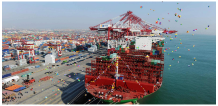

Trade From Space: Shipping Networks and The Global Implications of Local Shocks

Inga Heiland	Andreas Moxnes	Karen Helene Ulltveit-Moe	Yuan Zi
NTNU, UiO	UiO	UiO	IHEID
CEPR & CESifo	CEPR	CEPR	CEPR

Workshop on "Globalization, Shipping and Trade", October 2023, PSE

Motivation: Container shipping

- $\approx$ 50% of global trade
- the major innovation in 50 years
- by now $\approx$all countries have container ports $\rightarrow$ nodes of the network

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  - trade cost
  - dependency on infrastructure/shocks in third countries $\rightarrow$ externalities

Contributions

i) descriptives: document salient features of the global shipping network using satellite data

ii) reduced form: show that the network matters

- effects of the Panama Canal expansion 2016 on global bilateral trade

iii) structural:

- trade model with shipping network
- structural estimation of PA expansion effect
- quantify externalities from PA canal expansion
- more broadly, quantify externalities from all links in the network

Preview

i) document salient features of the global shipping network using satellite data

⇒ sparse, indirect, concentrated

ii) reduced-form analysis of the Panama Canal expansion

⇒ trade ↑ 10% for pairs using the canal

iii) use trade model with shipping routes to quantify externalities

⇒ $\widehat{Y}^{W} > 3 \times \widehat{Y}^{Panama}$

⇒ positive externalities outweigh negative externalities for 71% of all links

Literature

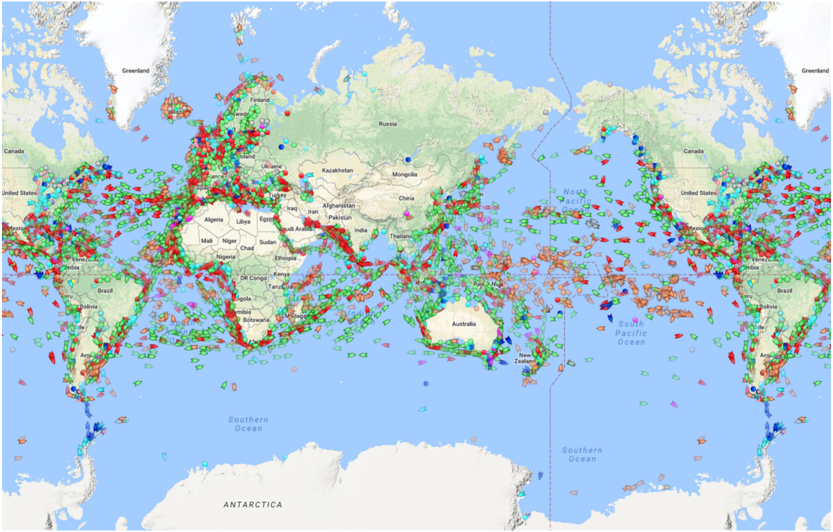
- **Transportation costs and containerization**
  - Bernhofen et al. (2016): The effect of the container revolution on trade
  - Brooks et al. (2018), Ducruet et al. (2019): Impact of containerization on economic geography
  - Behrens & Picard (2011), Wong (2018): Freight rate for containers, round trip, endogenous trade costs
  - Limao & Venables (2001), Wilmsmeier & Hoffmann (2008): Freight rates, distance & connectivity
- **Satellite data in economics / shipping**
  - Henderson et al. (2012): Night lights
  - Costinot et al. (2016): Soil, topography, crucially, climatic conditions
  - Review of the literature: Donaldson & Storeygard (2016)
  - Brancaccio et al. (2022): Endogeneity of trade costs in dry bulk market
  - Brancaccio et al. (2020): Search frictions in dry bulk market
  - Brancaccio et al. (2021): GE elasticity of trade with respect to fuel cost in dry bulk market
  - Ganapati et al. (2022): Endogenous container shipping network
- **Panama Canal/Suez Canal:**
  - Maurer & Rauch (2019): Effects on economic geography of the U.S.
  - Feyrer (2009): Trade effects of opening and closing the Suez Canal

DATA

Data: AIS

- AIS: Automatic Identification System
  - technology to track the movements of ships
  - ships have a transceiver that transmits and receives AIS signals
- Objectives:
  - safe navigation of ships: To see other ships and to be seen
  - allow authorities to monitor vessel movements (monitor fishing fleet, security, search & rescue, etc.)
- Near universal coverage of container ships:
  - the International Maritime Organization requires AIS to be fitted aboard international voyaging ships with gross tonnage ≥ 300

Data: AIS


Greenland
Canada
United States
Russia
Finland
Ukraine
Turkey
Kazakhstan
Mongolia
China
Iraq
Iran
Afghanistan
Pakistan
India
Thailand
Algeria
Libya
Mali
Niger
Chad
Sudan
Nigeria
Ethiopia
DR Congo
Kenya
Botswana
Brazil
Bolivia
Australia
North Pacific Ocean
South Pacific Ocean
Southern Ocean
Southern Ocean
ANTARCTICA
Greenland
Canada
United States
Brazil
Bolivia

Data

- AIS data from Marine Traffic on Port Calls
  - all port calls globally by container ships in 2016
  - ship ID, time stamp, arrival/departure port, current draught

- Clarkson World Fleet Register
  - ship ID, Scantling draught (draught when fully loaded), deadweight tons (dwt, weight carrying capacity)
  - info on draught + dwt $\longrightarrow$ Calculate ship cargo (tons) details

