The Impact of Climate Change on Global Trade through the Panama Canal

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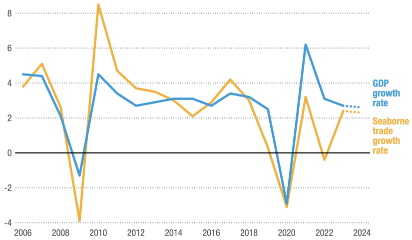
Global Trade in the Age of Climate Change

Maritime trade is shaped by trends in the world economy.



Source: UN Trade and Development (UNCTAD)

Trade routes can be affected by geopolitical conflict, human/technology factors, and **climate change**:

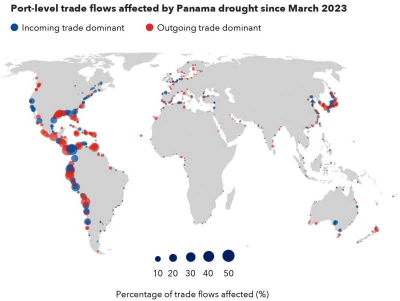
- ✓ Melting Arctic ice [Bekkers et al., 2018, Sibul and Jin, 2021]
- ✓ Changes in sea levels [Hanson and Nicholls, 2020, Martínez et al., 2023]
- ✓ Extreme weather events [Dallmann, 2019, Osberghaus, 2019]

The Panama Canal Hub

- ✓ An essential contributor to the **global economy**:
  - The Canal handles approximately 5% of world trade. ▸ Detail
  - 72% of transiting ships are going to or coming from U.S. ports.
  - Total revenue of almost 5 billion dollars ∼8.5% of Panama's GDP.
- ✓ Operates using a **lock system**: From sea to Gatun Lake levels.

Climate Variability Disruption:

- ✓ **ENSO** phenomenon
- ✓ Challenge to maintaining water levels in the **Gatun Lake**
- ✓ Panama Canal Authority (PCA) has reduced 40% of daily traffic in 2024.



Source: UN Global Platform; PortWatch

Research question

What is the economic impact of climate-related disruptions of the Panama Canal on international trade?

We need to understand the following pieces...

- ✓ How do variations in water availability in the Panama Canal affect vessel-level trade volumes? Detail
- ✓ Can climate-induced disruptions in strategic chokepoints be conceptualized as non-tariff trade barriers in a structural gravity framework?
- ✓ What are the potential welfare consequences of prolonged climate-driven disruptions to Panama Canal access under future scenarios?

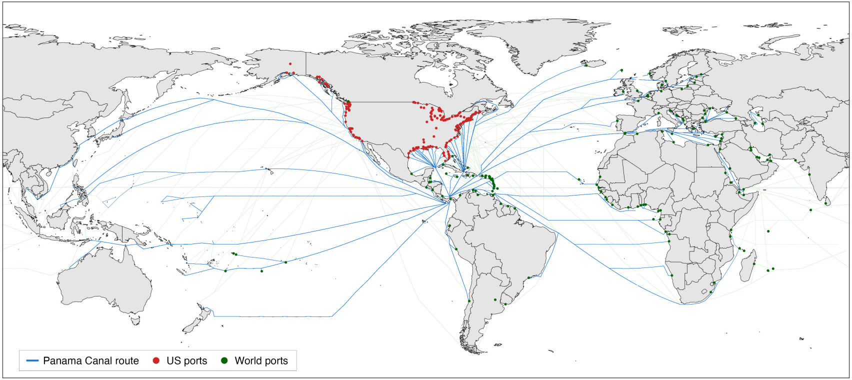
Related Literature and Contributions

- ✓ Impact of Climate change on bilateral trade flows [Martínez et al., 2023, Dunbar et al., 2023, Huppertz, 2024]
  - Localized water scarcity events can have cascading impacts on global trade flows.
- ✓ Non-Tariff Barriers and Climate Disruptions [Hummels and Schaur, 2013, Coșar and Demir, 2016]
  - The use of a natural barrier to understand climate change's impact on maritime trade.
- ✓ Tracing spatiotemporal changes in trade networks [Bekkers et al., 2018, Vishwakarma et al., 2022, Kulkarni et al., 2023]
  - Potentially rerouting of trade flows that impact the competitiveness of different regions.

