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

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Question

Has Permanent Forest designation successfully reduced deforestation in Indonesia's Outer Islands, and if so, how?

Why do we care?

- Indonesia's forests among world's largest, shrinking rapidly
- Protected forests play an important role in CO_2 sequestration
  - $\approx$1 year of global emissions 2000-20 (Duncanson et al. 2023)
- Effectiveness of protection unclear in Indonesia
  - 73% or more of logging output illegal in Indonesia (UNEP 2007)

Summary of Findings

Protection has:

- Small but meaningful (5-8 p.p. or $\approx$10%) impact on forest
- Prohibition on tree crops in Protected Forest drives result
  - Estimates suggest meaningful though highly imperfect enforcement

Outline

- Background & terminology
- Prior literature
- Data & sample selection
- Identification (RDD with covariates)
- Covariate balance (investigating continuity assumption)
- Pre-treatment differences (placebo tests)
- Impacts on forest cover and land use
- Conclusions

Background

- Most (120M of 190M ha.) of Indonesia is State Forest (Kawasan Hutan)
- The bulk of this (108M of 120M ha.) is Permanent Forest
  - Remainder is Conversion Forest
- Original delineation 1982-91 (varies by province), slight adjustments in 1999
- Boundaries did not coincide with clear actual or natural forest boundaries
  - Evidence follows
- Land categorization governs legal land use (next slide)

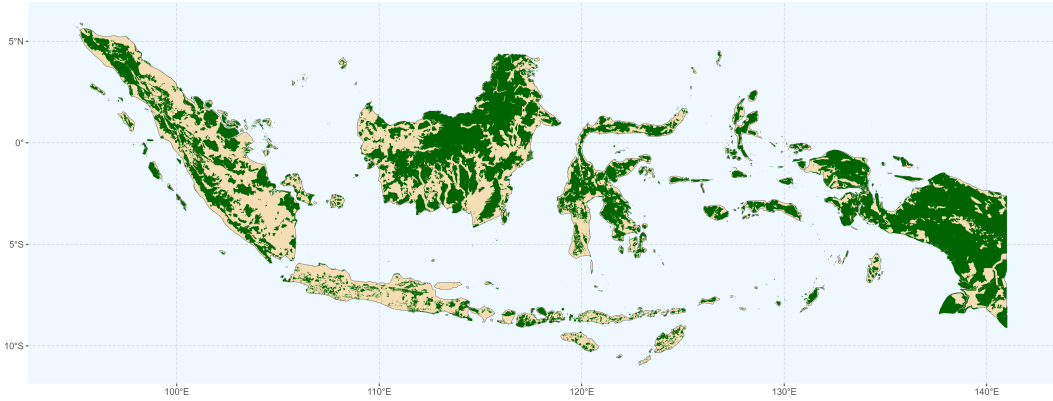
Legal Categories of Land in Indonesia

- Protected Forest
  - cannot be logged: nature reserves, etc.
- Production Forest
  - can be logged by concessionaires but not converted
- Conversion Forest
  - can be granted to tree crop concessionaires
  - can be released to BPN for private ownership
  - slated for "conversion" to non-forest
- Other Use Area
  - under administration of BPN (National Land Agency)
  - may be privately owned, no relevant use restrictions

Legal Categories of Land in Indonesia

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

Indonesia's Permanent Forest Area



Context

PF boundary likely did not follow discontinuity in potential outcomes:

- Bureaucratic incentives likely pushed towards expansive "forest" definition
  - forest concessions major form of patronage under Suharto (1967-1998) (Smith, 2003)
- E.g. in South Sumatra, MEF claimed 3$\times$ as much "forest" as Dutch colonial gov't had found $>$35 years earlier
  - despite significant ongoing deforestation (Fay, 2000)

Little scope for manipulation:

- Delineated by MEF with virtually no outside input, ignored claims (Santoso, 2003)
- Permanent Forest 2017 area agrees with 1999 aggregate within 4%
- 2016, 2021 Permanent Forest extremely similar

Literature

- Conflicting land claims key to tropical deforestation (Balboni et al. 2023)
- District division ↑ deforestation (↓ market power) (Burgess et al. 2012)
  - Their study: *across*-province variation in *district* policy
  - My study: *within*-district variation in *national* policy
- Measuring forest policy impacts through RDD designs:
  - Burgess et al. 2019 (change in forest policy in Brazil vs. neighbors)
  - Neal 2024 (impact of protected areas designation globally)
    - Uses a definition of "protected areas" much smaller than Perm. Forest
- Effectiveness of protection in EU (Grupp et al. 2023)

