When Trade Burns the Air: The Welfare Consequences of Agricultural Trade Liberalization

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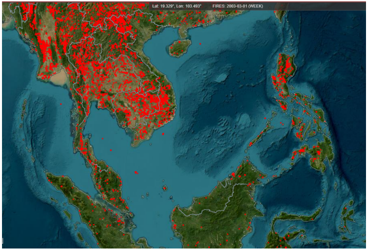
Southeast Asia (SEA) is a Major Agricultural Exporter

- Trade liberalization rapidly expanded agricultural exports in SEA:
  - 30B USD (2003) → 142B USD (2021)
  - 10.43% of global market in 2021

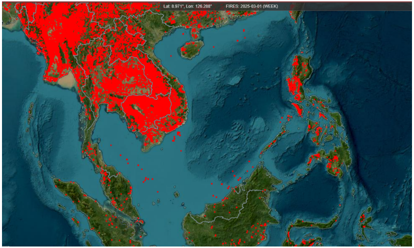
Figure: Growth in Agricultural Sector Exports in SEA Countries

More Trade, More Agriculture Fires

- Agricultural Output $\uparrow \Rightarrow$ Fires $\uparrow$
  - Land clearing
  - Soil fertility
  - Burning is affordable



(March 1–7, 2003)



(March 1–7, 2025)

Agricultural Fires: Local and Transboundary Pollution

- Air pollution can travel long distances

Burning Indonesian peat causes haze in Singapore

Radiocarbon measurements provide evidence that the origin of the haze over Sumatra's neighbors is peat, not deforestation and waste burning as many believed.

Taylor De Leon | Department of Civil and Environmental Engineering
November 21, 2018

Source from MIT News (2018)

Notes: geographical distance between Indonesia (Sumatra) and Singapore: 740 km)

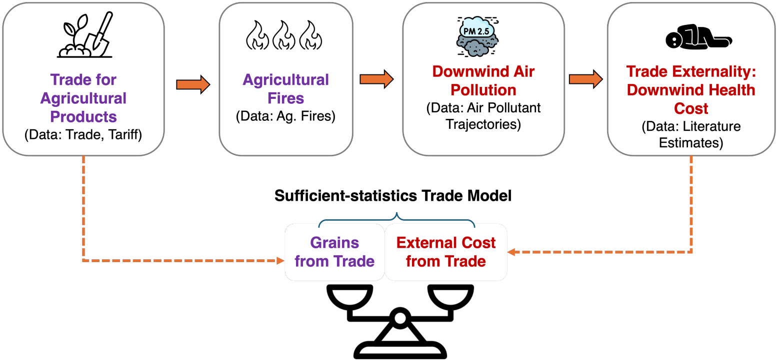
Research Questions

What is the welfare from trade if accounting for the pollution cost?

- Pollution Cost from Trade
  - The reduction in agricultural tariffs **increase** fires in SEA?
  - The domestic and transboundary pollution costs of these fires? (health)
- Gains from Trade
  - SEA Countries
  - The Rest of the World

→ Net welfare for each country in the world

Schematic Framework



Contribution

A framework to quantify trade-induced environmental externalities beyond bilateral trading partners, incorporating the full set of pollution-receiving regions.

- Measuring externalities requires linking:
  - origins of production and pollution,
  - mechanisms of pollutant transmission,
  - all exposed regions.
- Existing research typically examines only one part.
  - Exporter-side impacts (emissions, health, land use): Bombardini and Li (2020), Carreira et al. (2024), Du et al. (2024), Rodrigue et al. (2024), and Tanaka et al. (2022)
  - Importer-side impacts (import competition/substitution): Akerman et al. (2024), Gutiérrez and Teshima (2018), and Shi and Zhang (2023)
  - Few quantitative trade models focus mostly on CO_2 from transport: Cristea et al. (2013), Larch and Wanner (2017), and Shapiro (2016)

We construct a source–receptor matrix that maps emissions in each origin to exposure in each downwind region, making externalities spatially explicit and empirically traceable.

Contribution

We extend the pollution haven literature beyond manufacturing to the agricultural sector.

- Prior research focuses on how trade liberalization shifts manufacturing pollution across borders through the relocation of industrial production.
  - Cherniwchan et al. (2017), Ederington et al. (2005), Fowlie et al. (2016), D. Kellenberg (2012), and D. K. Kellenberg (2009)
- We provide the first systematic evidence of pollution haven dynamics in agriculture.

