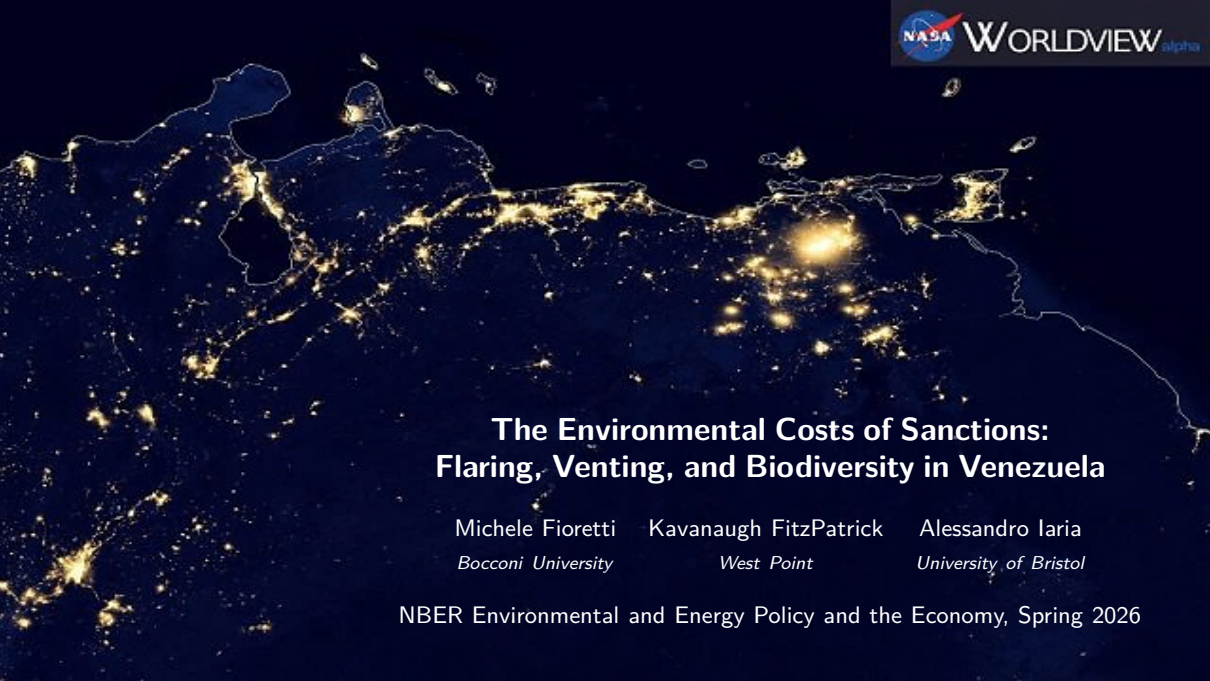


The Environmental Costs of Sanctions: Flaring, Venting, and Biodiversity in Venezuela

Michele Fioretti *Bocconi University*
Kavanaugh FitzPatrick *West Point*
Alessandro Iaria *University of Bristol*

NBER Environmental and Energy Policy and the Economy, Spring 2026

Sanctions reduce output. What about the environment?

- **Sanctions** are one of the most widely used punishment tools in foreign policy
  - Aim: (i) hurt the regime, (ii) reduce aggregate output
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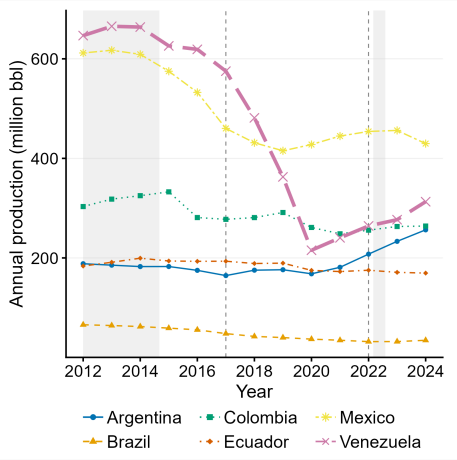
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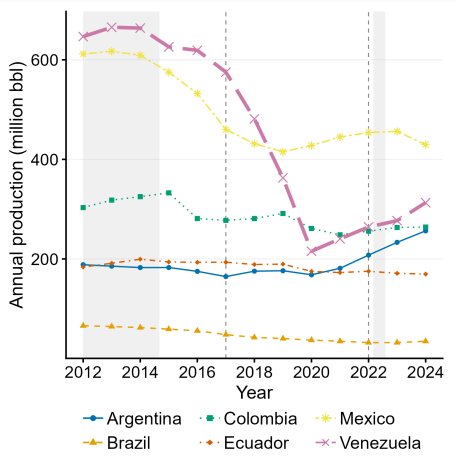
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- **This paper:** *What is the environmental cost of degradation, and how to limit it?*

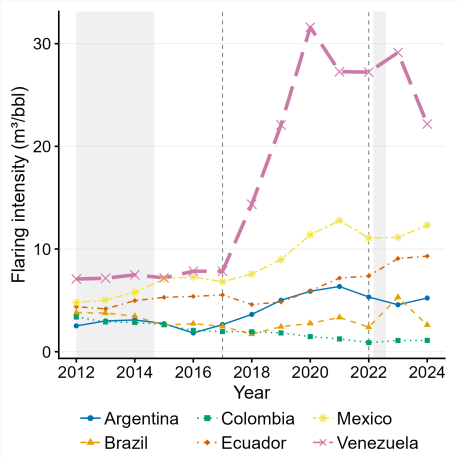
Venezuelan flaring tripled as production collapsed



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Flaring OPEX





Three times more flaring than what *proportional decline* would predict

This paper: a three-channel framework

- We decompose flaring into three channels, each with a distinct **policy** lever:
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  - Chevron was allowed to resume maintenance in 2022 $\rightarrow$ *maintenance*

Findings

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- **Biodiversity** *fall* under strain, *recover* under maintenance

Related literature

- **Sanctions and Venezuela's oil-sector collapse**
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- **Environmental pollution decomposition**
  - Shapiro & Walker (2018), Asker, Collard-Wexler & De Loecker (2024), Coulomb & Henriet (2026), Covert & Kellogg (2025)

  → Decompose pollution into composition, maintenance and strain

Roadmap

1. Theoretical framework
2. Background and data
3. Composition: which fields survive
4. Strain: gas-handling under sanctions
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A stylised model: setup and the sanctions shock

- Two heterogeneous fields controlled by an autocratic regime:

	Field S *(small, clean)*	Field L *(large, dirty)*
Capacity	Q_S	$Q_L > Q_S$
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- **Pre-sanctions:** running both is cheaper iff $F < (c_L - c_S)\, Q_S \underbrace{< \lambda F}_{\text{sanctions}}$
- **Sanctions** multiply the fixed cost ($F \mapsto \lambda F$); the threshold is overshot $\rightarrow$ S **exits**
  - *e.g., lost foreign expertise, evasion banking, parts substitution*

Sanctions raise damage along three channels

Derivation

- Damage at field i: $D_i = \alpha_i(m_i)\, q_i + \frac{\beta_i}{2}\, q_i^2$, with α_i decreasing in maintenance m_i

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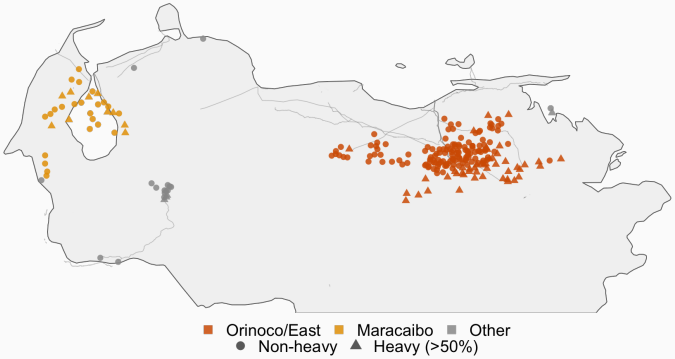
- Each term implies a different policy lever
- **A regression of intensity on field size confounds them**
  - Each channel needs its *own* empirical strategy

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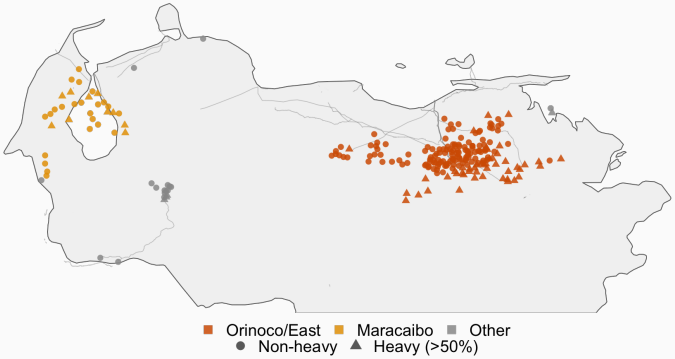
Two basins, three sanctions waves

Chronology



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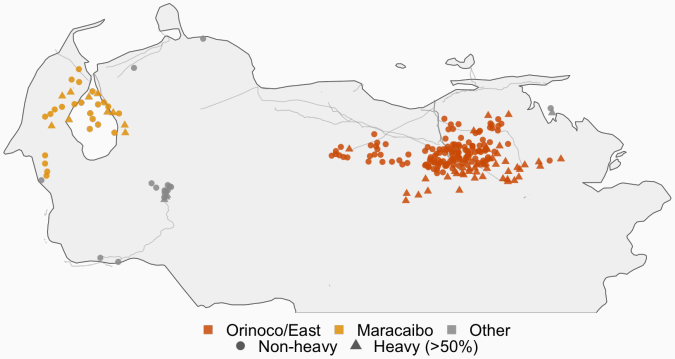


Wave 1

Aug 2017
E.O. 13808
financial sanctions on PDVSA

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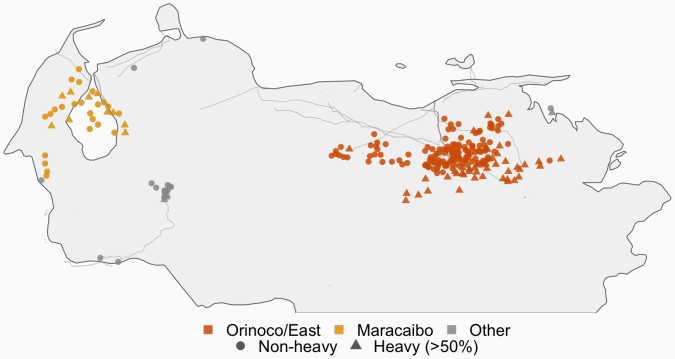


Wave 2 — **Jan 2019**
PDVSA designation
naphtha imports cut

Wave 1 — **Aug 2017**
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Wave 3 — **Nov 2022**
OFAC GL 41
Chevron resumes at 4 JVs

Wave 2 — **Jan 2019**
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Why heavy crude needs diluent



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- Associated gas rises with the crude at a near-fixed gas-oil ratio set by geology
- **After the 2019 import cuts**,
  - The heavy crude can no longer flow
  - Gas handling equipments harder to repair
- The only remaining gas sinks are **flares** and **vents**
  - Maracaibo (West) fields need no diluent