- Reduced form: Quarterly Comtrade 2013-2019 trade data ++

- Counterfactual: Eora MRIO global supply chain database ++

DESCRIPTIVES

Descriptives

Ships and Ports

Variable:	Obs	Median	Mean	Sd	Min	Max
Ships:						
# ports passed	4,941	64	68	40	1	312
# distinct ports passed	4,941	12	12	7	2	48
Ports:						
# incoming ships	514	206	652	1,458	5	14,486
# outgoing ships	514	201	652	1,455	5	14,421
Port pairs:						
# ships	4,158	38	81	169	5	2,779
deadweight tonnes (mio)	4,158	1	2	5	0	96

Note: Summary statistics are based on the port calls made by container ships in 2016. Only ships with deadweight tons>15,800 and trips with non-zero duration are used. Summary statistics include only routes taken by at least 5 ships and only routes between ports that appear both as arrival and departure ports.

Fact 1: Container ships typically operate on fixed routes

Ships and Ports

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Fact 2: Shipping is highly concentrated in space

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Fact 3: Few direct connections ⇒ Network is sparse

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Fact 3: Few direct connections $\Rightarrow$ Network is sparse

The 514 ports are allocated across 154 countries

- 6 % of all country pairs have direct port-to-port connections

$\Rightarrow$ a large share of trade travels on indirect routes

Summary: The shipping network

1. Container ships operate on fixed routes & serve a stable set of ports
2. Shipping activity is highly concentrated in space
3. Few direct connections $\Rightarrow$ network is sparse

APPLICATION

Application: Local shock and global implications

Panama Canal Expansion:

- a new, bigger and wider, lane of traffic was added $\rightarrow$ more and **bigger** ships
- expanded canal opened on 26 June 2016 (capacity $\uparrow$ 100%)

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Image Credit: US Energy Information Administration

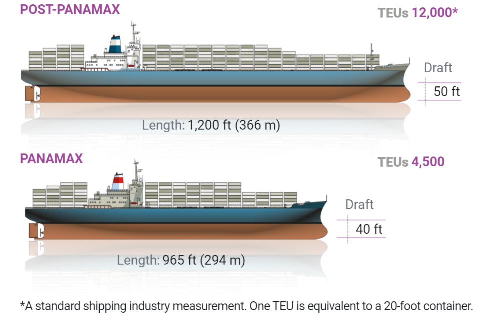
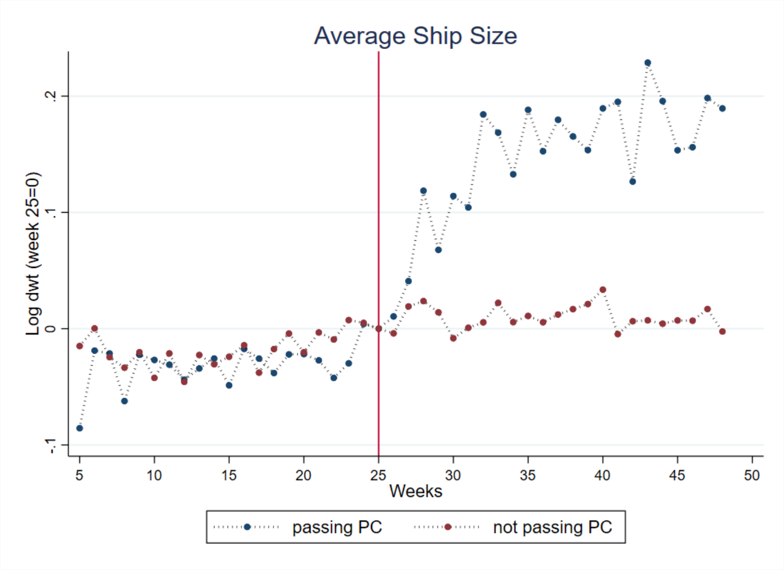


Image Credit: https://static.univision.com/

Ship size: Pre and post expansion



Global effects: DID bilateral trade

DiD:
$$\ln Exp_{ijt} = \beta Post_t * PanExposure_{ij0} + \delta \cdot Z_{ijt} + \delta_{ij} + \delta_{it} + \delta_{jt} + \varepsilon_{ijt}$$

- Exp_{ijt}: value of exports from country i to j in quarter $t \in$ 2013q1-2019q4
- $Post_t = 1$ if date $>$ Jun 2016
- $PanExposure_{ij0} \in [0, 1]$ Facts
- Controls Z_{ijt}
  - FTA_{ijt}
  - $\ln Dist_{ij}$, $Contig_{ij}$, $ComLang_{ij}$ interacted with $Post_t$
  - $dwtNeopanamax_{ij0}$ interacted with $Post_t$

Results

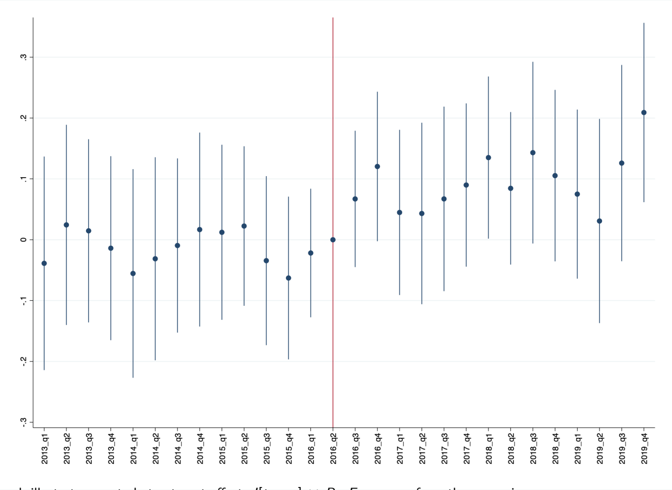
Robustness

The impact of the Panama Canal expansion on trade

	(1)	(2)
$Post_t \times PanExposure_{ij0}$	.105***	.108***
	(.038)	(.040)
Controls	No	Yes
FEs	ij,it,jt	ij,it,jt
Observations	199,177	199,177
Exporters/Importers	140/105	140/105
adj. R^2	.937	.937

