

The Origins and Control of Forest Fires in the Tropics

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Research Question

- In Indonesia, firms can clear land using a **cheap but risky** technology: illegal burning
- The paper asks whether firms use fire differently when the expected damage from fire spread is:
 - ▶ mostly **internalized** (spread onto their own land), versus
 - ▶ mostly **externalized** (spread onto others' land)
- It then asks which mechanism can limit this externality:
 - ▶ Private bargaining (Coase)
 - ▶ Public deterrence (Pigou)

Why is this important:

- Externality is an old question in public/environmental economics, but evidence on how externalities change firm behavior is limited
- Tropical fires matter for **local land damage, haze and health, biodiversity, and carbon emissions**
- The paper studies behavior at the **decision margin**: not just whether fires are harmful, but *when firms choose to use them*

Research Question

Sep 19, 2016 | Last Update: Feb 8, 2025

News

Indonesia's 2015 fires killed 100,000 people, study estimates

Harvard and Columbia University study finds death from smoke exposure "on a massive scale" in Indonesia, Malaysia and Singapore



Setting: why ownership categories matter

- Indonesia's **forest estate** is government owned, but production forest is often leased out as concessions (logging/oil palm/wood fibre)
- **Useful natural variation:** weather changes fire spreads probability
- **Useful institutional variation:** surrounding land can be own concession, other private concession, protected forest, unleased productive forest, or land outside forest estate (where people live)

Why I find this elegant: this patchwork of property-right regimes creates variation in who bears spread damages and the natural variation is completely exogenous

Data

- **Time period:** Oct 2000–Jan 2016
- **Fire hotspots:** MODIS Terra daily fire product, 1 km grid
- **Land classification & concessions:** forest estate boundaries, protected areas, logging/palm/wood fibre concessions
- **Deforestation:** Hansen et al.(2013) forest loss data at 30m resolution
- **Weather:** monthly wind speed, precipitation, and temperature (matched to 1 km pixels)
- **Regulation:** 2015 government investigations and sanctions

Sample Size

176,855 fires in the forest estate overall;
baseline analysis focuses on 39,189 fires started in **wood fibre and oil palm concessions** on Indonesia's major forested islands

▶ Table 1: sample details

Measuring the key object: ignition vs spread

- Link contiguous hotspots across space and days to recover likely individual fires
- **Day 1 pixels = ignition area**
- **Later contiguous pixels = spread area**
- This measurement is crucial because the paper needs the *decision to start a fire* and the *tail risk of subsequent spread*

Potential limitation: within-day spread is not observed separately, so measured spread is conservative

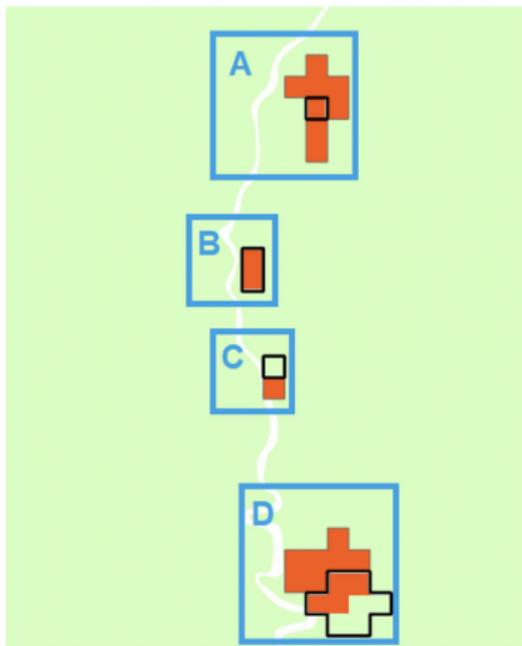
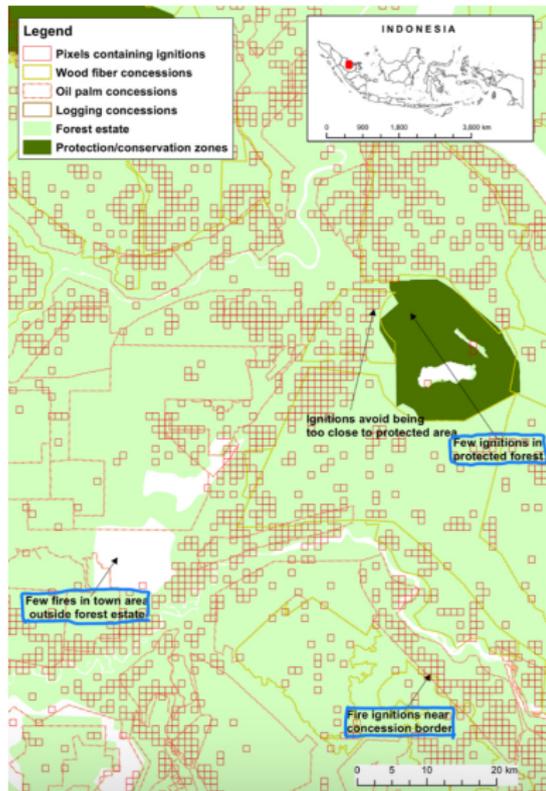