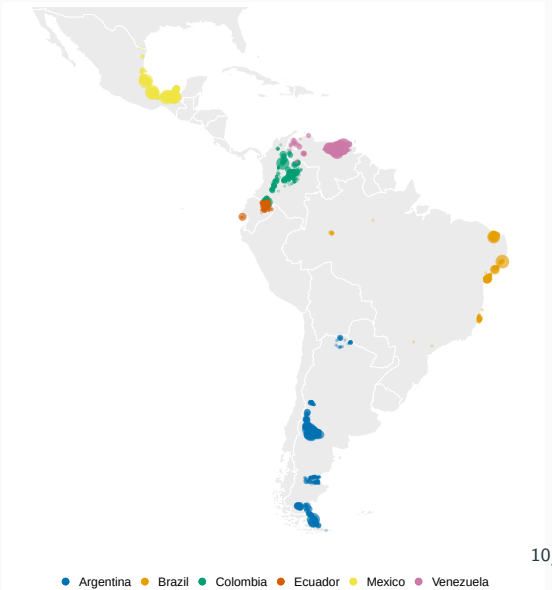
Five data sources, six countries, 2012–2024

▸ Descriptive stats

Data:

- **Rystad UCube:** field-level production, OPEX, CAPEX, ownership
- **World Bank VIIRS:** satellite flaring volumes, ▸ Detection threshold
- **TROPOMI:** atmospheric methane on 10×10 km cell-month panel
- **OSM + GEM:** oil-and-gas pipeline network

Sample: Venezuela + *unsanctioned* Argentina, onshore Brazil, Colombia, Ecuador, Mexico



Motivating fact

$$Y_{ift} = \alpha_i + \tau_t + \beta_h \left(\text{VEN}_i^{\text{Heavy}} \cdot \text{Post}_t\right) + \beta_n \left(\text{VEN}_i^{\text{Non-Heavy}} \cdot \text{Post}_t\right) + \varepsilon_{ift}$$

	Flaring		Operations	
	volume (Mm^3)	intensity (m^3/bbl)	production log(1+x)	OPEX log(1+x)
Heavy (VEN) × Post (β_h)				
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Field and Year FEs				
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	(6.83)	(47.03)		
Non-Heavy (VEN) × Post (β_n)	−19.9	−0.9		
	(18.80)	(11.93)		
Mean dept. var.	22.3	56.5		
Field and Year FEs	✓	✓		
SE clustered at asset	✓	✓		
Observations	7,763	7,763		

- Per-barrel intensity at heavy VEN fields **roughly triples** (+125 m^3/bbl on a pre-period mean of 56.5)

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→ **Where does the rise in *pollution per barrel* come from?**

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Composition: which fields survive?

- **Within-Venezuela survival regression**, ever-producing fields:

$$\mathbb{1}_{\{\text{prod}_{it}>0\}} = \alpha_i + \tau_t + \beta \cdot (\text{Post}_t \cdot \text{Large}_i^s) + \varepsilon_{it}$$

  - Field and year fixed effects; SE clustered at the asset level
  - Large_i^s: *pre-period size* above the within-VEN median

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- **Within-Venezuela survival regression**, ever-producing fields:

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  - Field and year fixed effects; SE clustered at the asset level
  - Large_i^s: *pre-period size* above the within-VEN median

- $\beta > 0$ means small fields exit more than large fields after sanctions

Composition: small fields exit, large fields survive

Event study | Ownership

Dep. var.: $\mathbb{1}_{\{\text{prod}_{it}>0\}}$	Full VEN		Heavy only	Non-heavy only
	OOIP	pre-prod		
	(1)	(2)		
Post × Large (β)	$+0.20^{***}$	$+0.15^{***}$		
	(0.04)	(0.04)		
Mean dept. var.	0.82	0.82		
Pre-flaring int. (m^3/bbl, prod-wgt.)	12.5	12.5		
Field and Year FEs	✓	✓		
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Observations	3,042	3,042		

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Event study | Ownership

Dep. var.: $\mathbb{1}_{\{prod_{it}>0\}}$	Full VEN		Heavy only		Non-heavy only
	OOIP	pre-prod	OOIP	pre-prod	
	(1)	(2)	(3)	(4)	
Post × Large (β)	$+0.20^{***}$	$+0.15^{***}$	$+\mathbf{0.23}^{***}$	$+0.15^{***}$	
	(0.04)	(0.04)	(0.05)	(0.05)	
Mean dept. var.	0.82	0.82	0.81	0.81	
Pre-flaring int. (m^3/bbl, prod-wgt.)	12.5	12.5	12.9	12.9	
Field and Year FEs	✓	✓	✓	✓	
SE clustered at asset	✓	✓	✓	✓	
Observations	3,042	3,042	2,535	2,535	

Composition: small fields exit, large fields survive

Event study | Ownership

Dep. var.: $\mathbb{1}_{\{\text{prod}_{it}>0\}}$	Full VEN		Heavy only		Non-heavy only	
	OOIP	pre-prod	OOIP	pre-prod	OOIP	pre-prod
	(1)	(2)	(3)	(4)	(5)	(6)
Post × Large (β)	$+0.20^{***}$	$+0.15^{***}$	$+\mathbf{0.23}^{***}$	$+0.15^{***}$	$+0.04$	$+0.02$
	(0.04)	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)
Mean dept. var.	0.82	0.82	0.81	0.81	0.89	0.89
Pre-flaring int. (m^3/bbl, prod-wgt.)	12.5	12.5	12.9	12.9	7.8	7.8
Field and Year FEs	✓	✓	✓	✓	✓	✓
SE clustered at asset	✓	✓	✓	✓	✓	✓
Observations	3,042	3,042	2,535	2,535	507	507

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- The size-survival effect is $\approx$ 15–23 **pp**, entirely driven by Heavy fields
  - → *Mechanism:* No fixed-cost F in conventional crude fields

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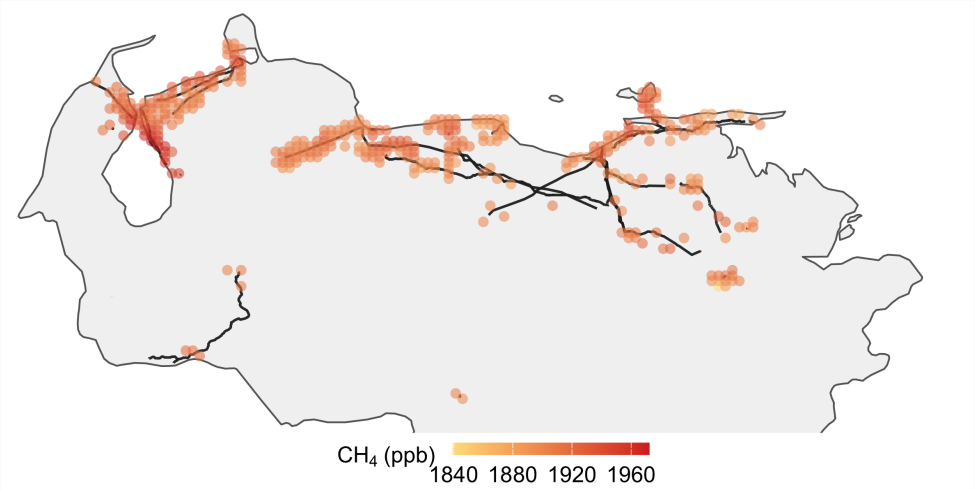
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- The size-survival effect is ≈ 15–23 **pp**, entirely driven by Heavy fields
  - → *Mechanism:* No fixed-cost F in conventional crude fields
- Heavy and non-heavy pre-period intensities were similar
  - → Composition contributes ≈ 0 to the rise in pollution

Roadmap

1. Theoretical framework
2. Background and data
3. Composition: which fields survive
4. **Strain: gas-handling under sanctions**
5. Maintenance: the Chevron license
6. Quantification and policy
7. Conclusion

Strain: where does the methane appear?



- *Note*: Methane data only available since November 2018

Strain: high-frequency naphtha-price response

▸ Regression table ▸ Biodiversity

- We use the **world price of naphtha** as an exogenous high-frequency proxy for diluent scarcity

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$$\log \text{Methane}_{ct} \;=\; \alpha_c + \tau_t + \theta_0 \log\ \text{Naphtha Price}_t \cdot \text{NearPipe}_c + \varepsilon_{ct}$$

$n = 9{,}138$, 10-by-10 km cell + year-month FE, cell-clustered SE

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- Contemporaneous elasticity: $\theta_0 \;=\; +\mathbf{3.05}^{***} \quad (SE = 0.91)$
  - A 1% rise in naphtha price
    → 3% rise in Orinoco pipeline-vicinity methane

▸ Lagged structure

Strain: ruling out non-sanctions stories

▸ Biodiversity

1. *Do all heavy-oil basins leak methane?* **No, only Venezuela does**
   - Venting at Mexico's Maya and Colombia's Llanos trends ↓

▸ Basin trends

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Basin trends

2. *Is venting a Venezuelan country-wide phenomenon?* **No, it is not**
   - Only the near-pipe cells rise; the rest of Venezuela rises *slower* than LATAM

Triple-diff

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Triple-diff

→ *Venting is the result of diluent starvation, which puts strain on the system*

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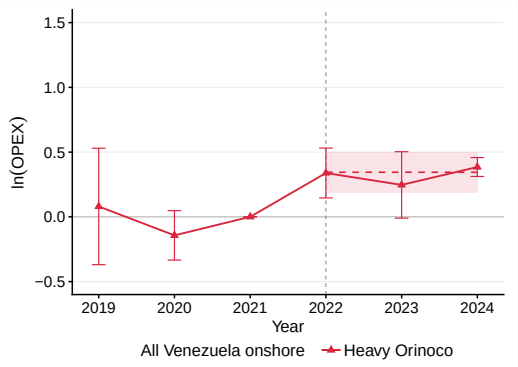
Maintenance: the Chevron license

- **OFAC General Licence 41** (Nov 2022) restored Chevron's operations at four joint-ventures
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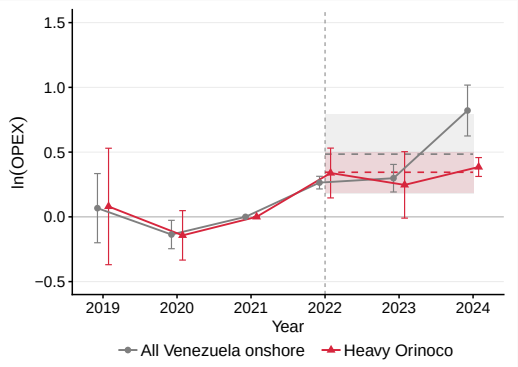
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OPEX: Heavy Orinoco vs. All Venezuela



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- **Per-barrel OPEX** is the empirical proxy for maintenance intensity

Flaring-on-maintenance elasticity

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- To estimate the elasticity of environmental outcomes to maintenance by:

$$\begin{aligned}\text{Flaring}_{it} = \alpha_i + \tau_t + \eta_0 \,\text{OPEXbbl}_{it} + \eta_1 \,\text{OPEXbbl}_{it} \cdot \text{Post 2017}_t \\ + \eta_2 \,\text{OPEXbbl}_{it} \cdot \text{Post 2022}_t \\ + \eta_3 \,\text{OPEXbbl}_{it} \cdot \text{Chevron}_i \\ + \eta_4 \,\text{Post 2022}_t \cdot \text{Chevron}_i \\ + \eta_5 \,\text{OPEXbbl}_{it} \cdot \text{Post 2022}_t \cdot \text{Chevron}_i + \varepsilon_{it}\end{aligned}$$