Note: Dependent variable is the log of imports from country i to country j in quarter t over the period $2013Q1 - 2019Q4$. The control variables are: an FTA indicator and geographical variables (distance, contiguity and common language) interacted with $Post_t$, and the share of deadweight tonnes traveling on Neopanamax ships on the route connecting i and j in the pre period interacted with $Post_t$. The triple interaction term in column 3 is an indicator variable for whether the number of hops between i and j is below of above the median number for the treated group. Standard errors are clustered by i, j. Significance levels: $*p < 0.1, **p < 0.05, ***p < 0.01$.

Treatment effects by quarter



Note: Graph illustrates quarterly treatment effects $I[t=q] \times PanExposure_{ij}$ from the regression $y_{ijt} = \beta \sum_{q=2013:q1}^{2019:q4} I[t=q] \times PanExposure_{ij} + \delta \cdot Z_{ijt} + \delta_{ij} + \delta_{it} + \delta_{jt} + \varepsilon_{ijt}$ where Z_{ijt} includes ln *Dist* interacted with quarter dummies. Solid lines indicate 90% confidence intervals.

QUANTIFICATION

Structural analysis

Spatial model of trade with shipping routes building on Allen & Arkolakis (2020) and Eaton & Kortum (2002)

CF I: PA expansion

- use the satellite data & network model to structurally estimate impact of PA canal expansion on trade cost

⇒ address SUTVA concern around DID

⇒ quantify impact on all countries' trade cost, trade, and real income

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CF II: drop any link

⇒ quantify network externalities in general

Model setup

- N locations (ports), i, j, k, ℓ
- L_i workers, no mobility, CES preferences over a continuum of varieties ν
- i can ship varieties to j along several routes r, at cost

$$\Pi_{k=1}^{K} t_{r_k, r_{k-1}}$$

- $t_{r_k, r_{k-1}}$: cost of kth leg

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$$\Pi_{k=1}^{K} t_{r_k, r_{k-1}}$$

- $t_{r_k, r_{k-1}}$: cost of kth leg
- producers in i draw "efficiency" $\epsilon_{ijr}(\nu) \sim \text{Frechet}(A_i, \theta)$

$$p_{ijr}(\nu) = w_i \frac{\Pi_{k=1}^{K} t_{r_k, r_{k-1}}}{\epsilon_{ijr}(\nu)}$$

- consumers chose cheapest location-route

Gravity equation

for total trade from i to j

$$X_{ij} = \tau_{ij}^{-\theta} \frac{Y_i}{\Pi_i^{-\theta}} \frac{E_j}{P_j^{-\theta}}$$

- with $\tau_{ij}^{-\theta} = \left(\sum_{r \in R_{ij}} \Pi_{k=1}^{K} t_{r_k, r_{k-1}}^{-\theta} \right)^{-1/\theta}$

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... and for traffic between two locations

$$\Xi_{k\ell} = t_{k\ell}^{-\theta} P_k^{-\theta} \Pi_\ell^{-\theta}$$

Counterfactual I : Panama Canal expansion

1. Estimate reduction in t_{kl} for segments using Panama.
2. Solve GE in changes using data and parameters.

Reduction in t_{kl}^{PC}

Assuming $t_{kl} = e^{-\delta PAExpand_{kl}} \nu_{kl}$ and inserting into $\Xi_{k\ell} = t_{k\ell}^{-\theta} P_k^{-\theta} \Pi_\ell^{-\theta}$ implies

$$\Delta \ln \Xi_{kl} = \theta\delta \times PAExpand_{kl} - \theta\Delta \ln \Pi_l - \theta\Delta \ln P_k - \theta\nu_{kl},$$

and

$$\Delta \ln t_{kl}^{PC} = -\delta = -\frac{\widehat{\theta\delta}}{\theta}$$

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Assuming constant unit values of shipped goods: $\Delta \ln \Xi_{kl} = \Delta \ln \Xi_{kl}^V$

$\Rightarrow$ we estimate $\widehat{\theta\delta} \approx .2$ details

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$\Rightarrow$ we estimate $\widehat{\theta\delta} \approx .2$ ▸ details

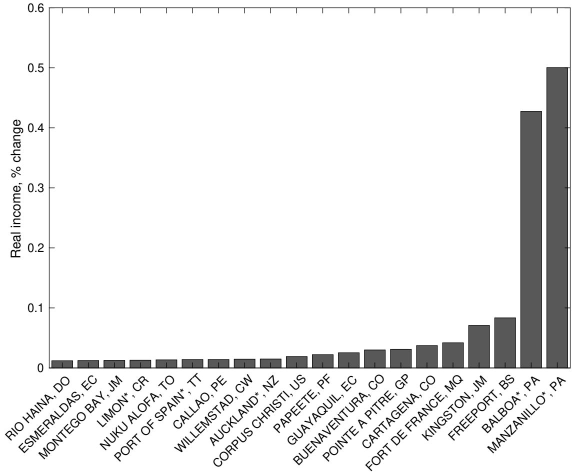
Assuming trade elasticity $\theta = 8$

$\Rightarrow$ $\Delta \ln t_{kl}^{PC} \approx -0.02$.