Background: Trade liberalization in Southeast Asia

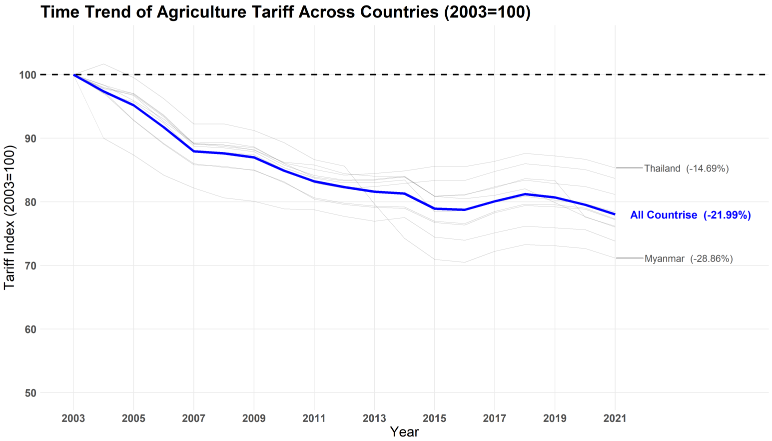


Figure: Reductions in Agricultural Tariffs in Ten SEA Countries

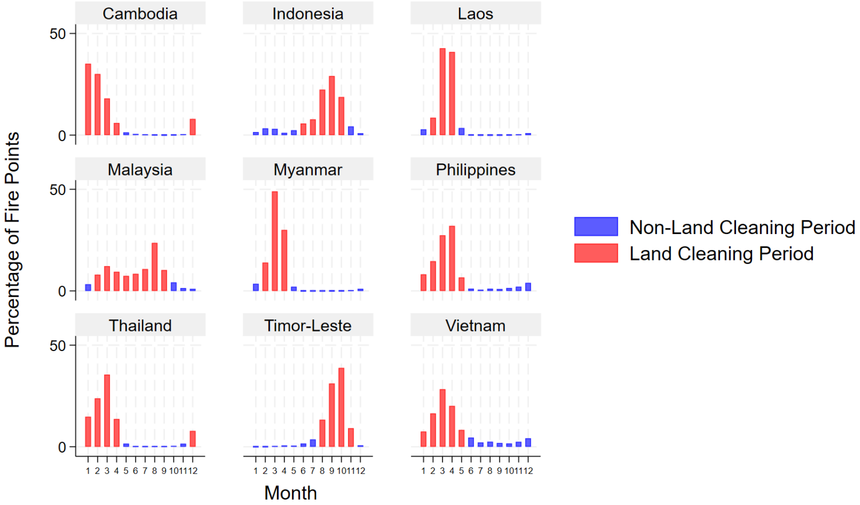
Background: Fire Use is Cheaper for Farmers

(a) Burning

(b) Machine

- Burning (Slash-and-Burn)
    - Lower Cost: $\sim$ \$5 per hectare
    - Low Time Cost
    - Unskilled Labor
- Mechanical clearing
    - Higher Cost: $\sim$ \$250 per hectare
    - More Time Cost
    - Skilled Labor

Background: Agricultural fires in the Land-clearing Period



Data: Mapping to $0.1^\circ \times 0.1^\circ$ Grid

	(1) Data Source	(2) Spatial Frequency	(3) Temporal Frequency
(a) Agriculture Fires			
Agriculture Fires	FIRMS	$0.01^\circ \times 0.01^\circ$ Grid	Daily, 2003–2021
(b) Trade Measures (Bilateral)			
Trade Volumes	UN Comtrade	Product-by-Ctry	Yearly, 2003–2021
Tariff	Teti (2025)	Product-by-Ctry	Yearly, 2003–2021
(c) Environment			
$PM_{2.5}$ Concentrations	Shen et al. (2024)	$0.01^\circ \times 0.01^\circ$ Grid	Monthly, 2003–2021
$PM_{2.5}$ Emissions by Fire	FINN	$0.1^\circ \times 0.1^\circ$ Grid	Monthly, 2003–2021
(d) Agriculture Activities			
Land Coverage	MODIS	0.5km×0.5km Grid	Yearly, 2002–2020
(e) Weather Controls			
Temperature	ERA5	$0.1^\circ \times 0.1^\circ$ Grid	Daily, 2003–2021
Precipitation	ERA5	$0.1^\circ \times 0.1^\circ$ Grid	Daily, 2003–2021
Dryness Index	ERA5	$0.1^\circ \times 0.1^\circ$ Grid	Daily, 2003–2021

Graphical Illustration: Ag. Export and Ag. Fires

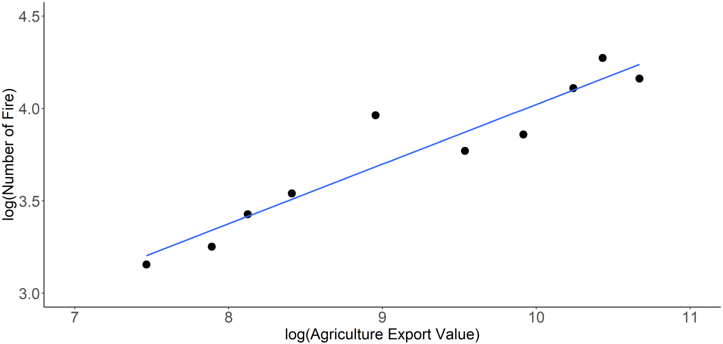


Figure: Binscatter Plot of Agricultural Exports and Fire Activity

Notes: Include meteorological controls: Temperature, precipitation, relative humidity, wind.

Graphical Illustration: Tariffs and Ag. Fires

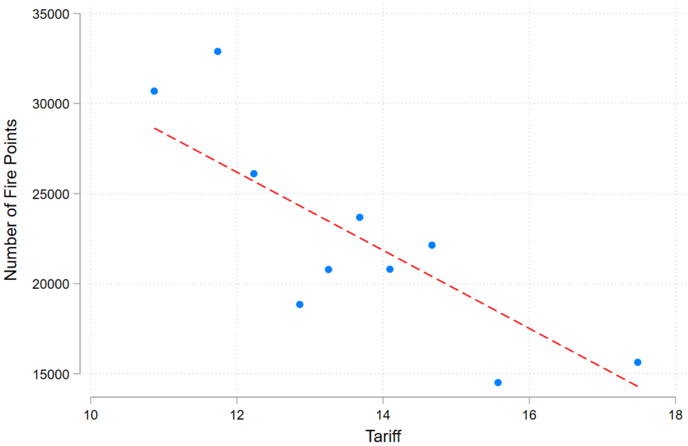


Figure: Binscatter Plot: Tariffs and Number of Fire Points

Notes: Include meteorological controls: Temperature, precipitation, relative humidity, wind.