Flaring-on-maintenance elasticity

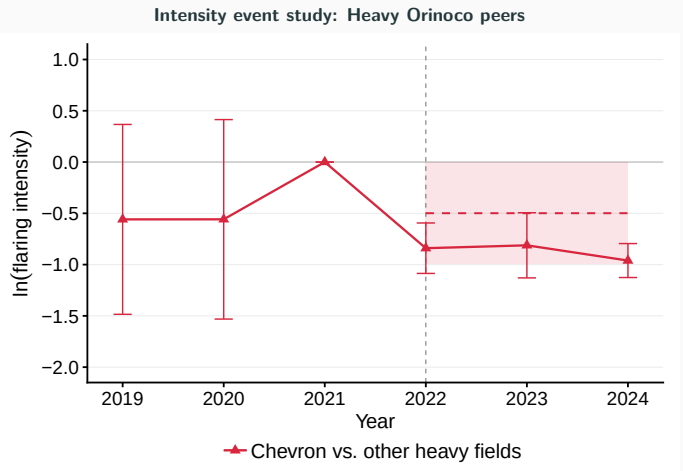
▸ Additional controls ▸ Biodiversity

	log(1 + flare vol.)
log(OPEX/bbl) (η_0)	-0.05^{*}
	(0.02)
× Post-2017 (η_1)	$+0.06^{*}$
	(0.03)
× Post-2022 (η_2)	-0.02^{***}
	(0.00)
× Chevron (η_3)	-0.82
	(2.19)
× Post-22 × Chev (η_5)	$\mathbf{-0.42}^{***}$
	(0.13)
Fixed effects	Field + Year
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Decomposing the headline ratio R

▸ Derivation ▸ 2-way Oaxaca

Directly from the data: mean flaring per barrel went from **12.6** to **38.0 m^3/bbl**, so

$$R \equiv \frac{\bar{\alpha}_{\text{post}}}{\bar{\alpha}_{\text{pre}}} = \frac{38.0}{12.6} \approx \mathbf{3} \qquad \Longleftrightarrow \qquad \frac{\bar{\alpha}_{\text{post}}}{\bar{\alpha}_{\text{pre}}} - 1 \approx \mathbf{2}$$

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Oaxaca decomposition of this 2× rise into composition + within-field channels:

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- **Composition**: heavy share 0.94 → 0.95 → $r_{\text{comp}} \approx \mathbf{0.004}$

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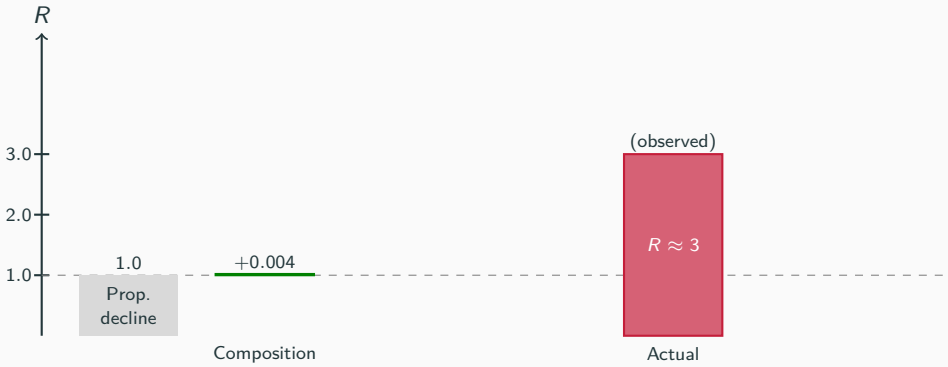
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- Next: open up r_{within} into maintenance and strain

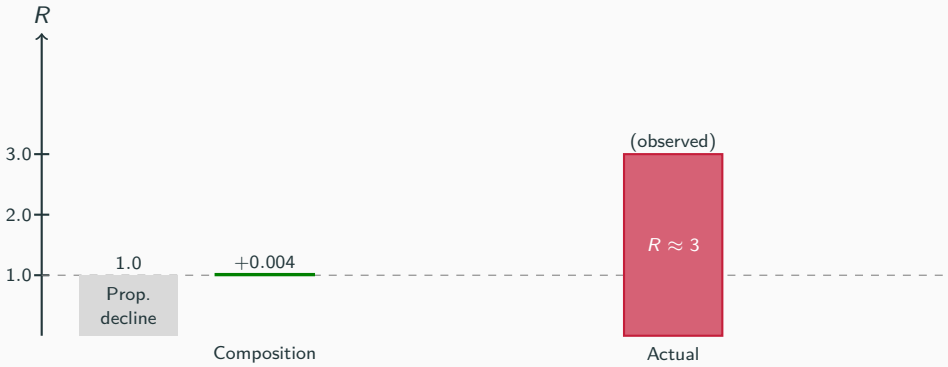
Decomposing flaring

pop-weighted



Decomposing flaring

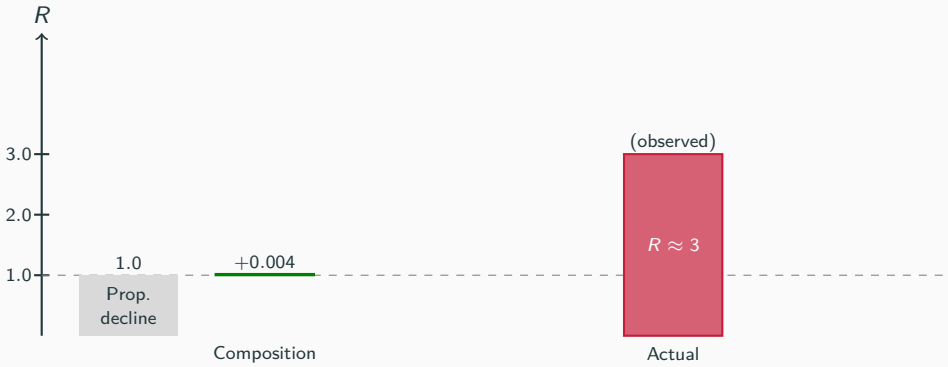
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- **Maintenance**: with $\eta_5 = -0.42$

Decomposing flaring

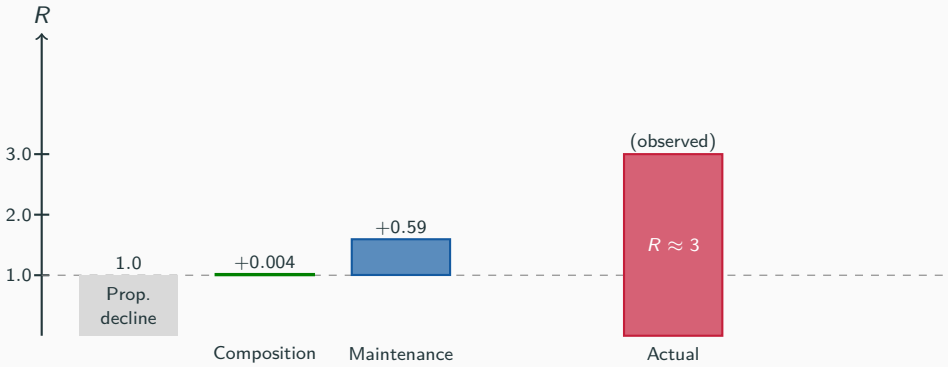
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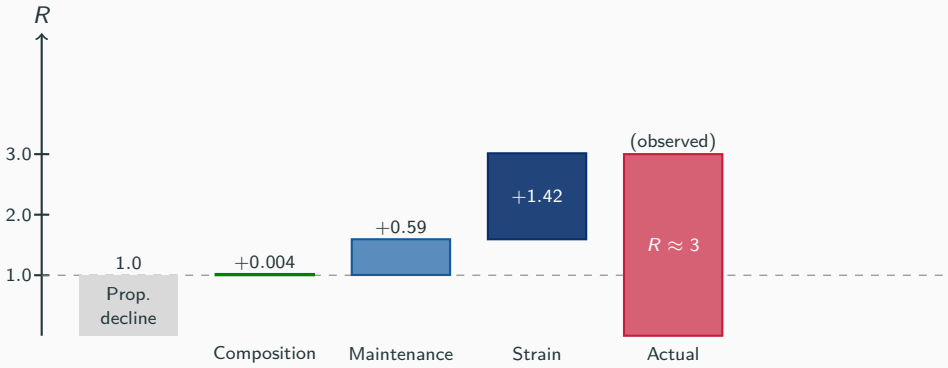
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- **Maintenance**: with $\eta_5 = -0.42$ and $\Delta \log OPEX = -0.61$, $r_{\text{maint}} \approx (e^{\eta_5 \cdot \Delta \log OPEX} - 1) \cdot r_{\text{within}} \approx \mathbf{+0.59}$
- **Strain** (residual): $r_{\text{strain}} = r_{\text{within}} - r_{\text{maint}} \approx 2.0 - 0.59 \approx \mathbf{+1.42}$

From mechanisms to three instruments

- **Targeted carve-outs** (license inputs at specific firms)
  - The Chevron quasi-experiment tells that 10% $\uparrow$ OPEX/bbl $\Rightarrow$ 4% $\downarrow$ flaring
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- **The Venezuelan pattern is not unique**
  - Russia (post-2014/2022) & Iran (post-2018): output ↓, per-barrel emission↑

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Thank you

Appendix

US sanctions on Venezuela, 2017–2022

Back

Date	Instrument	Scope	What it cut (or restored)
Aug 2017	E.O. 13808	US-person dealings in *new debt and equity* issued by Venezuela / PDVSA.	**Financial.** PDVSA loses US capital-market access; operational dealings (parts, services, naphtha) remain legal.
Jan 2019	E.O. 13857 (OFAC designation of PDVSA)	All US-person transactions with PDVSA prohibited; secondary sanctions reach non-US counterparties.	**Operational.** PDVSA severed from USD clearing and US inputs. **Naphtha diluent supply collapses**, the key Orinoco-pipeline bottleneck.
Nov 2022	OFAC General Licence 41 (GL-41)	Carve-out for Chevron at four named JVs (PetroBoscan, PetroIndependencia, PetroIndependiente, PetroPiar); rest of sector still sanctioned.	**Partial reversal.** Restores OPEX, parts, expertise, banking, naphtha at the four fields. Sale proceeds settle pre-existing PDVSA debt to Chevron, *not* state revenue: coercive bite preserved.

Notes: A series of 2020 secondary-sanctions orders extended the operational perimeter of the 2019 regime to non-US counterparties; we group these with the Jan-2019 wave because the underlying operational regime is the same. GL-41 is the natural experiment we exploit in the maintenance section.

Derivation of the three-channel decomposition

Back

Setup. $D_i = \alpha_i(m_i)\, q_i + \frac{\beta_i}{2}\, q_i^2$. Target q^* with $Q_S < q^* < Q_L$. Since $c_S < c_L$, cheaper field runs at capacity: pre, $(q_S, q_L) = (Q_S,\ q^* - Q_S)$; post, $(0,\ q^*)$.