Sample

- Unit of observation: grid point (1km equally spaced grid)
- Sample limited to initially forested areas of outer islands
  - Map 1: ≈1985 RePPProT land use
    - Mapping by Transmigration Program separately from MEF
    - Forest area agrees closely with independent FAO estimates
    - Used as best available map by World Cons. Monitoring Center
  - Map 2: 1990 MEF land use
    - Does not align with Permanent Forest boundaries
  - Limit to areas forested on both maps
- "Donut" of 500m to account for pixel outcomes/map imprecision

Identification

Local-linear covariate-adjusted RD estimator (Calonico et al. 2019)

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

Requires standard RD assumptions (continuous expectation functions at cutoff, no perfect manipulation), plus:

- treatment must not shift covariate X means

Identifies the local treatment effect of PF designation on marginal areas

Controls

Controls:

- boundary fixed effects for *max. 20km* boundary *within district*
- elevation, slope, ruggedness, mean temperature + precipitation
- distance to nearest river, coast, city
- suitability for rice, soy, oil palm, cassava, coffee, cocoa

Point of controls is to (possibly) increase precision, since they must not jump

Covariate Balance

Problem: Several geographic covariates not balanced in the full sample

- Some but not all boundaries follow real discontinuities in geography
- Problem also affects Dell (2010), Asher et al. (2021)...

Solution (as in previous papers): limit to geographically balanced segments

- Boundary mean elev. below 500m (eliminate mountains)
- Approximated slope in sample around boundary $< 2\%$

Geography well-balanced across these boundaries

- Evidence follows

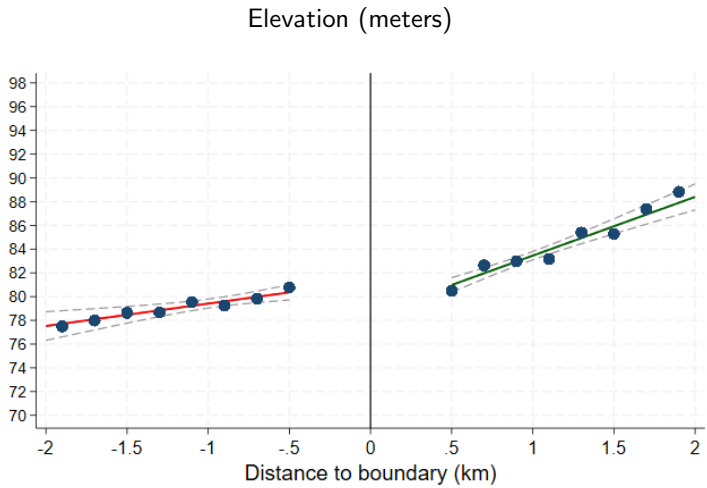
Balance Tests: Geography

Table: Geographic Covariates

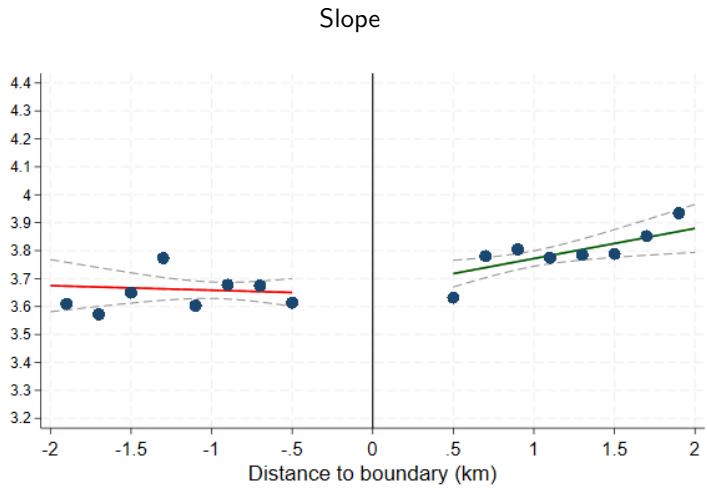
	(1) Elev.	(2) Slope	(3) Rugg.	(4) Rain	(5) Temp	(6) RiverDist	(7) CoastDist	(8) CityDist
Conventional	-2.80***	0.02	-0.03	-0.23	0.01***	0.06	0.01	-0.08
	(1.06)	(0.07)	(0.28)	(0.46)	(0.00)	(0.05)	(0.06)	(0.06)
Robust	-2.23	0.13	0.58	0.99	0.01	0.24	0.19	-0.25
	(3.35)	(0.23)	(0.91)	(1.84)	(0.01)	(0.18)	(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

