# Understanding Port Performance and the Role of Infrastructure

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# World Ports

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  - 90% of world trade volume is carried by ships
- With just-in-time production, crucial that they operate efficiently
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  - 90% of world trade volume is carried by ships
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- Yet recently great disruptions ▸ covid
- What are the drivers of port efficiency?
- Optimal design of port system?

# This Paper

- Collect detailed datasets on both
  - outputs (port service times and queues)
  - and inputs (capacity, infrastructure, capital and labor)
- Estimate a port "production function"
  - a micro-model of port technology
  - model explains why ports are prone to disruption
  - understand role of different inputs
- Calculate whether inputs are misallocated across ports

# Today's Results

- Results indicate
  - Substantial heterogeneity in port productivity
  - Nature of port operation makes them very susceptible to disruptions
  - Wait times sensitive to both labor and infrastructure
  - Reallocation of inputs can substantially lower wait times

# Related Literature

- Trade, Transportation, Infrastructure
  - Koopmans (1949), Allen and Arkolakis (2019), Fajgelbaum and Schaal (2020)
  - Donaldson and Hornbeck (2016), Donaldson (2018), Fajgelbaum and Schaal (2020), Allen and Arkolakis (2021)
  - Ports: Clark, Dollar and Micco (2004), Blonigen and Wilson (2006), Friedt and Wilson (2020), Ducruet, Juhasz, Nagy, and Steinwender (2021), Brooks, Gendron-Carrier, and Rua (2021)
  - Shipping: Hummels and Skiba (2004), Hummels (2007), Hummels, Lugovskyy, and Skiba (2009), Ishikawa and Tarui (2018), Asturias (2020), Brancaccio, Kalouptsidi, and Papageorgiou (2020), Wong (2020), Ganapati, Wong, and Ziv (2021), Heiland, Moxnes, Ulltveit-Moe, and Zi (2021), Brancaccio, Kalouptsidi, Papageorgiou, and Rosaia (2022)
  - Supply Chain Disruptions: Carvalho, Nirei, Saito and Tahbaz-Salehi (2021), Alessandria and Ruhl (2022), Grossman, Helpman and Lhuillier (2022)

# Outline

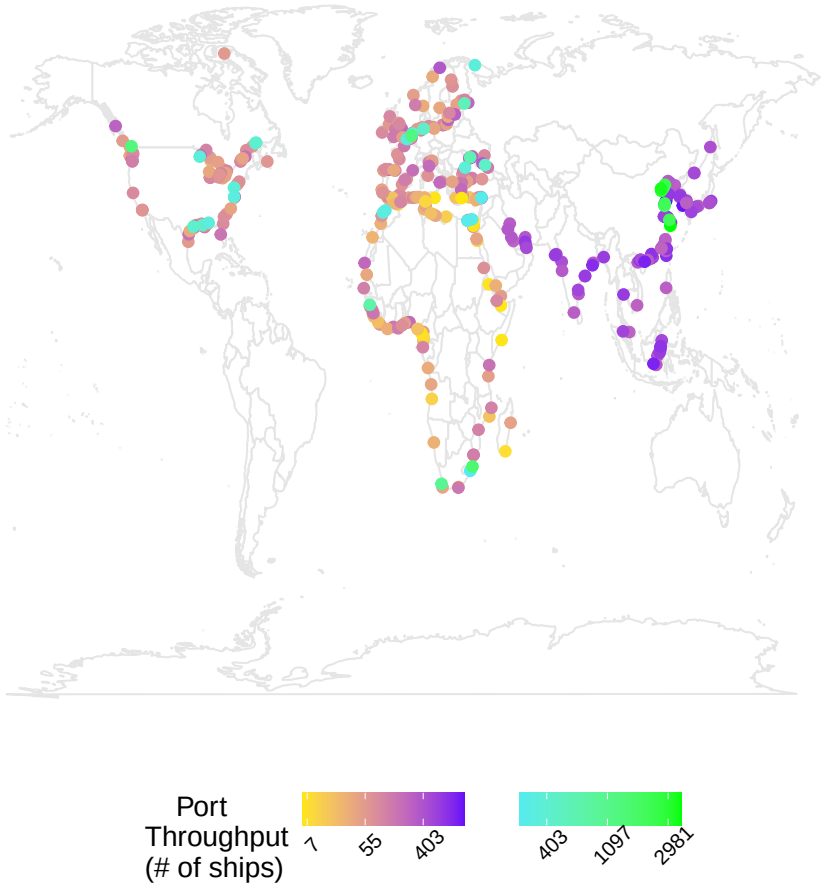
1. Industry Description and Data
2. Facts
3. Port Production Function
4. Misallocation and Disruptions

# Industry Description and Data

# World Ports: Basics

- Port: maritime facility where ships can load / discharge cargo
  - focus on bulk carriers (raw materials and commodities) ▸ details
    - half of world trade volume
- Substantial heterogeneity

