All aboard: The effects of port development

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Motivation

- **Seaports play a vital role in the global trading system**
  - 80% of goods trade crosses sea ports UNCTAD, 2019
  - Precondition for participation in global production networks Rodrigue, 2016
- **Modern port development entails substantial local costs**

  "Across the planet, the expansion of seaports is becoming tougher, notes Jean-Paul Rodrigue, a professor of transport geography at Hofstra University in Long Island. Space in the right locations is scarce. Critics of development, especially among environmentalists, are not."

  The Economist, January 14th 2023
- **How do local costs affect the gains from port development?**
  - How are they distributed across space?
  - What are the gains from port development?
  - What determines the geographic location of ports?
  - Use major technological shock to port development: containerization

Outline of the paper

1. **Stylized facts:** the local effects of containerization
   - Increased shipping flows in cities exogenously more suited to containerization
   - Container ports expand more where land is less scarce
   - Boom in shipping *does not* translate into population inflows

$\Rightarrow$ Container port cities lose attractiveness despite gains from market access

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2. **Quantitative spatial model** consistent with stylized facts
   - Endogenous port development
   - Benefits from market access
   - Loss of attractiveness due to land use and disamenities

   $\Rightarrow$ Aggregate and distributional effects of port development

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    - Endogenous port development
    - Benefits from market access
    - Loss of attractiveness due to land use and disamenities

   ⇒ Aggregate and distributional effects of port development

3. **Counterfactuals**
    - Roll back containerization to estimate welfare effects of containerization
    - Targeted port development policies: Maritime Silk Road

   ⇒ Substantially more reallocation than in a standard model

Related literature

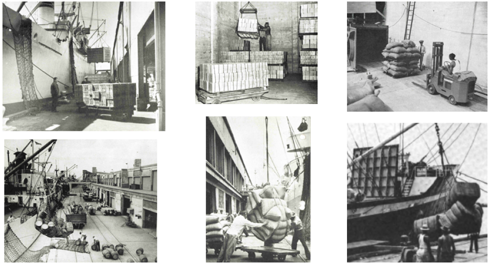
- **Trade leads to agglomeration benefits**
  Armenter et al. (2014), Bleakley and Lin (2012), Coşar and Fajgelbaum (2016), Fajgelbaum and Redding (2021), Nagy (2022)
- **Booming industries lead to local crowding-out of tradables**
  Alcott and Kenniston (2018), Corden and Neary (1982), Krugman (1987) Pines and Sadka (1985), Solow (1972), Solow and Vickrey (1971)

  ⇒ This paper: Account for loss of attractiveness as well as market access mechanism
- **Estimating the effects of transport infrastructure** Redding and Turner (2015)
  - Economic impacts of containerization Altomonte et al. (2018), Bernhofen (2016), Brooks et al. (2021), Coşar and Demir (2017), Gomtsyan (2016), Holmes and Singer (2017), Hummels (2007), Bridgman (2021), Wong (2022) Heiland et al. (2022), Ganapati et al. (2022), Koenig et al. (2023)
  - General equilibrium benefits from transport infrastructure improvements Donaldson (2018), Donaldson and Hornbeck (2016), Heblich et al. (2020)
  - Endogenous trade costs Allen and Arkolakis (2021), Brancaccio et al. (2019), Fajgelbaum and Schaal (2020), Santamaria (2020)

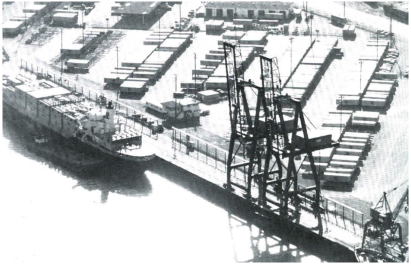
  ⇒ This paper: Allow for endogenous port development to study local and aggregate effects

Outline

Containerization: A revolutionary new technology in the late 1960s



Source: Annual reports from the port authorities of New Orleans and Seattle, 1950, 1951, 1952, 1955



Source: Annual Report. The Port Authority of Seattle, 1967

- *"The bottleneck in freight transport has always been the interface between transport modes, especially the crucial land/sea interface"* McKinsey (1972)

Benefits of containerization

- **Containerization reduced ship turnaround times by 70% – 95%**

  "Today a container ship can be unloaded and loaded in a matter of 48 hours or less, whereas in the past it took from 7 to 10 days [...] to discharge the same amount of cargo." Port of San Francisco (1971)

- **This led to reduction in transshipment costs by 70% – 85%** Rodrigue (2016)
  - Through increased utilization of ships
  - Through larger ships (economies of scale)
    - Average size of newly-built container ships increased by 402% between 1960 and 1990 Miramar Ship Index, Haworth (2020)
  - Through reduced capital tied up in inventory

- **Transshipment costs had accounted for a large share of transport costs** Eyre (1964), Levinson (2010)