Quantification: Data and parameters

Variable	Description	Value	Source
θ	Trade elasticity	8	Previous literature
$\hat{t}_{kl}$	Canal transport costs, change	.98	Estimated
α	Value per tonne of traffic	USD 1,734	Calibrated
Ξ_{kl}^{V}	Initial traffic flows (volume)		MarineTraffic, 1st half 2016
Y_i	Initial Expenditure		Eora Global Supply Chain Database; WDI; INSEE. 2015

Results: Network externalities



Global gains:
128 billion USD
3.14 x Panama's gains

Panama's cost:
5.25 billion USD

Reduced-form regression: Simulated $\hat{X}_{ij}$

Reduced-form regression: Simulated $\hat{X}_{ij}$

Dependent variable: $\hat{X}_{ij}$ (simulated)	Port pair	Country pair
$PanExposure_{ij}$	.083***	.085***
	(.002)	(.006)
Source/destination FE	Yes	Yes
Observations	240,064	10,253
Dep. ports/Arr. ports	490/492	138/102
adj. R^2	.726	.736

Notes: Dep. var. is the relative change in exports from port i to port j implied by the model, $\hat{X}_{ij}$. All columns in include i and j fixed effects. Standard errors clustered by i and j. Significance levels: $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

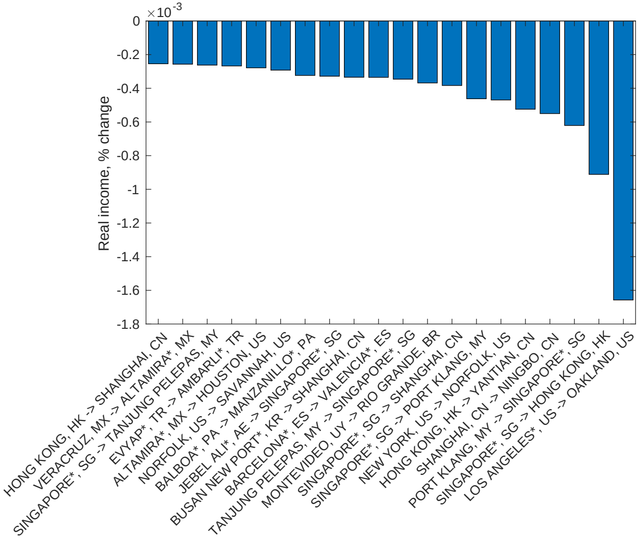
Counterfactual II: Global Network Externalities

- Drop one link kl at a time, i.e. set $t_{kl} = \infty$.
  - 3,821 different counterfactuals.

- Quantify the real wage impact on both k, l and others.

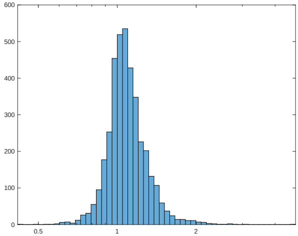
Results: Most important links

- For each dropped link kl, calculate $\widehat{W}^{-kl} = \sum_{n \neq k,l} \frac{Y_n}{Y^W} \frac{\hat{w}_n^{kl}}{\hat{P}_n^{kl}}$.



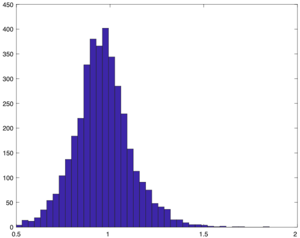
Results: Externalities with and without network

- For each dropped link *kl*, we calculate ($ loss for the world) / ($ loss for *kl*):



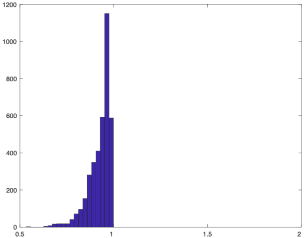
Network model:

- average: 1.21
- 71% > 1



No-network model:

- average: .96
- 36% > 1



No-network model, $\tau_{ij} = \tau_{ji}$:

- average: .93
- 0% > 1

Summary and conclusions

Novel data $\longrightarrow$ new insights about the shipping network

- few direct connections, large concentration
- **routes** are key for understanding exposure to local shocks

Application: PC expansion, reduced form and structural

- widespread gains from local infrastructure improvement
- World gains $>$ Panama gains
- network externalities are large in general

Computing container ship cargo

back

- From draught and dwt to cargo (tonnes): We need
  - 3 ship characteristics: maximum (scantling) draught H_s, minimum (ballast) draught H_B, deadweight tonnes DWT
  - current draught H_A
- To calculate effective tonnes of cargo (B) on a given trip
  - if actual draught $H_A < H_B \implies$ assume ship in ballast
  - if actual draught $H_A \geq H_B$ assume laden ship and calculate tonnes of cargo as:

$$B = DWT * \left(\frac{H_A - H_B}{H_S - H_B} \right)$$

U.S. customs data

back

Correlations with Freight costs

	(1)	(2)	(3)	(4)	(5)
$lnHours_{ij}$	.004***		.005***	.004***	.004***
	(.000)		(.001)	(.001)	(.001)
$lnDist_{ij}$		.005*	-.001	.002	-.001
		(.001)	(.001)	(.001)	(.001)
$lnShips_{ij}$				-.000	.000
				(.001)	(.001)
$lnAvgDWT_{ij}$				-.005***	-.005***
				(.000)	(.000)
FEs	j,p	j,p	j,p	j,p	j,p
Observations	167,227	167,227	167,227	167,227	187,011
Exporter/US ports	61/20	61/20	61/20	61/20	61/20
Products	13,086	13,086	13,086	13,086	13,296
adj. R^2	0.152	0.152	0.152	0.152	0.156