Figure: Algorithm used to track contiguous hotspots across days

Are these fires economic behavior or random nature?



- Fires are sparse in protected areas and populated places
- Fires are heavily concentrated in **oil palm and wood fibre concessions**, not logging concessions
- This pattern suggests that many observed fires are part of a **land-clearing technology choice**, not just natural ignitions

Figure: Ignitions and concession areas

Fire as part of the land-clearing process

- They match 30m forest loss to 1 km fire pixels
- Recent deforestation strongly predicts subsequent ignition
- Moving from 0 to 100% deforested in a pixel implies about a **285% increase** in ignitions in next year
- Later lags turn negative (consistent with a tight clearing cycle)

Why this matters: it validates the premise that ignition is a strategic economic decision

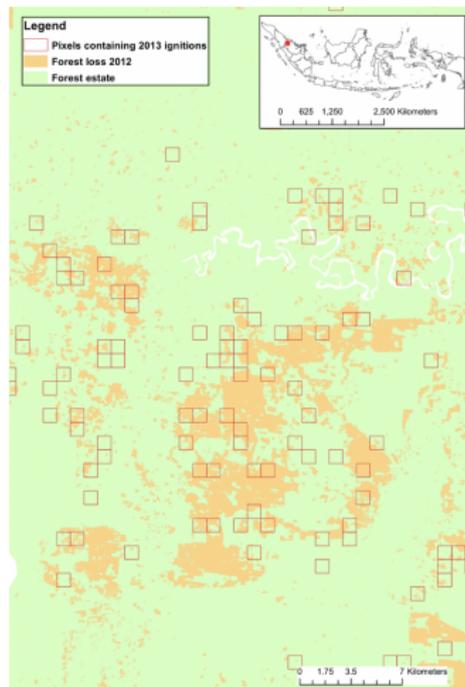


Figure: overlap between 2012 deforestation and 2013 ignitions

Empirical Intuition

Behavioral logic

A firm would use fire if the **private benefit of burning** exceeds the **expected private cost of fire spread**

Expected cost of ignition $\approx \underbrace{P(\text{spread} \mid \text{weather})}_{\text{time-varying}} \times \underbrace{\text{spread damage}}_{\text{depend on nearby land ownership}}$

- If surrounding land is mostly **own land**, risky weather should deter ignition
- If surrounding land is mostly **unleased public land**, risky weather should deter ignition less
- If surrounding land is **populated/private land**, deterrence may be even stronger because sanctions and political backlash are larger

Step 1: show spread risk is predictable from weather

TABLE 3
Impact of wind speed, temperature and precipitation on fire spread

Dependent variable = Average fire spread area (burned area minus ignition area)	Pixel FE	Pixel Month & Year FE
Wind speed in km/h	0.1466*** (0.04407)	0.1510*** (0.04452)
Temperature (Celsius)	0.7767*** (0.1598)	0.5700*** (0.1679)
Precipitation (mm)	-0.004932*** (0.0008665)	-0.006626*** (0.0008751)
Observations	5,897	5,897
Mean of Dep. Var.	4.608	4.608

