Maritime Security as a Global Public Good: Trade Frictions, Chokepoint Vulnerability, and a Scenario Engine Using AIS Shipping Density

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Motivation

- $\sim$80% of world trade by volume traverses the oceans (Verschuur et al., 2023)
- Trade funnels through a small number of physical bottlenecks: straits, canals, narrow sea lanes
- When security breaks down $\Rightarrow$ rerouting, congestion, elevated trade costs
- The U.S. Navy provides security at these chokepoints as a **global public good** (Bueger et al., 2024)
- **Key question:** What is the economic value of this security provision?

Research Question

Central Question

How sensitive is the global maritime trading system to disruptions at critical chokepoints, and what is the economic value of security provision that prevents or mitigates such disruptions?

- Approach: scenario-based quantitative spatial framework
- Not causal estimation — counterfactual simulation
- Builds on transportation networks literature (Fajgelbaum and Schaal, 2020a; Allen and Arkolakis, 2022)
- AIS data from IMF (Cerdeiro et al., 2020) for empirical grounding

Literature: Maritime Security as a Public Good

- Maritime security exhibits classic public-good properties: **non-rivalry** and partial **non-excludability** (Bueger et al., 2019, 2024)
- Legal foundations: freedom of navigation, passage through straits (Kraska, 2015)
- Economic costs of insecurity documented:
  - Piracy: ransoms, insurance, rerouting, deterred investment (One Earth Future Foundation, 2010)
  - African development impacts (Mbekeani and Ncube, 2011)
- Gap: the *value* of security provision remains poorly quantified

Literature: Trade Frictions & Maritime Risk

- Besley et al. (2015): piracy acts as a **cost shifter** for international shipping
  - Spatial/temporal variation in piracy risk $\Rightarrow$ shipping cost impacts
- Verschuur et al. (2023): chokepoint disruptions cause systemic GDP impacts
  - Some scenarios: several % of GDP for vulnerable economies
- Port congestion literature: capacity constraints $\Rightarrow$ freight rate increases (Notteboom, 2006; Du et al., 2020)
- Maritime transport economics: market structure, pricing (Morabito, 2023)

Literature: Quantitative Spatial Economics

- Foundational framework: Redding and Rossi-Hansberg (2017)
  - Locations differ in productivity; trade costs govern flows across space
- Regional and urban extensions: Allen and Arkolakis (2025), Redding (2025)
- Key toolkit: iceberg trade costs, gravity trade flows, hat-algebra counterfactuals
- Agglomeration foundations: Duranton and Puga (2004)
- Geography of development: Desmet and Henderson (2015)
- "What can be learned": Proost and Thisse (2019)

Literature: Transportation Networks & Congestion

- Fajgelbaum and Schaal (2020a): optimal transport networks in spatial equilibrium
  - Endogenous route choice; optimal networks concentrate on high-traffic corridors
- Allen and Arkolakis (2022): welfare effects of infrastructure with endogenous congestion
- Donaldson (2025): comprehensive survey of infrastructure evaluation
- Congestion pricing: Hierons (2024)
- Political fragmentation: Bordeu (2025)
- Network model structure: Rossi-Hansberg (2020)

Literature: AIS Data & Research Gap

- AIS data: cornerstone of modern maritime economics (Kerbl, 2022)
- COVID shock on container flows: Cariou and Cheaitou (2021)
- Nowcasting world trade from AIS: Cerdeiro and Komaromi (2020)
- IMF World Seaborne Trade Monitoring System: Cerdeiro et al. (2020)

Gap

No existing work combines a global maritime network model with endogenous rerouting and congestion to value security provision under counterfactual disruptions.