Specification: Tariffs' Impacts on Fires

Grid-by-year panel regression, 2003-2021, OLS:

$$Y_{ict} = \alpha + \beta T_{ct} + \delta \mathbf{W}_{ict} + \rho_t + \pi_i + \rho_t \mathbf{X}_{2003,c} + \rho_t \mathbf{M}_{2003,ic} + \varepsilon_{ict} \quad (1)$$

- Y_{ict}: # of fire points in grid i in country c in year t.
- T_{ct}: tariff measures on agriculture products in grid i in country c in year t; weight by $t-1$ year product level trade volumes share.
- $\mathbf{W}_{ict}$: grid-level time-variant weather controls.
- π_i and ρ_t: grid fixed effects and year fixed effects.
- $\mathbf{X}_{2003,c}$ and $\mathbf{M}_{2003,c}$: baseyear characteristics at the country level and at the grid level: export value, tariff, #of fire points, crop coverage.
- Standard errors clustered at the grid level.

Effects of Tariffs on Fires (Baseline Result)

- 1 pp reduction in agricultural tariff increases grid-level fire points by 0.18-0.20 units (3.9-4.3%).

	(1) Fire Points	(2) Fire Points	(3) Fire Points	(4) Fire Points
Tariff	-0.1884***	-0.1782***	-0.1831***	-0.2034***
	(0.0188)	(0.0189)	(0.0204)	(0.0202)
Average Fire Points	4.55	4.67	4.67	4.67
Number of Grids	44,811	43,650	43,650	43,650
Observations	851,409	829,350	829,350	829,350
R-squared	0.5223	0.5242	0.5292	0.5550
Grid FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Weather Controls	No	Yes	Yes	Yes
2003 Country Chars × Year FE	No	No	Yes	Yes
2003 Grid Chars × Year FE	No	No	No	Yes

Results by Land-Cleaning Period

- Impacts are more salient in land-cleaning periods: account for 98.3% fire increases.

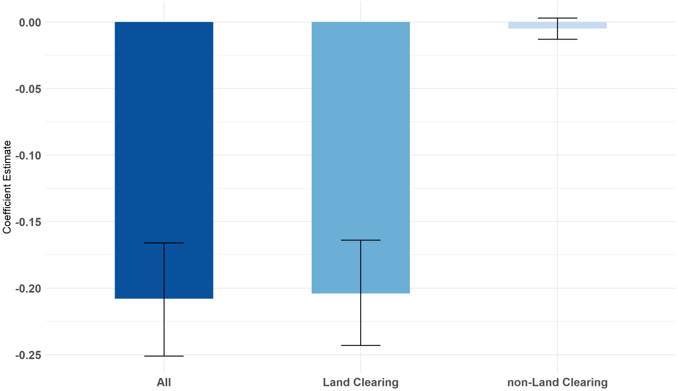


Figure: Results by Agricultural Conditions

The Impact of Trade on Fire Activity by Land Suitability

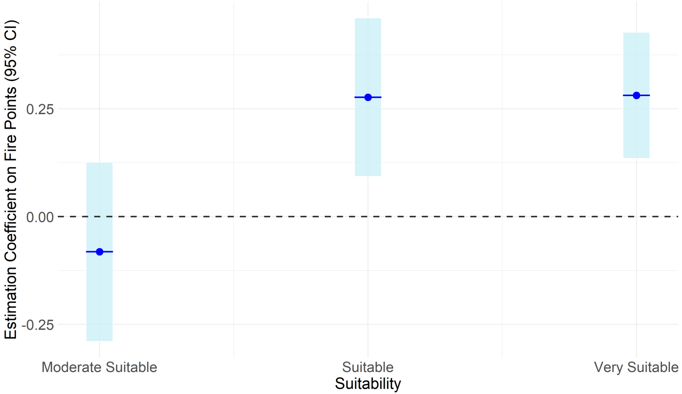


Figure: The Impact of Trade (Ag. Export) on Fire Activity by Land Suitability

The Impact of Trade on Fire Activity by Land Suitability

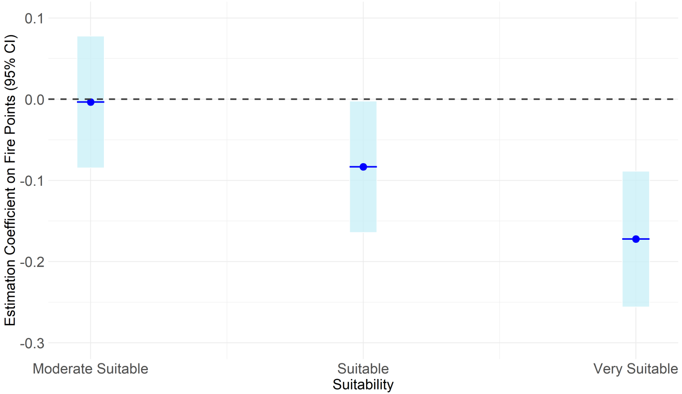


Figure: The Impact of Trade (MFN Tariff) on Fire Activity by Land Suitability

Robustness Checks

1. Alternative Specifications
   - Different controls
   - Intensive and Extensive Margin: PPML, Log ▸ more
2. Alternatives Outcomes ▸ more
   - Emissions of $PM_{2.5}$ and CO_2
   - Fire Stringency Brightness of Fire Points
   - Burn Areas
3. Alternatives Tariff Measures ▸ more
   - MFN Tariff