- Estimate average spread area as a function of wind speed, temperature, precipitation, number of ignitions, pixel FE, month FE, year FE
- Result: fires spread more in **windier, hotter, and drier** conditions
- So they can construct the **weather spread risk index**

note: they use wind *speed*, not wind direction because monthly average wind direction is not predictive in this setting

Step 2: define what land is at risk if the fire spreads

- For each 1 km pixel inside a concession, construct a 6 km radius buffer nearby
- Classify surrounding pixels into:
 - ▶ same concession,
 - ▶ other private concession,
 - ▶ protected forest,
 - ▶ unleased productive forest,
 - ▶ outside forest estate

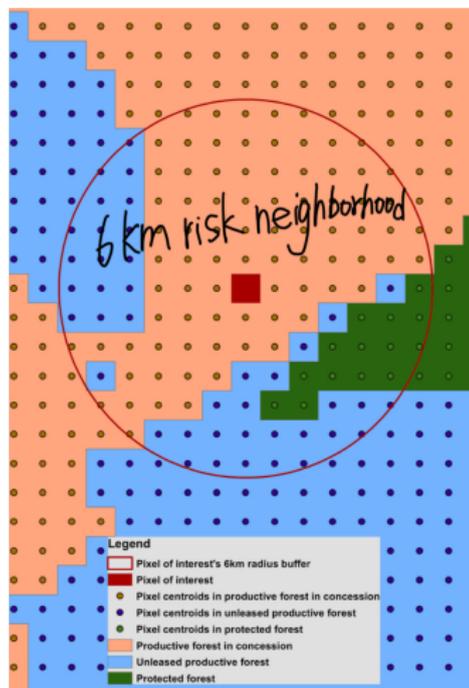


Figure: Illustration of pixel buffer classification

Identification Strategy

$$E[\text{Ignitions}_{imt}] = \exp \left(\beta_1 \widehat{Risk}_{imt} + \sum_j \beta_{2j} \widehat{Risk}_{imt} \times \text{NeighborLandType}_{ij} + \gamma_i + \delta_m + \delta_t + \text{controls} \right)$$

- Outcome: number of ignitions in pixel i in month m in year t
- estimate a Poisson panel with pixel & month-year fixed effects
- Standard errors clustered by $50 \text{ km} \times 50 \text{ km}$ grid cells
- The omitted category in the main regressions is the amount of nearby land in the same concession → Interpretation: coefficients measure how firms behave when the marginal spread risk falls on others rather than themselves

What variation identifies the key coefficients?

Within the same pixel, compare risky vs safer months;

Across pixels, compare locations with different neighboring land types

Main finding: externality does affect ignition behavior

Panel B: With Pixel FE and Risk Index	Pixel M & Y FEs	Pixel M & Y FEs	Pixel M & Y FEs	Pixel M & Y FEs	Pixel M & Y FEs	Pixel M & Y FEs
Risk index in standard deviation units	1.4917*** (0.09977)	1.5552*** (0.1312)	1.6800*** (0.1068)	1.2147*** (0.1323)	1.7296*** (0.09198)	1.6305*** (0.1493)
Risk index * Num pixels in 6 km buffer in different concession from central pixel	0.002908** (0.001295)	0.001821 (0.001205)	0.001715 (0.001228)	0.002579** (0.001281)	0.0009974 (0.001109)	0.0001657 (0.001018)
Risk index * Num pixels in 6 km buffer outside forest estate	-0.005398*** (0.001933)	-0.005288*** (0.001902)	-0.005022** (0.001964)	-0.005332*** (0.001891)	-0.006712*** (0.001890)	-0.005686*** (0.001881)
Risk index * Num pixels in 6 km buffer in protected forest	0.0001807 (0.001910)	0.0002852 (0.001666)	-0.0008821 (0.001733)	0.0002628 (0.001853)	-0.001448 (0.001819)	-0.0009820 (0.001590)
Risk index * Num pixels in 6 km buffer in productive forest outside concession	0.006804*** (0.001546)	0.006722*** (0.001585)	0.005522*** (0.001514)	0.006611*** (0.001499)	0.004797*** (0.001326)	0.004700*** (0.001297)