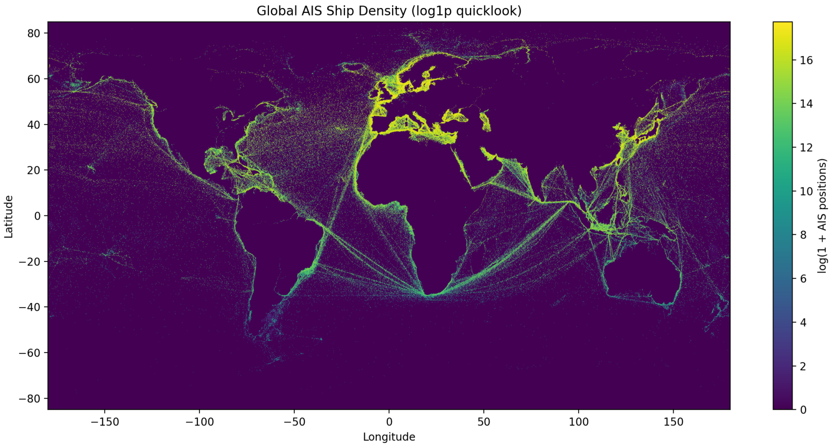
Data: AIS Ship Density Raster

- Source: IMF World Seaborne Trade Monitoring System (Cerdeiro et al., 2020)
- Period: January 2015 – February 2021
- Resolution: $0.005^\circ \times 0.005^\circ$ ($\approx$ 500m $\times$ 500m at equator)
- Each cell: total count of AIS position reports
- Format: single GeoTIFF ($\sim$9 GB) + overview pyramids ($\sim$3 GB)
- Processing: overviews for visualization, windowed reads for chokepoints

HIGLY Skewed Data

Median cell $= 0$, P90 $= 1$, P99 $\approx$ 8.6M, Max $\approx$ 50.6M

Global Shipping Density (Log Scale)



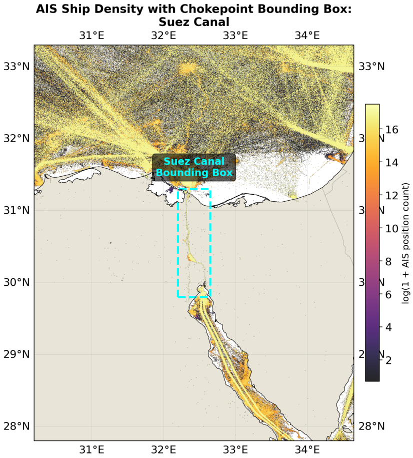
Extremely right-skewed: most ocean is empty; traffic concentrates at sea lanes and chokepoints.

Chokepoint Definitions: Bounding Box Approach

Six chokepoints defined as geographic bounding boxes:

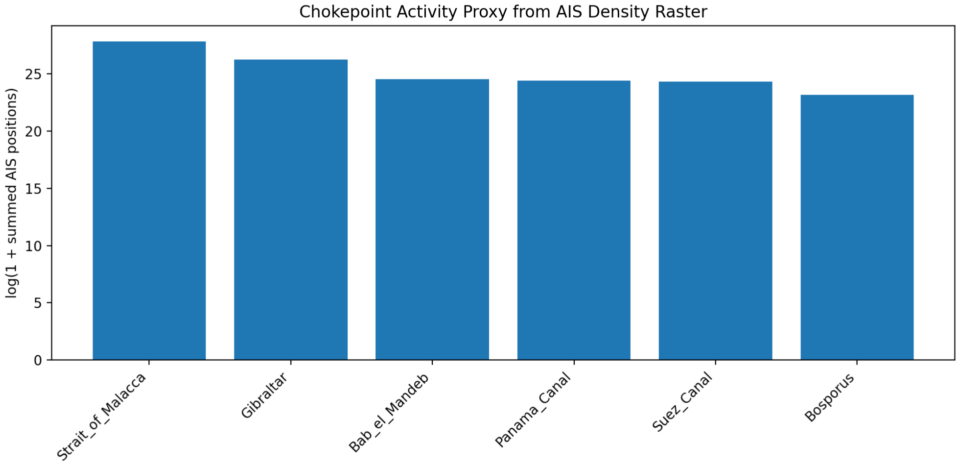
1. **Suez Canal**
2. Bab el-Mandeb
3. Strait of Malacca
4. Panama Canal
5. Bosporus
6. Gibraltar

Selected per Verschuur et al. (2023); Bueger et al. (2024).