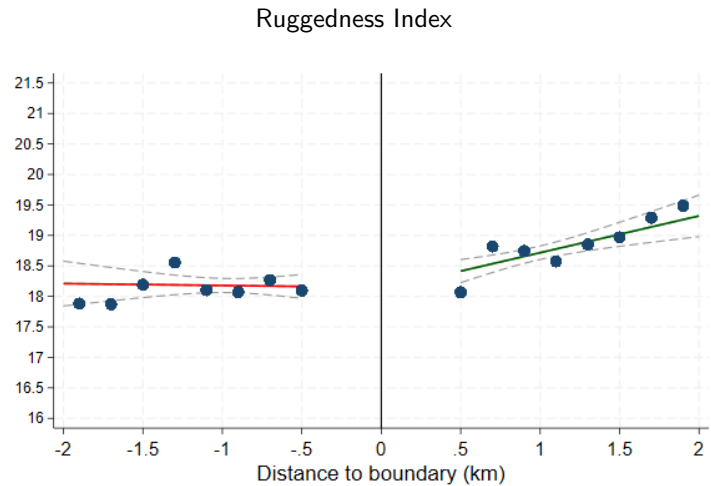
Elevation


Elevation (meters)
98
96
94
92
90
88
86
84
82
80
78
76
74
72
70
-2
-1.5
-1
-.5
0
.5
1
1.5
2
Distance to boundary (km)

Slope


Slope
4.4
4.3
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
-2
-1.5
-1
-.5
0
.5
1
1.5
2
Distance to boundary (km)

Ruggedness


Ruggedness Index
21.5
21
20.5
20
19.5
19
18.5
18
17.5
17
16.5
16
-2
-1.5
-1
-.5
0
.5
1
1.5
2
Distance to boundary (km)

Placebo Tests

- Outcomes might differ across the boundary because:
  - Boundaries followed unobserved discontinuity in suitability for forests
  - Boundaries followed pre-existing extent of forests
- I argue spurious results unlikely by showing null results on:
  - FAO ecologists' estimates of naturally forested areas
    - MacKinnon et al. 1982
  - Satellite-observed tree cover just prior to delineation
    - Hansen & Song 2018
  - Tropical Moist Forest detected in 1990 and 1991
    - Vancutsem et al. 2021

Order of Specifications

Estimation:

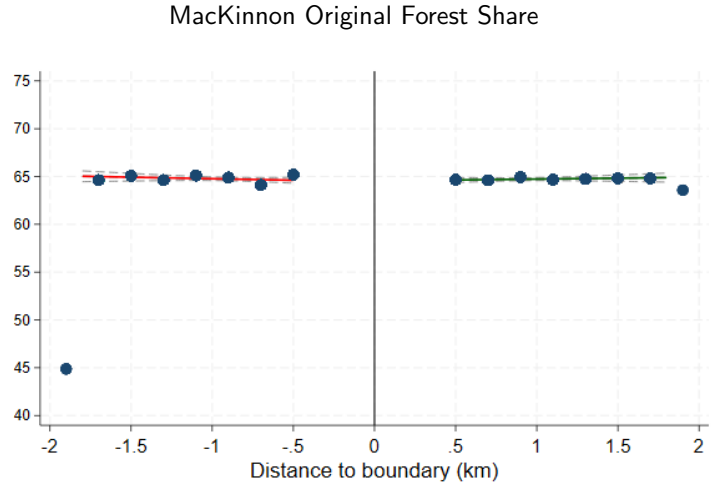
- Both "conventional" and Calonico et al. (2014) "robust" estimates and SEs
- Calonico et al. (2020) "optimal" bandwidth and ad-hoc 2km bandwidth
- SEs clustered at 2012 district
- Level not identified due to segment FEs; plots normalized to sample means

Specifications

1. RD with boundary segment FEs, optimal bandwidth
2. RD with boundary segment FEs & geophysical controls, optimal bandwidth
3. RD with boundary segment FEs, 2km bandwidth
4. RD with boundary segment FEs & geophysical controls, 2km bandwidth