More Exposed to Tariff Reductions: Less Existing Cropland

- Grids with **More** Cropland vs. Grids with **Less** Cropland

$$Y_{ict} = \alpha + \sum_{k=1}^{6} \beta^k CC_{ic,t-1}^k T_{ct} + \sum_{k=1}^{6} \gamma^k CC_{ic,t-1}^k + \delta \mathbf{W}_{ict} + \rho_t + \pi_i + \tau_{ct} + \rho_t \mathbf{M}_{2003,ic} + \varepsilon_{ict} \quad (2)$$

- $CC_{ic,t-1}^k$: cropland coverage in grid i in country c in year $t-1$.
    - 0%, 0-20%, 20-40%, 40-60%, 60-80%, 80-100%.
    - $80 - 100\% \rightarrow$ reference group.
- $\beta^1 \sim \beta^6$: relative effects of tariff reductions on fire points

Heterogeneity by Agricultural Conditions

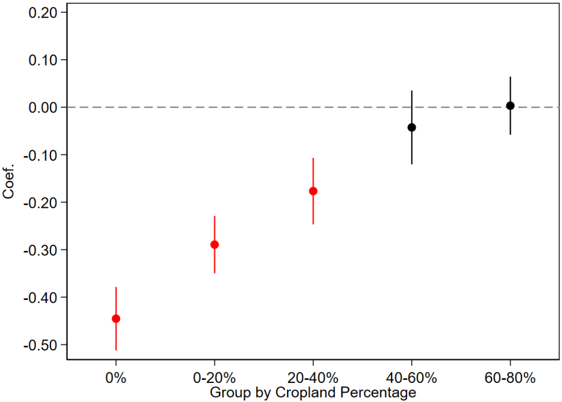
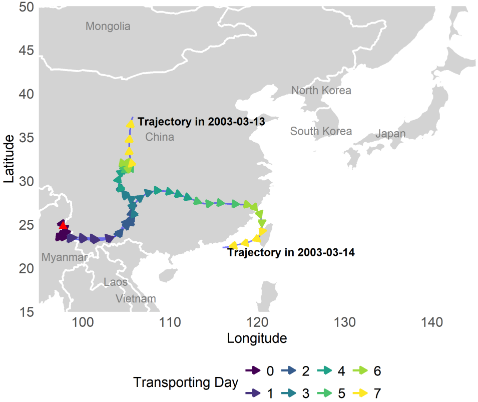


Figure: Results by Agricultural Conditions

From Local Ag Fires to Transboundary Pollution



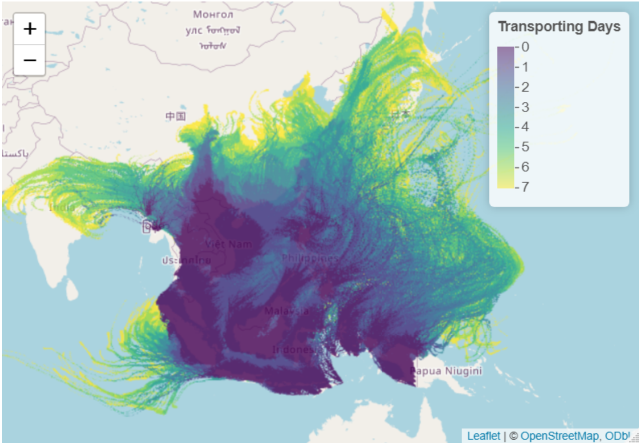
Notes: Trajectories From Myanmar

- 7-day Trajectory Pollution transporting trajectory
  - NOAA Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) Model

▸ Details

Pollution Transport Trajectories

- daily trajectories for all cells in SEA regions from 2003 to 2021. (303,590,300 trajectories in total)

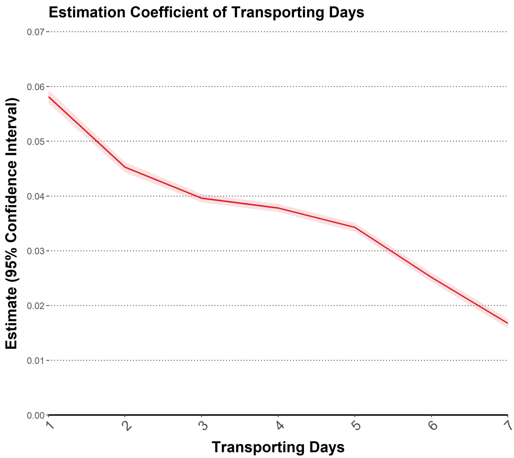


Trajectory Exposure in June, 2004

Effect of Transported Ag. Fire on Air Pollution

We estimate the pollution effect of transported fires via

$$PM_{2.5jm} = \alpha_j + \tau_m + \sum_{w=1}^{7} \beta_w T_{jmw} + \gamma' X_{jmw} + \varepsilon_{jmw}, \qquad (3)$$