↑ most negative
 most positive

- Ignitions are more likely near **unleased productive forest** than near own land
 - ▶ **positive** interaction for unleased productive forest
 - ▶ **negative** interaction for land outside the forest estate
 - ▶ much smaller (some insignificant) effect for neighboring private concessions
- Firms are least careful when spread damages fall on "no man's land"

How big is the externality?

- The paper runs a counterfactual: what if firms treated all nearby land as if it were land **outside the forest estate**, i.e. the category that most strongly deters ignition?
- Result: ignitions would fall by roughly **55–57%**
- Also important: the strongest deterrence is near **populated land**, which likely reflects both higher social costs and stronger expected punishment
- The paper identifies **relative internalization across land types**, not the full social optimum

Private solutions: evidence for Coasian internalization

Panel B: With Pixel FE and Risk Index	Pixel M & Y FEs	Pixel M & Y FEs	Pixel M & Y FEs	Pixel M & Y FEs	Pixel M & Y FEs	Pixel M & Y FEs
Risk index in standard deviation units	2.2479*** (0.2672)	1.9464*** (0.2988)	2.5293*** (0.2697)	2.0550*** (0.3242)	2.1930*** (0.2773)	2.0458*** (0.3746)
Risk index * Num pixels in 6 km buffer in same concession as central pixel	-0.006106*** (0.002049)	-0.004528** (0.002063)	-0.003583* (0.001959)	-0.006342*** (0.001992)	-0.002884 (0.002035)	-0.001190 (0.002048)
Control: Risk index × Island	NO	YES	NO	NO	NO	YES
Control: Risk index × Concession Type	NO	NO	YES	NO	NO	YES
Control: Risk index × Forest Cover 2000	NO	NO	NO	YES	NO	YES
Control: Risk index × Concession Area	NO	NO	NO	NO	YES	YES
Observations	480,780	480,780	480,780	480,240	480,780	480,240
Mean of Dep. Var.	0.00797	0.00797	0.00797	0.00798	0.00797	0.00798

Notes: Poisson regressions. Robust standard errors clustered at level of 50km² grid cells. Sample: Pixels whose buffer contains land in a single or at most two concessions, pixels inside wood fibre and palm oil concessions inside forest estate excl Java and Lesser Sunda Islands. Omitted category: "Num pixels in 6 km buffer outside same concession as central pixel" and interaction with spread risk (Panel B). * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure: no detectable differential treatment of own vs neighboring private land

- Restrict to cases where the 6 km buffer contains at most **two private parties**: own concession + one neighboring concession
- In this setting, firms treat risky spread to the neighboring private concession **similarly to risky spread to their own land**

Authors' interpretation: When property rights are clear and transaction costs are plausibly lower, firms may bargain to internalize private damages in the spirit of Coase (1960)

Public solutions: consistent with Pigouvian deterrence

Dummy = 1 if firm investigated	(1)	(2)
Pixels in productive forest in others' concessions burned by fire	-0.1255** (0.05490)	-0.1612 (0.1020)
Pixels outside forest estate burned by fire	-0.1395 (0.1062)	-0.1819 (0.1129)
Pixels in unleased productive forest burned by fire	-0.09042*** (0.01928)	-0.01749 (0.02786)
Pixels in protected forest burned by fire	0.03249 (0.08073)	0.1345 (0.09235)
Total area of fires burned Sep 2014-Aug 2015	0.02951*** (0.005408)	0.01310** (0.006278)
Population in fire extent	0.0006448*** (0.0001997)	0.0007291*** (0.0001961)
Control: Islands	NO	YES
Control: Concession Type	NO	YES
Control: Forest Cover 2000	NO	YES
Control: Concession Area	NO	YES
Observations	600	600
Mean of Dep. Var.	0.157	0.157