Note: Dependent variable is freight costs computed as cif/fob margin as share of the import value. Unit of observation is the freight cost of containerized imports by US port, country of origin, and product (10-digit HTS code). The sample is based on US trade in 2016 and include only transactions where the US port of entry is also the port of unlading. Columns (1)-(4) include only those port-country pairs where a US port is connected to only one port in the partner country. Column (5) includes all port-country pairs and the values of all independent variables are computed as averages across multiple ports in the exporting country. All regressions include fixed effects for US ports and products. Standard errors are clustered at the product level. Significance levels: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Chinese customs data (2006)

back

For export transactions by sea:

- CHN → transit country → destination country

For import transactions by sea:

- origin country → transit country → CHN

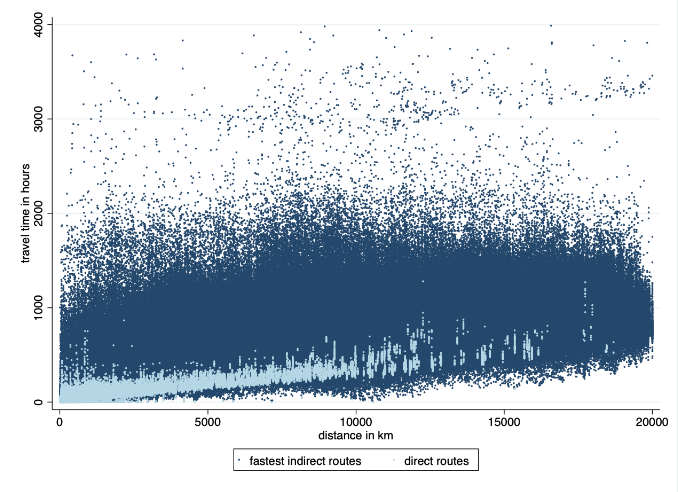
⇒ 6350 "triplets"

Comparison with calculated fastest paths (AIS data)

- 87% of paths to/from CHN overlap with one triplet
- matched triplets account for 81% of Chinese maritime trade

Shortest travel time versus distance

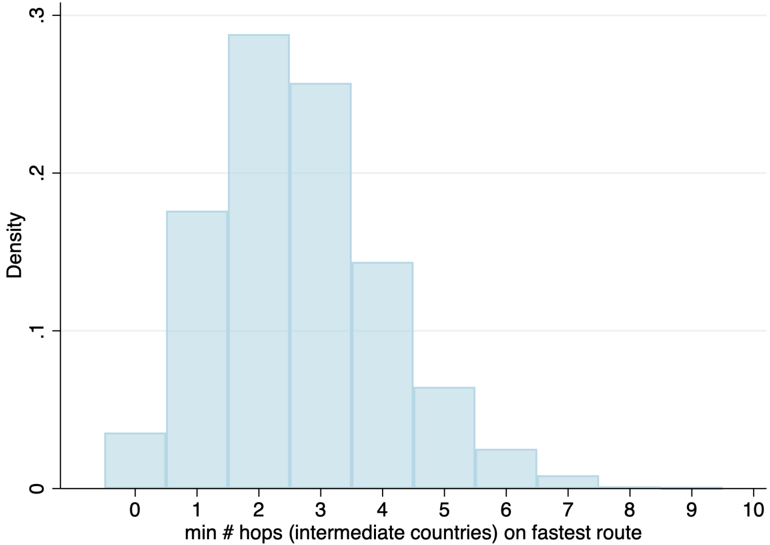
back



Note: Figure plots travel times between two ports against their geodetic distance.

Descriptives: Number of hops

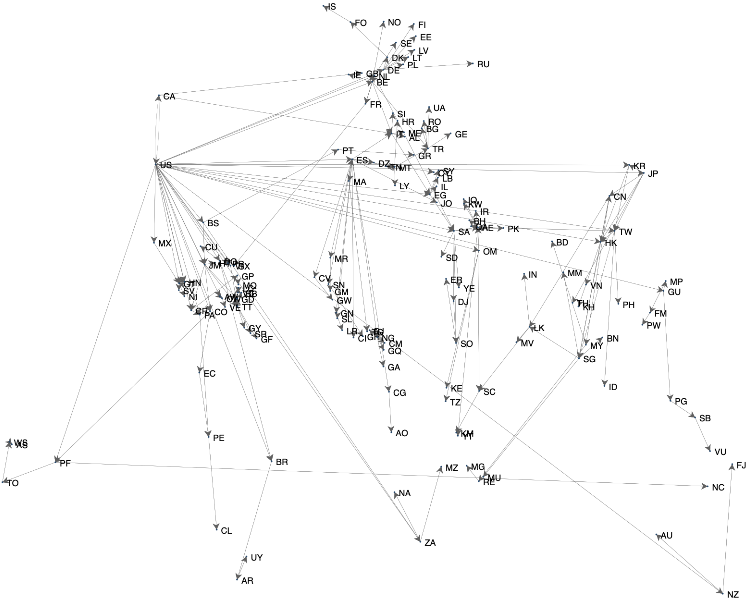
back



Note: The figure shows the distribution of the number of hops (intermediate countries) along the fastest route between all country pairs in the sample. The average (median) is 2.6 (3). For countries with multiple ports, the number of hops refers to the route with the lowest number of hops.