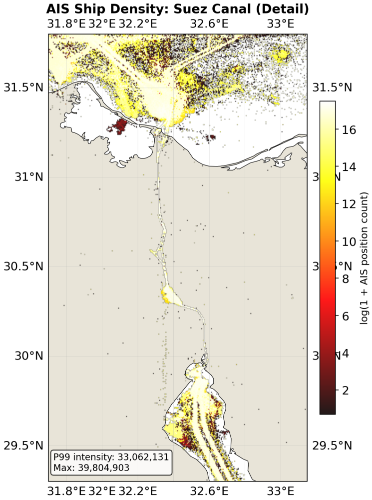
Suez Canal: AIS density with bounding box

Chokepoint Traffic Intensity



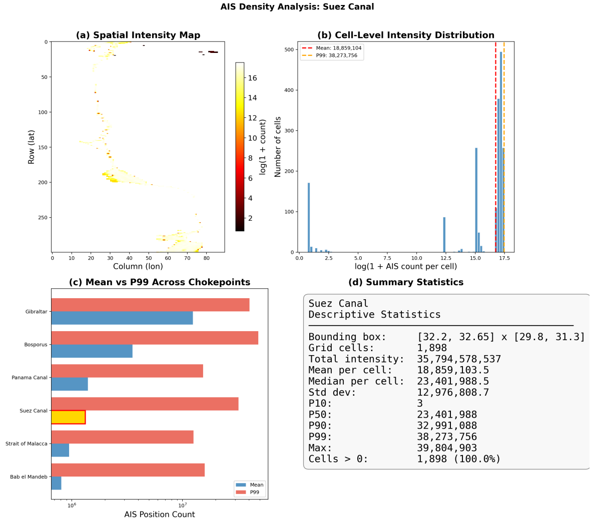
Traffic intensity ranking across six chokepoints from AIS density data.

AIS Density Detail: Suez Canal



Traffic concentrates along the canal corridor and approach channels from Port Said and Suez.

Suez Canal: Descriptive Statistics



Methods: Maritime Transport Network

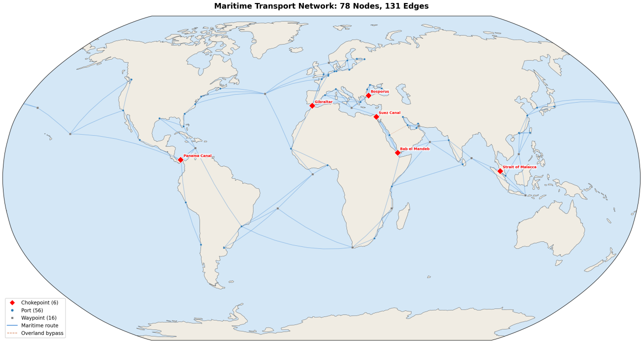
$G = (\mathcal{J}, \mathcal{E})$: 78 nodes, $\sim$155 edges

- **56 ports**: major world ports at real coordinates
- **6 chokepoints**: maritime bottlenecks
- **16 waypoints**: ocean routing nodes

Key design: **bypass-dependent**

- Black Sea $\rightarrow$ Bosporus (bypass: rail at $5\times$)
- Malacca bypass: Lombok Strait
- Suez bypass: Cape of Good Hope

1,540 port-to-port OD pairs



78-node maritime network with bypass routes

Methods: Edge Cost Specification

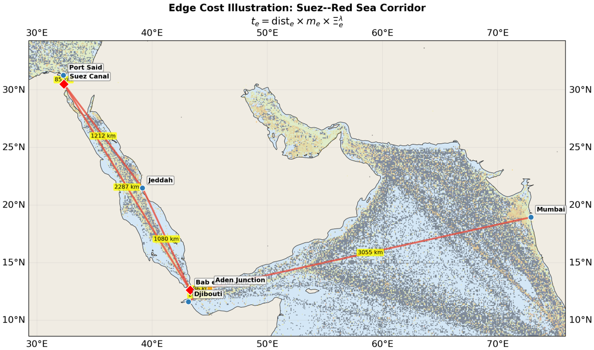
Generalized cost of edge e:

$$t_e = \bar{t}_e \cdot (\Xi_e)^{\lambda}$$

$$\bar{t}_e = \text{dist}_e \cdot m_e$$

- Ξ_e: AIS congestion proxy
- $\lambda \geq 0$: congestion elasticity
- m_e: security/risk multiplier