Placebo Test: MacKinnon Original Ecosystem

▸ Table



Placebo Test: MacKinnon Original Ecosystem

Back

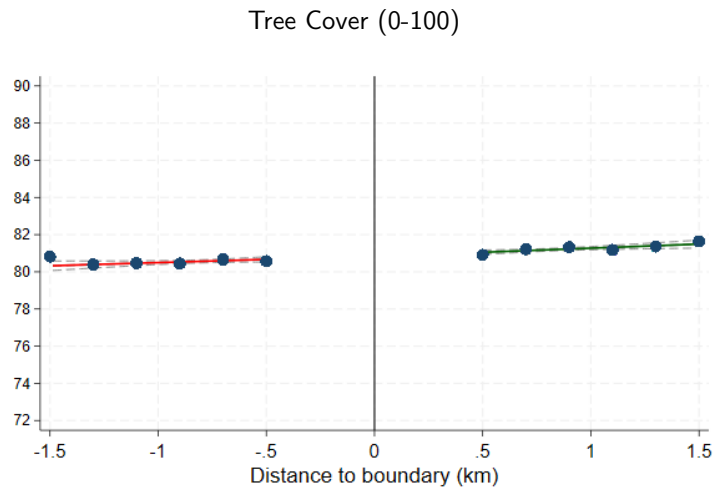
Table: Original Forest Cover Share (0-100)

	(1)	(2)	(3)	(4)
Conventional	0.092	0.114	0.039	0.079
	(0.417)	(0.406)	(0.379)	(0.369)
Robust	0.165	0.037	0.346	0.244
	(1.612)	(1.620)	(1.227)	(1.208)
Bandwidth (km)	1.81	1.80	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	64.74	64.76	64.82	64.82
Samp. SD	47.78	47.77	47.75	47.75
N	55,109	54,926	62,343	62,342

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

Placebo Test: Hansen & Song 1982-1984 Tree Cover

▸ Table



Placebo Test: Hansen & Song 1982-1984 Tree Cover

Back

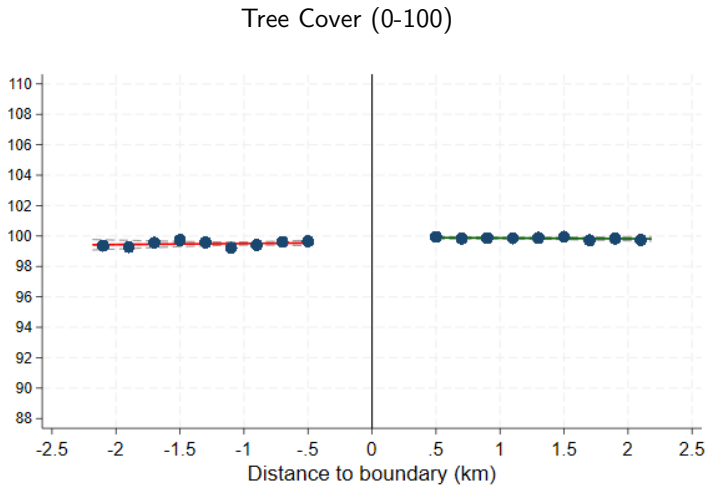
Table: Tree Cover (0-100)

	(1)	(2)	(3)	(4)
Conventional	-0.045	-0.017	0.051	0.059
	(0.269)	(0.257)	(0.160)	(0.164)
Robust	-1.450	-1.440	-0.391	-0.381
	(1.136)	(1.072)	(0.549)	(0.543)
Bandwidth (km)	1.45	1.49	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	80.91	80.93	81.03	81.03
Samp. SD	13.17	13.17	13.10	13.10
N	41,639	43,061	62,309	62,306

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

Placebo Test: Vancutsem et al. 1990-91 Forest Cover

▸ Table



Placebo Test: Vancutsem et al. 1990-91 Forest Cover

Back

Table: Forest Cover (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
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Impacts of Permanent Forest Categorization

At this point I have hopefully convinced you that:

- Permanent Forest designation did not always follow real discontinuities
- In the analysis sample,
  - geography is continuous across the boundary
  - natural forest suitability is continuous across the boundary
  - pre-treatment forest cover is level across the boundary
  - all areas initially forested (equally) in 1990-91 (treatment start)

Going forward I will interpret estimates as "impacts" of PF designation

- Identified treatment effect is local to well-balanced areas

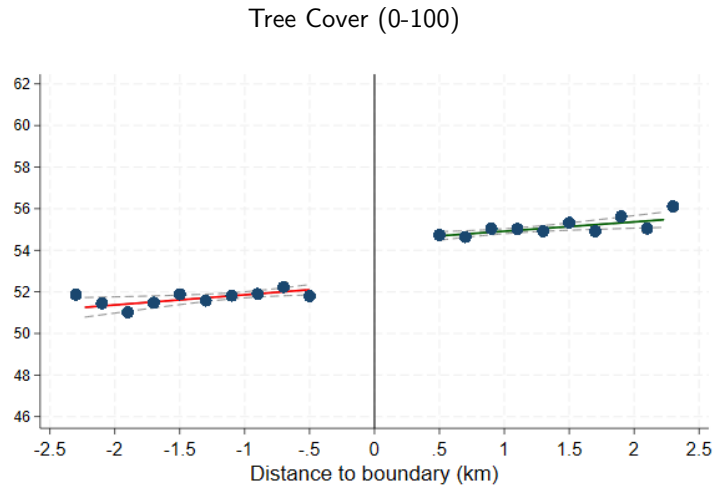
Measurement

- Remote observation can automatically detect **trees** by spectral signature
- Cannot reliably differentiate natural forests from planted trees