Monthly data sources

- ✓ Panama Canal - Hydrological (Daily): 1960 - 2024
  - Hydrological: Lake levels, inflows, runoff.
  - Meteorological: Precipitation, temperature, humidity.
- ✓ U.S. International Trade by Port: 2010 - 2024
  - Average U.S. Imports and Exports Detail
  - U.S. Trade by Commodity and Coast (i.e., East vs West Coast) Detail
- ✓ Nighttime Lights: 2014 - 2024
  - Remote sensing of nighttime light emissions
- ✓ IMF Port watch and Searoute py:
  - Representative ports and chokepoints (e.g., Panama Canal)
  - Shortest sea route between two points on Earth

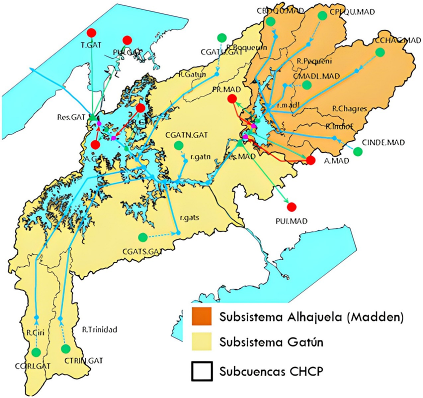
U.S. Maritime Trade Routes



From 2024 data: U.S. Census Bureau, IMF Port watch, and Searoute py

- ✓ 157 US ports, 170 countries.
- ✓ 25% of the total trade (i.e., imports and exports) from the U.S. uses the Panama Canal.

The Panama Canal Watershed (PCW)



Source: Territorial Planning Assessment (PIOTA 2021).

Measuring the Water scarcity in the Panama Canal ($f_{ws}(PC)$):

- ✓ $f^1_{ws}(\cdot)$: Gatun Lake (GL) level (ft).
- ✓ $f^2_{ws}(\cdot)$: Panama Canal Watershed (PCW) precipitation (mm).

Gravity estimation framework

Gravity equation describe trade flows F_{eit} between an origin (exporter) e and destination (importer) i at time t as [Head and Mayer, 2014]

$$F_{eit} = S_{et} M_{it} \phi_{eit} \tag{1}$$

where

- ✓ S_{et} and M_{it} are exporter and importer-specific terms
- ✓ ϕ_{eit} is a trade cost (i.e., bilateral resistance term).

The bilateral resistance term is usually modeled as

$$\phi_{eit} = d_{ei}^{\alpha_t} \exp\left(\mathbf{W}'_{eit} \beta_t\right)$$

where

- ✓ d_{ei} a measure of physical distance between the two countries
- ✓ $\mathbf{W}_{eit}$ a collection of bilateral variables that affect trade
- ✓ α_t the elasticity of trade flows with respect to distance

Climate change effect on bilateral resistance

- ✓ Effect of distance to vary as average temperature changes (ΔT) [Martínez et al., 2023, Huppertz, 2024]

$$\phi_{eit} = d_{ei}^{\alpha_t + \delta_1 \Delta T_{et} + \delta_2 \Delta T_{it}} \exp\left(\mathbf{W}'_{eit}\beta_t\right)$$

- ✓ Impact of hurricanes (h) on seaborne trade routes [Dunbar et al., 2023]

$$\phi_{eit} = d_{ei}^{\alpha_t + \sum_{p=-5}^{5} \delta_p h_{ei,t+p}} \exp\left(\mathbf{W}'_{eit}\beta_t\right)$$

Impact of the water scarcity in the Panama Canal (i.e., GL levels, PCW precipitation) on the international trade

$$\phi_{eit} = d_{ei}^{\alpha_t + \gamma_1 f_{ws}(PC)} \exp\left(\mathbf{W}'_{eit}\beta_t\right) \tag{2}$$

Empirical strategy: OLS

The intuitive gravity model takes the following log-linearized form

$$\log F_{eit} = \log S_{et} + \log M_{it} + \log(\phi_{eit})$$

With exporter-period and importer-period fixed effects η_{et} and ξ_{it}.

$$\begin{aligned}\log F_{eit} &= \eta_{et} + \xi_{it} + \log\left(\phi_{eit}\right) + \epsilon_{ijt} \\ &= \eta_{et} + \xi_{it} + \alpha_t \tilde{d}_{ei} + \tilde{d}_{ei} f_{ws}(PC) + \mathbf{W}'_{eit}\boldsymbol{\beta}_t + \epsilon_{ijt} \\ &= \eta_{et} + \xi_{it} + \alpha_t \tilde{d}_{ei} + \gamma_1 \mathbb{1}_{\mathrm{PC}}(e,i) f_{ws}(PC) + \mathbf{W}'_{eit}\boldsymbol{\beta}_t + \epsilon_{ijt}\end{aligned}$$

Issues with OLS in the gravity model:

- ✓ Log-linearizing the gravity model introduces a log error term, which leads to inconsistency when the error term is heteroskedastic.
- ✓ Zero trade flows are relatively common in the bilateral trade matrix.