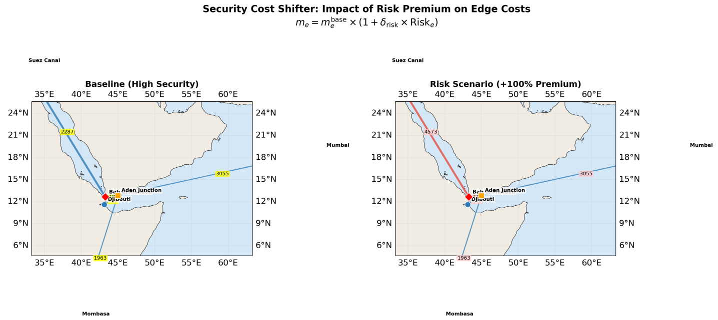
(Allen and Arkolakis, 2022; Hierons, 2024)



Suez–Red Sea corridor with edge distances

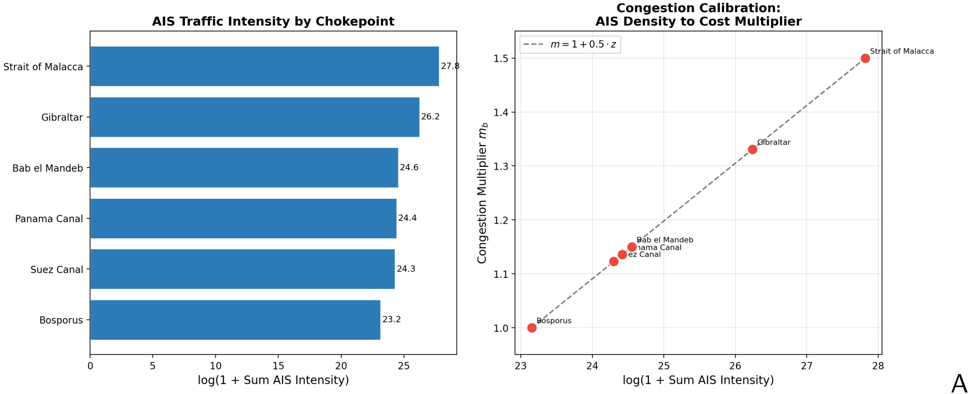
Methods: Security as a Cost Shifter

$$m_e = m_e^{\text{base}} \cdot (1 + \delta_{\text{risk}} \cdot \text{Risk}_e) \cdot (1 - \delta_{\text{sec}} \cdot S_e)$$



Left: baseline costs. Right: +100% risk premium doubles edge costs at Bab el-Mandeb (Besley et al., 2015).

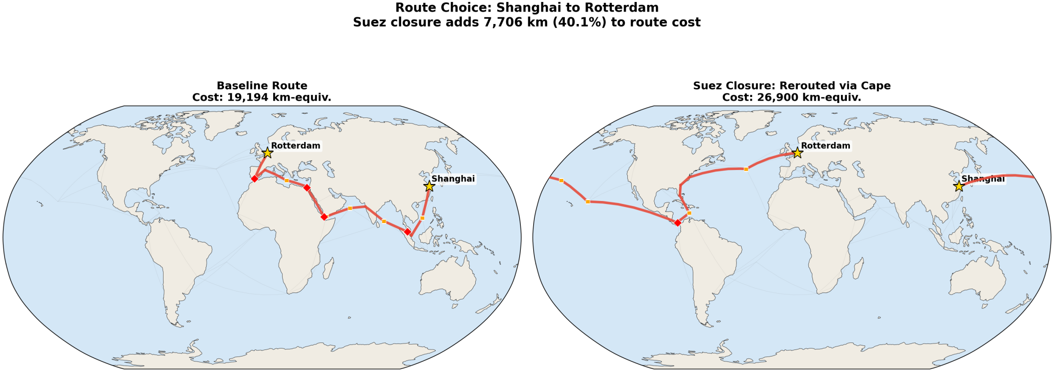
Methods: Congestion Calibration from AIS