Case: Singapore

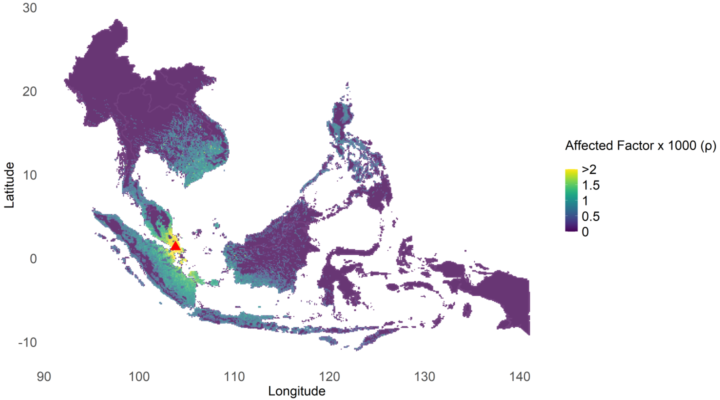


Figure: The Impact of Fires on Pollution in Singapore

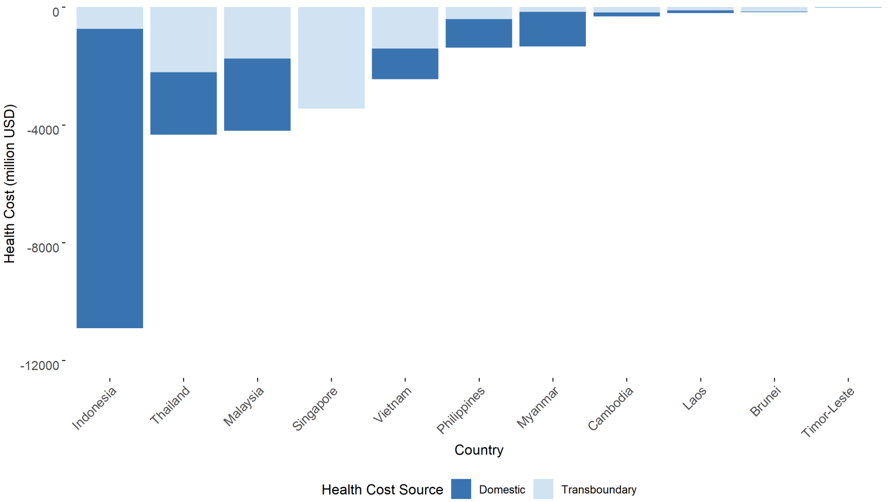
The Cost of Trade-induced Agriculture Fire

Total impact per fire

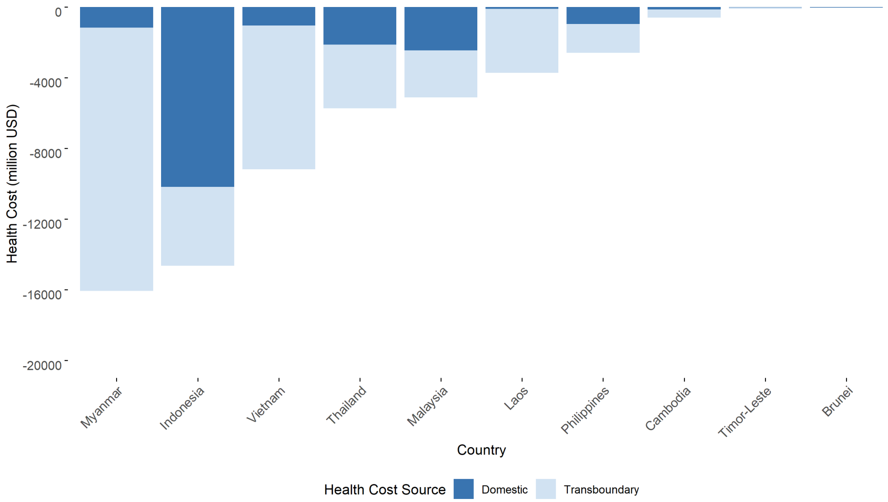
$$\begin{aligned}\Lambda_{ij} &= \mu_j \cdot \rho_{ij} \\ &= \underbrace{VSL_c \cdot a \cdot \text{Pop}_j \cdot \rho_{ij}}_{\text{Mortality Cost}} + \underbrace{b \cdot \text{Pop}_j \cdot \rho_{ij}}_{\text{Morbidity Cost}}\end{aligned} \tag{4}$$

- ρ_{ij}: $\Delta Fires_i \rightarrow \Delta PM_{2.5j}$
- μ_j: $\Delta PM_{2.5j} \rightarrow \Delta HealthCost_j$
- a: $\Delta PM_{2.5} \rightarrow \Delta Mortality$ (He et al., 2020)
- b: $\Delta PM_{2.5} \rightarrow \Delta Morbidity$ (Barwick et al., 2024)
- Pop_j: resident population in grid cell j.