Total damage (let $\alpha_i^{\text{pre}} \equiv \alpha_i(m_i^{\text{pre}})$, $\alpha_L^{\text{post}} \equiv \alpha_L(m_L^{\text{post}})$):

$$D^{\text{pre}} = \alpha_S^{\text{pre}} Q_S + \tfrac{\beta_S}{2}\, Q_S^2 + \alpha_L^{\text{pre}}(q^* - Q_S) + \tfrac{\beta_L}{2}(q^* - Q_S)^2$$

$$D^{\text{post}} = \alpha_L^{\text{post}} q^* + \tfrac{\beta_L}{2}(q^*)^2$$

Linear part of ΔD (add and subtract $\alpha_L^{\text{pre}} Q_S$):

$$\alpha_L^{\text{post}} q^* - \alpha_S^{\text{pre}} Q_S - \alpha_L^{\text{pre}}(q^* - Q_S) \;=\; \underbrace{(\alpha_L^{\text{pre}} - \alpha_S^{\text{pre}})\, Q_S}_{\text{Composition}} \;+\; \underbrace{(\alpha_L^{\text{post}} - \alpha_L^{\text{pre}})\, q^*}_{\text{Maintenance}}$$

Quadratic part ($\beta_S \approx 0$, since S runs well below capacity; use $a^2 - b^2 = (a-b)(a+b)$):

$$\tfrac{\beta_L}{2}\left[(q^*)^2 - (q^* - Q_S)^2\right] \;=\; \underbrace{\tfrac{\beta_L}{2}\, Q_S\, (q_L^{\text{post}} + q_L^{\text{pre}})}_{\text{Strain}}$$

Combining:

$$\Delta D = (\alpha_L^{\text{pre}} - \alpha_S^{\text{pre}})\, Q_S \;+\; \left[\alpha_L(m_L^{\text{post}}) - \alpha_L(m_L^{\text{pre}})\right] q^* \;+\; \tfrac{\beta_L}{2}\, Q_S\, (q_L^{\text{post}} + q_L^{\text{pre}}). \qquad \square$$

Derivation of the R decomposition

Back

Notation. $\bar{\alpha} \equiv \frac{\text{total flaring}}{\text{total production}}$; s_H = heavy-field share of production; $\bar{\alpha}_H$, $\bar{\alpha}_{NH}$ = production-weighted intensities within heavy / non-heavy.

By definition $\bar{\alpha} = s_H \bar{\alpha}_H + (1 - s_H)\bar{\alpha}_{NH}$. Subtracting pre from post:

$$\bar{\alpha}_{\text{post}} - \bar{\alpha}_{\text{pre}} \;=\; \underbrace{\Delta s_H \left(\bar{\alpha}_{H,\text{pre}} - \bar{\alpha}_{NH,\text{pre}}\right)}_{\text{composition (Oaxaca)}} \;+\; \underbrace{s_{H,\text{post}}\, \Delta\bar{\alpha}_H + (1 - s_{H,\text{post}})\, \Delta\bar{\alpha}_{NH}}_{\text{within-field intensity}}$$

Divide both sides by $\bar{\alpha}_{\text{pre}}$:

$$R - 1 \;=\; r_{\text{comp}} \;+\; r_{\text{within}}, \qquad r_{\text{comp}} = \frac{\Delta s_H \left(\bar{\alpha}_{H,\text{pre}} - \bar{\alpha}_{NH,\text{pre}}\right)}{\bar{\alpha}_{\text{pre}}}, \quad r_{\text{within}} = \frac{s_{H,\text{post}} \Delta\bar{\alpha}_H + (1 - s_{H,\text{post}})\Delta\bar{\alpha}_{NH}}{\bar{\alpha}_{\text{pre}}}$$

Data: $s_{H,\text{pre}} = 0.94$, $s_{H,\text{post}} = 0.95$, $\bar{\alpha}_{H,\text{pre}} \approx \bar{\alpha}_{NH,\text{pre}}$ pre-sanctions $\rightarrow$ $r_{\text{comp}} \approx 0.00$, $r_{\text{within}} \approx R - 1 \approx 2.0$.

Splitting within-field into maintenance vs strain. Chevron elasticity $\eta_5 \equiv \partial \log \bar{\alpha}_H / \partial \log m_L = -0.42$; heavy-field OPEX drops by $\Delta \log m_L = -0.61$:

$$\Delta \log \bar{\alpha}_H^{\text{maint}} = \eta_5 \cdot \Delta \log m_L = +0.256 \iff \bar{\alpha}_H \text{ rises by } e^{0.256} - 1 \approx 29\%$$

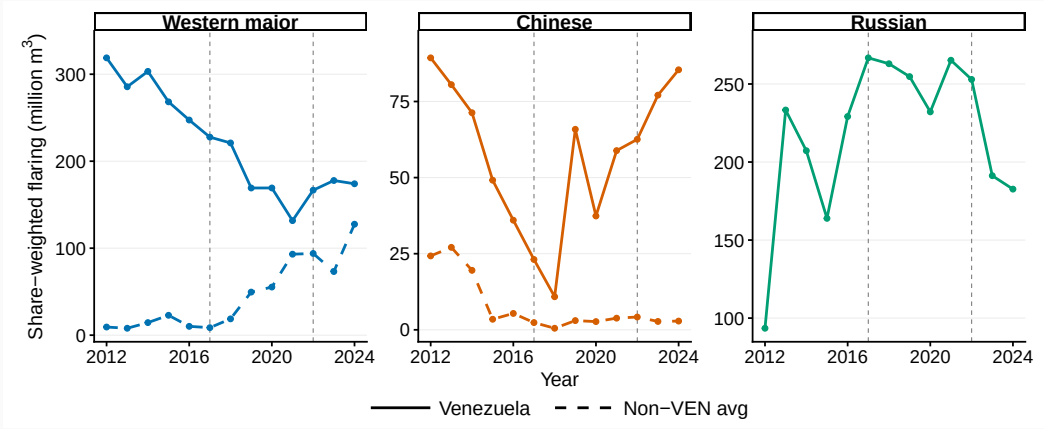
The maintenance multiplicative rise is the maintenance share of r_{within}; strain is the residual.

$$r_{\text{maint}} = \left(e^{\eta_5\, \Delta \log m_L} - 1\right) r_{\text{within}} \approx 0.292 \cdot 2.01 \approx \mathbf{0.59}, \qquad r_{\text{strain}} = r_{\text{within}} - r_{\text{maint}} \approx \mathbf{1.42}$$

Final accounting: $R \approx 1 + r_{\text{comp}} + r_{\text{maint}} + r_{\text{strain}} \approx 1 + 0.00 + 0.59 + 1.42 \approx \mathbf{3.0}$.

Composition: who increased flaring?

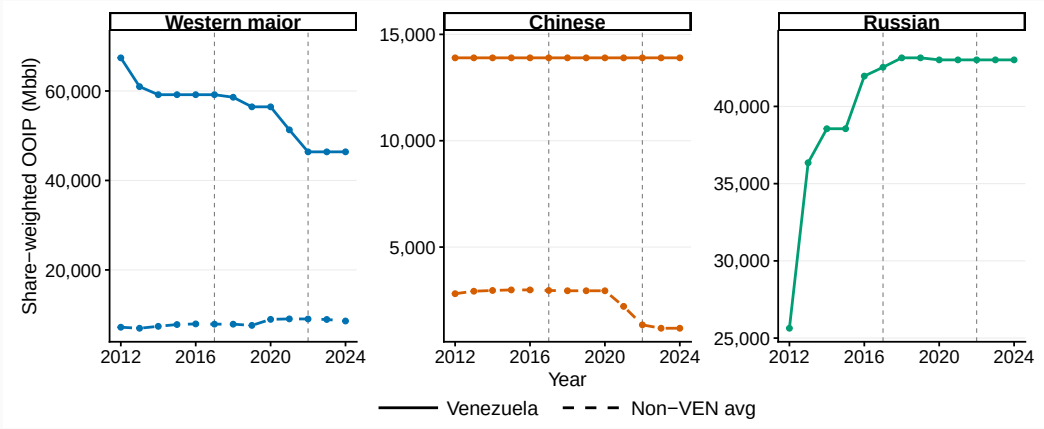
ES by owner Back



Share-weighted VIIRS flaring volume by partner group

Composition: who increased flaring?

ES by owner Back



Share-weighted oil-in-place by partner group

Strain: pollution tracks broader biodiversity damage

Back Regression table
eBird coverage

- **Our pollution measures track biodiversity damage more broadly**
  - Methane reduces avian abundance and species richness at $R = 50$–75 km
  - Flaring reduces abundance at $R = 25$ km and richness sharply at $R = 25$ km

Strain: pollution tracks broader biodiversity damage

Back Regression table
eBird coverage

- **Our pollution measures track biodiversity damage more broadly**
  - Methane reduces avian abundance and species richness at $R = 50$–75 km
  - Flaring reduces abundance at $R = 25$ km and richness sharply at $R = 25$ km
- Two pollutants, two scales: flare bites at 25 km, CH_4 takes over at 50–75 km — both concentrating in Orinoco
- Full eBird checklist-level horse-race regressions

Regression table

Pollution and biodiversity: methane + flare horse race

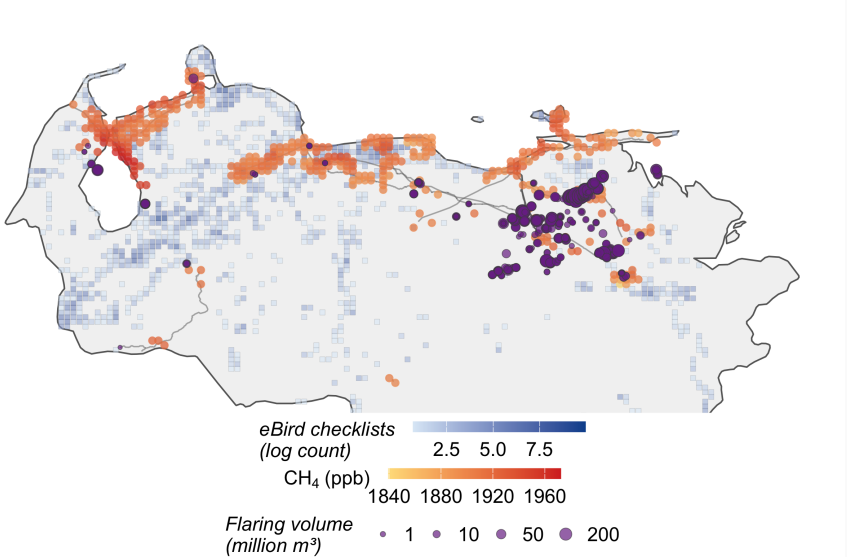
Back

	log(1 + abundance)			Species richness		
	$R = 25$ km	$R = 50$ km	$R = 75$ km	$R = 25$ km	$R = 50$ km	$R = 75$ km
	(1)	(2)	(3)	(4)	(5)	(6)
log(1 + Methane$_4$) (std)	-0.03^{**}	$\mathbf{-0.03}^{***}$	$\mathbf{-0.02}^{*}$	-0.11	$\mathbf{-0.33}^{***}$	$\mathbf{-0.33}^{**}$
	(0.01)	(0.01)	(0.01)	(0.12)	(0.11)	(0.13)
log(1 + Flare) (std)	$\mathbf{-0.05}^{**}$	0.00	0.01	$\mathbf{-0.75}^{***}$	-0.05	-0.25
	(0.02)	(0.02)	(0.02)	(0.21)	(0.19)	(0.26)
Mean dept. var.	3.54	3.49	3.47	14.92	14.44	14.34
Cell FE, year-month FE, effort controls	Yes	Yes	Yes	Yes	Yes	Yes
SE clustered at cell	Yes	Yes	Yes	Yes	Yes	Yes
Observations	49,851	80,094	93,884	49,851	80,094	93,884