Figure: government most responsive where people are affected

- The authors use 2015 investigation lists to infer where fires the government is most likely to punish
- Larger fires are more likely to trigger investigation, fires that burn **populated areas** are especially likely to trigger investigation.
- This matches the main result: firms are particularly cautious when spread risk is to land outside the forest estate

My read: the evidence is more qualitative than fully structural, but it is quite persuasive that firms anticipate a non-uniform punishment function

Other mechanisms: weaker or mixed evidence

- **Reputation / firm size:** larger firms use less fire on average, but the paper finds little evidence that they internalize the unleased-land externality more strongly
- **RSPO membership:** at most weak evidence of reducing ignitions overall; little evidence it changes the externality margin
- **Prosecution of officials:** little evidence that anti-corruption prosecutions reduce risky or externality-inducing fire setting
- **State ownership:** government-owned concessions have fewer fires on average, but not clearly more sensitivity to external costs

▶ Appendix: Tables 7, 10, and 11

What I like about the paper

- **Clean conceptual mapping from theory to empirics.** The paper directly designs tests that correspond to Pigou/Coase:
 - ▶ ownership boundaries should matter if externalities are not internalized
 - ▶ boundaries should matter less when bargaining is feasible
 - ▶ public deterrence should align with the government's objective function
- **Strong identification logic.** By comparing the same location across months with different spread risk, they reduce concerns that “high-fire places” are simply different. This is a great way to exploit quasi-exogenous variation
- **Impressive measurement contribution: ignition vs spread at scale**
- **Policy-relevant within development contexts.** The paper speaks to state capacity, land rights, firm behavior, and environmental regulation in a low-income setting

Why I especially like this for a metrics reading group: the design is creative, but the logic is still transparent enough to explain on one board

What I think the authors can improve

- **Critique 1: the Coase interpretation is suggestive, not definitive**
 - ▶ Similar treatment of neighboring private concessions could reflect bargaining, but it could also reflect **similar firefighting capacity across adjacent concessions, common contractors, common parent ownership, joint liability expectations, or correlated monitoring**
- **Critique 2: some institutional and measurement objects are static or coarse**
 - ▶ concession boundaries are static over 2000-2016
 - ▶ weather is mostly monthly
 - ▶ ignition and containment effort are not fully separated
 - ▶ within-day spread is folded into ignition
- **Critique 3: the punishment evidence is strongest for 2015**, so it is somewhat indirect as a measure of expectations over the whole period

Concrete Suggestions

- **To sharpen the Coase interpretation:**
 - ▶ compare neighboring concessions under the **same parent group** vs truly unrelated firms
 - ▶ use proxies for bargaining frictions such as distance, road connectivity, or local market concentration
 - ▶ test whether results are stronger where legal liability or repeated interaction is more plausible
- **To address static boundaries:**
 - ▶ use any time-varying concession issuance data (if available)
- **To strengthen the mechanism story:**
 - ▶ separate ignition from containment where possible
 - ▶ connect pre-2015 enforcement episodes to firms' expected sanctions

Questions and Topics for Discussion

- **What evidence would convince us that the “Coase” result is really bargaining**, rather than shared capacity, common monitoring, or expected legal liability?
- **Can this empirical design travel (externality)?** e.g. illegal fishing, industrial pollution, mining tailings, or groundwater extraction?
- **How should we interpret populated-land avoidance?** As Pigouvian deterrence, as political salience, or both?

Summary

- **Question:** Do environmental externalities shape firm's behavior?
- **Data:** Combine a satellite-based measure of fire *ignition* and *spread* with weather-driven spread risk and the ownership of surrounding land
- **Main Result:** Firms overuse fire when nearby damages fall on **unleased government land** ("no man's land"); they behave much more cautiously when spread risks fall on **populated land** and, in some settings, on **neighboring private concessions**

MY TAKEAWAY

The paper's main contributions are methodological:

- turn a classic externality question into a clean empirical design
- concrete behavioral mechanism that connects theory, data, and policy

Thank You!

Questions or Comments?