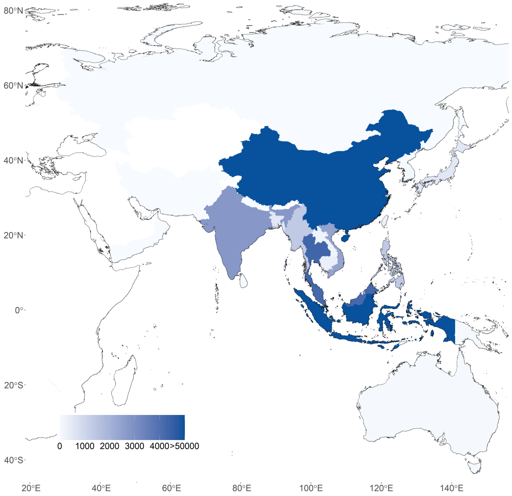
Results: The Health Costs in SEA Countries (Receptors)



Results: The Health Costs from SEA Countries (Sources)



Results: Health Costs in Countries/Regions Affected by Trade-Induced Agricultural Fires (million USD)



Results: Marginal Health Costs

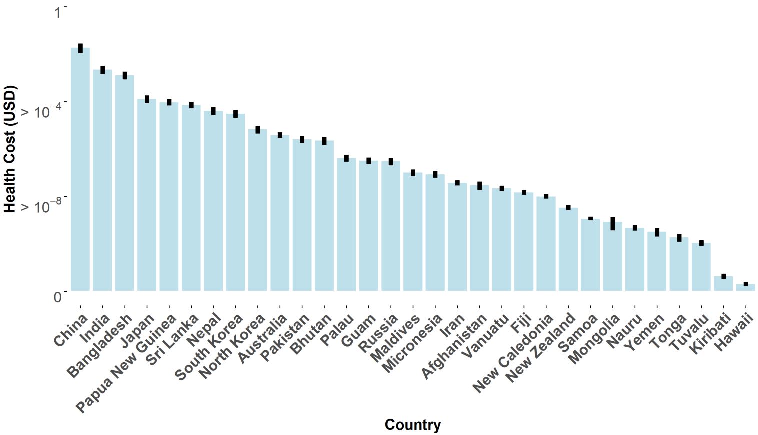


Figure: Costs of Trade-induced Fires per 1 USD Ag. Export

Model: Trade Gains with Environmental Externality

Quantify how agricultural trade affects welfare when trade generates transboundary pollution.

- Two sectors: Agriculture (A) and Non-agriculture (N)
- Cobb-Douglas across sectors: $U_j = (C_j^A)^{\alpha_j^A}(C_j^N)^{\alpha_j^N}$
- CES within sectors: $\sigma_s > 1$
- CRS: $c_i^s = w_i a_i^s$
- Tariffs as trade cost: $t_{ij}^s \to$ price $p_{ij}^s = (1 + t_{ij}^s) w_i a_i^s$

Gravity structure and domestic expenditure share (Arkolakis et al., 2012):

$$\lambda_{ij}^s = \frac{[(1 + t_{ij}^s) w_i a_i^s]^{1-\sigma_s}}{\sum_k [(1 + t_{kj}^s) w_k a_k^s]^{1-\sigma_s}}$$

Model: Trade Gains with Environmental Externality

ACR real income change:

$$\widehat{W}_{j,t} = \prod_{s \in \{A,N\}} \left(\frac{\lambda^s_{jj,t}}{\lambda^s_{jj,0}} \right)^{-\alpha^s_j / \varepsilon_s}$$

Net welfare change considering environmental externality:

$$\Delta V_{j,t} = \underbrace{\left[\prod_s \left(\frac{\lambda^s_{jj,t}}{\lambda^s_{jj,0}} \right)^{-\alpha^s_j / \varepsilon_s} - 1 \right] W_{j,0}}_{\text{Trade gains}} - \underbrace{\sum_i \mu_j \pi_{ij} \chi_i (x^A_{i,t} - x^A_{i,0})}_{\text{Health costs}}$$

Policy experiments: Liberalization, autarky, bilateral agreements, etc.

Calculation Details

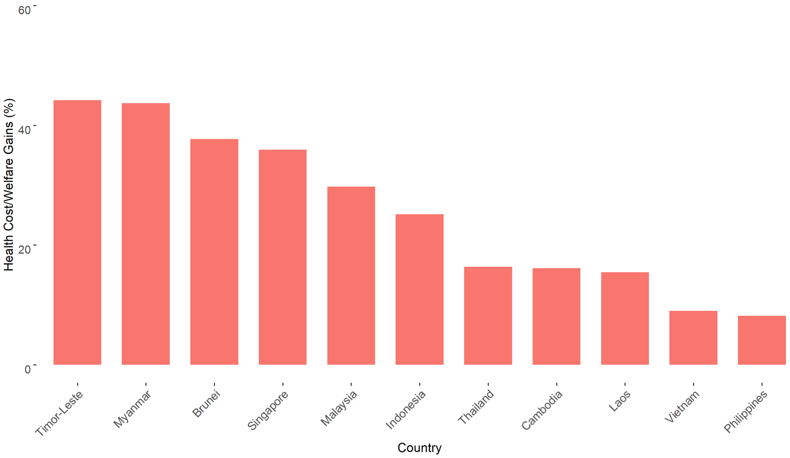
Welfare Gains from Agricultural Tariff Reduction in SEA Regions (2021 vs 2003

Country	%	Million USD
Panel A. Southeast Asian Countries		
Myanmar	0.20	14124.96
Philippines	0.10	16826.82
Thailand	0.09	26449.40
Cambodia	0.24	1981.24
Malaysia	0.11	14124.96
Brunei	0.05	465.69
Singapore	0.05	9600.59
Indonesia	0.07	43410.54
Laos	0.34	1320.56
Viet Nam	0.15	27180.64
Total	0.32	144452.30
Panel B. Rest of the World		
China (Mainland)	0.13	1397208.00
United States	-0.00	-33262.11
World Total	0.2	2756532

As a comparison: gains from trade in US in 2000 is 0.7-1.4% (Arkolakis et al., 2012).