  > *"The ability to ship things long distances fairly cheaply has been there since the steamship and the railroad. What was the big bottleneck was getting things on and off the ships. A large part of the costs of international trade was taking the cargo off the ship, sorting it out, and dealing with the pilferage that always took place along the way. So, the first big thing that changed was the introduction of the container."* Krugman (1995)

Outline

Data sources

- Unique novel worldwide city-level shipping dataset: information on bilateral shipping flows and population
  - Decadal: 1950-1990
  - Port-city: cities with a port in the city in at least one year
  - 2,636 cities; thereof 553 port cities

- Data sources
  - Daily ship movements by port as published in "Lloyd's List"
    - One week sample per decade
    - 2,543 ports with positive shipping flows in at least one decade
  - Population data: "Villes Géopolis" for cities $\geq$ 100,000 inhabitants in at least one year

Port and non-port cities

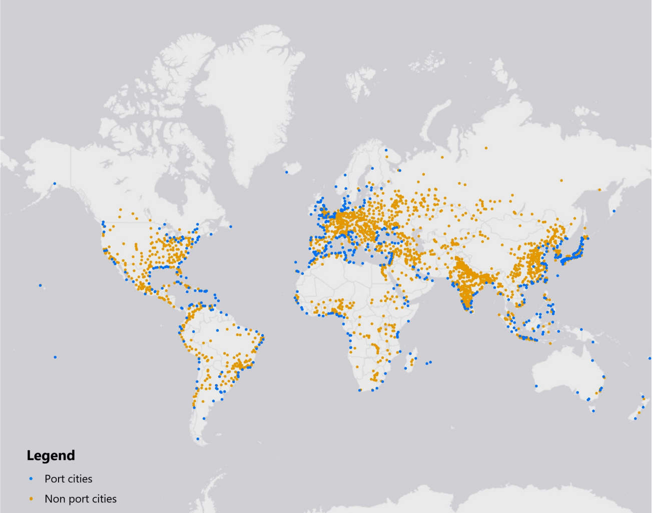
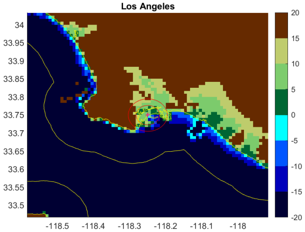


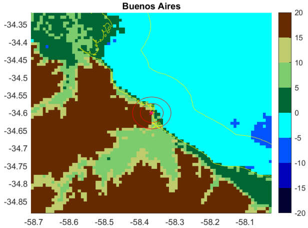
Figure: Port and non-port cities from Geopolis

Outline

An exogenous measure of suitability for containerization

- **Challenge:** Containerization not adopted at random
- **Solution:** A port city's suitability for containerization depends on its sea depth Brooks et al. (2021), Altomonte et al. (2018)
- **Our innovation:** Use contemporary granular data on oceanic depth around the port to measure naturally endowed depth
  - Measure depth of cells around but not directly at the port
  - Operationalize as: Log count cells deeper than 30ft (9.144m) in ring with radius 3-5km around closest coastal point of port



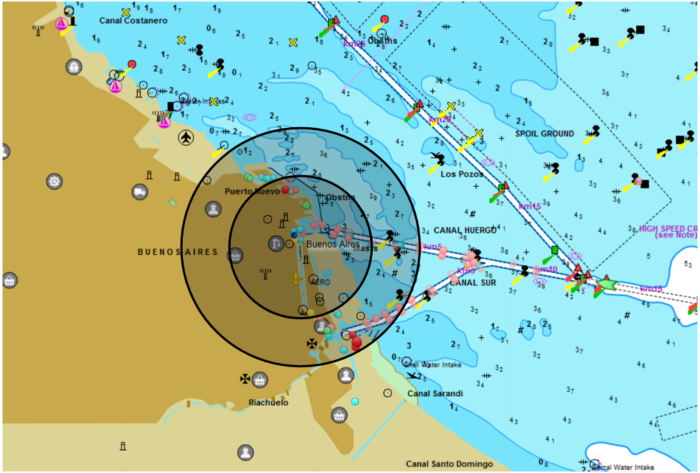


Potential issues with the depth measure

- Is a contemporary measure of depth picking up endogenous dredging? No
- Is a contemporary measure of depth picking up land reclamation? No
- Are there pre-trends? No

Does the depth measure capture endogenous dredging?

Examine by handcoding dredging using nautical maps for 100 randomly selected ports



Nautical map of Buenos Aires. Source: marinetraffic.com

Does the depth measure capture endogenous dredging?

	Dredging		
	(1)	(2)	(3)
Depth	-0.058**	-0.042*	-0.028
	(0.025)	(0.024)	(0.028)
Observations	100	100	100
R-squared	0.059	0.138	0.250
FE	none	continent	coastline

Notes: Robust standard errors. Notation for statistical significance: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

- Dredging is detected at shallower ports → our measure captures naturally endowed depth

Is depth correlated with land reclamation?