Fastest routes from the U.S.

back



PC Exposure

▸ back

Define $PanExposure_{ij0} \in [0, 1]$

- port-to-port level: $PanExposure_{ij0} = 1$ if fastest route between two ports passes PC in pre-period
- aggregation to country-pair level: port-size-weighted average if multiple port-to-port connections

Country pairs with exposure		Global trade exposed		Importers with exposure	
(1) # pairs	(2) % of total	(3) value in trn $	(4) % of total	(5) # importers	(6) % of total
3,623	14 %	1.8	12 %	144	66 %

Data sources: AIS, BACI

Indirect routes

▸ travel time ▸ stability

We identify *fastest* indirect route between any two ports using

- observed schedule of departures/arrivals by port
- search algorithm to find the fastest path from i to j at any time h in 2016
- select the most frequent “route" (sequence of intermediate ports)

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⇒ most country pairs trade along routes involving 2/3 other countries

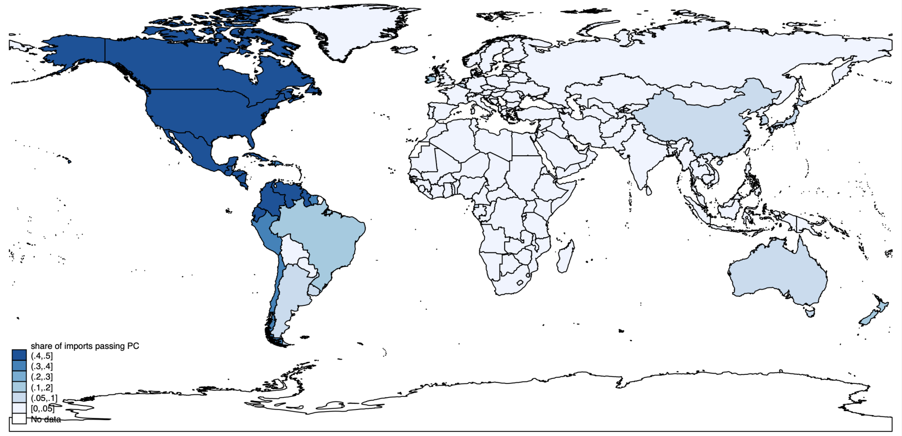
⇒ identify routes involving Panama Canal

Fastest route $\neq$ cheapest?

- important cost factors (fuel, labor, capital) highly correlated with time
- supportive evidence: U.S. customs data; Chinese customs data

PC Exposure, cont'd

back



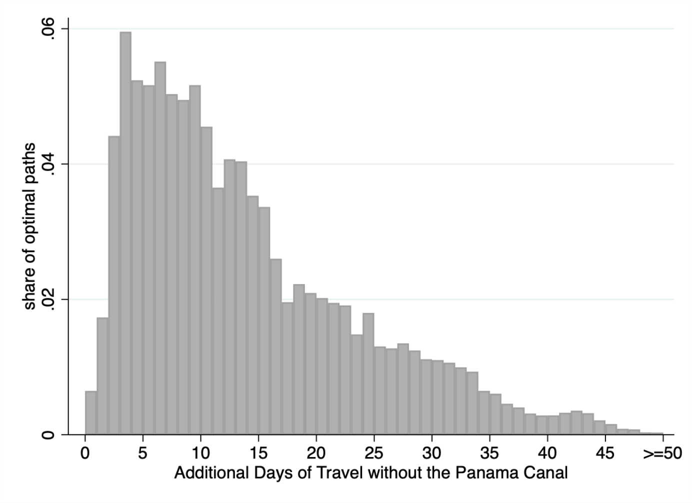
Note: The figure shows the share of imports passing through the Panama Canal in total imports by country

Travel time without PC

back

Travel time without PC

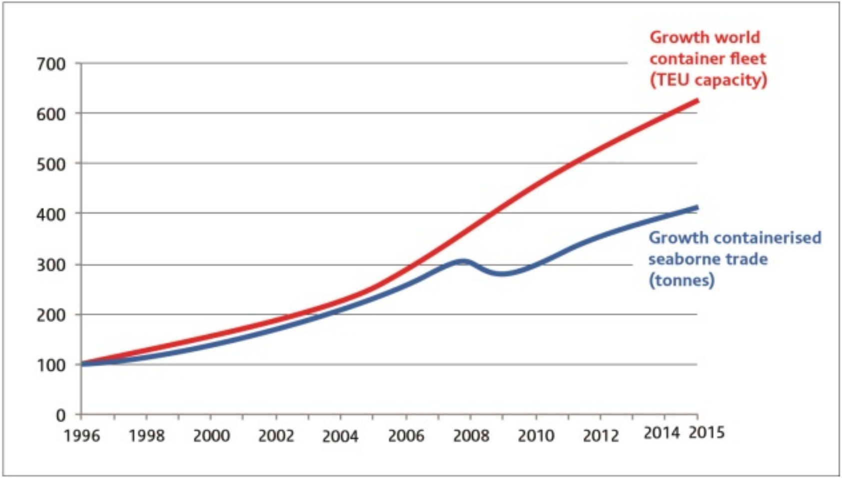
back



Note: The figure shows the distribution of port-to-port travel time differences with vs. without the Panama Canal for the pairs that are using the Panama canal according to our algorithm.