Notes: Horse race of TROPOMI CH_4 (strain) and VIIRS flare (composition) on bird abundance and species richness at three buffer radii. Flare bites at $R = 25$ km, CH_4 takes over at $R = 50$–75 km; both concentrate in Orinoco.

eBird coverage and methane/flaring overlay

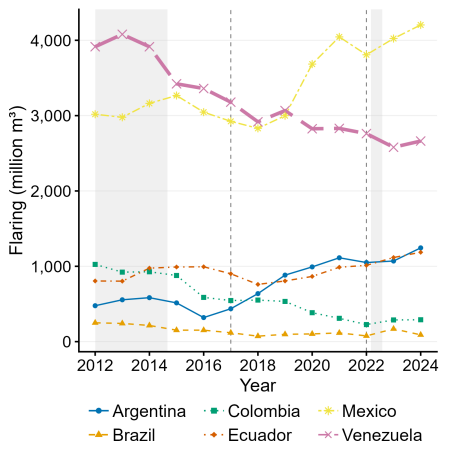
Back



Fioretti, FitzPatrick, Iaria

Figure 2(a): Total flaring volume by country

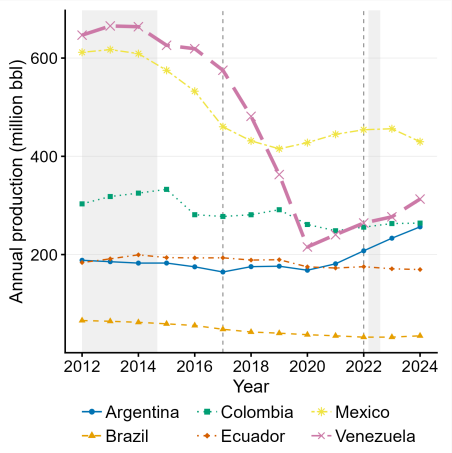
Back



Total VIIRS flaring volume allocated to Rystad fields within 15 km (million m^3), 2012–2024. Dashed lines: 2018 (financial sanctions) and 2022 (OFAC Licence 41). Grey bars: Brent > $100/bbl. Brazil onshore only.

Figure 2(c): Total crude production by country

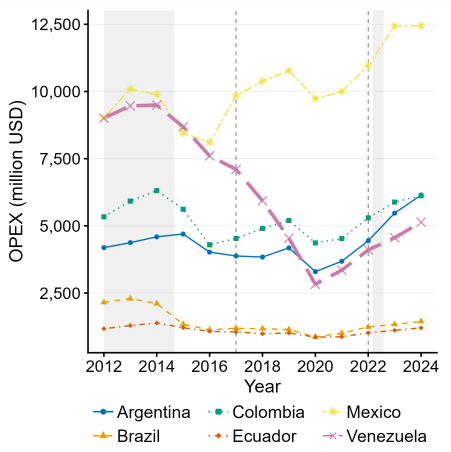
Back



Total annual crude oil production (million bbl), six LATAM countries, 2012–2024. Dashed lines: 2018 and 2022. Grey bars: Brent > $100/bbl. Brazil onshore only.

Figure 2(d): Total OPEX by country

Back



Total annual operational expenditure (million USD), six LATAM countries, 2012–2024. Dashed lines: 2018 and 2022. Grey bars: Brent > $100/bbl. Brazil onshore only.

Descriptive statistics

Back

	Argentina	Brazil	Colombia	Ecuador	Mexico	Venezuela
Panel (a): Geology & Reservoir						
Water depth (m)	520.8 (540.3)	134.0 (161.6)	410.3 (829.1)	336.8 (388.5)	-146.1 (808.3)	111.0 (173.4)
Reservoir depth (m)	1872.1 (767.7)	1427.8 (736.8)	2446.3 (1235.9)	2572.5 (650.7)	3219.1 (1902.0)	2293.2 (1137.6)
Porosity (%)	7.6 (8.6)	2.8 (6.4)	6.5 (8.8)	18.2 (3.2)	4.2 (7.0)	9.8 (12.7)
Temperature (°C)	60.4 (19.2)	50.3 (18.5)	74.2 (27.2)	78.9 (16.7)	88.1 (37.5)	72.3 (36.1)
OOIP (million bbl)	106.9 (529.5)	14.7 (127.7)	63.8 (460.8)	224.8 (764.0)	130.8 (840.6)	1016.6 (5248.7)
Recovery factor (%)	35.1 (13.9)	31.7 (20.5)	28.5 (12.3)	24.7 (7.8)	45.7 (236.3)	32.1 (14.7)
Panel (b): Production & Economics (pre-period mean)						
Production (kbbl/d)	0.4 (1.7)	0.1 (0.9)	0.6 (5.7)	2.0 (7.1)	1.1 (12.3)	3.9 (20.3)
OPEX (M USD)	4.8 (21.2)	1.3 (10.8)	4.8 (42.3)	4.7 (16.2)	6.0 (52.4)	18.2 (87.8)
CAPEX (M USD)	6.9 (32.6)	1.0 (6.3)	5.0 (35.2)	9.1 (34.9)	6.1 (45.5)	14.0 (62.9)
NOC ownership share (%)	25.1 (40.8)	23.9 (42.0)	20.4 (36.7)	38.8 (47.7)	24.7 (42.7)	51.5 (41.3)
Panel (c): Field Counts						
Number of fields	1,313	1,502	1,455	265	2,132	666
Share onshore (%)	91.2%	100.0%	95.3%	95.8%	66.5%	79.9%
Panel (d): Flaring (pre-period mean)						
Flaring intensity, 7.5 km (m^3/bbl)	48.2 (209.6)	15.3 (32.7)	25.2 (116.6)	19.3 (142.6)	63.8 (263.3)	310.8 (633.6)
Flaring intensity, 15 km (m^3/bbl)	36.3 (192.4)	28.8 (64.0)	17.6 (97.6)	14.5 (120.8)	52.3 (235.7)	195.6 (548.1)
Flaring volume, 7.5 km (M m^3)	3.4 (8.9)	6.4 (17.9)	9.9 (14.9)	22.0 (40.1)	41.8 (106.4)	110.6 (277.4)
Flaring volume, 15 km (M m^3)	2.3 (7.0)	4.5 (14.2)	7.0 (13.4)	15.8 (35.9)	30.7 (90.8)	85.7 (274.2)

How we allocate WB flaring to Rystad fields

Back

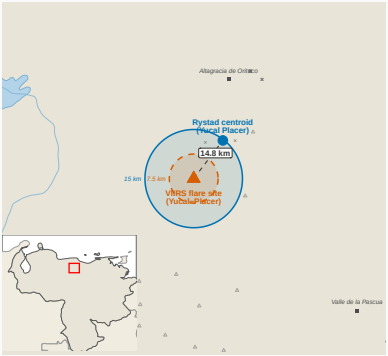
- Stage 1 — fuzzy name matching. Jaro–Winkler distance (threshold ~ 0.12, mutual best-match) links WB flare-site names to Rystad field names.
- Stage 2 — production-weighted gravity. For unmatched flare-sites, distribute volume across nearby Rystad fields with weight $\propto \text{production}/(\text{distance} + 100\ \text{m})^2$.
- Three candidate radii tested: 7.5 km, 10 km, 15 km.
- Headline: 15 km, because oil-field infrastructure (wells, separators, flare stacks) extends several km from the Rystad-reported field centroid.
- Two-stage design ensures named flares are anchored to the correct field even when the geocoded coordinates drift.

Why we use 15 km: the Yucal Placer example

Back

Name−matched field missed by 7.5 km radius, captured by 15 km

Venezuela: Yucal Placer field −−− VIIRS flare and Rystad centroid 14.8 km apart



Orange triangle = VIIRS flare site; blue circle = Rystad field centroid.
Orange dashed circle = 7.5 km radius (misses field); blue solid circle = 15 km radius (captures field).
Small symbols: nearby VIIRS flares (x) and Rystad fields (triangles).

WB VIIRS flare site and Rystad centroid sit 14.8 km apart at Yucal Placer — fuzzy name matching confirms they are the same field, but a 7.5 km buffer misses it. 25% of name-matched Venezuelan pairs exceed 7.5 km; the 15 km buffer recovers nine of the thirteen at-risk matches.

Allocation coverage by country and radius

Back

Country	Radius	Match rate (%)	Vol. alloc. rate (%)
Argentina	7.5 km	68.3	69.9
Argentina	15 km	89.3	90.3
Brazil	7.5 km	15.1	9.7
Brazil	15 km	18.6	12.3
Colombia	7.5 km	89.6	97.5
Colombia	15 km	92.3	97.8
Ecuador	7.5 km	97.7	99.7
Ecuador	15 km	100.0	100.0
Mexico	7.5 km	84.8	92.3
Mexico	15 km	89.0	95.8
Venezuela	7.5 km	70.2	75.2
Venezuela	15 km	92.1	98.8
Total	7.5 **km**	68.8	77.8
Total	15 **km**	80.3	91.4

At 15 km, our procedure allocates 98.8% of Venezuelan WB flaring volume and 91.4% across the six LATAM countries. Brazil's low rate reflects the offshore concentration of flaring; we restrict Brazil to onshore fields.

What does VIIRS actually detect, and what does it miss?

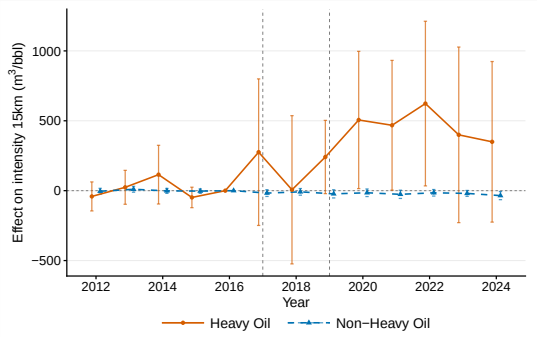
Back

- **Sensor:** Suomi-NPP VIIRS, M10 SWIR (1.6 μm), $\sim$ 750 m at nadir, nightly overpass (Elvidge et al. 2013, 2016)
- **Algorithm:** Planck-curve fit per subpixel hot source $\Rightarrow$ temperature, area, radiant heat
- **Threshold:** retain only $T > 1{,}100\,^{\circ}\mathrm{C}$; flares burn 1,300–2,200 K, hotter than any other terrestrial source, so the cut isolates flaring
- **Volume:** satellite vol. $(m^3) = 0.0281\times$ radiant heat (W); $r = 0.85$ vs. Cedigaz on-site reports
- **Coverage:** $\approx$ **10,000** flare sites globally per year; we allocate $\approx 91\%$ of WB volume to a Rystad field within 15 km
- **Missed:** sub-threshold and cool ($<1{,}100\,^{\circ}\mathrm{C}$) flares; cloud-obscured nights; **vented (uncombusted) gas**
- **Complement:** venting is the strain channel; **TROPOMI methane** sees what VIIRS misses

Event study: heavy-oil DiD — intensity (IPW)

Back

$$Y_{ift} \;=\; \alpha_i + \tau_t + \sum_{k \neq 2016} \left[\beta_k^{h} \, \mathrm{VEN}_i^{\text{Heavy}} + \beta_k^{n} \, \mathrm{VEN}_i^{\text{Non-Heavy}} \right] \mathbb{1}\{t = k\} + \varepsilon_{ift}$$

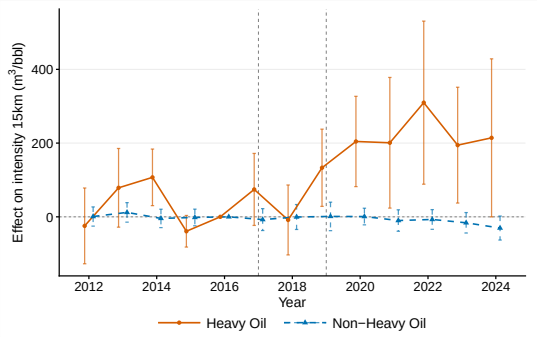


Y_{ift}: flaring intensity (m^3/bbl, 15 km radius). **IPW-weighted** on pre-period geological covariates. Field + year FE; SE clustered at the asset.