- Data on coastal land reclamation from Martín-Antón et al. (2016)

	Coastal Land Reclamation (Indicator)		
	(1)	(2)	(3)
Depth	0.0008	0.0038	-0.0003
	(0.0093)	(0.0096)	(0.0106)
Observations	553	553	553
R-squared	0.00001	0.07991	0.12925
FE	none	continent	coastline

Notes: Dependent variable is equal to one in case coastal land reclamation was reported and zero otherwise. Robust standard errors in parentheses. Notation for statistical significance: *** p<0.01, ** p<0.05, * p<0.1.

Stylized Fact 1: Depth predicts shipping, but only after 1960

$$\ln(Ship_{it}) = \sum_{j=1960}^{1990} \beta_j * Depth_i * \mathbb{1}(Year = j) + \sum_{j=1960}^{1990} \phi_j * \ln(Pop_{i,1950}) * \mathbb{1}(Year = j) + \alpha_i + \delta_t + \epsilon_{it}$$

	Dependent Variable: ln(Shipment)						
Independent Variables	(1)	(2)	(3)	(4)	(5)		
Depth × post 1970							0.247***
							(0.059)
Depth × 1960	-0.051	-0.035	-0.051	0.029	0.050	-0.055	
	(0.063)	(0.060)	(0.063)	(0.069)	(0.066)	(0.068)	
Depth × 1970	0.222***	0.255***	0.222***	0.233***	0.278***	0.213***	
	(0.069)	(0.066)	(0.069)	(0.077)	(0.082)	(0.071)	
Depth × 1980	0.188**	0.235***	0.188**	0.212**	0.291***	0.192**	
	(0.079)	(0.078)	(0.079)	(0.085)	(0.090)	(0.081)	
Depth × 1990	0.255***	0.307***	0.255***	0.222**	0.312***	0.283***	
	(0.086)	(0.084)	(0.086)	(0.087)	(0.099)	(0.087)	
Observations	2765	2765	2765	2765	2765	2360	2765
2765							
R-squared	0.126	0.120	0.126	0.248	0.131	0.142	0.126
0.126							
Number of cities	553	553	553	553	553	472	553
553							
Coastline × Year FE			×	✓	×	×	×
×							
Saiz × Year FE			×	×	✓	×	×
×							
[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Stylized Fact 2: Container ports expanded more where land was less constrained

a) **Container ports require land ...**

> *"No pier facilities in the Bay Area today are capable of handling the new space requirements on this scale of new and larger container ships. (...) thus more berthing and backup area is needed"*
> Port of San Francisco (1971)
>
> *"Containerization involves a large consumption of terminal space. A container ship of 5,000 TEU requires a minimum of 12 hectares of unloading space, while unloading its containers entirely would require the equivalent of about seven double-stack trains of 400 containers each."* Rodrigue (2016)

- For example, when Seattle introduced containerization, its land intensity doubled
- Even today, more containerized ports use more land, holding total cargo fixed (analysis based on contemporary satellite data)

b) **... which makes them expand more in areas where land is less constrained**

- Within cities, existing terminals expanded away from the city center; new terminals were added on the outskirts
- Across cities, shipping increased more in cities where land constraints to expansion smaller

Increased land intensity of containerization: Evidence from Seattle

Extensive port development in the 1960s. 43% of cargo volume containerized by 1973

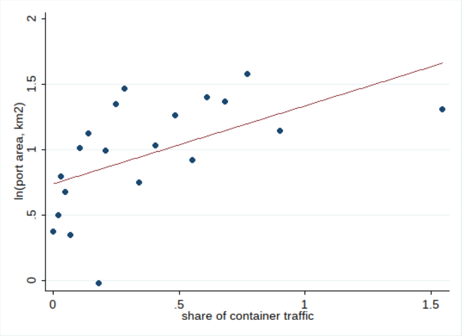
Completed container terminal, 1970

Year	Area (sq. ft)	Throughput (short tons)	Area per ton
1961	8,651,016	2,022,192	4.28
1973	33,547,908	4,135,795	8.11
Change (%)	288%	105%	90%

Sources: Property Books; *Annual Reports*.

Port areas and share of containerized cargo: Evidence from satellite data

- Port areas for random subset of port cities from Google Earth
- Total and container traffic data from Le Journal de la Marine Marchande (JMM), 2008-2009



Notes: The figure shows the correlation between the area of ports and the share of container traffic at the port; the latter is defined as (container traffic in TEUS * 12 tons per TEU)/total merchandise traffic in tons.