Empirical strategy: PPML

Suppose that the exporter/importer fixed effects as well as all determinants of ϕ_{eit} are combined into $\mathbf{H}_{eit}$ vector and that the coefficients on these variables are ζ.

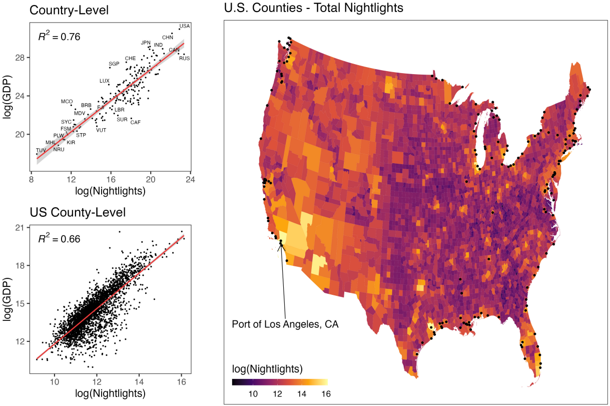
The pseudo-Poisson maximum likelihood estimation (PPML) delivers consistent ζ as long as [Silva and Tenreyro, 2006]:

$$
\begin{aligned}
\mathbb{E}\left[F_{eit} \mid \mathbf{H}_{eit}\right] &= \exp\left(\mathbf{H}'_{eit}\zeta\right) \\
&= \exp\left(\eta_{et} + \xi_{it} + \log\left(\phi_{eit}\right)\right) \\
&= \exp\left(\eta_{et} + \xi_{it} + \alpha_t \tilde{d}_{ei} + \tilde{d}_{ei} f_{ws}(PC) + \mathbf{W}'_{eit}\boldsymbol{\beta}_t\right) \\
&= \exp\left(\eta_{et} + \xi_{it} + \alpha_t \tilde{d}_{ei} + \gamma_1 \mathbb{1}_{\mathrm{PC}}(e,i) f_{ws}(PC) + \mathbf{W}'_{eit}\boldsymbol{\beta}_t\right)
\end{aligned}
$$

with exporter-period and importer-period fixed effects η_{et} and ξ_{it}.

Measuring Economic Growth from Outer Space

Nightlights as a proxy of the exporter and importer-specific terms (e.g., GDP, infrastructure use, and industrial output) [Henderson et al., 2012].



From 2023 data: World Bank, U.S. BEA, and Nighttime Lights

Impact of PC disruptions on Trade Flows

	GL level (ft)		PCW Precip. (10 mm)	
	PPML	OLS	PPML	OLS
log(distance)	-0.5987*	-0.9138***	-0.5985*	-0.9137***
	(0.3306)	(0.3520)	(0.3305)	(0.3520)
PC use	-0.1964	0.3022	-0.7840***	-0.3640**
	(0.3116)	(0.3546)	(0.1851)	(0.1776)
PC use × Lake level (ft)	**-0.0073****	-0.0080**		
	(0.0030)	(0.0038)		
PC use × Precip. (10 mm)			**-0.0014****	-0.0004
			(0.0006)	(0.0005)
Num. Obs.	1,012,329	1,012,329	1,012,329	1,012,329
Num. US Counties	157	157	157	157
Num. Countries	170	170	170	170
FE: Time x Exporter	X	X	X	X
FE: Time x Importer	X	X	X	X

Note: The outcome variable is the monthly vessel-level trade value (USD). Two disruption measures in the Panama Canal (PC) are used: Gatun Lake (GL) water levels and precipitation within the Panama Canal Watershed (PCW). Standard errors are clustered at both the exporter and importer levels. (*** $p < 0.01$, ** $p<0.05$, * $p<0.1$).