Event study: heavy-oil DiD — intensity

Back

$$Y_{ift} = \alpha_i + \tau_t + \sum_{k \neq 2016} \left[\beta_k^h \, \text{VEN}_i^{\text{Heavy}} + \beta_k^n \, \text{VEN}_i^{\text{Non-Heavy}} \right] \mathbb{1}\{t = k\} + \varepsilon_{ift}$$

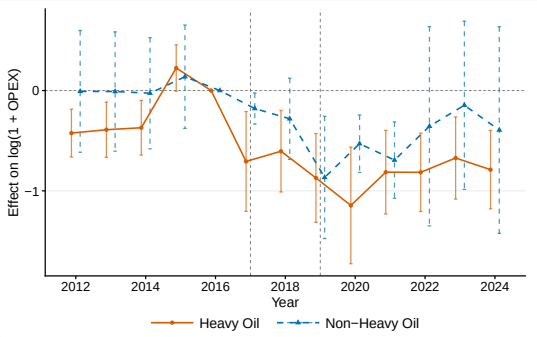


Y_{ift}: flaring intensity (m^3/bbl, 15 km radius). Field + year FE; SE clustered at the asset.

Event study: heavy-oil DiD — log OPEX

Back

$$Y_{ift} = \alpha_i + \tau_t + \sum_{k \neq 2016} \left[\beta_k^h \, \mathrm{VEN}_i^{\text{Heavy}} + \beta_k^n \, \mathrm{VEN}_i^{\text{Non-Heavy}} \right] \mathbb{1}\{t = k\} + \varepsilon_{ift}$$

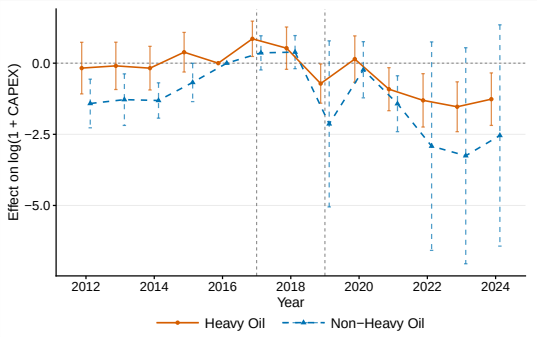


$Y_{ift} = \log(1 + \mathrm{OPEX}_{ift})$. Field + year FE; SE clustered at the asset.

Event study: heavy-oil DiD — log CAPEX

Back

$$Y_{ift} \;=\; \alpha_i + \tau_t + \sum_{k \neq 2016} \left[\beta_k^{h} \, \mathrm{VEN}_i^{\text{Heavy}} + \beta_k^{n} \, \mathrm{VEN}_i^{\text{Non-Heavy}} \right] \mathbb{1}\{t = k\} + \varepsilon_{ift}$$

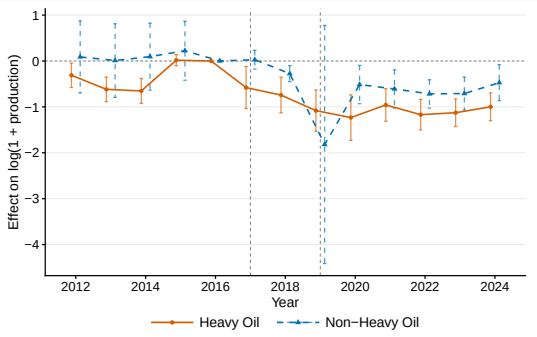


$Y_{ift} = \log(1 + \mathrm{CAPEX}_{ift})$. Field + year FE; SE clustered at the asset.

Event study: heavy-oil DiD — log production

Back

$$Y_{ift} \;=\; \alpha_i + \tau_t + \sum_{k \neq 2016} \left[\beta_k^{h} \, \mathrm{VEN}_i^{\text{Heavy}} + \beta_k^{n} \, \mathrm{VEN}_i^{\text{Non-Heavy}} \right] \mathbb{1}\{t = k\} + \varepsilon_{ift}$$

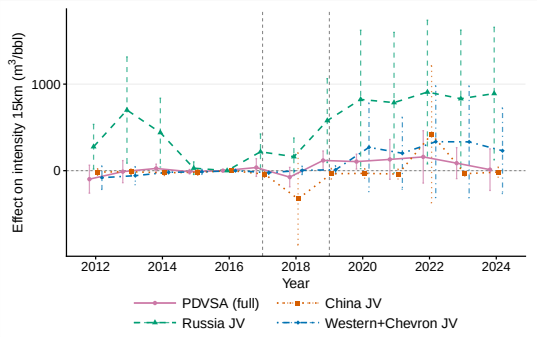


$Y_{ift} = \log(1 + \text{production}_{ift})$. Field + year FE; SE clustered at the asset.

Event study by ownership group — intensity

Back

$$Y_{ift} \;=\; \alpha_i + \tau_t + \sum_{g \in \mathcal{G}} \sum_{k \neq 2016} \beta_k^g \, \mathrm{VEN}_i^g \, \mathbb{1}\{t = k\} + \varepsilon_{ift}, \quad \mathcal{G} = \{\text{PDVSA, Russia JV, China JV, Western+Chevron JV}\}$$

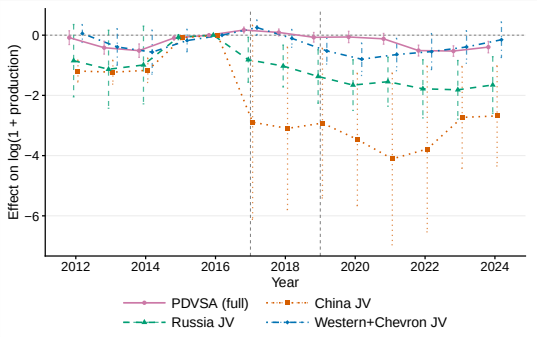


Y_{ift}: flaring intensity (m^3/bbl, 15 km radius). Field + year FE; SE clustered at the asset.

Event study by ownership group — log production

Back

$$Y_{ift} \;=\; \alpha_i + \tau_t + \sum_{g \in \mathcal{G}} \sum_{k \neq 2016} \beta_k^g \, \mathrm{VEN}_i^g \, \mathbb{1}\{t = k\} + \varepsilon_{ift}, \quad \mathcal{G} = \{\text{PDVSA, Russia JV, China JV, Western+Chevron JV}\}$$

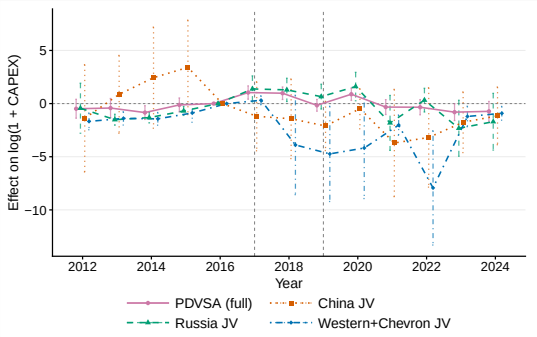


$Y_{ift} = \log(1 + \text{production}_{ift})$. Field + year FE; SE clustered at the asset.

Event study by ownership group — log CAPEX

Back

$$Y_{ift} \;=\; \alpha_i + \tau_t + \sum_{g \in \mathcal{G}} \sum_{k \neq 2016} \beta_k^g \, \mathrm{VEN}_i^g \, \mathbb{1}\{t = k\} + \varepsilon_{ift}, \quad \mathcal{G} = \{\text{PDVSA, Russia JV, China JV, Western+Chevron JV}\}$$

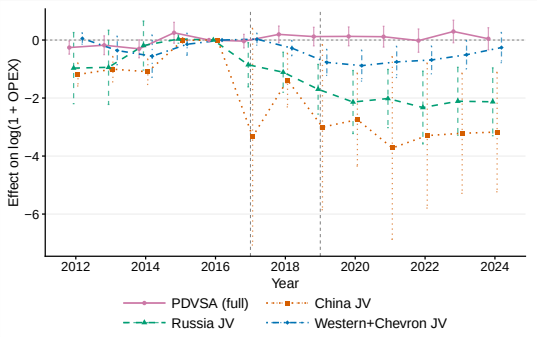


$Y_{ift} = \log(1 + \mathrm{CAPEX}_{ift})$. Field + year FE; SE clustered at the asset.

Event study by ownership group — log OPEX

Back

$$Y_{ift} \;=\; \alpha_i + \tau_t + \sum_{g \in \mathcal{G}} \sum_{k \neq 2016} \beta_k^g \, \mathrm{VEN}_i^g \, \mathbb{1}\{t = k\} + \varepsilon_{ift}, \quad \mathcal{G} = \{\text{PDVSA, Russia JV, China JV, Western+Chevron JV}\}$$

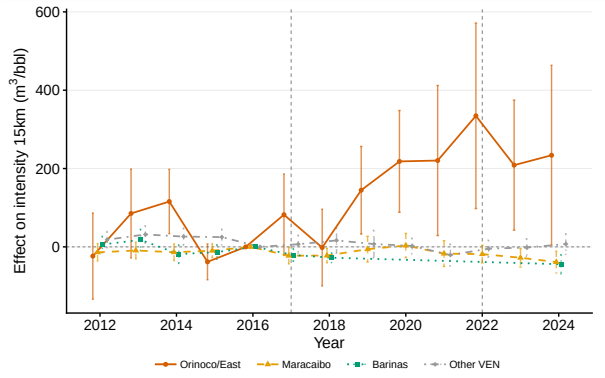


$Y_{ift} = \log(1 + \mathrm{OPEX}_{ift})$. Field + year FE; SE clustered at the asset.

Composition: flaring-intensity dynamics by Venezuelan region

Back

$$Y_{ift} = \alpha_i + \tau_t + \sum_{r \in \mathcal{R}} \sum_{k \neq 2016} \beta_k^r \, \text{VEN}_i^r \, \mathbb{1}\{t = k\} + \varepsilon_{ift}, \quad \mathcal{R} = \{\text{Orinoco/East, Maracaibo, Barinas, Other VEN}\}$$



Y_{ift}: flaring intensity (m^3/bbl, 15 km radius). Field + year FE; SE clustered at the asset. Dashed: 2017 (E.O. 13808) and 2022 (OFAC Licence 41).

Naphtha-price elasticity by basin

Back

$$\log \mathrm{XCH}_{4\,ct} \;=\; \alpha_c + \tau_t + \theta_0 \,\log(\mathrm{Naphtha})_t \cdot \mathrm{NearPipe}_{d,c} + \varepsilon_{ct}$$

	$d = 10$ km	$d = 20$ km	$d = 50$ km
Panel A: All Venezuela ($n = 25{,}520$)			
log(Naphtha) × NearPipe (×1,000)	+0.54	+0.60	+0.22
	(0.75)	(0.61)	(0.52)
Panel B: Orinoco only ($n = 9{,}124$)			
log(Naphtha) × NearPipe (×1,000)	$+2.68^{**}$	$\mathbf{+3.05}^{***}$	$+2.53^{***}$
	(1.11)	(0.91)	(0.84)
Panel C: Maracaibo only (placebo) ($n = 4{,}218$)			
log(Naphtha) × NearPipe (×1,000)	-2.56^{*}	-3.61^{**}	+0.01
	(1.40)	(1.53)	(1.34)

Each column varies the pipeline-proximity threshold d. Cell + year-month FE; SE clustered at the cell level (in parentheses).