Land intensity of containerization: Evidence from satellite data

	Ln(Port area, km2)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Ln(Container traffic, TEUs)	0.288***	0.127***	0.133***	0.151***	0.153***	0.144***	
	(0.049)	(0.045)	(0.044)	(0.047)	(0.046)	(0.053)	
Ln(Total merchandise traffic, tons)		0.375***	0.283*	0.311***	0.247	0.356***	0.506***
		(0.080)	(0.166)	(0.080)	(0.161)	(0.118)	(0.069)
Ln(Non-bulk traffic, tons)			0.014		0.008		
			(0.099)		(0.096)		
Ln(Country GDP/capita)				0.311***	0.292**		
				(0.108)	(0.134)		
Container traffic share							0.562***
							(0.209)
Observations	123	123	73	122	73	123	123
R-squared	0.287	0.395	0.327	0.431	0.352	0.672	0.398
% change							0.75
Country FEs	×	×	×	×	×	✓	×

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

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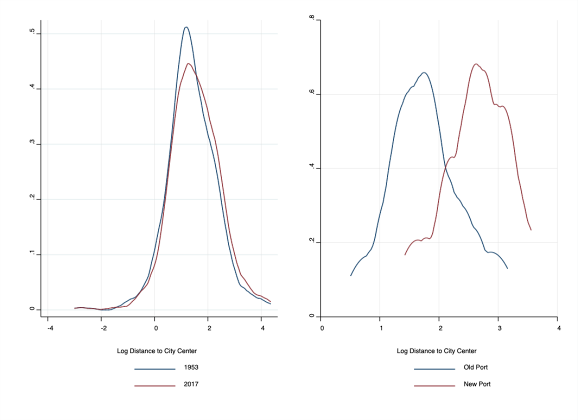
Change of port location within cities

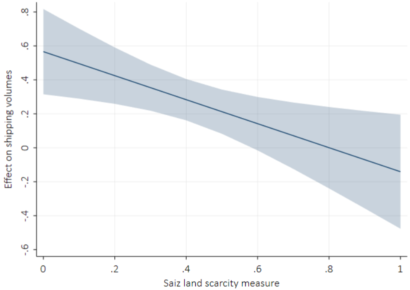
- Within cities, the geocodes of existing ports moved on average about 1 km from the city center
- Within cities, the geocodes of new ports are around 9 km farther from city center



Across cities, shipping increased more in cities where land constraints to expansion smaller

- $Saiz_i$ measures land scarcity: the share of cells within 50km of the city that cannot be built on (Saiz, 2010)

$$\ln Ship_{it} = \beta * Depth_i * (Y \geq 1970) + \gamma * Depth_i * Saiz_i * (Y \geq 1970)$$
$$+\eta * Saiz_i * (Y \geq 1970) + \sum_{i=1}^{4} \phi_i Ln(Pop_{1950}) * \mathbb{1}(Year = y) + \alpha_i + \delta_t + \epsilon_{it}$$



Stylized Fact 3: Boom in shipping does not lead to population inflows

$$\Delta \ln Pop_i = \beta * \Delta \ln Ship_i + \alpha * \ln(Population_{1950}) + \epsilon_i$$

	(1) ΔIn(Population)	(2) ΔIn(Population)	(3) Δ In(Shipment)	(4) ΔIn(Population)
Δ In(Shipment)	0.013	0.006		
	0.052	*0.022*		
	(0.009)	(0.073)		
	{0.014}	{0.115}		
Depth			0.272***	0.002
			*0.134****	*0.003*
			(0.086)	(0.020)
Observations	531	531	531	531
Pop. 1950	✓	✓	✓	✓
Specification	OLS	2SLS	FS	RF
KP F-stat		9.98		

Notes: Standardized coefficient italicized. Robust standard errors in parentheses, Conley standard errors in curly brackets. *** p<0.01, ** p<0.05, * p<0.1.

Outline

A model of cities and endogenous port development

- The world consists of a finite number of port and inland cities
  - Each city produces a city-specific good using land and labor $\Rightarrow$ incentive to trade
  - But trade is costly: land shipping, sea shipping and *transshipment costs*

A model of cities and endogenous port development

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  - But trade is costly: land shipping, sea shipping and *transshipment costs*

- In port cities, land owners allocate fixed supply of land between production of city-specific good and transshipment
  - *Port development:* Increasing the share of land used for transshipment, $F(r)$ ...
    - ... reduces transshipment cost, as endogenous transshipment costs are decreasing in land
    - ... decreases the amount of land available for production
      $\Rightarrow$ Production uses land and labor, productivity features agglomeration economies
    - ... creates negative amenity externalities associated with port activity:

$$a(r) = \bar{a}(r)\left[1 + Shipping(r)\right]^{-\rho}$$

Production | Demand

The role of transshipment services

- Shipping routes are either **land-only** or **land-and-sea** routes
- Cost of **land-only route**

$$\omega(\rho) = 1 + \phi_{\varsigma}(d(\rho))$$

  - $d(\rho)$ is length of the route

- Cost of **land-and-sea route** between r and s through port cities $p_0, \ldots, p_M$

$$\omega(r, p_0) \cdot \prod_{m=0}^{M-1} [1 + \phi_{\tau}(d(p_m, p_{m+1}))] \cdot \prod_{m=0}^{M} [1 + O(p_m)] \cdot \omega(p_M, s)$$

  - $d(p_m, p_{m+1})$ is distance between subsequent port cities
  - $O(p_m)$ is the price of transshipment at p_m