# World Ports




- We focus on the largest 100 ports in North America

# Data

- Ship movements, 2010-2021 (AXS Marine)
  - all port calls (timestamp for arrival at anchorage, loading start/end, commodity)

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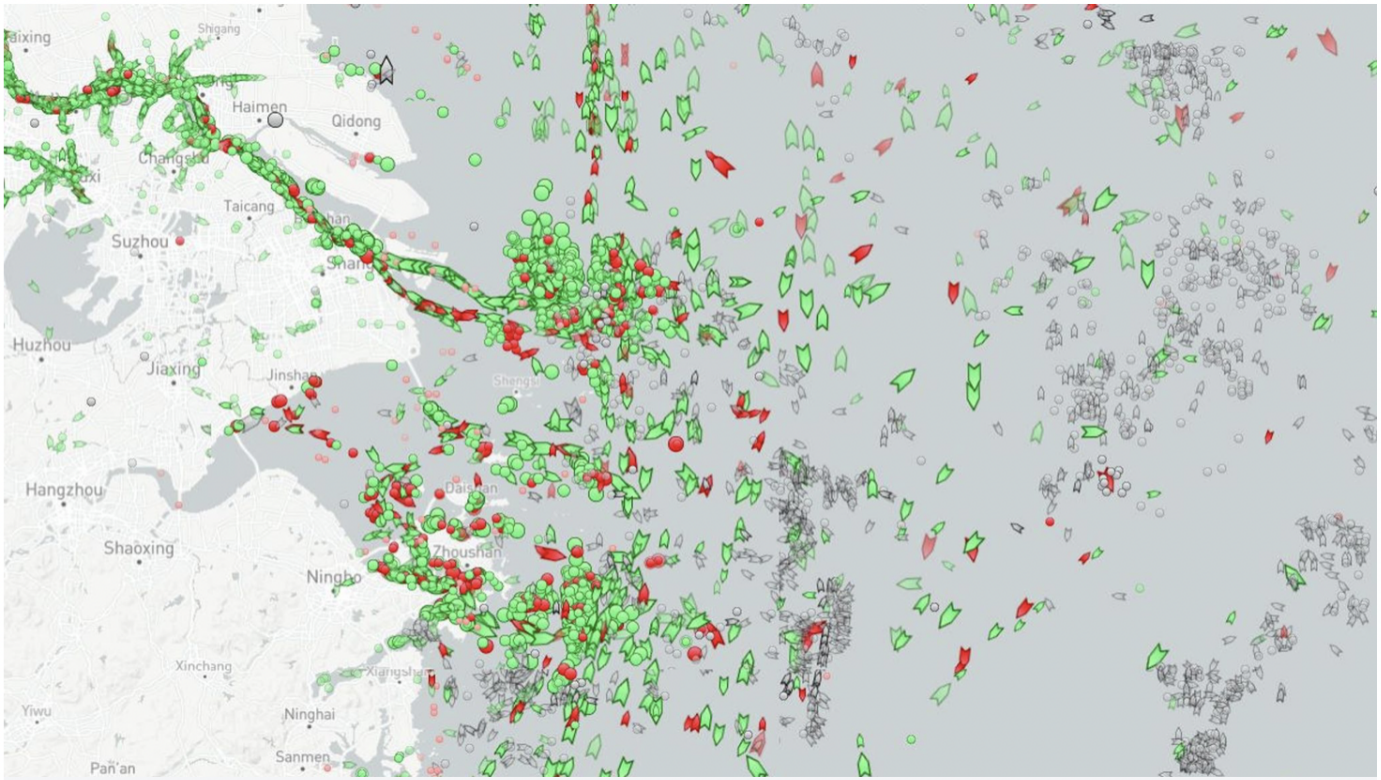
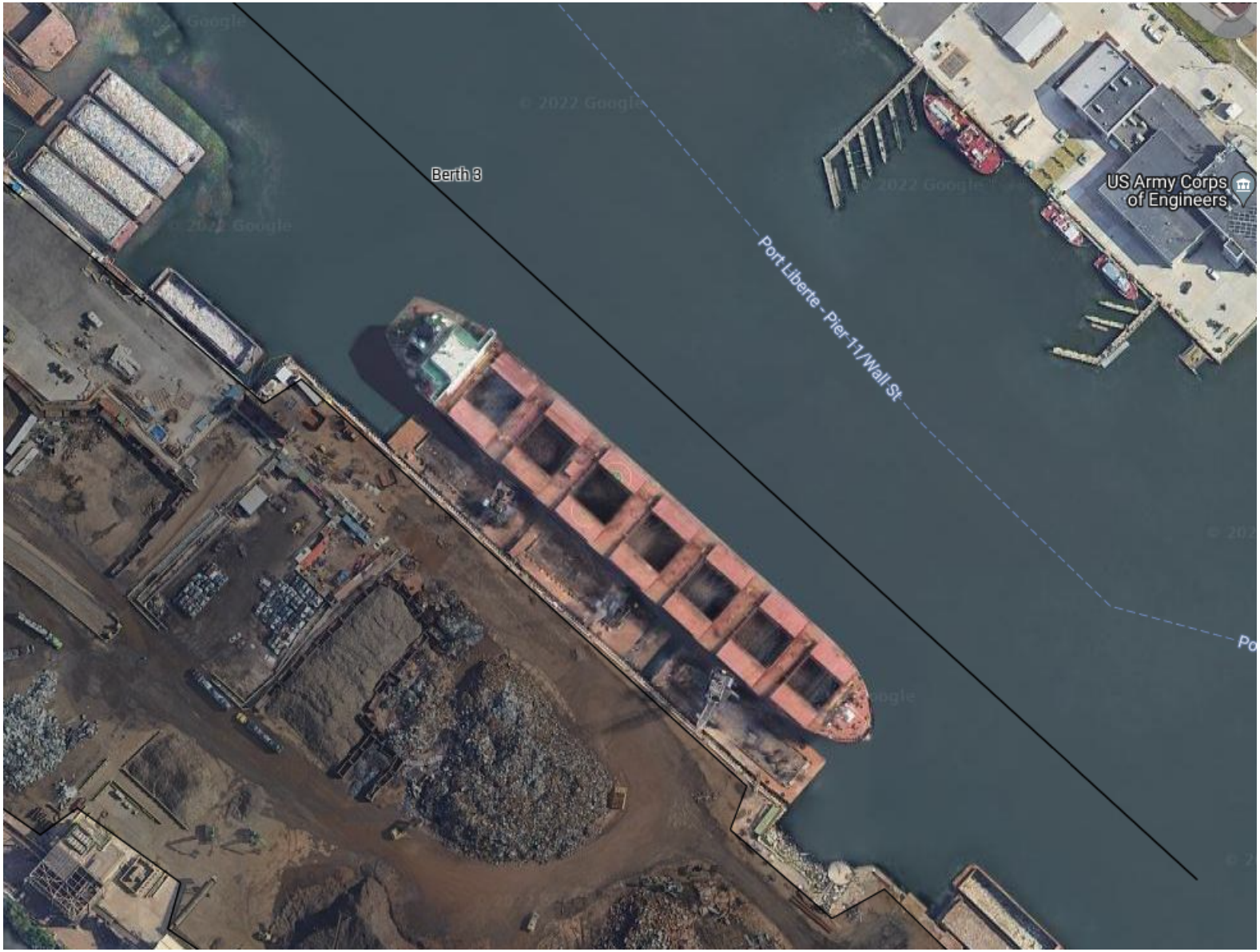