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Appendix

The paper does **not** claim that weather only affects fire spread and never affects ignition directly. Instead, it estimates the direct effect of the risk index and asks whether that effect differs by **who would bear spread damages**. With pixel FE and rich interactions, the identifying question is narrower: *when risky weather arrives, do firms behave differently depending on neighboring land ownership?*

- Stronger than pure cross-sectional comparisons
- Still leaves interpretation questions—especially around the Coase mechanism—but the main externality result is quite compelling

Appendix: basic descriptive statistics

TABLE 1
Summary statistics

	Mean	SD	Min	Max	Median
Weather data:					
Precipitation (mm)	246	110	0	1,684	243
Wind speed (km/h)	6.1	4.3	.00047	34	4.8
Temperature (Celsius)	26	1.4	18	30	27
Fire data:					
Total area burned (km ²)	3.86	10.25	0.86	468.47	1.72
Total days burned	1.29	1.05	1.00	24.00	1.00
Number of ignitions	44,454				
Probability of ignition in pixel-month-year	.00037				
Share of pixels where ignition ever observed	.055				
Concession data:					
Concession area (km ²)	223	398			
Cumulative area—all concessions (km ²)	517,135				
Cumulative area—wood fibre concessions (km ²)	116,133				
Cumulative area—palm oil concessions (km ²)	126,651				
Cumulative area—logging concessions (km ²)	274,351				
Number of concessions	2,320				

Notes: Sample is restricted to pixels within all three concession types (logging, palm oil, wood fibre), within the forest estate, and on major forested islands (excluding Java and Lesser Sunda Islands). Weather variables summaries are further restricted to pixels where all three weather variables are available.

Appendix: full main-results table

TABLE 4
Impact of surrounding land type and weather spread risk index on ignitions

Dependent variable =	M & Y	M & Y	M & Y	M & Y	M & Y	M & Y
Number of fires in pixel*month*year						
Panel A: Main Effects	FEs	FEs	FEs	FEs	FEs	FEs
Num pixels in 6 km buffer in different concession from central pixel	-0.0003792 (0.001224)	-0.001031 (0.001221)	-0.001327 (0.001379)	-0.0003496 (0.001183)	-0.004132*** (0.001231)	-0.003449** (0.001352)
Num pixels in 6 km buffer outside forest estate	-0.004299 (0.002827)	-0.005344* (0.002782)	-0.003694 (0.002772)	-0.004868* (0.002785)	-0.007249** (0.002904)	-0.006340** (0.002725)
Num pixels in 6 km buffer in protected forest	-0.003021 (0.003517)	-0.002409 (0.003390)	-0.003398 (0.003357)	-0.002552 (0.003555)	-0.006464* (0.003442)	-0.003716 (0.003310)
Num pixels in 6 km buffer in productive forest outside concession	0.006811*** (0.001389)	0.005703*** (0.001289)	0.005840*** (0.001503)	0.006853*** (0.001340)	0.002958** (0.001320)	0.003059** (0.001332)
Average population density in 6 km buffer	-0.0002214 (0.0007278)	-0.003029*** (0.001139)	-0.0005682 (0.0007585)	-0.001081 (0.0008058)	-0.001033 (0.0008176)	-0.004961*** (0.001236)
Control: Island	NO	YES	NO	NO	NO	YES
Control: Concession Type	NO	NO	YES	NO	NO	YES
Control: Forest Cover 2000	NO	NO	NO	NO	YES	YES
Control: Concession Area	NO	NO	NO	NO	YES	YES
Observations	39,945,420	39,945,420	39,945,420	39,908,340	39,945,420	39,908,340
Mean of Dep. Var.	0.000974	0.000974	0.000974	0.000973	0.000974	0.000973
	Pixel	Pixel	Pixel	Pixel	Pixel	Pixel
Panel B: With Pixel FE and Risk Index	M & Y FEs	M & Y FEs	M & Y FEs	M & Y FEs	M & Y FEs	M & Y FEs
Risk index in standard deviation units	1.4917*** (0.09977)	1.5552*** (0.1312)	1.6800*** (0.1068)	1.2147*** (0.1323)	1.7296*** (0.09198)	1.6305*** (0.1493)
Risk index * Num pixels in 6 km buffer in different concession from central pixel	0.002908** (0.001295)	0.001821 (0.001205)	0.001715 (0.001228)	0.002579** (0.001281)	0.0009974 (0.001109)	0.0001657 (0.001018)
Risk index * Num pixels in 6 km buffer outside forest estate	-0.005398*** (0.001933)	-0.005288*** (0.001902)	-0.005022** (0.001964)	-0.005332*** (0.001891)	-0.006712*** (0.001890)	-0.005686*** (0.001881)
Risk index * Num pixels in 6 km buffer in protected forest	0.0001807 (0.001910)	0.0002852 (0.001666)	-0.0008821 (0.001733)	0.0002628 (0.001853)	-0.001448 (0.001819)	-0.0009820 (0.001590)
Risk index * Num pixels in 6 km buffer in productive forest outside concession	0.006804*** (0.001546)	0.006722*** (0.001585)	0.005522*** (0.001514)	0.006611*** (0.001499)	0.004797*** (0.001326)	0.004700*** (0.001297)