Provision of transshipment services

- Transshipment cost per unit of good shipped through port city r is

$$[\nu(r) + \psi(F(r))]\,\mathit{Shipping}(r)^{\lambda}$$

  - $\nu(r)$ is exogenous transshipment cost at r (natural geography, etc.)
  - ψ is a decreasing and convex function of land used for transshipment services, $F(r)$
  - $\mathit{Shipping}(r)$ is value of shipping through r; a congestion externality if $\lambda > 0$
  - Per-unit nature of costs implies that model preserves gravity of trade flows
  - By competition among port city landlords, the price of transshipment services becomes equal to the unit transshipment cost in equilibrium

Equilibrium

- Equilibrium population of city r

$$N(r)^{\iota_1} = \iota_2 a(r)^{\iota_3} A(r)^{\iota_4} [1 - F(r)]^{\iota_5} \cdot$$

$$\sum_s a(s)^{\iota_6} A(s)^{\iota_7} [1 - F(s)]^{\iota_8} N(s)^{\iota_9} \mathbf{E}[T(r,s)]^{1-\sigma}$$

- Effect of port development on city population:
  - Decreasing transshipment costs lower $\mathbf{E}[T_t(r,s)]$, thus increase population: market access effect
  - Extensive land use for the port in city r decreases production, hence population: crowding-out effect
  - Increasing shipping activity lowers port city amenities $a(r)$: disamenity effect

Model-Guided Test of Local Benefits and Costs

What is the direct effect of shipping flows once we control for MA?

$$\ln Pop_{it} = \phi_1 * \ln Ship_{it} + \phi_2 * \ln MA_{it} + \alpha_i + \delta_t + \epsilon_{it}$$

- Model suggests $\phi_1 < 0$ and $\phi_2 > 0$
- MA term estimated as: $MA_{it} = \sum_{s=1}^{S} \frac{POP_{st}^{\iota_8}}{\mathbf{E}[T_t(i,s)]^{\sigma-1}}$
  - $\mathbf{E}\left[T_t\left(i,s\right)\right]^{\sigma-1}$ estimated using least-cost path between any bilateral city pair, accounting for the time-varying transshipment cost of crossing ports (using estimates from Blonigen and Wilson 2008)
  - Fundamental parameter values for ι_8 taken from the literature
- Identification: two endogenous variables
  - Own port depth $PD_i * \mathbb{1}(Y >= 1970)$
  - $MAIV_{it} = \sum_s \frac{\widehat{POP}_{st}^{\iota_8}}{(T_{1950}(i,s))^{\sigma-1}}$
    - ★ $\widehat{POP}_{st}$ predicted population based on the number of frost free days ▸ IV details

Direct effect of shipping is negative once we control for MA

	ln(Population)			
	(1)	(2)	(3)	(4)
ln(Ship)	-0.001	-0.159**		
	(0.006)	(0.065)		
	{0.005}	{0.051}		
ln(Market Access)	1.512***	7.103***		
	(0.536)	(0.795)		
	{0.317}	{0.854}		
Depth × post 1970			0.275***	0.007***
			(0.058)	(0.001)
			{0.051}	{0.001}
Market Access IV			7.188	1.927***
			(5.428)	(0.140)
			{5.748}	{0.188}
Observations	2696	2696	2696	2696
Number of cities	544	544	544	544
Year FE	✓	✓	✓	✓
City FE	✓	✓	✓	✓
Population 1950 × Year	✓	✓	✓	✓
Specification	OLS	2SLS	FS	FS
KP F-stat		9.63		

Notes: Standard errors clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

▸ Robustness

Outline

Taking the model to the data

- Combine 1990 data on
  - city population
  - shipping flows
  - GDP per capita
    - GDP per capita data from nightlight satellite pictures and city-level GDP per capita for subset of cities
- with the structure of the model to recover city-specific
  - fundamental amenities $\bar{a}(r)$
  - productivities $A(r)$
  - exogenous transshipment costs $\nu(r)$
- that rationalize the data for given set of parameters, inland, sea and transshipment costs

Calibration of transshipment cost function and port disamenities

- Choose endogenous transshipment cost function such that $\psi'(F) = 1 - F^{-\beta}$
  - β drives land intensity of transshipment technology
  - Set $\beta = 0.031$ to match correlation between shipping and port share observed in the data (0.47)
    - ★ Calculate correlation in data using high-quality port size data for 7 ports
    - ★ Model-implied correlation almost identical (0.46) if calculated for same 7 ports

- Choose disamenity parameter ρ to match the cost of pollution per ship
  - Estimated economic cost includes deaths, medical care for illnesses, missed school and work days from pollution
  - Estimated to be \$ 30 bn annually for the ports of LA and Long Beach (THE Impact Project Policy Brief Series 2012)

- Remaining parameters from the literature parameters

Counterfactuals

1. Roll Back Containerization
2. Targeted Port Development: The Maritime Silk Road

Counterfactual 1: Roll back containerization

- Decrease land intensity of transshipment technology
  - Change β such that average port area increases by 75% from counterfactual to inversion, keeping shipping and land rents fixed (i.e., holding traffic fixed) (from port area estimation in first part)