The green and red dots show the mass congestion of cargo vessels and tankers off the coast of Shanghai. Pic: MarineTraffic

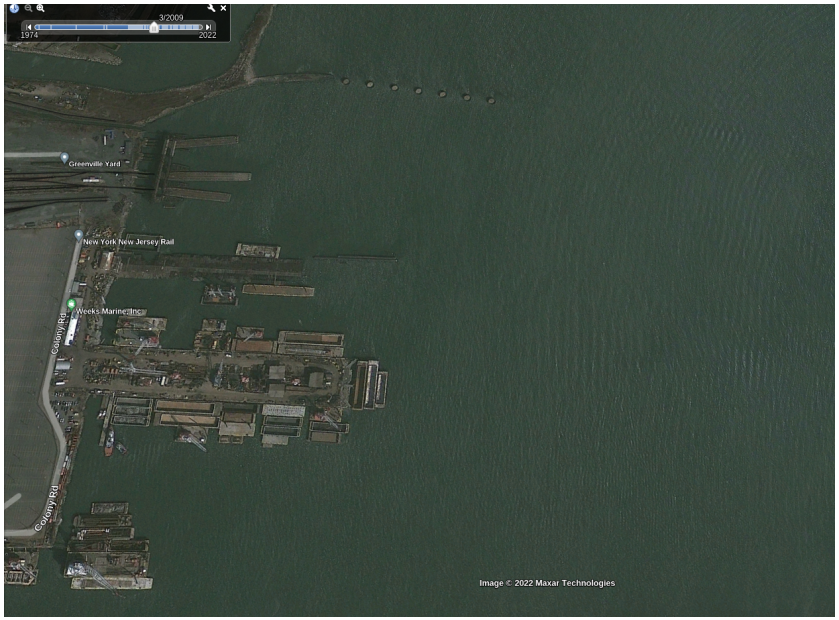
# Data: Infrastructure

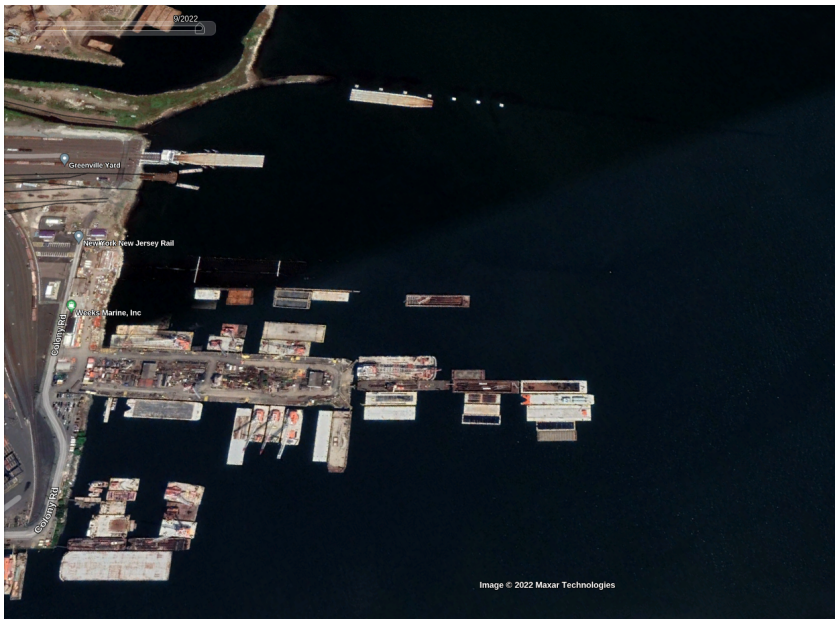
- Port infrastructure, 2009-2022
  - manual collection from Google Earth
    - length of berths
    - storage areas (e.g. silos, container space, warehouses)
    - cranes
    - railroad connection

# Data Collection: Newark



# Data Collection: Newark 2009 vs. 2022



# Data: Labor

- Port employment
  - All unions must report membership to Department of Labor
  - Obtain annual membership to Longshoremen unions
  - Match to ports based on zipcode ▸ high correl to manhours

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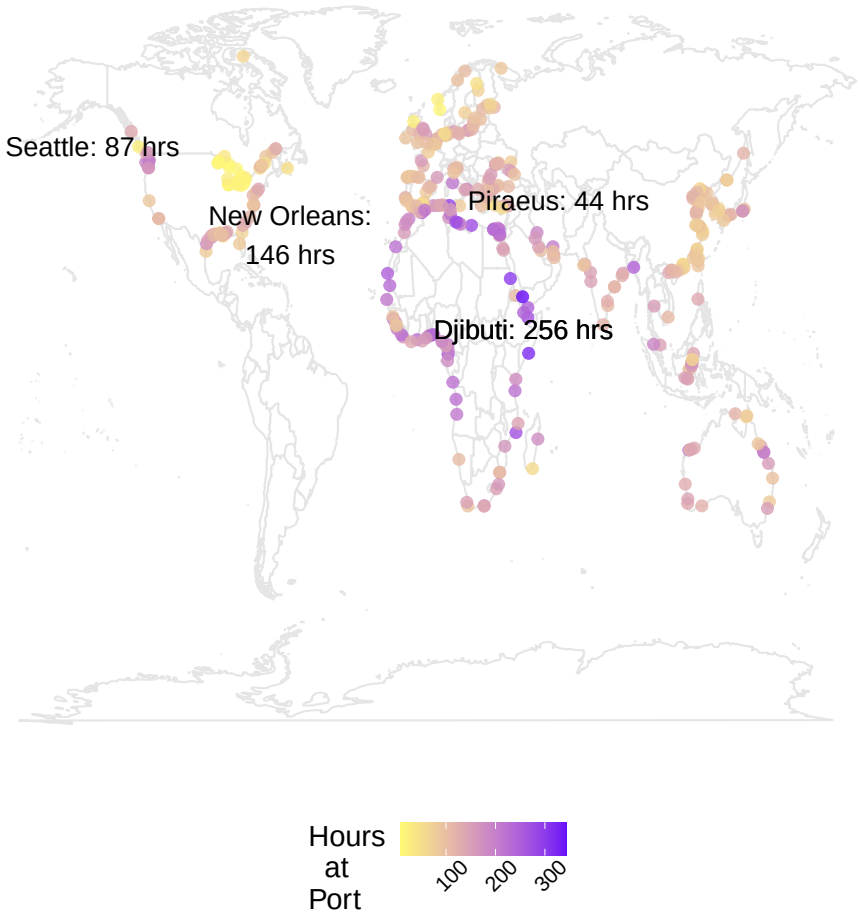
# Facts

# Time at Port

- Key metric of port efficiency: time at port
  - determines port throughput
  - affects efficiency of total supply chain
  - large costs
- On average (median) 118 hours (83 hours)
  - +60% on top of total trip time
  - at $14K per day, direct cost $69K (plus ripple effects e.g. ground transport, inventory management, etc)