Land Type	**Forest?**	**Tree Cover?**
Natural forest	Yes	Yes
Planted forest (forestry land)	Yes	Yes
Planted tree crops (estate crops)	No	Yes
Treeless land	No	No

2015 Tree Cover (DiMiceli et al. 2015)

▸ Table



2015 Tree Cover (DiMiceli et al. 2015)

Back

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

Concessions

De jure,

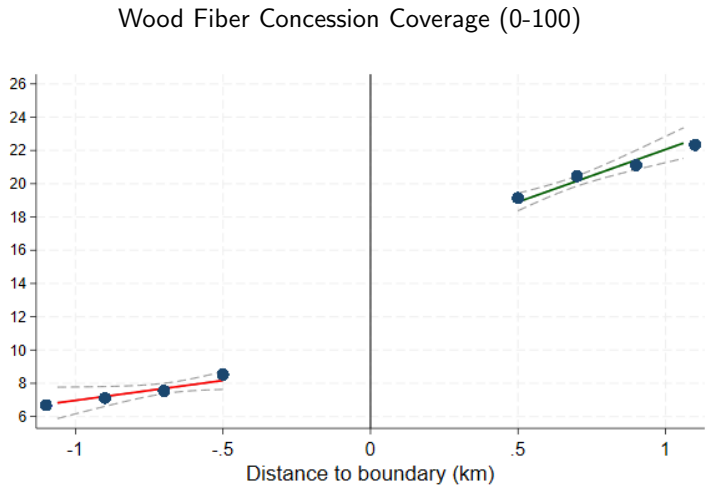
- Wood fiber concessions must be inside Permanent Forest
- Oil palm concessions must be outside Permanent Forest

But note that

- Not all concessions are used, so land use effects may differ
- Official data may miss district-issued concessions

Wood Fiber Concessions c. 2016 (MEF via GFW)

▸ Table



Wood Fiber Concessions c. 2016 (MEF via GFW)

Back

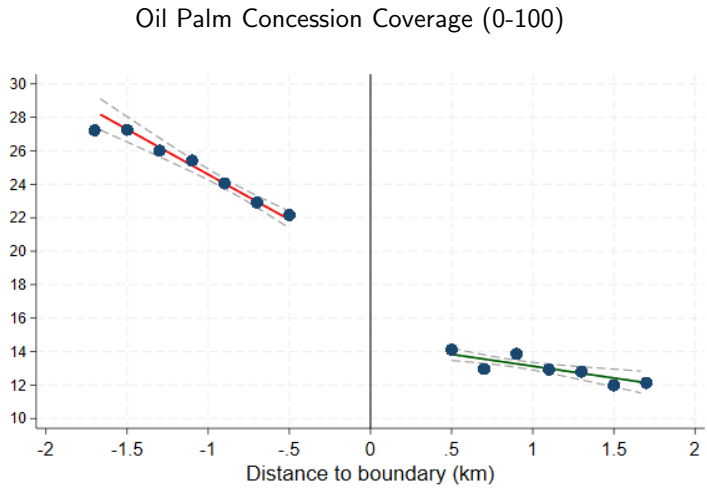
Table: Wood Fiber Concession Coverage (0-100)

	(1)	(2)	(3)	(4)
Conventional	6.180***	6.166***	8.993***	8.957***
	(1.910)	(1.877)	(1.351)	(1.351)
Robust	-1.860	-0.981	6.145***	6.133***
	(7.823)	(7.700)	(2.120)	(2.117)
Bandwidth (km)	1.05	1.06	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	14.60	14.67	15.10	15.10
Samp. SD	35.31	35.38	35.81	35.81
N	24,914	25,482	62,207	62,202

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

Oil Palm Concessions c. 2015 (MEF via GFW)

▸ Table



Oil Palm Concessions c. 2015 (MEF via GFW)