Non-contemporaneous naphtha-price elasticity

Back

$$\log \mathrm{XCH}_{4ct} \;=\; \alpha_c + \tau_t + \theta_\ell \, \log(\mathrm{Naphtha})_{t-\ell} \cdot \mathrm{NearPipe}_c + \varepsilon_{ct}, \quad \ell \in \{0,1,2,3\}$$

	(1) Contemp.	(2) Lag-1	(3) Lag-2	(4) Lag-3
$\log N_t \times Pipe_{20}$	$+3.053^{***}$ (0.907)			
$\log N_{t-1} \times Pipe_{20}$		$+2.235^{**}$ (1.092)		
$\log N_{t-2} \times Pipe_{20}$			$+2.136^{**}$ (1.019)	
$\log N_{t-3} \times Pipe_{20}$				$+2.882^{***}$ (1.067)
Cell FE	✓	✓	✓	✓
Year-month FE	✓	✓	✓	✓
Cell-month obs	9,138	9,138	9,138	9,138

Cross-country wellhead-pipeline trends

Back

$$\log \mathrm{XCH}_{4\,ict} \;=\; \alpha_i + \tau_t + \phi\,(t \cdot \mathrm{PipeWell}_i) + \sum_g \psi_g\,(t \cdot \mathrm{PipeWell}_i \cdot \mathbb{1}\{i \in g\}) + \varepsilon_{ict}$$

Per-year log XCH_4 trend ($\times$1,000)	Wellhead pipelines
Venezuela — Orinoco/East	$+\mathbf{1.30}^{***}$ (0.44)
Mexico — Maya basin	-2.51^{***} (0.15)
Colombia — Llanos	-0.81^{***} (0.14)
Cell FE, year-month FE	✓
SE clustered at cell (in parentheses)	✓
Observations (cell-months)	$\approx$ 158,484

Six-country LATAM panel of pipeline-wellhead cells. The two cleanly comparable unsanctioned heavy-oil regions (Mexico Maya, Colombia Llanos) decline; only the Venezuelan Orinoco rises.

Cross-country LATAM identification

Back

$$\log \mathrm{XCH}_{4\,ict} \;=\; \alpha_i + \tau_t + \phi_1 \left(t \cdot \mathrm{NearPipe}_{d,i} \cdot \mathrm{VEN}_c\right) + \phi_2 \left(t \cdot \mathrm{NearPipe}_{d,i}\right) + \delta \left(t \cdot \mathrm{VEN}_c\right) + \varepsilon_{ict}$$

Per-year log XCH_4 trend ($\times$1,000)	d=10 km	d=20 km	d=50 km
VEN $\times$ NearPipe $\times$ t $(\hat{\phi}_1)$	$+\mathbf{1.03}^{***}$	$+\mathbf{0.88}^{***}$	$+\mathbf{0.72}^{***}$
	(0.17)	(0.14)	(0.12)
NearPipe $\times$ t $(\hat{\phi}_2)$	-0.32^{***}	-0.29^{***}	-0.26^{***}
	(0.02)	(0.01)	(0.01)
VEN $\times$ t $(\hat{\delta})$	-0.81^{***}	-0.89^{***}	-1.06^{***}
	(0.07)	(0.07)	(0.09)
Within-VEN near-pipe $(\hat{\phi}_1 + \hat{\phi}_2)$	$+0.78^{***}$	$+0.67^{***}$	$+0.47^{***}$
Cell FE, year-month FE	✓	✓	✓
SE clustered at cell	✓	✓	✓
Cell-month obs. ($\approx$ 2.6M)	full LATAM grid, 2018–2024		

Strain: biodiversity robustness

Back

- **Bird-relocation triple-diff vs Colombia:** $\hat{\beta}_3 \approx 0$ Bird test
- **Large-OOIP biodiversity gradient** OOIP gradient

Bird-relocation test: triple-difference with Colombia placebo

Back

Test. If birds physically displace away, then post-2017 richness should *rise* at Venezuelan cells *far* from oil relative to the corresponding Colombian cells:

$$\overline{\text{richness}}_{cy} = \alpha_c + \tau_y + \beta_1 (\text{POST}_y \cdot \text{VEN}_c) + \beta_2 (\text{POST}_y \cdot \text{FAR}_c) + \beta_3 (\text{POST}_y \cdot \text{VEN}_c \cdot \text{FAR}_c) + \varepsilon_{cy}$$

Triple-difference coefficient	$\hat{\beta}_3$
POST × VEN × FAR-from-oil	$+\mathbf{0.39}$
	(2.14)
	$[\,p = 0.85\,]$
Cell FE / Year FE	✓ / ✓
SE clustered at cell	✓
$\text{FAR}_c = \mathbb{1}\{c > 10\,\text{km from any oil field}\}$	
Reference group: Colombia	

We disregard long-haul migration (e.g., Caribbean islands) because the guilds that drive the chevron-license abundance gain are forest insectivores, granivores, and frugivores, which are mostly sedentary.

OOIP-biodiversity gradient: large fields, fewer birds

Back

	Total richness			log(1 + abundance)		
	(1)	(2)	(3)	(4)	(5)	(6)
log(OOIP)× Orinoco	-0.89^{***}	-0.03	-0.13	-0.10^{***}	-0.05^{***}	-0.05^{**}
	(0.20)	(0.13)	(0.14)	(0.03)	(0.02)	(0.02)
log(OOIP)× Maracaibo	-0.53^{***}	$+0.09$	$+0.03$	-0.17^{***}	-0.03^{**}	-0.04^{**}
	(0.18)	(0.12)	(0.11)	(0.04)	(0.01)	(0.01)
Year-month FE	✓	✓	✓	✓	✓	✓
Observer FE	—	✓	—	—	✓	—
Observer × Year FE	—	—	✓	—	—	✓
Effort controls	✓	✓	✓	✓	✓	✓
SE clustered at cell	✓	✓	✓	✓	✓	✓
Observations	40,481	40,418	40,336	40,481	40,418	40,336

Flaring on OPEX intensity: triple-difference under 4 FE structures

Back

	log(1 + flaring volume)			
	(1)	(2)	(3)	(4)
log(OPEX/bbl) (η_0)	-0.05^{*}	-0.05	-0.04	-0.03
	(0.02)	(0.03)	(0.02)	(0.06)
$\times$ Post 2017 (η_1)	$+0.06^{*}$	$+0.06^{*}$	$+0.05^{*}$	$+0.01$
	(0.03)	(0.03)	(0.03)	(0.02)
$\times$ Post 2022 (η_2)	-0.02^{***}	-0.02^{***}	-0.02^{***}	-0.07^{***}
	(0.00)	(0.00)	(0.00)	(0.01)
$\times$ Chevron (η_3)	-0.82	-0.93	-0.88	-0.19
	(2.19)	(2.20)	(2.21)	(1.82)
$\times$ Post22 $\times$ Chev (η_5)	$\mathbf{-0.42}^{***}$	$\mathbf{-0.42}^{**}$	$\mathbf{-0.43}^{***}$	$\mathbf{-0.31}^{***}$
	(0.13)	(0.14)	(0.13)	(0.07)
Post 2022 $\times$ Chevron (η_4)	Yes	Yes	Yes	Yes
Field FE	Yes	Yes	Yes	—
Owner-group FE	—	—	—	Yes
Year FE	Yes	Yes	Yes	Yes
Heavy share $\times$ Year	—	Yes	—	—
Orinoco-East $\times$ Year	—	—	Yes	—
N obs	2,344	2,344	2,344	2,332

Maintenance: robustness

Back

The Chevron license result is robust to:

- **Species richness**: improves less than abundance
  - Average effect:$\approx +32\%$ vs.$\approx +79\%$
  - *Individuals return first, new species need time to colonise*

Richness event study

- **Guild-level event study:** forest insectivores rise immediately and stay elevated ($\approx +0.6$, $p < 0.01$); frugivores transient; granivores null; waterbirds null/negative

Guild ES

  - Why guilds responded differently

Bird guilds

- No pollution–effort selection in eBird (12 effort coefficients, all insignificant)

Selection

Maintenance shock: bird abundance and species richness

◂ Back ▸ Bird ES (abundance)

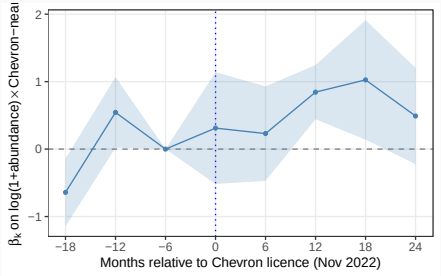
	log(1 + abundance)			log(1 + richness)		
	(1)	(2)	(3)	(4)	(5)	(6)
OPEX per barrel (log, η_0)	−0.16	−0.44	+0.13	+0.01	−0.13	−0.17
	(0.37)	(0.37)	(0.23)	(0.13)	(0.10)	(0.18)
× Post 2017 (η_1)	+0.23	+0.51	−0.07	+0.03	+0.16*	+0.20
	(0.37)	(0.36)	(0.22)	(0.12)	(0.10)	(0.18)
× Post 2022 (η_2)	−0.07	−0.02	−0.15	−0.07*	−0.04	−0.10
	(0.05)	(0.05)	(0.12)	(0.04)	(0.03)	(0.07)
× Chevron (η_3)	−2.28***	−2.14***	−1.45***	−0.31***	−0.28	+0.06
	(0.35)	(0.37)	(0.32)	(0.11)	(0.21)	(0.18)
× Post22 × Chev (η_5)	**+1.64****	**+1.44****	**+1.64***	+0.20	+0.10	+0.01
	(0.78)	(0.59)	(0.85)	(0.23)	(0.27)	(0.50)
Post22 × Chev level	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	Cell+YM	Cell+YM+Obs	Cell+YM+Obs×Yr	Cell+YM	Cell+YM+Obs	Cell+YM+Obs×Yr
Cluster	Cell	Cell	Cell	Cell	Cell	Cell
N obs	7,565	7,522	7,457	7,565	7,522	7,457

Notes: Same Chevron triple-interaction specification as the flaring regression on the main slide. Outcome is log(1 + abundance) in cols (1)–(3) and log(1 + richness) in cols (4)–(6), from eBird checklists within 30 km of a Chevron GL-41 JV. Abundance η_5 is positive and significant across all three FE structures; richness η_5 is positive but not statistically significant (slower recovery channel: individuals return before new species).

Maintenance ES: bird abundance recovers post-licence

Back | Bird ES (richness)

$$\log(1+\text{abundance})_{ict} = \alpha_i + \tau_t + \sum_{k \neq -6\text{m}} \beta_k \, \mathbb{1}\{\text{bin}_t = k\} \cdot \text{NearChev}_i + \mathbf{X}'_{ict}\boldsymbol{\delta} + \varepsilon_{ict}$$



i = 10 ×10km cell, c = checklist, t = year-month; NearChev$_i$: $\leq$ 30 km from an OFAC Licence 41 Chevron JV. Cell/YM/observer FE; effort controls $\mathbf{X}_{ict}$; SE clustered at cell.