Overcapacity: Global Fleet

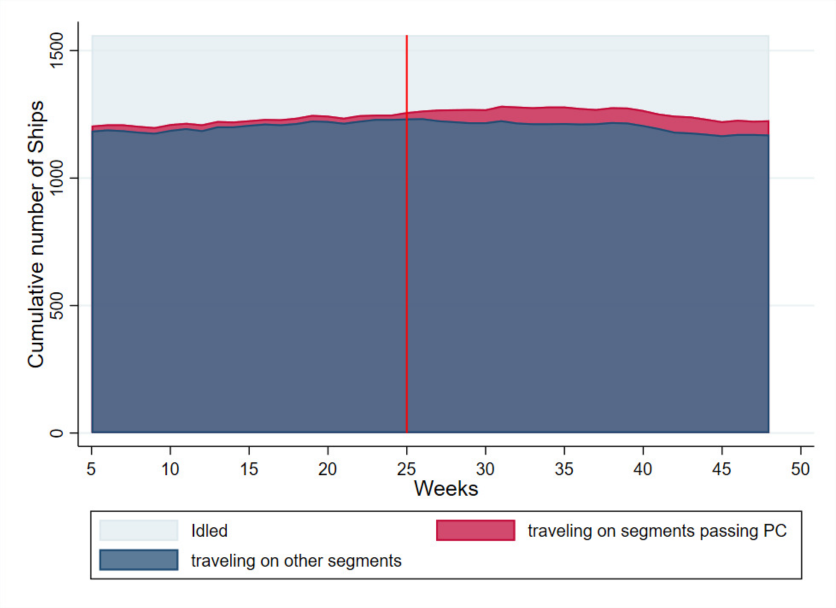
back



Source: *The Impact of Mega Ships*, ITF Report

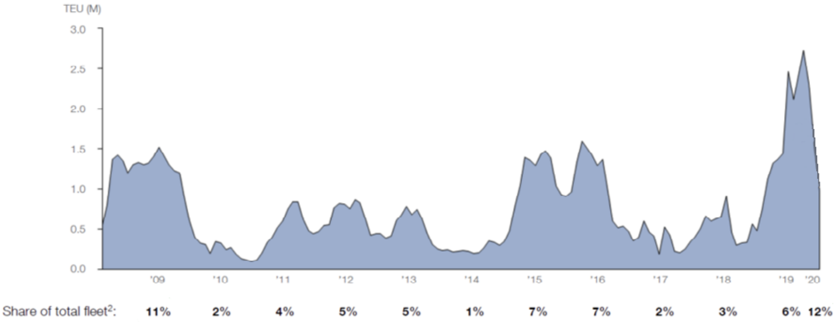
Overcapacity: Post-Panamax Ships

▸ back



Overcapacity II

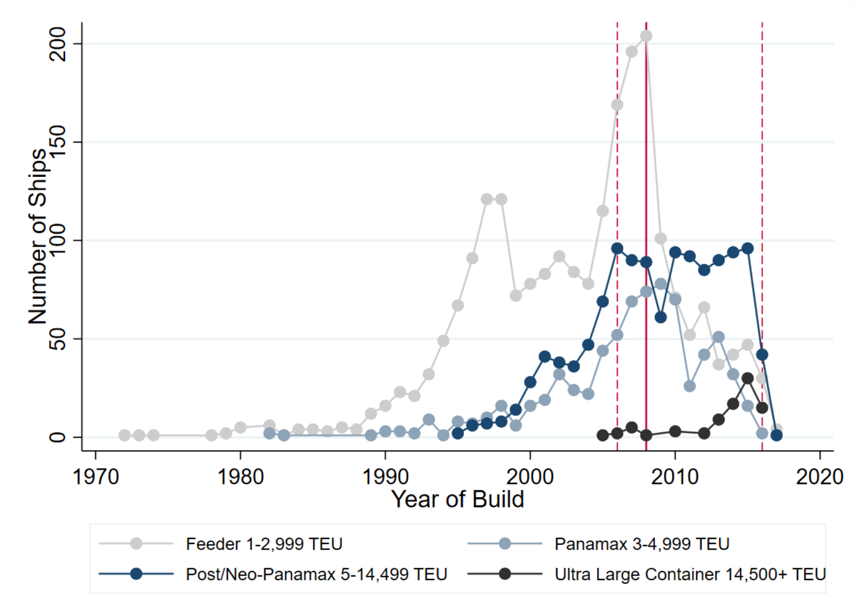
▸ back



Source: Global Trade Monitor

Ship building

back



Robustness checks

Robustness check:	2019Q4 dropped	Balanced sample	Monthly data	PanExposure: all paths Weighted avg.	PanExposure: all paths Simple avg.	No raw materials	Hours saved
$Post_t \times PanExp^1_{ij}$	.102**	.097*	.082**	.103**	.098**	.082***	
	(.040)	(.054)	(.040)	(.048)	(.048)	(.027)	
$Post_t \times PanExp^3_{ij}$							.023***
							.008
Observations	193,450	86,576	600,884	199,177	199,177	198,696	199,177
Exporters/Importers	140/105	133/36	140/107	140/105	140/105	140/105	140/105
adj. R^2	.937	.947	.900	.937	.937	.939	.937

Note: Dependent variable is the log of imports from country i to country j in quarter t over the period $2013Q1 - 2019Q4$ in columns (2,4,5). In column (1) the last quarter of 2019 is dropped. Column (3) is based on monthly data for the full sample period. Column (2) is restricted to set of pairs for which trade flows exist in every quarter. All columns include ij, it and jt fixed effects as well as controls. The control variables are: an FTA indicator and geographical variables (distance, contiguity and common language) interacted with $Post_t$, and the share of deadweight tonnes traveling on Neopanamax ships on the route connecting i and j in the pre period interacted with $Post_t$. Columns (4) and (5) are based on a *PanExposure* measure computed as a weighted (column (4)) and simple (column (5)) average across the exposure of all paths between two ports in i and j, rather than the exposure of the most frequent route. Weights in column (4) are given by the amount of time for a which a certain path was optimal, that is, the number of hours between the start date of the path and the start date of the previous optimal path relative to the length of the pre period. Standard errors are clustered by i and j in columns (1,3-7). In column (2) where the number of importers is very low, standard errors are clustered by ij. Significance levels: $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