PC disruptions on U.S. Imports and Exports

	GL level (ft)		PCW Precip. (10 mm)	
	Imports	Exports	Imports	Exports
log(distance)	-0.5561	-0.6513*	-0.5559	-0.6512*
	(0.5035)	(0.3789)	(0.5033)	(0.3789)
PC use	-0.1628	-0.3338	-0.8255***	-0.7128***
	(0.4435)	(0.3713)	(0.2714)	(0.2186)
PC use $\times$ Lake level (ft)	**-0.0083****	-0.0046		
	(0.0037)	(0.0041)		
PC use $\times$ Precip. (mm)			**-0.0018*****	-0.0004
			(0.0007)	(0.0005)
Num. Obs.	463,467	548,862	463,467	548,862
Num. US Counties	157	157	157	157
Num. Countries	170	170	170	170
FE: Time x Exporter	X	X	X	X
FE: Time x Importer	X	X	X	X

Note: The table reports Poisson pseudo-maximum likelihood (PPML) estimates of monthly vessel-level trade value (USD) on Panama Canal (PC) disruptions.

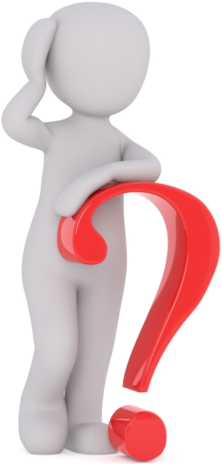
Using Nightlights Instead of Fixed Effects

	GL level (ft)		PCW Precip. (10 mm)	
	FE	Nightlights	FE	Nightlights
log(distance)	-0.5987***	0.1484***	-0.5985***	0.1483***
	(0.0238)	(0.0000)	(0.0238)	(0.0000)
PC use	-0.1925	-0.8052***	-0.7840***	-0.1562***
	(0.2723)	(0.0000)	(0.0197)	(0.0000)
Nighlights importer (Avg. rad)		0.0000***		0.0000***
		(0.0000)		(0.0000)
Nighlights exporter (Avg. rad)		0.0000***		0.0000***
		(0.0000)		(0.0000)
PC use $\times$ Lake level (ft)	-0.0074**	**0.0077*** **		
	(0.0032)	(0.0000)		
PC use $\times$ Precipitation (mm)			-0.0014**	**-0.0002*** **
			(0.0006)	(0.0005)
Num. Obs.	1,012,329	689,533	1,012,329	689,533
Dates Covered	2010-2024	2014-2024	2010-2024	2014-2024
FE: Time x Exp	X		X	
FE: Time x Imp.	X		X	
Controls: Lake level		X		
Controls: Precip.				X

Conclusions and Future work

- ✓ Water scarcity effect on trade routes using the Panama Canal:
  - Trade falls by **0.73% per foot drop** (i.e., $\sim 3.7\%$ trade reduction if the future levels are 5 feet lower [DNV GL, 2014]).
  - **10 mm decrease** in monthly precipitation reduces trade by **0.14%** (i.e., $\sim 8.4\%$ trade reduction during extremely dry months).
- ✓ Heterogeneity analysis:
  - The trade impact appears more pronounced on imports.
  - Satellite-measured nightlight intensity captures relevant economic changes over time (e.g., policy changes, infrastructure disruptions).
- ✓ Future Research Directions
  - Nonlinear Effects
  - Disaggregated Sectoral Impacts
  - Adaptation & Rerouting Analysis

Questions?



Which economies use the Panama Canal?

Routes	PCU/MS 2023	PCU/MS 2024	% Δ PCU/MS
East Coast U.S. - Asia	246,768,488	204,056,339	-17.31%
East Coast U.S. - W.C. South America	48,063,058	36,621,051	-23.81%
South America Intercoastal	26,037,602	30,509,715	17.18%
Europe - West Coast South America	25,799,446	20,293,355	-21.34%
East Coast U.S. - W.C. Central America	19,685,783	19,042,652	-3.27%
Europe - West Coast U.S.	15,457,079	14,181,845	-8.25%
U.S. Intercoastal including Alaska and Hawaii	11,884,991	13,580,741	14.27%
Central America Intercoastal	8,797,454	9,432,120	7.21%
E.C. Central America - W.C. South America	9,509,440	9,255,494	-2.67%
E.C. South America - Asia	16,336,445	7,944,913	-51.37%
E.C. South America - W.C. Central America	7,632,903	6,776,150	-11.22%
E.C. South America - West Coast U.S.	6,229,097	5,422,850	-12.94%
Asia - E.C. Central America	7,730,648	5,046,868	-34.72%
East Coast U.S. - Oceania	5,942,570	4,639,835	-21.92%
West Indies - Asia	5,164,159	3,979,433	-22.94%
W.C. Central America - Europe	3,016,240	2,960,520	-1.85%
Europe - Oceania	2,564,343	1,359,786	-46.97%
Asia - Europe	2,015,420	1,236,419	-38.65%
E.C. Central America - West Coast US	2,201,127	1,210,800	-44.99%
All Other Routes	40,300,417	25,542,186	-36.62%
Total	**511,136,710**	**423,093,072**	