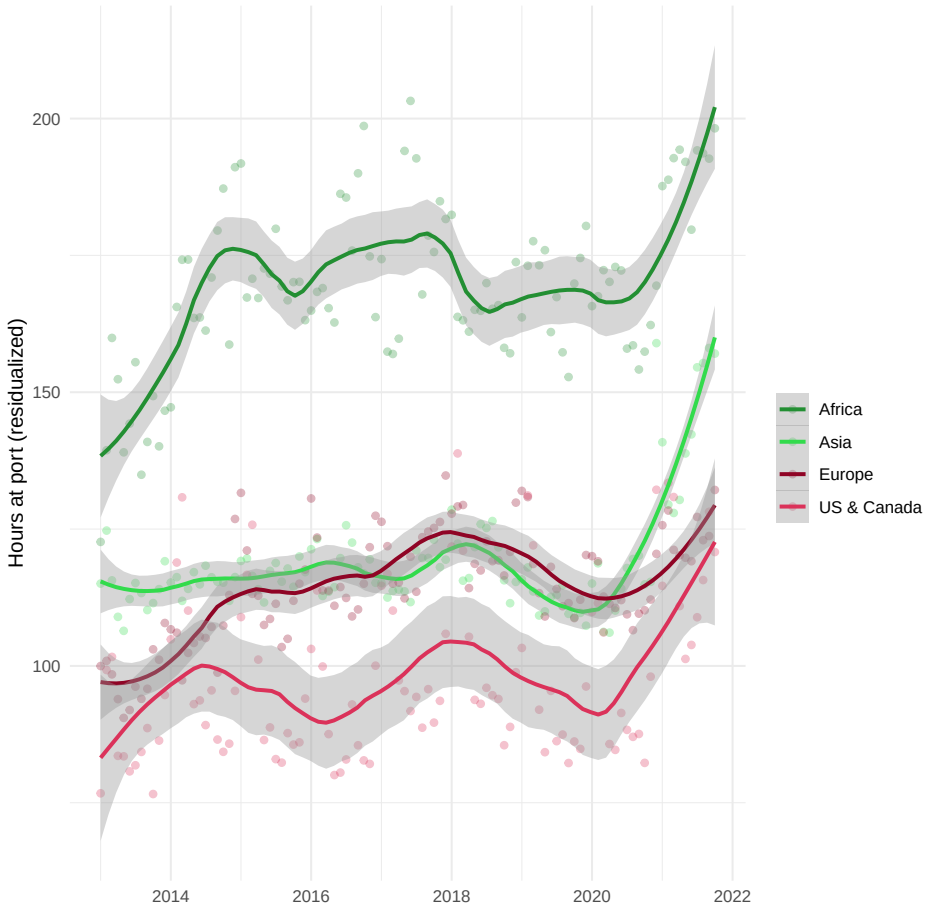
# Time at Port: Massive Dispersion




residualized on ship size and commodity

▸ not driven by port size

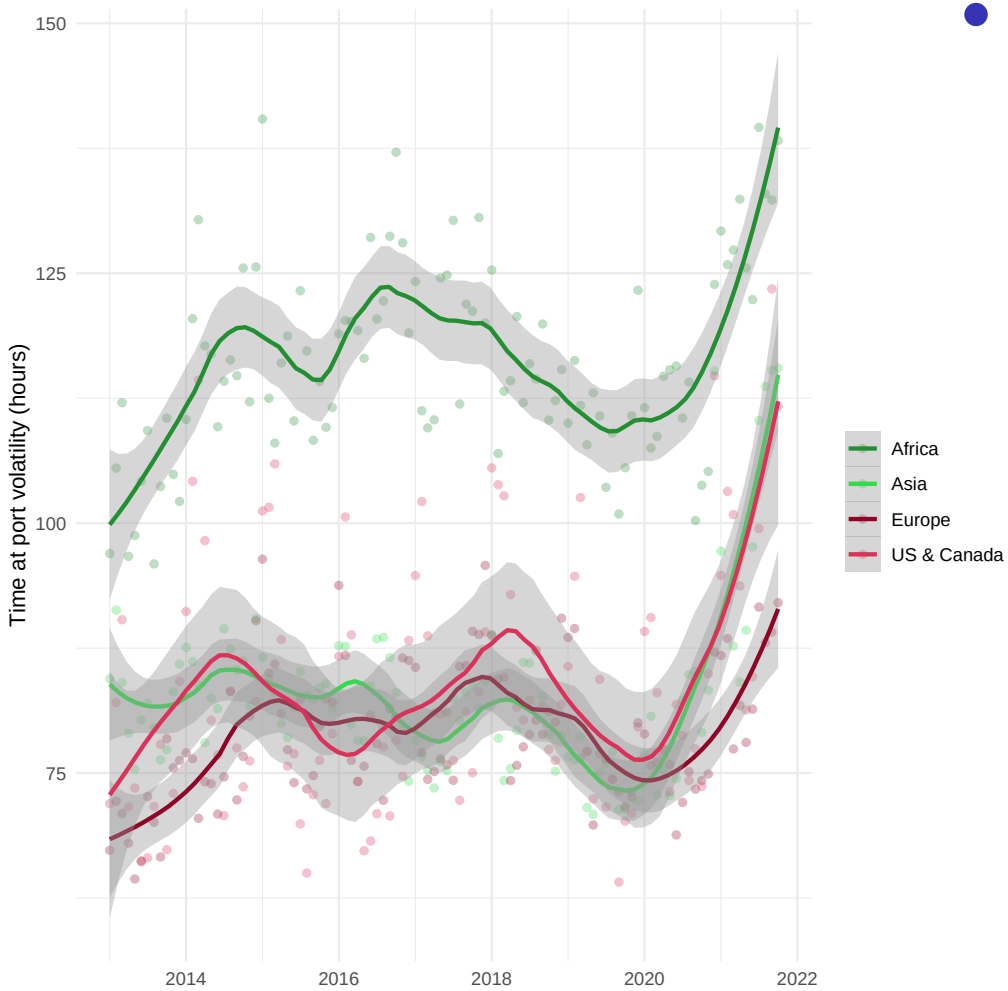
# Time at Port: Prone to Disruptions




- By fall 2021, increased by
  - 25% for North America
  - 35% for Asia
  - 16% for Europe
  - 18% for Africa

residualized on ship size and commodity

# Time at Port: Prone to Disruptions




- Also uncertainty explodes
  - 53% for North America
  - 53% for Asia
  - 20% for Europe
  - 21% for Africa

residualized on ship size and commodity

# Cost of Time at Port and Uncertainty

- How costly is time at port and its volatility?
- We estimate the demand of port $j$:

$$\ln \lambda_{jt} = \alpha_1 \ln TT_{jt} + \alpha_2 \ln \sigma\left(TT_{jt}\right) + \alpha_j + \alpha_t + \epsilon_{jt}$$

where

  - $\lambda_{jt}$ the monthly arrival of ships
  - $TT_{jt}$ time at port
  - $\sigma\left(TT_{jt}\right)$ the standard deviation of time at port

# Demand: Cost of Uncertainty

| | Tons handled monthly (log) |
|---|---|
| Average time at port | $-0.06^{***}$ |
| | (0.014) |
| Standard deviation time at port | $-0.07^{***}$ |
| | (0.007) |