Appendix: Impact of reputation concerns on ignitions and externalities (Table 7)

TABLE 7
Impact of reputation concerns on ignitions and externalities

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable =	M & Y FEs	M & Y FEs	M & Y FEs	M & Y FEs	Panel	Panel
Number of fires in pixel*month*year					M & Y FEs	M & Y FEs
Panel A: Main Effects						
Num concessions owned by firm	-0.01071*** (0.002540)	-0.00603*** (0.002648)	-0.0004549*** (0.0001061)	-0.0002332** (0.00009236)	-0.2506* (0.1204)	-0.2510* (0.1204)
Concession Area						
Firm is RSPO member in month-year						
Control: Island	NO	YES	NO	YES	NO	YES
Control: Concession Type	NO	YES	NO	YES	NO	YES
Control: Forest Cover 2000	NO	YES	NO	YES	-	-
Control: Concession Area	NO	YES	-	-	NO	YES
Observations	39,945,420	39,948,340	39,948,420	39,948,340	2,063,700	2,063,340
Mean of Dep. Var.	0.000974	0.000973	0.000974	0.000973	0.00842	0.00842
Panel B: With Risk Index						
Risk Index in standard deviation units	1.7439*** (0.06457)	1.7747*** (0.1080)	1.8618*** (0.06182)	1.7796*** (0.1045)	1.8669*** (0.07294)	2.0401*** (0.1342)
Risk Index * Num concessions owned by firm	-0.004282 (0.002703)	0.0003917 (0.0030443)				
Risk Index * Concession Area		-0.0005383* (0.0001398)	-0.0003737*** (0.0001044)	-0.0002402* (0.0001400)		
Firm is RSPO member in month-year						
Risk Index * Firm is RSPO member in month-year					-0.3805** (0.1508)	0.0003338* (0.0002018)
						-0.3285*** (0.1151)
						0.0001398 (0.1245)

Appendix: Impact of prosecutions on ignitions and externalities (Table 10)

TABLE 10
Impact of prosecutions on ignitions and externalities

Dependent variable =	Pixel	Pixel	Pixel	Pixel
Number of fires in pixel*month*year	Island x MY FEs	Island x MY FEs	Island x MY FEs	Island x MY FEs
Prosecuted region	0.1387 (0.2045)	-0.1068 (0.1711)	-2.8879*** (0.4849)	-4.1580*** (0.5424)
Risk index in standard deviation units		1.6412*** (0.1209)	1.6535*** (0.1372)	1.9500*** (0.2798)
Risk index * Prosecuted region		0.2855*** (0.06411)	0.8427*** (0.1972)	1.6719*** (0.1882)
Risk index * Num pixels in 6 km buffer in same concession as central pixel			-0.0004704 (0.0007648)	-0.001125 (0.0009987)
Num pixels in 6 km buffer in same concession as central pixel * Prosecuted region			0.003367*** (0.001252)	0.009761*** (0.001044)
Risk index * Num pixels in 6 km buffer in same concession as central pixel * Prosecuted region			-0.001783** (0.0006969)	-0.004642*** (0.001212)
Observations	4,536,857	4,525,226	4,525,226	566,215
Control: Island interactions	NO	YES	YES	YES
Control: Concession Type interactions	NO	YES	YES	YES
Control: Forest Cover 2000 interactions	NO	YES	YES	YES
Control: Concession Area interactions	NO	YES	YES	YES
Mean of Dep. Var.	0.00858	0.00858	0.00858	0.0109