- Lag matches a maintenance backlog clearing (parts ordered, equipment swapped, gas-handling restored)

Two-way Oaxaca decomposition: Heavy × Size

Back

$$\bar{\alpha}_{\text{post}} - \bar{\alpha}_{\text{pre}} = \sum_g \underbrace{\Delta s_g \cdot \bar{\alpha}_{g,\text{pre}}}_{\text{composition}} + \sum_g \underbrace{s_{g,\text{post}} \cdot \Delta\bar{\alpha}_g}_{\text{within-cell}}, \quad g \in \{\text{H,NH}\} \times \{\text{L,S}\}$$

Cell (g)	s_{pre}	s_{post}	α_{pre}	α_{post}	Composition	Within-cell
Heavy × Large	80.7%	85.4%	9.94	22.77	+0.47	+10.96
Heavy × Small	0.6%	0.4%	23.52	75.81	−0.05	+0.19
Non-heavy × Large	18.5%	13.9%	1.79	2.13	−0.08	+0.05
Non-heavy × Small	0.2%	0.3%	0.83	0.14	+0.00	−0.00
Total					+0.34 (3%)	+11.20 (97%)

- ≈ 97% of the rise is within-cell intensity change at H×Large fields (9.94 → 22.77 m^3/bbl)
  - This is the strain + maintenance story
- Composition is small (∼4% of R, *positive* from the between-Heavy share gain;
  - within-Heavy size composition is trivially negative
  - Slide 13's $\beta = +0.23$ on size-survival identifies the fixed-cost margin but moves the production-weighted average only by −0.004 R-units — too small to matter

Guild-level decomposition

Back

$$\log(1+\text{abundance})_{ict} = \alpha_i + \tau_t + \omega_o + \sum_{g \in \mathcal{G}} \theta_g \, \text{Guild}_c^{(g)} \cdot \text{NearChev}_i \cdot \text{Post 2022}_t + \mathbf{X}'_{ict}\boldsymbol{\delta} + \varepsilon_{ict}$$

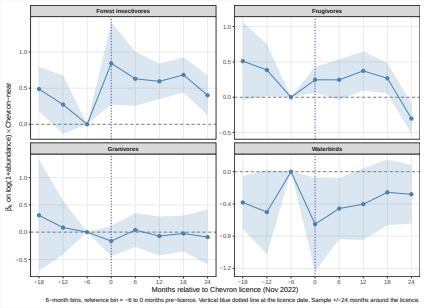
log(1 + abundance)	(1)	(2)	(3)
Guild × (NearChev × Post):			
Forest insectivores	+0.60***	+0.51***	+0.04
	(0.18)	(0.17)	(0.31)
Frugivores	+0.29	+0.20	+0.35
	(0.24)	(0.22)	(0.33)
Granivores	+0.26	+0.25	+0.63
	(0.20)	(0.22)	(0.39)
Waterbirds	−0.26	−0.18	+0.05
	(0.22)	(0.15)	(0.37)
FE	Cell + YM	+ Observer	+ Observer × Year
Effort controls	✓	✓	✓
N (checklist-cells)	2,584	2,579	2,573

Cell-level Chevron-vs-Western-JV DiD on log abundance per guild, ±24 months around the licence date. Forest insectivores' canopy/understory niches are most sensitive to local air quality.

Maintenance ES by guild

Back · Pooled table

$$\log(1+\text{abundance}_g)_{ict} = \alpha_i + \tau_t + \sum_{k\neq -6\text{m}} \beta_k^{(g)}\, \mathbb{1}\{\text{bin}_t = k\} \cdot \text{NearChev}_i + \mathbf{X}'_{ict}\boldsymbol{\delta} + \varepsilon_{ict}, \quad g \in \{4 \text{ guilds}\}$$

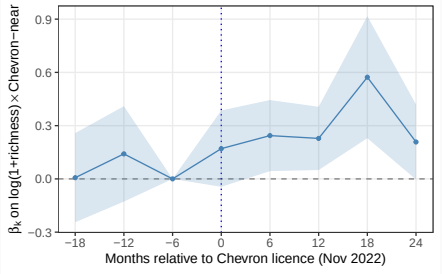


- **Forest insectivores**: jump to $+0.84^{***}$ at $t = 0$, then steady $+0.6$–0.7^{***} through $+24$m
- **Frugivores**: positive, builds to $+0.37^{***}$ at $+12$m, but reverses to -0.30^{***} at $+24$m
- **Granivores**: *null* at every horizon — a clean within-cell placebo
- **Waterbirds**: negative through the post-period (no positive response), consistent with their distinct ecology

Maintenance ES: species richness recovers slowly

Back

$$\log(1 + \text{richness})_{ict} = \alpha_i + \tau_t + \sum_{k \neq -6\text{m}} \beta_k \, \mathbb{1}\{\text{bin}_t = k\} \cdot \text{NearChev}_i + \mathbf{X}'_{ict}\boldsymbol{\delta} + \varepsilon_{ict}$$



i = 10 ×10km cell, c = checklist, t = year-month; NearChev$_i$: ≤ 30 km from an OFAC Licence 41 Chevron JV. β_k = differential log(1 + ric
vs. ref bin −6 m. Cell/YM/observer FE; effort controls $\mathbf{X}_{ict}$; SE clustered at cell.

- Magnitudes ≈ 1/4–1/2 of the abundance response: **individuals return first, new species require time to colonise**

Forest insectivores

Back



Photo: Hector Bottai, CC BY-SA 4.0, via Wikimedia Commons

Myrmotherula longipennis (Long-winged Antwren)

Who is in the guild. Antbirds (Thamnophilidae), antwrens, woodcreepers, gnatcatchers, many tyrant flycatchers; small understory and mid-story passerines that glean or sally for arthropods in primary and mature secondary forest.

Ecological traits relevant to the shock.

- Prey base (flying and leaf-litter insects) is highly sensitive to ambient air quality — flaring plumes, $\mathrm{NO_x}$, $\mathrm{SO_2}$ and black carbon depress local arthropod biomass within months
- Sedentary, small home ranges ($<$ a few ha) $\rightarrow$ local pollution and habitat conditions, not regional averages, drive abundance
- Short generation times and high turnover allow fast numerical response when local conditions improve

Why this guild responded fastest. The Chevron licence cut per-barrel flaring at treated fields, removing the direct combustion-plume stressor on the insect prey base. Forest insectivores re-occupied the cleaner airshed within one 6-month bin ($+0.84$ at $t = 0$, $\approx +0.6$ sustained). They are the guild for which the air-quality channel of the maintenance shock should bite first.

Frugivores

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Ramphastos tucanus (White-throated Toucan)

Who is in the guild. Toucans, cotingas, manakins, tanagers, larger thrushes, parrots, and other canopy/subcanopy species whose diet is dominated by fruit (and arils, nectar in some).

Ecological traits relevant to the shock.

- Large home ranges and seasonal/altitudinal movement tracking fruiting phenology → short-run abundance responds to whether nearby trees fruit, not only to airshed quality
- Dependent on canopy tree health; fruit production lags any change in stress by one or more flowering cycles
- Many are wide-ranging and re-distribute opportunistically, so a local pulse of better conditions can attract birds that later disperse

Why the response was transient. Frugivores rose with the initial post-licence improvement (peak $+0.37$ at $+12$m) but reversed by $+24$m. Consistent with a mobile guild responding to a temporary local fruiting/forage pulse rather than to a persistent change in habitat carrying capacity.

Granivores

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Photo: Félix Uribe, CC BY-SA 2.0, via Wikimedia Commons

Sporophila intermedia (Grey Seedeater)

Who is in the guild. Seedeaters (*Sporophila*, *Sicalis*), saltators, grassquits, finches, doves; open-country and grassland species that feed on grass seeds and small fruits.

Ecological traits relevant to the shock.

- Diet (seeds from grasses and herbaceous plants) is not transmitted via insect food webs → weak coupling to short-run changes in ambient air quality
- Occupy open and edge habitats (savanna, pasture, agricultural margins) that are largely unaffected by local oil-field flaring intensity
- Many are nomadic seed-tracking specialists, so local pulses are absorbed by movement rather than density changes

Why the null is informative. Granivores share the same observers, cells, and year-month shocks as the responding guilds — they differ only in ecology (seeds, not insects; open country, not forest canopy). A spurious post-licence bump at Chevron-near cells (better eBird coverage, observer concentration, etc.) would lift granivores too. It doesn't. So the response we see in forest insectivores is **mechanism-specific**, not an artefact common to all birds in the area.

Waterbirds

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Eudocimus ruber (Scarlet Ibis)

Who is in the guild. Herons and egrets, ibises (incl. Scarlet Ibis, a national symbol of Venezuela), storks, kingfishers, ducks, shorebirds; species tied to wetlands, mangroves, rivers and estuaries.

Ecological traits relevant to the shock.

- Exposure runs through *water* (produced-water discharges, hydrocarbon spills, sediment contamination) rather than the air
- Restoring maintenance budgets at well-pads need not reduce produced-water contamination on the same timescale — pipelines, separators and disposal infrastructure are a separate failure mode
- Many are wide-ranging colonial nesters, so local cell-level abundance is a noisier signal of local conditions

Why the response is null/slightly negative. The Chevron-licence shock acts primarily on combustion-related emissions; it does not directly target the produced-water or spill channels that drive waterbird outcomes. A null here is therefore consistent with the air-quality interpretation of the positive effect on forest insectivores.

eBird selection: pollution does not predict effort

Back

	$\log(1 + \text{CH}_4)$		$\log(1 + \text{VIIRS flare})$	
Dependent variable	Coef.	(SE)	Coef.	(SE)
$\log(1 + \#$ checklists)	-0.016	(0.015)	-0.021	(0.031)
Mean log(duration)	-0.007	(0.018)	-0.011	(0.030)
Mean distance (km)	$+0.018$	(0.016)	-0.017	(0.032)
Mean # observers	$+0.020$	(0.017)	$+0.008$	(0.035)
Traveling share	-0.022	(0.018)	-0.045	(0.038)
Mean start hour	$+0.000$	(0.020)	$+0.017$	(0.037)
Cell FE		✓		
Year-month FE		✓		
SE clustered at cell		✓		
N (cell-months)		7,239		

Each row is a separate regression of a standardised (z-scored) effort or coverage outcome on standardised $\log(1 + CH_4)$ *and* $\log(1 + \textit{VIIRS flare})$ *at* $R = 50$ *km. Sample: post-period Venezuelan cell-months with non-missing TROPOMI methane, 2018–2024. Cell and year-month FE; SE clustered at the cell level.*

- All twelve coefficients individually insignificant (largest $|t| = 1.22$)

Population-weighted R

Back

Weighting	R	Change vs. unweighted
Unweighted (paper headline)	2.72	—
Population, 10 km buffer	3.25	+19%
Population, 30 km buffer (focal)	**2.93**	**+8%**
Population, 50 km buffer	2.86	+5%

- Population shares (30 km): Orinoco fields 64%, Maracaibo fields 25%, Other 11%
- Surviving heavy operations sit near Maturin, El Tigre, Anaco, Punta de Mata (north of the Orinoco belt) and around Lake Maracaibo — not in empty savanna
- Population weighting *raises* R by 5 to 19%
- **The headline $R \approx 2.7$–3.3 is, if anything, a lower bound on the welfare-relevant damage gap**