00	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	62.99	62.92	62.91	62.91
Samp. SD	48.28	48.30	48.30	48.30
N	63,329	62,370	62,314	62,312

Standard errors in parentheses

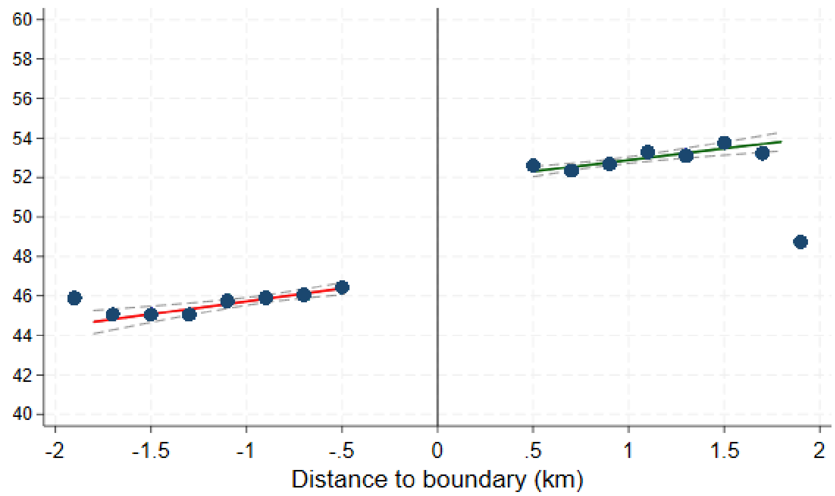
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.6.2 Approximated Forest Cover

I produce an independently derived measure of forested land in 2014 by setting the fraction of tree cover in the DiMiceli et al. (2022) data to zero in areas detected as tree crops by Petersen et al. (2016). The resulting outcome variable is a continuous measure of the share of land covered by trees that are not part of tree crop plantations in approximately 2014.

Estimates of the change in forest cover at the boundary using this measure are roughly consistent with those obtained when using the MEF data on forests. Estimates suggest that the boundary has generated a roughly 5-6 percentage point gap across the boundary, in the expected direction of greater forest cover within the Maintained Forest area, compared with a roughly 7.5-8 percentage point gap estimated using the official MEF data. Note that both estimates of the effect on forest cover are significantly larger than the effect on overall tree cover, highlighting the importance of carefully separating

Non-Tree Crop Forest (0-100)



different types of tree cover in this context.

Table 8: Non-Tree Crop Forest (0-100)

	(1)	(2)	(3)	(4)
Conventional	4.677***	4.732***	4.737***	4.778***
	(0.627)	(0.618)	(0.602)	(0.602)
Robust	6.153***	6.028***	5.021***	5.140***
	(1.812)	(1.691)	(1.387)	(1.369)
Bandwidth (km)	1.76	1.80	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	49.72	49.74	49.90	49.90
Samp. SD	29.02	29.00	28.96	28.96
N	53,411	54,971	62,342	62,341

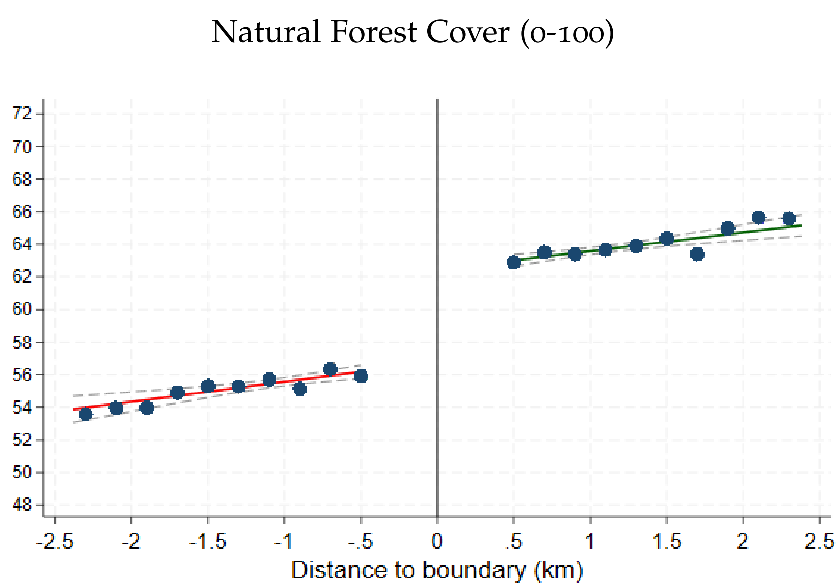
Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.7 Natural Forest Cover

Although areas growing trees for lumber or pulpwood are forested, these areas have substantially lower biodiversity than natural (non-planted) forests. For this reason it is worthwhile to consider whether the differences in forest cover across the boundary reflect higher levels of natural forests inside the boundary, or whether all of the additional forest cover consists of planted forests with low ecosystem services value. As in the case of forest cover, there are two plausible measures of natural forest. One is the official MEF land cover data; the other is generated by setting the tree cover share from DiMiceli et al. (2022) to zero in areas detected as planted trees by Petersen et al. (2016). I examine estimated impacts on each of these outcomes in turn.