AIS intensity $\rightarrow$

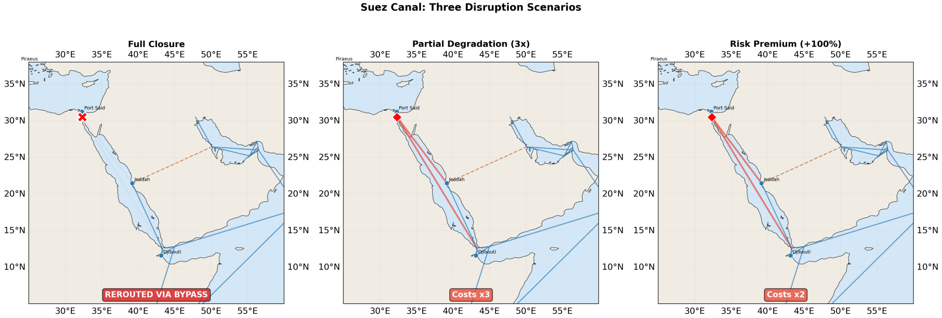
congestion multiplier $m_b \in [1, 1.5]$ via log-scaling (Notteboom, 2006; Du et al., 2020).

Methods: Route Choice Before/After



Shanghai → Rotterdam: Suez closure forces rerouting via North Pacific → Panama (Cariou and Cheaitou, 2021).

1. **Full closure**: Remove chokepoint b; recompute all 1,540 shortest paths
2. **Partial degradation**: Multiply edge costs by $\alpha \in \{1.25, \ldots, 10.0\}$
3. **Security risk premium**: Apply $\delta_{\text{risk}} \in \{10\%, \ldots, 200\%\}$ per chokepoint



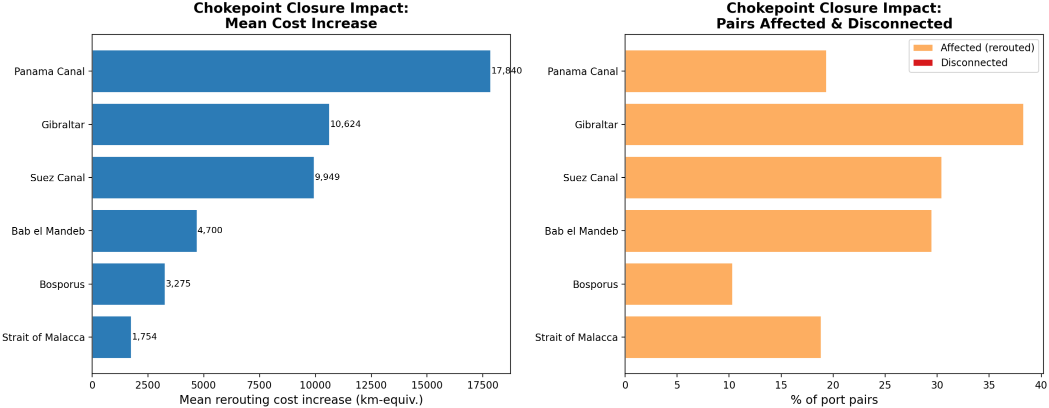
Suez Canal: 3 scenarios illustrated

Results: Full Closure — Vulnerability Ranking

Chokepoint Removed	Mean Δ (km)	Affected	Disconn.	Total
Panama Canal	17,840	298	0	1,540
Gibraltar	10,624	590	0	1,540
Suez Canal	9,949	469	0	1,540
Bab el-Mandeb	4,700	454	0	1,540
Bosporus	3,275	159	0	1,540
Strait of Malacca	1,754	290	0	1,540