- Increase exogenous transshipment costs, especially in deep ports
  1. Undo dependence of exogenous transshipment costs on depth
  2. Increase exogenous transshipment costs uniformly to match 25% decrease in median port cost due to containerization (Rodrigue, 2009)

$\Rightarrow$ Shock corresponds to 1/3 (4.7pp) of overall increase in world trade/GDP between 1960 and 1990 (15pp)

$\Rightarrow$ Implies an increase of 3 pp in port size for the median port

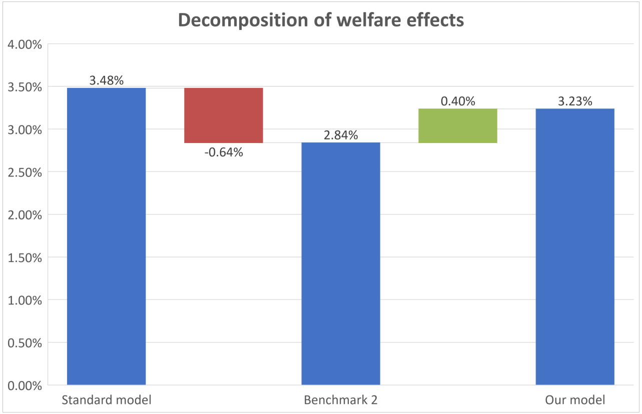
Test of the model: model captures stylized facts

- Net benefits: effect of shipping on population
- Land heterogeneity: effect of depth interacted by land rents on shipping

	Our model	Standard model with disamenities	Standard model
Net benefits	-0.030	0.095*	0.191***
	(0.048)	(0.049)	(0.049)
Land heterogeneity	-0.013**	-0.007	-0.007
	(0.005)	(0.005)	(0.005)

Notes: Standardized coefficients, robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Decomposition of aggregate effects



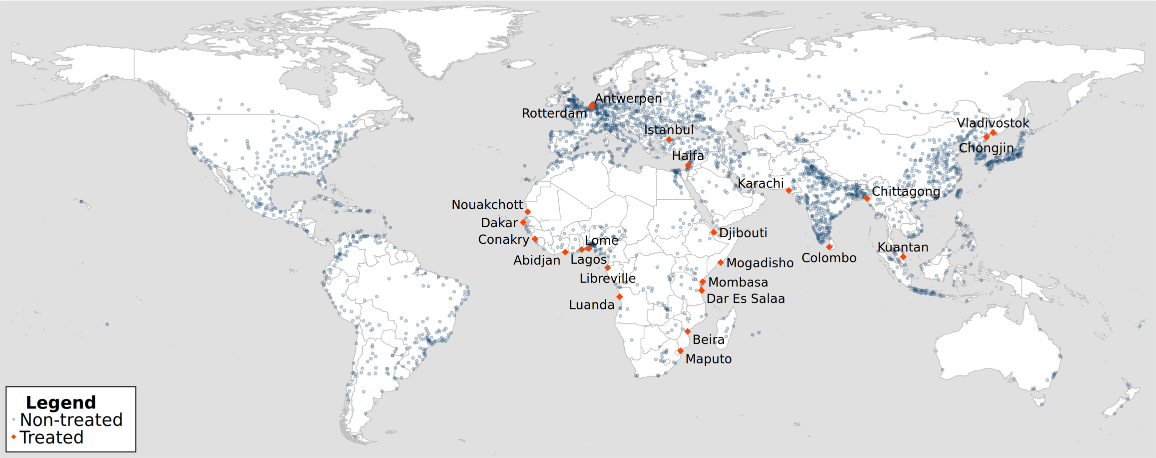
- **Standard model:** Exogenous reduction in transshipment cost, no resources needed
- **Benchmark 2:** Add land resource cost, but same land share for all ports
- **Our model:** Increased specialization as ports optimally choose land shares (reallocation)

Counterfactual 2: targeted port development in the Maritime Silk Road

- Maritime Silk Road project: Chinese government subsidies to a number of African, Asian and European ports
  - Part of China's *Belt and Road Initiative (RBI)*

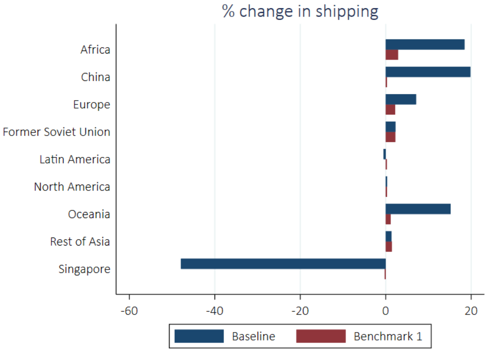
- Study the effect of a 10% exogenous transshipment cost reduction in the 24 targeted port cities that are in our sample

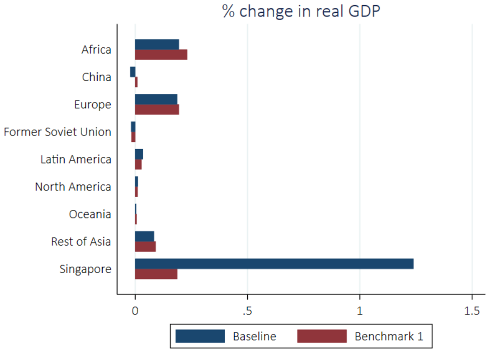
Treated Ports: Maritime Silk Road



Distributional effects across regions

- In the baseline model, reallocation effects substantially amplified by the port development mechanism
- Gains in shipping do not necessarily translate into gains to GDP!