Threats to identification

Endogenous network

- routes
  - exposure is very stable [95.3% –; 2.5%↑; 2.2%↓]
  - high time cost of substituting between exposed/non-exposed routes
- ships
  - overcapacity
  - control variable $dwtNeopanamax_{ij0}$ interacted with $Post_t$

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Opening date was uncertain, but expansion was not

- investment in port capacity/ships prior to expansion ?
  - decline in ship building
  - many ports already handled much bigger ships
  - no pretrends

Model setup

Price of variety ν from i shipped to j via r

$$p_{ijr}(\nu) = w_i \frac{\prod_{k=1}^{K} t_{r_k, r_{k-1}}}{\epsilon_{ijr}(\nu)}$$

- "efficiency" $\epsilon_{ijr}(\nu) \sim \text{Frechet}(A_i, \theta)$

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Consumers chose cheapest location-route

- total trade from *i* to *j*

$$X_{ij} = \tau_{ij}^{-\theta} \frac{Y_i}{\Pi_i^{-\theta}} \frac{E_j}{P_j^{-\theta}}$$

- with $\tau_{ij}^{-\theta} = \left(\sum_{r \in R_{ij}} \prod_{k=1}^{K} t_{r_k, r_{k-1}}^{-\theta} \right)^{-1/\theta}$

Panama exposure derived from the model

Likelihood that ij uses link $k\ell$:

$$\pi_{ij}^{k\ell} = \left(\frac{\tau_{ij}}{\tau_{ik} t_{k\ell} \tau_{\ell j}} \right)$$

We parameterize shipping cost as

$$t_{k\ell} = \left(\frac{TravelTime}{ShipSize} \right)^{\delta} \qquad \text{or} \qquad t_{k\ell} = TravelTime^{\delta}$$

$\Rightarrow$ model-based exposure measure: π_{ij}^{PA}

Impact of the PC expansion on traffic

back

We estimate the impact of *PAExpand* on container traffic $\Xi^V_{k\ell}$ along 3 margins

- by definition:

$$\Delta\Xi^V_{k\ell} = \Delta \ln ShipSize_{kl} + \Delta \ln Frequency_{kl} + \Delta lnUtilization_{kl}$$

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Dependent variable	Δ ln $ShipSize_{kl}$		Δ ln $Frequency_{kl}$		Δ ln $Utilization_{kl}$	
	(1)	(2)	(3)	(4)	(5)	(6)
$PAExpand_{kl}$	.22***	.12*	.01	.02	.05	.02
	(.05)	(.06)	(.12)	(.15)	(.04)	(.05)
Source/dest. FE	No	Yes	No	Yes	No	Yes
Obs	3,595	3,403	3,595	3,403	3,595	3,403

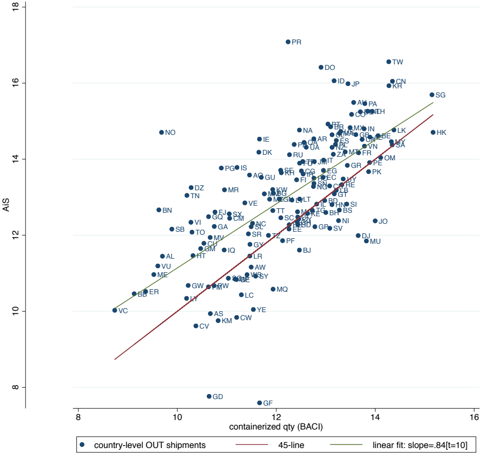
Notes: The difference Δ refers to the change from the 1st to 2nd half of 2016. $ShipSize_{kl}$ is calculated as the average across all trips on a given segment. $Frequency_{kl}$ is the number of ships using the segment. $Utilization_{kl}$ is traffic Ξ_i relative to capacity ($ShipSize_{kl} \times Frequency_{kl}$). $PanamaCanal_{kl}$ is an indicator taking the value one if the segment uses the Panama Canal. Regressions are weighted by the initial level of traffic Ξ_{kl}. Robust standard errors in parentheses. Significance levels: $*p < 0.1, **p < 0.05, ***p < 0.01$.

Table 1: Regressions with Panama exposure derived from the model

	(1)	(2)	(3)	(4)
Exposure measure:	Travel time		Travel time & Ship size	
	continuous	$\pi_{ij}^{PA} > .3$	continuous	$\pi_{ij}^{PA} > .3$
$Post_t \times PanExposure_{ij}$	.151**	.086**	.130**	.094**
	(.065)	(.042)	(.066)	(.045)
Observations	192,810	192,810	192,810	192,810
Exporters/Importers	138/102	138/102	138/102	138/102
adj. R^2	.936	.936	.936	.936

Note: Dependent variable is the log value of imports from country i to country j in quarter t over the period $2013Q1 - 2019Q4$. All columns include it, jt and ij fixed effects and control variables; an FTA indicator and geographical variables (distance, contiguity and common language) interacted with $Post_t$, and the share of deadweight tonnes traveling on Neopanamax ships on the route connecting i and j interacted with $Post_t$. Standard errors are clustered by i and j. Significance levels: $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

AIS flows vs Comtrade flows distributed over shortest paths



plot of AiS flows (OUT) at the country level against country-level outflows implied by sending all countries bilateral containerized trade along shortest routes