Ratio of Health Costs to Gains in Southeast Asia in SEA

- Costs account for **20%** of the welfare gains in SEAs.



Welfare Analysis Considering Pollution-Health Costs and Trade Gains

- Costs account for **2%** of the welfare gains globally.

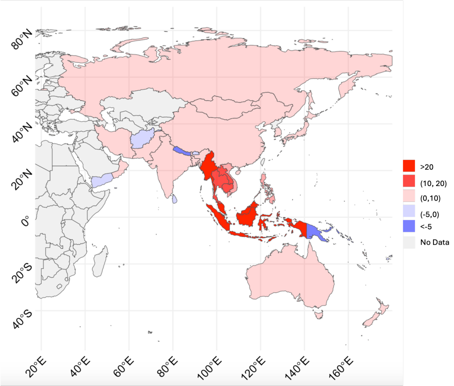


Figure: Cost/Gain Ratio (%) across Countries, 2001-2021

Conclusion

- Lower agricultural tariffs **increased** agriculture fire in SEA.
  - 1 pp reduction in agricultural tariff increases grid-level fire points by 0.18-0.20 units (3.9-4.3%).
  - Impact concentrates on areas with less crop cultivation.
- The fire-induced pollution will affect both **local** and **transboundary** air quality, and its impact will decrease over the transport days.
- Health costs may constitute a large proportion of the welfare gains from trade.
  - Costs account for 2% of the welfare gains from tariff reduction globally.
  - Costs account for 20% of the welfare gains from tariff reduction for SEA countries.

Thank You!

Questions or comments are welcome.

Yuhang Pan
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Background: Trade liberalization in Southeast Asia

Internal Integration

1992 — ASEAN Free Trade Area (AFTA)

1995~1999 — Vietnam, Laos, Myanmar, and Cambodia joined the ASEAN

2010 — ASEAN Trade in Goods Agreement (ATIGA)

2015 — ASEAN Economic Community (AEC)

International Agreement

2004 — ASEAN–China (ACFTA) – Early Harvest

2006 — ASEAN–Korea AKFTA

2008 — ASEAN–Japan (AJCEP)

2009 — ASEAN–Australia–New Zealand (AANZFTA), ASEAN–India(AIFTA)

2010 — ASEAN–China (ACFTA)

2020 — RCEP

Background: Managing Agricultural Fires in SEA is a Challenge

2009 — **Indonesia**: Environmental Law (2009)

2016 — **Brunei**: EPM Order (2016)

2019 — **Thailand**: Forest Fire Control Act (2019)

2022 — **Vietnam**: Law on Environmental Protection (2022)

2002 — **ASEAN**: Agreement on Transboundary Haze (2002)

2023 — **ASEAN**: Transboundary Haze Pollution Control Coordinating Centre (Proposed and Endorsed)

Policy Conflicts & Failures

- Limited government capacity
  - Insufficient funding, weak enforcement structures, and lack of penalties for non-compliance
- Lack of affordable land-clearing alternatives.
- Inadequate monitoring and control

Intensive Margin vs Extensive Margin

	(1) Any Fire Points	(2) ln(Fire Points)	(4) Any Fire Points	(5) Fire Points
Tariff	-0.0046***	-0.0166***	-0.0010***	-0.0363***
	(0.0005)	(0.0017)	(0.0008)	(0.0021)
PPML Marginal Effect			-0.0062***	-0.2180***
			(0.0005)	(0.0127)
Specification	OLS	OLS	PPML	PPML
Observations	829,350	398,639	646,228	646,228
R-squared	0.6253	0.6176		
Grid FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes
2003 Country Chars $\times$ Year FE	Yes	Yes	Yes	Yes
2003 Grid Chars $\times$ Year FE	Yes	Yes	Yes	Yes

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Robustness Checks: Alternative Measures of Tariffs

- Use MFN (most favored nation) tariffs as tariff measures: similar findings.

	Total Fire Points (1)	Land-Cleaning Period (2)	Non-Land-Cleaning Period (3)
MFN Tariff	-0.1913***	-0.1895***	-0.0018
	(0.0192)	(0.0179)	(0.0034)
Observations	829,350	829,350	829,350
R-squared	0.5550	0.5584	0.2858
Grid FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes
2003 Country Chars × Year FE	Yes	Yes	Yes
2003 Grid Chars × Year FE	Yes	Yes	Yes

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Robustness Checks: Alternative Measures of Fires and Air Pollution

	Brightness (Kelvin) (1)	Average Burning Area (km^2) (2)	$PM_{2.5}$ Emissions (Million Ton, log) (3)	CO_2 Emissions (Ton, log) (4)
Tariff	-1.3714***	-0.4678***	-0.0128***	-0.0148***
	(0.1464)	(0.0472)	(0.0019)	(0.0018)
Observations	829,350	829,350	429,344	429,344
R-squared	0.6293	0.6060	0.6814	0.6681
Grid FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes
2003 Country Chars × Year FE	Yes	Yes	Yes	Yes
2003 Grid Chars × Year FE	Yes	Yes	Yes	Yes

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Mechanism: Deforestation for Land Clearing

- 1 pp reduction in agricultural tariff reduces grid-level forest cover by 0.03-0.06%.