| N | 7,997 |
| $R^2$ | 0.67 |
| Port FE | Yes |
| Month FE | Yes |

- Moving from 25th to 75th prcntile of either average time at port or the standard deviation reduces demand by 17%
- Coefficient on standard deviation underscores importance of just in time production

# Port Production Function

# Inputs and Output

- Port $j$ inputs:
  - labor, $l_{jt}$
  - capital (cranes), $c_{jt}$
  - infrastructure (berths, storage), $K_{jt}$
  - productivity, $\omega_{jt}$
- Port $j$ output: total time at port
  - service time + wait time

# Output: Time at Port

- What is time at port of a ship arriving at port $j$ at $t$?

$$TT_{jt} \equiv \underbrace{T_{jt}}_{\text{service time}} + \underbrace{\frac{Q_{jt}}{K_{jt}} T_{jt}}_{\text{wait time (queueing)}}$$

where ▸ shown from M/M/K queueing model

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  - $T_{jt}$: service time (driven by *labor, productivity*)
  - $K_{jt}$: max ships handled at a time (driven by *infrastructure*)
  - $Q_{jt}$: ships in queue (endogenous, also depends on port *demand*)

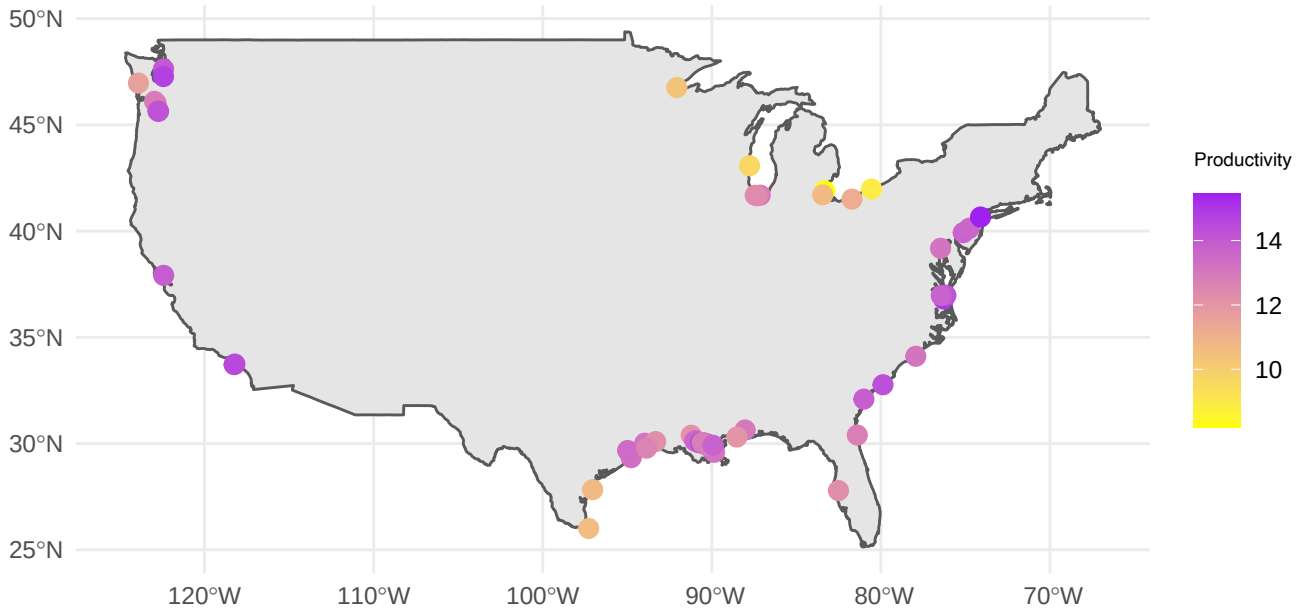
# Service Time (T) Inputs

- Service time of port $j$ at time $t$:

$$T_{jt} = T\left(\frac{l_{jt}}{s_{jt}}, \omega_{jt}\right)$$

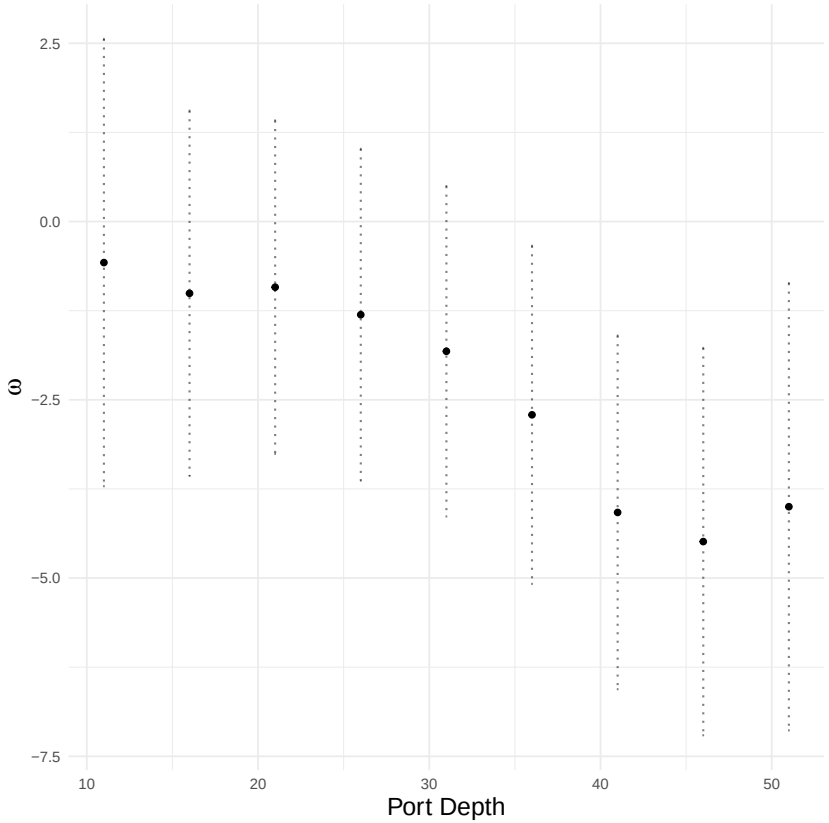
where $l_{jt}$ labor, $s_{jt}$ ships handled at $t$, and $\omega_{jt}$ productivity

# Productivity Estimates




- Increasing productivity from 25th to 75th percentile reduces service times to 1/6
- Substantial dispersion

# Productivity Estimates: Role of Geography




| | $\omega_{jt}$ | |
|---|---|---|
| tide range | 0.231 | |
| | (0.076) | |
| open in weekends | | −9.371 |
| | | (9.266) |