Back

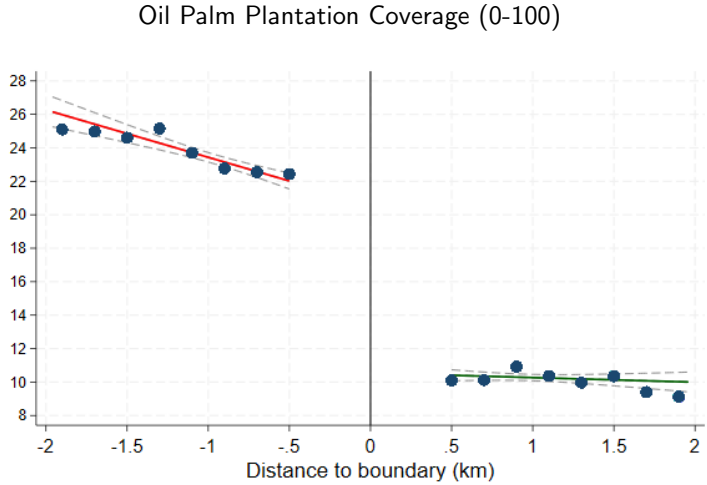
Table: Oil Palm Concession Coverage (0-100)

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

Oil Palm Plantations 2015 (Gaveau et al. 2022)

▸ Table



Oil Palm Plantations 2015 (Gaveau et al. 2022)

Back

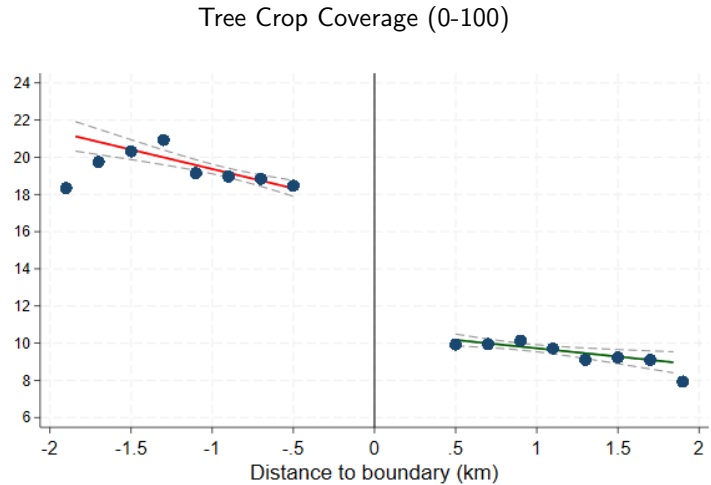
Table: Oil Palm Plantation Coverage (0-100)

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

Tree Crops c. 2014 (Petersen et al. 2016)

▸ Table



Tree Crops c. 2014 (Petersen et al. 2016)

Back

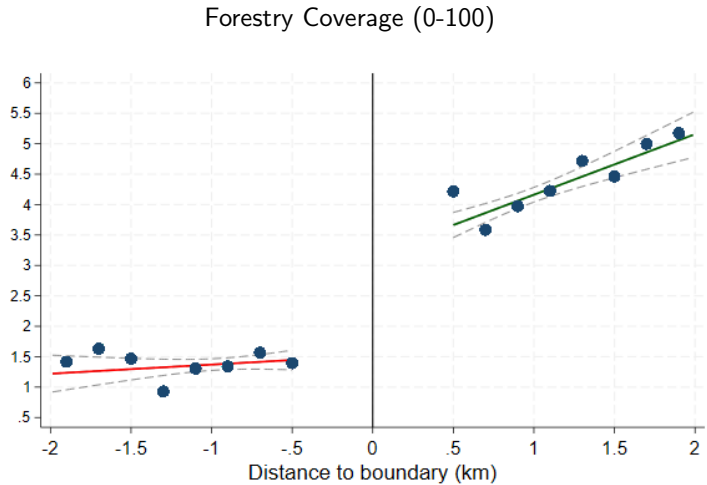
Table: Tree Crop Coverage (0-100)

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

Planted Forest c. 2014 (Petersen et al. 2016)

▸ Table



Planted Forest c. 2014 (Petersen et al. 2016)

Back

Table: Forestry Coverage (0-100)

	(1)	(2)	(3)	(4)
Conventional	1.671***	1.642***	1.638***	1.644***
	(0.505)	(0.497)	(0.498)	(0.498)
Robust	1.667*	1.916**	1.861**	1.894**
	(0.855)	(0.948)	(0.940)	(0.938)
Bandwidth (km)	2.11	1.99	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	3.11	3.08	3.08	3.08
Samp. SD	17.37	17.29	17.29	17.29
N	65,936	61,728	62,176	62,167