Conclusion

- Large, expensive port cities continue to invest heavily in maintaining their status as first tier ports
- Our analysis suggests it is not obvious that this is actually beneficial
- London and San Francisco lost their status as first-tier ports after containerization and the land has been put to excellent alternative use.

West India Quays, London – Before and After Redevelopment

Thank you!

Outline

Balancing of naturally endowed depth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	ln(Shipping flows 1950)	ln(Population 1950)	Δln(Shipping flows)	Δln(Population)	ln(GDP pc country)	Latitude	Longitude
Depth	-0.2308**	-0.1953***	-0.0351	0.0135*	-0.0215	-0.4541	1.7585
	(0.0955)	(0.0389)	(0.0606)	(0.0076)	(0.0301)	(0.7176)	(2.1507)
Residualized depth	-0.0416		-0.0507	-0.0003	0.0065	0.3900	2.4352
	(0.0977)		(0.0636)	(0.0082)	(0.0308)	(0.7160)	(2.1867)
Observations	553	553	553	532	472	553	553

Notes: Δln(ship count) and Δln(pop) are the growth rates between 1950 and 1960. Robust standard errors in parentheses. Notation for statistical significance: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

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Production

- Competitive firms can freely enter the production of the city-specific good
- Representative firm can produce with standard technology

$$q(r) = \widetilde{A}(r)\, n(r)^{\gamma} (1 - F(r))^{1-\gamma}$$

  - $n(r)$ is number of workers hired
  - $1 - F(r)$ is land used for production at competitive land rent $R(r)$

- Production is subject to external increasing returns

$$\widetilde{A}(r) = A(r)\, N(r)^{\alpha}$$

  - $N(r)$ is the population of city r

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Workers

- Countries $c = 1, ..., C$ are exogenous collections of cities
- Country c has $\overline{N}_c$ workers j who choose $r \in c$ to maximize utility

$$u_j(r) = \left[\sum_s q(r,s)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} a(r)\, b_j(r)$$

  - $q(r,s)$ is consumption of the good made in city s
  - $a(r)$ are amenities in city r
  - $b_j(r)$ is iid city taste shifter, distributed Fréchet$(1/\eta)$
    - η shows severity of mobility frictions
- Disamenities associated with port activity

$$a(r) = \bar{a}(r)\left[1 + Shipping(r)\right]^{-\rho}$$

- Each worker supplies 1 unit of labor for competitive wage $w(r)$
- Land owners have the same preferences as workers but are immobile

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Shipping

- Firm j from r can ship its good to s over a route ρ at iceberg cost

$$T(\rho, j) = \overline{T}(\rho)\,\epsilon(\rho, j)$$

  - $\epsilon(\rho, j)$ iid across firms, routes and time, distributed Weibull(θ)

- Firm learns $\epsilon(\rho, j)$ after making production decisions (Allen and Arkolakis, 2019)
  - Ex ante probability of choosing route ρ between r and s

$$\pi(\rho|r, s) = \frac{\overline{T}(\rho)^{-\theta}}{\sum_{\rho' \text{ between } r \text{ and } s} \overline{T}(\rho')^{-\theta}}$$

  - Expected shipping cost between r and s

$$\mathbf{E}\left[T(r, s)\right] = \Gamma\left(\frac{\theta + 1}{\theta}\right)\left[\sum_{\rho \text{ between } r \text{ and } s} \overline{T}(\rho)^{-\theta}\right]^{-1/\theta}$$

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Model-inspired specification: Robustness

	ln(Population)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln(Ship)	-0.159**	-0.156**	-0.147**	-0.084**	-0.080	-0.164**	-0.231***	-0.215***
	(0.065)	(0.067)	(0.072)	(0.041)	(0.058)	(0.074)	(0.066)	(0.081)
ln(Market Access)	7.103***	6.982***	6.613***	0.588	7.111***	5.692***	10.090***	9.400***
	(0.795)	(0.844)	(1.043)	(2.918)	(0.713)	(1.354)	(1.250)	(1.514)
Observations	2696	2696	2696	2696	2696	2303	2696	2696
R-squared	0.417	0.429	0.467	0.755	0.507	0.544	(1.250)	(1.514)
Number of cities	544	544	544	544	544	464	544	544
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
City FE	✓	✓	✓	✓	✓	✓	✓	✓
Population 1950 × Year	✓	✓	✓	✓	✓	✓	✗	✗
Coastline × Year FE	✗	✗	✗	✓	✗	✗	✗	✗
Saiz × Year	✗	✗	✗	✗	✓	✗	✗	✗
GDP pc (country) 1960 × Year	✗	✗	✗	✗	✗	✓	✗	✗
Specification	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
Drop Cities in Market Access IV	none	$\leq$ 200	$\leq$ 500	none	none	none	none	none
Borusyak Hull correction	none	none	none	none	none	none	worldwide	30° lat
KP F-stat	9.63	9.16	7.75	4.02	8.64	8.43	12.98	8.694