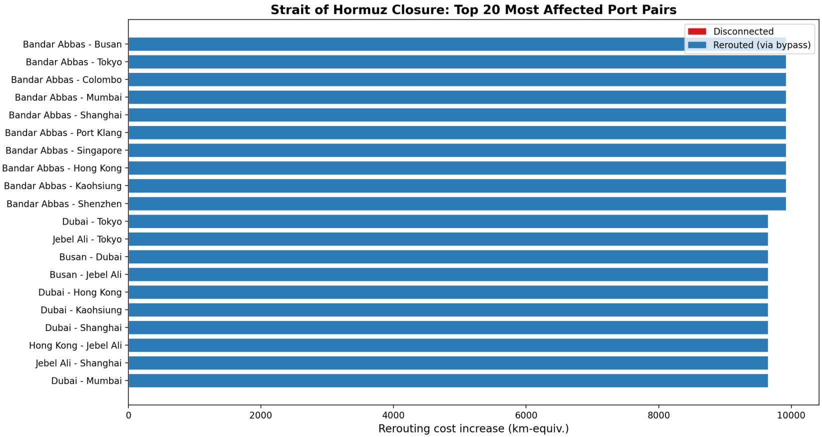
0 disconnected pairs: bypass routes (overland, Lombok, Cape of Good Hope) ensure all ports remain connected.

Results: Full Closure — Visual Summary



Left: mean rerouting cost. Right: fraction of 1,540 pairs affected by each closure.

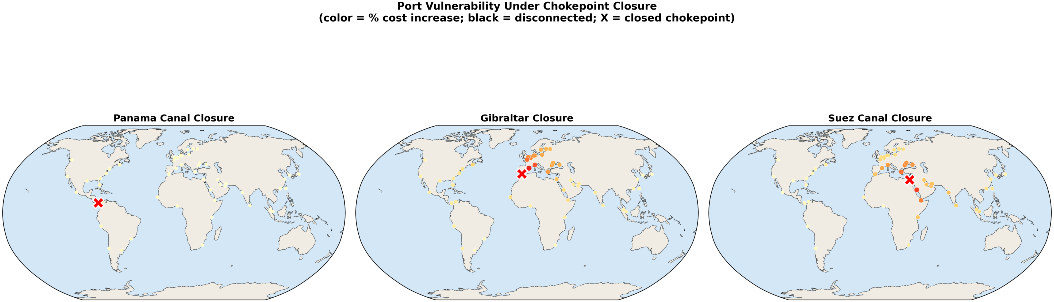
Results: Suez Canal Closure



469 pairs affected. Asia–Europe traffic rerouted via Cape of Good Hope or Panama Canal.

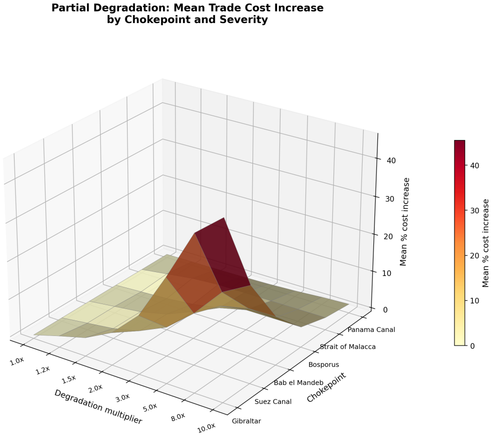
Mean $\Delta = 9{,}949$ km, Max $\Delta = 23{,}317$ km. 0 pairs disconnected.

Results: Port Vulnerability Under Closure



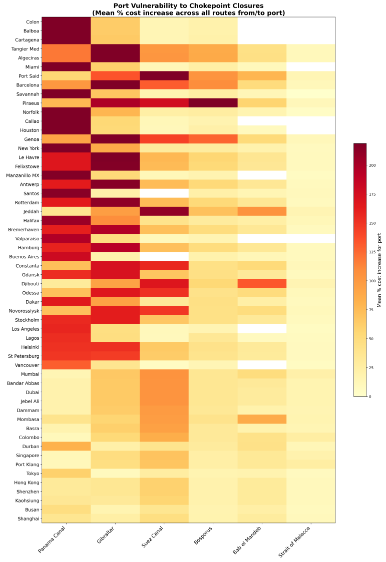
Port color = mean % cost increase. X = closed chokepoint. Panama, Gibraltar, Suez shown.

Results: Partial Degradation Surface



At $\alpha = 5$: Gibraltar +26.5%, Suez +12.7%, Bab el-Mandeb +10.1%, Bosporus +4.5%.