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

Forest & Natural Forest

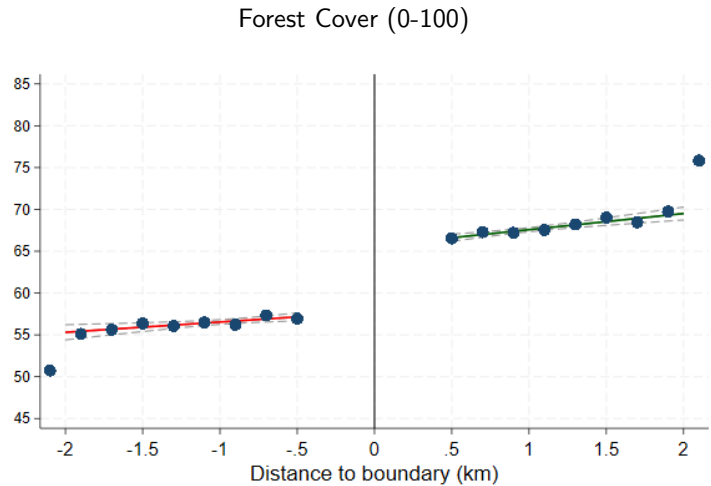
Tree cover $\geq$ Forest $\geq$ Natural Forest

Two approaches:

- Use MEF estimates separating tree crops, forestry, natural forest
- Approximate by combining remote sensing data:
  - Forest $\approx$ (Tree Cover) - (Tree Crops)
  - Natural Forest $\approx$ (Tree Cover) - (Tree Crops) - (Forestry Land)
- Sources:
  - Gaveau et al. 2022 (oil palm only)
  - Petersen et al. 2016

Forest 2015 (MEF)

▸ Table



Forest 2015 (MEF)

Back

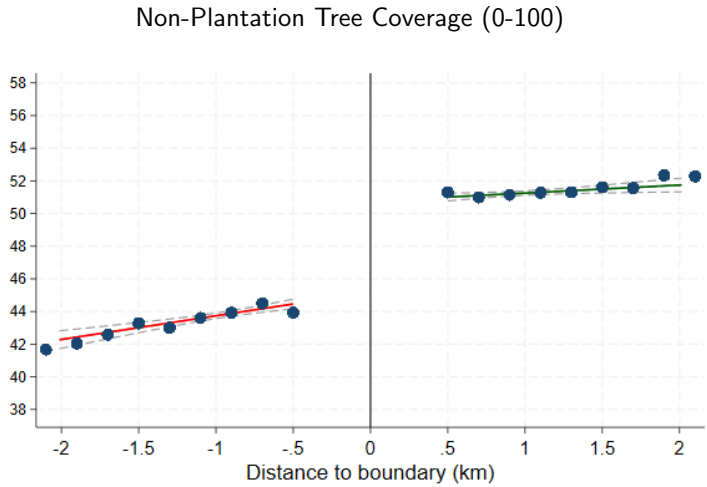
Table: Forest Cover (0-100)

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

"Forest" 2015 (DiMiceli - Gaveau Oil Palm)

▸ Table



"Forest" 2015 (DiMiceli - Gaveau Oil Palm)

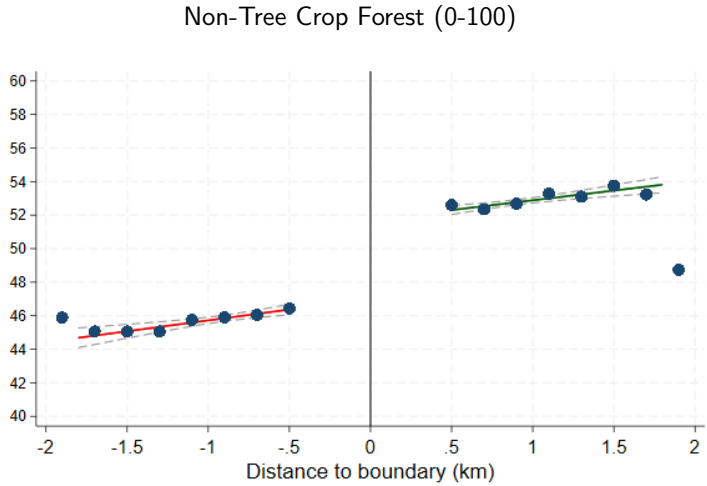
Back

Table: Non-Plantation Tree Coverage (0-100)