Notes: Standard errors clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

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Alternative explanation: declining labor intensity

- **Declining labor intensity of port technology**
  - Employment in water transport in the U.S. was 0.12% of population in 1960 (fell by 23% until 1987)
  - Too small to offset estimated market access effect in either estimation (3.8%) or model (2.25%)

Stylized Fact 3: Full panel specification

	Panel regression				
	(1)	(2)	(3)	(4)	(5)
Independent Variables	ln(Population)	ln(Shipment)	ln(Population)	ln(Shipment)	ln(Population)
ln(Shipment)	0.015				
	0.035				
	(0.049)				
Depth × post 1970		0.268***	0.004		
		*0.143****	*0.005*		
		(0.058)	(0.013)		
Depth × 1960				-0.042	-0.003
				(0.064)	(0.008)
Depth × 1970				0.246***	0.007
				(0.069)	(0.013)
Depth × 1980				0.213***	-0.002
				(0.079)	(0.017)
Depth × 1990				0.280***	0.002
				(0.086)	(0.020)
Observations	2734	2734	2734	2734	2734
Number of cities	552	552	552	552	552
Year FE	✓	✓	✓	✓	✓
City FE	✓	✓	✓	✓	✓
Population 1950 × Year	✓	✓	✓	✓	✓
Specification	2SLS	FS	RF	dynamic FS	dynamic RF
KP F-stat	21.13				

Notes: Standard errors clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

Stylized Fact 3: Robustness

	ln(Population)			
	(1)	(2)	(3)	(4)
ln(Ship)	0.015	-0.071	0.018	-0.015
	(0.049)	(0.060)	(0.051)	(0.051)
Observations	2734	2734	2734	2338
R-squared	0.717	0.759	0.717	0.756
Number of cities	552	552	552	471
Year FE	✓	✓	✓	✓
City FE	✓	✓	✓	✓
Population 1950 × Year	✓	✓	✓	✓
Coastline × Year FE	×	✓	×	×
Saiz × Year	×	×	✓	×
GDP pc (country) × Year	×	×	×	✓
Specification	2SLS	2SLS	2SLS	2SLS
KP F-stat	21.13	13.71	16.26	19.48

Notes: "Depth" indicates the port suitability measure interacted with decade dummy or indicator for decades including and after 1970. Standard errors clustered at the city level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

IV for population growth: number of frost free days

- Migration towards places with warm winters (Oi, 1997; Rappaport, 2007)

  $$\ln Pop_{it} = \sum_k \beta_k * frostfree_i * \mathbb{1}(t = k) + FE_i + FE_{ct} + \epsilon_{it}$$

- $frostfree_i$ = average number of frost free days, 1961-1990 (FAO GAEZ)
  - *Note:* frostfree is uncorrelated with depth
- Predicted population:
  $\widehat{lnPop}_{it} = \sum_k \widehat{\beta}_k * frostfree_i * \mathbb{1}(t = k) + \widehat{FE}_i$

	(1)	(2)
Variables	lnpop	lnpop
frostfreeXy1960	0.0007***	0.0003*
	(0.0001)	(0.0002)
frostfreeXy1970	0.0017***	0.0006***
	(0.0001)	(0.0003)
frostfreeXy1980	0.0028***	0.0012***
	(0.0001)	(0.0003)
frostfreeXy1990	0.0039***	0.0013***
	(0.0002)	(0.0004)
Observations	12368	12368
R-squared	0.729	0.839
Number of cities	2568	2568
Year FE	✓	×
City FE	✓	✓
Country-Year FE	×	✓

Notes: Standard errors clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

Structural parameters and inland, sea costs

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- Calibrate values of structural parameters based on the literature

Parameter	Target
$\alpha = 0.06$	Agglomeration externalities (Ciccone and Hall, 1996)
$\gamma = 0.84$	Non-land share in production (Desmet and Rappaport, 2017)
$\eta = 0.15$	Migration elasticity (Kennan and Walker, 2011)
$\sigma = 4$	Elasticity of substitution across goods (Bernard et al., 2003)
$\theta = 203$	Idiosyncratic shipping cost dispersion (Allen and Arkolakis, 2019)
$\lambda = 0.074$	Congestion externalities in transshipment (Abe and Wilson, 2009)

- Choose inland and sea costs that are exponential in distance

$$\phi_\varsigma(d) = e^{t_\varsigma d} \qquad \phi_\tau(d) = e^{t_\tau d}$$

where t_ς and t_τ are set to estimates by Allen and Arkolakis (2014)