6.7.1 MEF Natural Forest (2015)



Using the percentage of land classified as natural forest by the MEF as an outcome, it appears that there is a small but economically meaningful and highly significant impact on the natural forest cover gap. The share of land covered by natural forests is approximately 5-7 percentage points higher within the Maintained Forest.

Table 9: Natural Forest Cover (0-100)

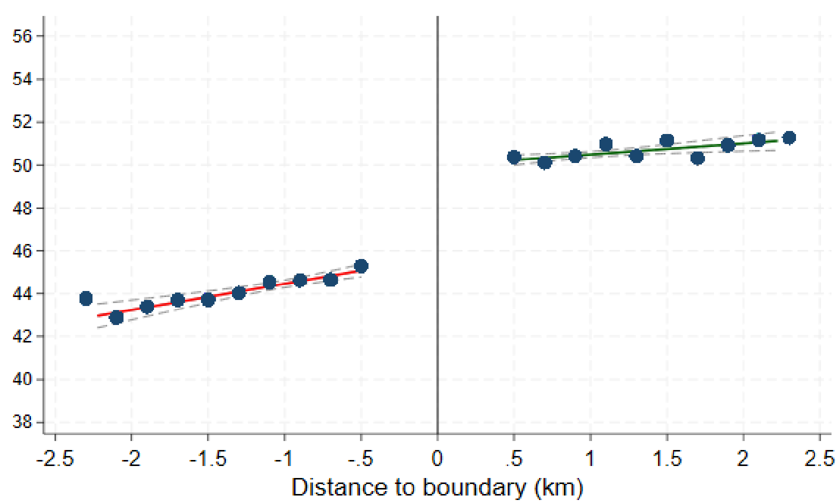
	(1)	(2)	(3)	(4)
Conventional	5.506***	5.708***	5.944***	6.127***
	(0.865)	(0.862)	(0.945)	(0.940)
Robust	6.763***	6.927***	5.262**	5.501**
	(1.734)	(1.729)	(2.333)	(2.284)
Bandwidth (km)	2.39	2.38	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	60.23	60.23	59.81	59.81
Samp. SD	48.94	48.94	49.03	49.03
N	76,016	75,701	62,339	62,339

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.7.2 Approximated Natural Forest Cover

Non-Planted Tree Coverage (0-100)



When approximate natural forest cover is used at the outcome, estimated effects are of a similar magnitude to those estimated using MEF data, though the point estimate is slightly smaller. Estimates from all specifications are significant at the 1% level.

Table 10: Non-Planted Tree Coverage (0-100)

	(1)	(2)	(3)	(4)
Conventional	4.284***	4.322***	4.297***	4.337***
	(0.619)	(0.619)	(0.623)	(0.623)
Robust	4.319***	4.383***	4.337***	4.432***
	(1.139)	(1.134)	(1.401)	(1.386)
Bandwidth (km)	2.23	2.23	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	47.81	47.81	47.71	47.71
Samp. SD	30.74	30.74	30.76	30.76
N	70,314	70,304	62,333	62,331

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Thus, it appears that the Maintained Forest boundary has produced small but meaningful gaps in forest cover, in the range of 4-7 percentage points of land area. This indicates that the boundary is at least marginally effective in limiting the loss of natural forest to areas outside the Maintained Forest; differences in forest cover are not solely attributable to more forestry land inside the boundary.

7 Conclusion

Using a geographical regression discontinuity design, I assess the effectiveness of Indonesia's policy of prohibiting deforestation within the Maintained Forest. Estimates show small but meaningful increases in forest cover across the boundary that did not exist prior to the establishment of the boundary, suggesting that the boundary does protect the designated area, though highly imperfectly. I decompose the change in tree cover into component parts, showing that forest cover and natural forest cover are also higher on the protected side of the boundary. This difference appears to be attributable in large part to significant lower land use for tree crops such as oil palm just inside the Maintained Forest boundary.

Because protection of the Maintained Forest may relocate deforestation activity outside the protected area itself, these estimates of net differences in forest cover across the treatment boundary do not necessarily correspond to the gross impact of forest protection on forest cover at the boundary. Future work will attempt to assess the aggregate impact of imposing Maintained Forest protection using a spatial land use model that will incorporate the spatial spillovers and general equilibrium effects created by a policy that constrains economic activity on the majority of Indonesia's land.

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