	(1)	(2)	(3)	(4)
Conventional	5.612***	5.607***	5.602***	5.623***
	(0.640)	(0.635)	(0.639)	(0.637)
Robust	7.309***	7.397***	7.312***	7.397***
	(1.344)	(1.306)	(1.335)	(1.321)
Bandwidth (km)	1.99	2.01	2.00	2.00
Geog. Controls	No	Yes	No	Yes
Clustering	Kab.	Kab.	Kab.	Kab.
Samp. Mean	47.90	47.93	47.91	47.91
Samp. SD	29.10	29.10	29.10	29.10
N	62,092	62,823	62,357	62,357

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

"Forest" 2014 (DiMiceli - Petersen Tree Crops)



"Forest" 2014 (DiMiceli - Petersen Tree Crops)

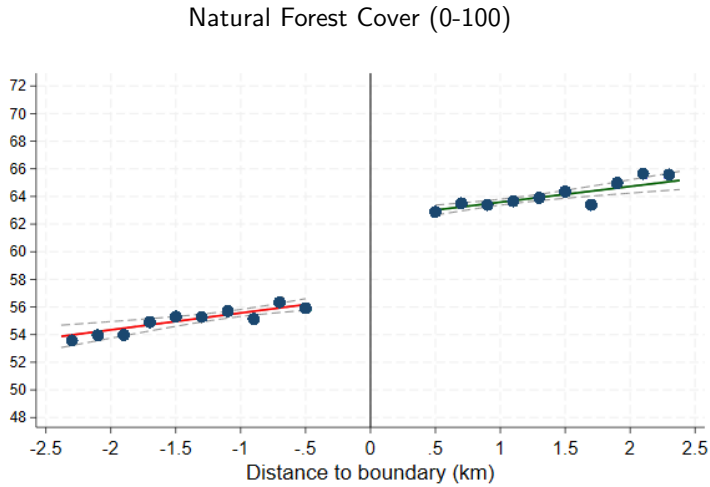
Table: Non-Tree Crop Forest (0-100)

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

Natural Forest (MEF, 2015)

▸ Table



Natural Forest (MEF, 2015)

Back

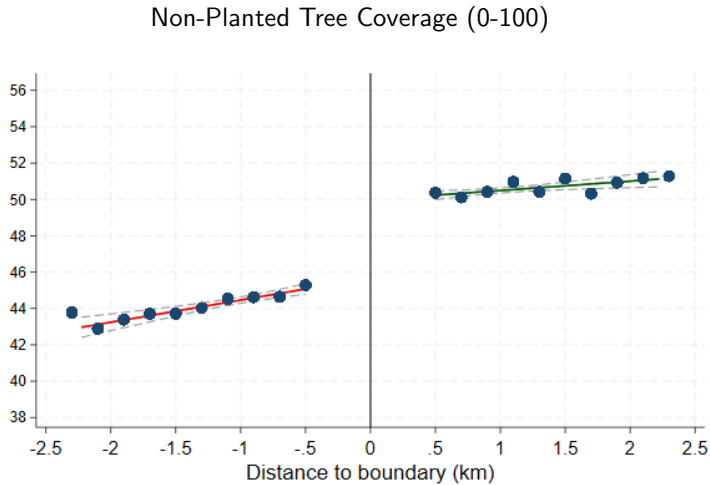
Table: Natural Forest Cover (0-100)

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

"Natural Forest" 2014 (DiMiceli - Petersen Planted Trees)

▸ Table



"Natural Forest" 2014 (DiMiceli - Petersen Planted Trees)

Back

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

Conclusion

- Boundary increases forest cover by roughly 6-7.5 p.p. ($\approx$ 12%)
- Slightly smaller ($\approx$4-7 p.p.) impact on natural forest
- Mechanism: Permanent Forest boundary cuts tree crop land in half
  - In both Gaveau et al. (oil palm) and Petersen et al. (all tree crops) measures
  - More than fully accounts for natural forest differences
  - Still far from zero!
- Smaller ($\approx$2.5 p.p.) impact on remote-sensed tree cover
- Unclear evidence on official concessions
  - Conventional RD point estimates suggest small but meaningful impact
  - Not significant effects using robust estimator with optimal bandwidth

Next Steps

- Additionality concerns with RD (Andam et al. 2008)
  - Enforcement may relocate, not reduce, deforestation
- Plan: examine impacts of enforcement in spatial production, land use model
  - Calibration:
  - RD estimate provides targeted moment for enforcement effectiveness parameter
  - Indodapoer kabupaten-level sectoral output by year
  - MEF annual land use rasters
  - Edwards (2019) estimates discipline economic benefits of palm oil
- Investigate how environment/development tradeoff varies with enforcement strength. How steep is protection tradeoff in aggregate?

Appendix