Notes: Poisson regressions. Robust standard errors clustered at level of provinces. Sample: Columns (1) to (3): All pixels inside wood fibre and palm oil concessions inside forest estate excl Java and Lesser Sunda Islands. Columns (4): pixels whose buffers contain only own concession land and unleased productive forest, inside wood fibre and palm oil concessions inside forest estate excl Java and Lesser Sunda Islands. Omitted category: Interaction of risk index and "Num pixels in 6 km buffer outside same concession as central pixel". The control interactions vary from column to column. Column 2 includes all controls interacted with the "Risk index" variable. Columns 3 and 4 include triple and all possible lower order interactions for all controls with "Risk index" and "Prosecuted region" variables. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Appendix: Impact of government ownership on ignitions and externalities (Table 11)

TABLE 11
Impact of government ownership on ignitions and externalities

Dependent variable = Number of fires in pixel*month*year	M & Y	M & Y
Panel A: Main Effects	FEs	FEs
Government owns concession	-0.3446** (0.1476)	-0.4903*** (0.1606)
Control: Island	NO	YES
Control: Concession Type	NO	YES
Control: Forest Cover 2000	NO	YES
Control: Concession Area	NO	YES
Observations	39,945,420	39,908,340
Mean of Dep. Var.	0.000974	0.000973
	Pixel	Pixel
Panel B: With Pixel FE and Risk Index	M & Y FEs	M & Y FEs
Risk index in standard deviation units	1.7166*** (0.05612)	1.7766*** (0.1038)
Risk Index * Government owns concession	-0.09681 (0.1462)	-0.0008355 (0.1582)
Control: Risk Index x Island	NO	YES
Control: Risk Index x Concession Type	NO	YES
Control: Risk Index x Forest Cover 2000	NO	YES
Control: Risk Index x Concession Area	NO	YES
Observations	4,731,300	4,723,560
Mean of Dep. Var.	0.00822	0.00822
	Pixel	Pixel
Panel C: With Pixel FE, Surrounding Land Ownership, and Risk Index	M & Y FEs	M & Y FEs
Risk index in standard deviation units	2.8076*** (0.2528)	2.2158*** (0.2506)
Risk Index * Num pixels in 6 km buffer in same concession as central pixel	-0.01063*** (0.002531)	-0.004303*** (0.001791)
Risk Index * Government owns concession	1.2378 (1.4612)	1.1240 (1.3080)
Risk Index * Num pixels in 6 km buffer in same concession as central pixel * Government owns concession	-0.007570 (0.01228)	-0.003257 (0.01102)
Control: Risk Index x Island x Government owns concession	NO	YES
Control: Risk Index x Concession Type x Government owns concession	NO	YES
Control: Risk Index x Forest Cover 2000 x Government owns concession	NO	YES
Control: Risk Index x Concession Area x Government owns concession	NO	YES
Observations	751,860	750,240
Mean of Dep. Var.	0.00824	0.00823

Notes: Poisson regressions. Robust standard errors clustered at level of 50 km² grid cells. Panel (A), (B): all pixels inside wood fibre and palm oil concessions inside forest estate excl Java and Lesser Sunda Islands. Panel (C): pixels whose buffers contain only own concession land and unleased productive forest, inside wood fibre and palm oil concessions inside forest estate excl Java and Lesser Sunda Islands. Omitted category for panel (C): "Num pixels in 6 km buffer outside same concession as central pixel" and interactions. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$