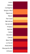
Results: Port Vulnerability Matrix



56 ports × 6 chokepoints. Color = mean % cost increase under full

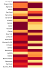
Results: Port Vulnerability Matrix — Hotspots (Zoom-ins)

Panama Canal (highest cells)



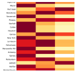
Colon; Balboa; Cartagena; Callao; Norfolk; New York; Savannah; Houston; Miami; Manzanillo MX.

Gibraltar (highest cells)



Le Havre; Tangier Med; Algeciras; Barcelona; Genoa; Felixstowe; Antwerp; Rotterdam; Bremerhaven; Hamburg.

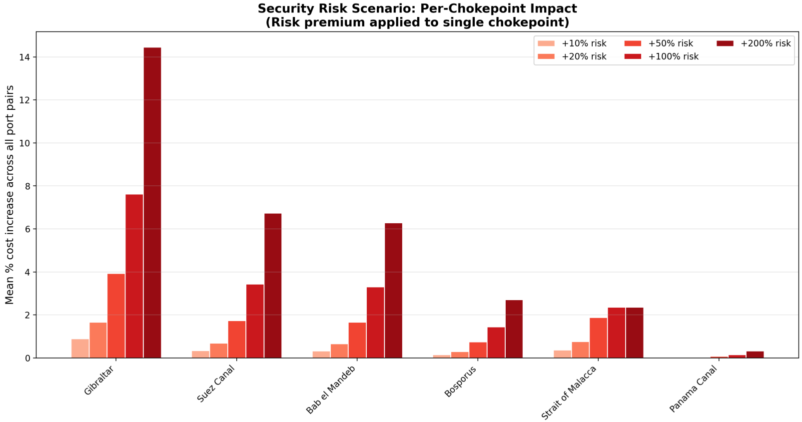
Suez Canal (highest cells)



Port Said (peak); Jeddah (very high). Secondary (visually lighter): Piraeus; Djibouti.

Bosporus (highest cell)

Results: Per-Chokepoint Security Risk



Pure scenario: risk premium applied to *one chokepoint at a time*. No "high/low" categorization.

Results: Daily Rerouting Cost of Closure

Chokepoint	Daily Vessels	Detour (km)	Cost/Day (Low)	Cost/Day (High)
Gibraltar	219	10,624	\$116M	\$233M
Panama	37	17,840	\$33M	\$66M
Suez Canal	53	9,949	\$27M	\$53M
Malacca	233	1,754	\$20M	\$41M
Bosporus	118	3,275	\$19M	\$39M
Bab el-Mandeb	68	4,700	\$16M	\$32M

Low = \$50/km; High = \$100/km. Aggregate: \$230–460M/day across all chokepoints.

The Hegemonic Dividend

- **Daily costs**: Gibraltar closure alone ⇒ \$117–233M/day in rerouting costs
- **Aggregate**: simultaneous closure of all six chokepoints ⇒ \$85–170B/year
- The "hegemonic dividend" = avoided cost from maintaining security
- Dividend is **increasing in risk**: value of security rises as conditions worsen
- Heterogeneous benefits: bypass-dependent ports (Black Sea) benefit most

(Bueger et al., 2024; Besley et al., 2015; One Earth Future Foundation, 2010)

Structural Patterns

- **Two types of chokepoints**:
  - *Through-corridor* (Malacca, Gibraltar, Suez, Panama): rerouting costs, gradual impact
  - *Bypass-dependent* (Bosporus): expensive overland rerouting at $5\times$ cost
- **Policy implications differ**: capacity expansion vs. redundancy investment
- **Nonlinear severity**: severity curves accelerate at high α for corridor chokepoints
- **Supply chain resilience**: Panama Canal closure produces largest mean detour (17,840 km)
- **Connects to:** optimal networks (Fajgelbaum and Schaal, 2020a), congestion (Hierons, 2024), spatial policy (Fajgelbaum and Gaubert, 2020)