	Forest Cover Change (% annual, 0-100)			
	(1)	(2)	(3)	(4)
Tariff	0.0595***	0.0586***	0.0254***	0.0289***
	(0.0046)	(0.0046)	(0.0053)	(0.0052)
Observations	851,409	829,350	829,350	829,350
R-squared	0.1136	0.1148	0.1208	0.1278
Grid FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes
2003 Country Chars × Year FE	Yes	Yes	Yes	Yes
2003 Grid Chars × Year FE	Yes	Yes	Yes	Yes

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Trade-induced Fires Over Time

We obtain trade-induced fires in the source cell i from 2003 to year t by using Eq (2):

$$\Gamma_{it} \times \Delta Tariff = \sum_{k=1}^{3} \sum_{m=2003}^{t-1} \beta^k \times CC^k_{ic,m} \times (Tariff_{c,m+1} - Tariff_{c,m}) \quad (5)$$

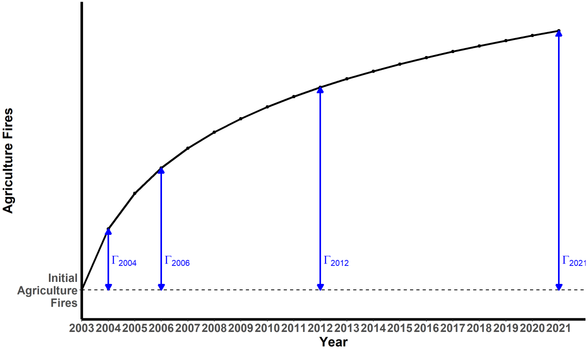

Figure: Results by Agricultural Conditions

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Parameters Preparation

Variable	Definition	Data Source
$X_{ij,t}$	Bilateral trade flow: exports from i to j in year t (nominal value).	UN Comtrade (via WITS)
$t_{ij,t}$	Ad valorem tariff rate imposed by importer j on goods from exporter i in year t.	Teti (2025)
$\tau_{ij,t}$	Iceberg trade cost implied by tariffs: $\tau_{ij,t} = 1 + t_{ij,t}$.	Computed from tariff data (see above).
$y_{j,t}$	Total expenditure (domestic absorption) in country j: $y_{j,t} = \sum_i X_{ij,t} = GDP_{j,t} + M_{j,t} - X_{j,t}$.	World Bank (for GDP, imports, exports).
$\lambda_{ij,t}$	Expenditure share: fraction of j's total spending on goods from i, $\lambda_{ij,t} = X_{ij,t}/y_{j,t}$.	Computed from trade flows and total expenditure (see above).
L_i	Labor endowment of country i (kept fixed in counterfactuals).	World Bank (labor force, population).
ε	Trade elasticity (slope of import demand with respect to trade costs).	Calibrated from Simonovska and Waugh (2014): 0.116 for agriculture sector, and 0.111 for non-agriculture sector.

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Iteration Algorithm

1. **Initialization.** Choose an initial wage vector $w^{(0)}$ and normalize one country's wage (e.g. $w_A = 1$).

2. **Expenditure shares.** For each sector $s = 1, \ldots, S$, compute

$$\lambda_{ij}^{s,(m)} = \frac{\left(w_i^{(m)} \tau_{ij}^{s\prime}\right)^{-\theta^s}}{\sum_k \left(w_k^{(m)} \tau_{kj}^{s\prime}\right)^{-\theta^s}}. \tag{6}$$

- $w_i^{(m)}$: wage in exporter country i at iteration m (labor is mobile across sectors within a country);
- $\tau_{ij}^{s\prime}$: iceberg trade cost for sector s goods from i to j under the counterfactual tariff scenario;
- $\theta^s > 0$: trade elasticity for sector s;
- $\lambda_{ij}^{s,(m)}$: share of importer j's expenditure on sector s allocated to exporter i at iteration m.

Iteration Algorithm

3. **Income update.** Using wages from the previous iteration,

$$y_j^{(m)} = w_j^{(m)} L_j,$$

allocating nominal incomes across sectors using expenditure weights η_j^s (the share of sector s in country j's final demand). Compute country i's sectoral sales:

$$y_i^{s,(m+1)} = \sum_j \lambda_{ij}^{s,(m)} \, \eta_j^s \, y_j^{(m)}.$$

Aggregate across sectors to obtain total nominal income:

$$y_i^{(m+1)} = \sum_s y_i^{s,(m+1)}.$$

Iteration Algorithm

4. **Wage update.** Compute new wages:

$$w_i^{(m+1)} = \frac{y_i^{(m+1)}}{L_i},$$

and renormalize using the chosen numeraire.

5. **Convergence check.** If

$$\max_i \left| w_i^{(m+1)} - w_i^{(m)} \right| < \text{tol},$$

stop; otherwise, return to step 2.

back

Model Setup

- N countries indexed by $i = 1, \ldots, A, \ldots, N$.
- Consumers in each country have CES preferences
- Perfect competition
- Tariffs (from exportor i to importer j in year t) map to iceberg costs:

$$\tau_{ij,t} = 1 + t_{ij,t} \tag{7}$$