Source: Panama Canal, Transit statistics. Panama Canal Universal Measurement System (PC/UMS)

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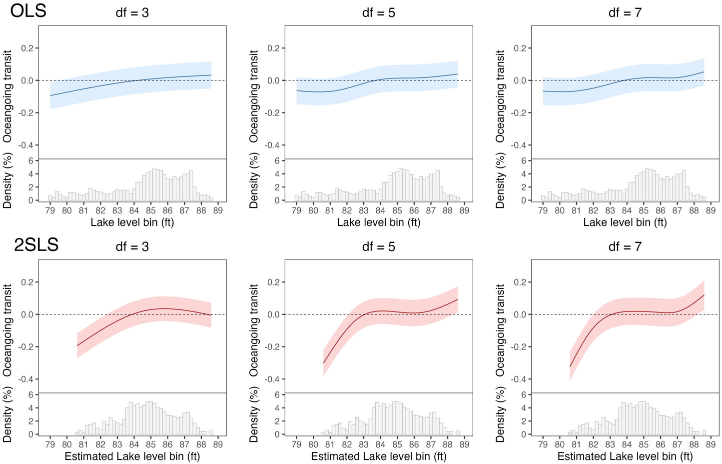
The effect of Lake level on Oceangoing transit



An additional day of exposure to the lake levels below 81 ft reduces oceangoing transits up to 0.2 points or about 20%.

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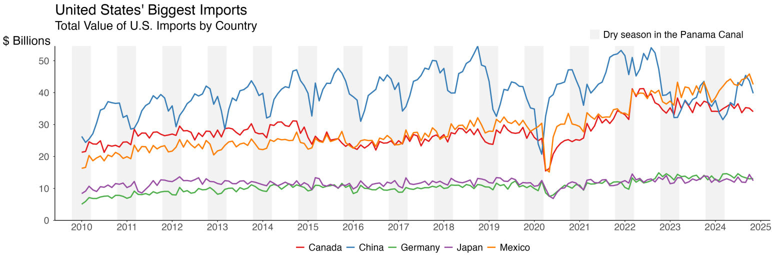
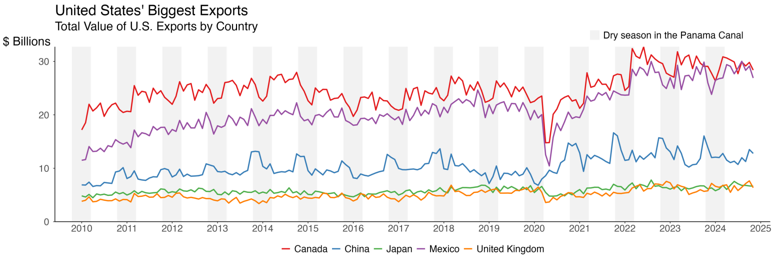
US imports and exports





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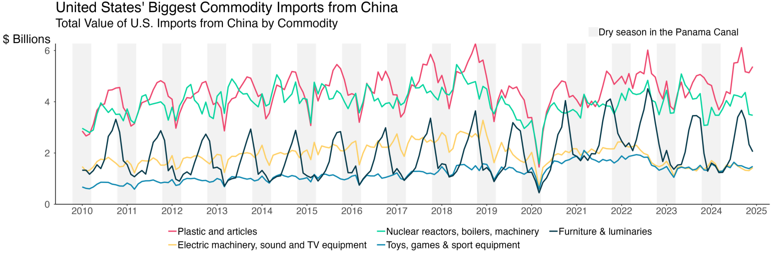
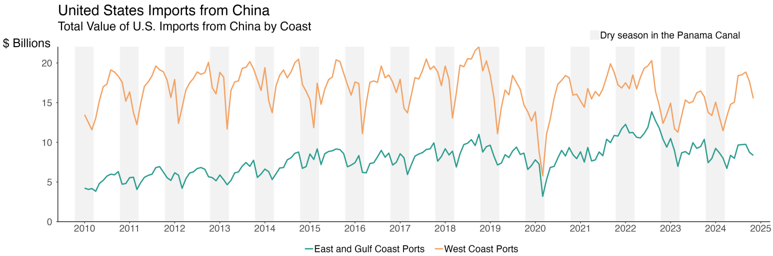
International Trade by commodity and coast





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