Limitations

- **Static aggregate**: single 2015–2021 snapshot; no temporal dynamics
- **Aggregate density**: AIS counts, not shipped value; no vessel-type distinction (Kerbl, 2022)
- **No welfare computation**: delta costs, not GE welfare changes (Redding and Rossi-Hansberg, 2017)
- **Exogenous security**: risk premiums are sensitivity inputs, not calibrated
- **Stylized network**: 78 nodes captures major routes but not all alternatives
- All results labeled as **“partial-exercise” estimates**

Policy Implications

1. **Resource allocation**: prioritize through-corridor chokepoints (Gibraltar, Suez, Bab el-Mandeb) for capacity maintenance (Fajgelbaum and Gaubert, 2020)
2. **Redundancy investment**: bypass-dependent chokepoints need alternative infrastructure (overland routes)
3. **Burden-sharing**: economic case for security strengthens as risk rises (One Earth Future Foundation, 2010; Mbekeani and Ncube, 2011)
4. **Supply chain diversification**: corridor-dependent ports should develop alternative routing (Bordeu, 2025)
5. **Optimal security allocation**: spatial policy framework (Fajgelbaum and Gaubert, 2025; Gaubert et al., 2025)

Future Research Directions

1. **Vessel-level AIS**: OD flow matrices, route-choice models (Kerbl, 2022; Fajgelbaum and Schaal, 2020a,b)
2. **Bilateral trade data**: calibrate full spatial equilibrium (Allen and Arkolakis, 2025; Redding, 2025)
3. **Insurance & risk data**: calibrate security parameters (Besley et al., 2015)
4. **Naval presence proxies**: move from simulation to causal inference (Proost and Thisse, 2019)
5. **Dynamic extensions**: stochastic disruptions (Bordeu, 2025; Desmet and Henderson, 2015)
6. **Optimal allocation**: security budget across chokepoints (Rossi-Hansberg, 2004; Fajgelbaum et al., 2019)

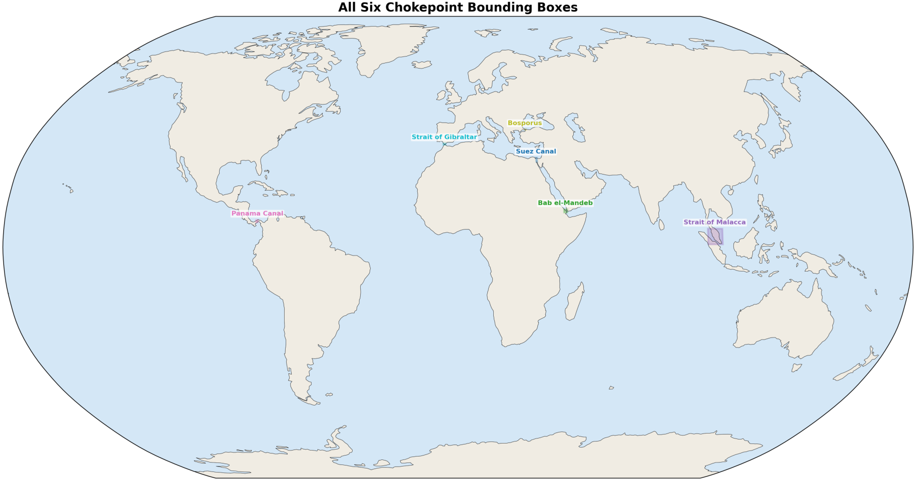
Conclusion

Takeaways

1. Chokepoint disruptions produce **large, heterogeneous** trade-cost impacts
   - Panama: 17,840 km mean rerouting; Suez: 9,949 km; Gibraltar: 10,624 km
2. Two vulnerability types: **rerouting** (through-corridor) vs **expensive bypass** (bypass-dependent)
3. The **hegemonic dividend** is increasing in the risk environment
4. Daily closure costs: **\$16M–\$233M/day** depending on chokepoint
5. This is a **replicable framework** identifying data needs for full causal assessment

Bueger et al. (2024); Fajgelbaum and Schaal (2020a); Besley et al. (2015); Verschuur et al. (2023)

Appendix: All Chokepoint Bounding Boxes



Six chokepoint bounding boxes overlaid on world map. Individual zooms in paper appendix.

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