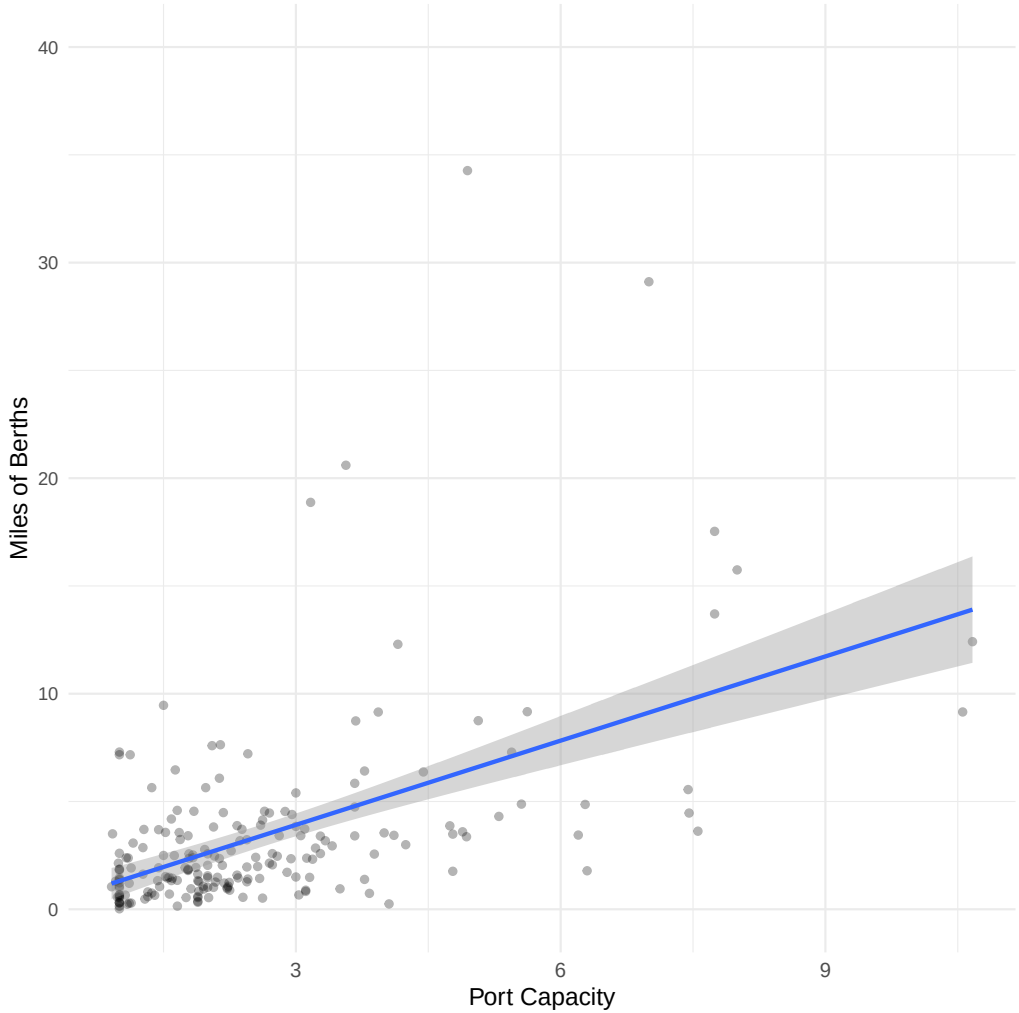
- Ports that are deeper and have lower tide range are more productive

# Capacity (K) Inputs

- Can measure $K_{jt}$ directly
  - measure number of ships contemporaneously handled in the port
  - condition on ships waiting
  - take max over some horizon

# Correlation Between K and Infrastructure

## Port Capacity, K




- Also, $K$ estimate is consistent with the industry "70% rule" ▸ cap utilization

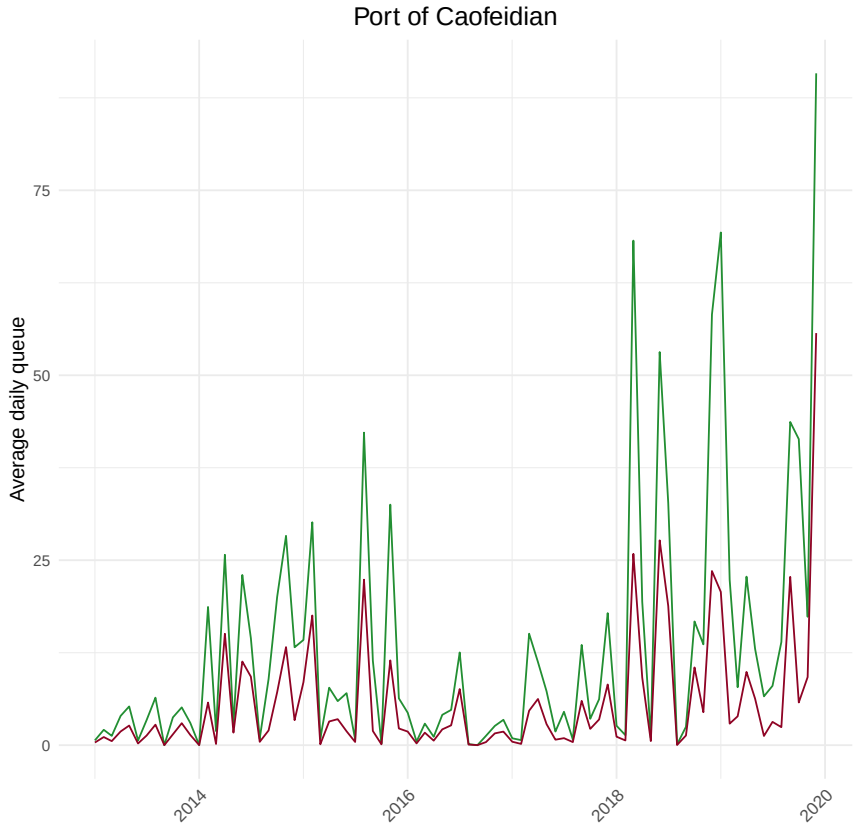
# Questions

- Port Disruptions:
  - Are US ports stable?
  - How much would we have to adjust $L$ vs. $K$ to avoid the COVID disruption? ▸ covid policies
- Input Misallocation
  - Are $L$ and $K$ optimally allocated across US ports?

# Port Disruptions

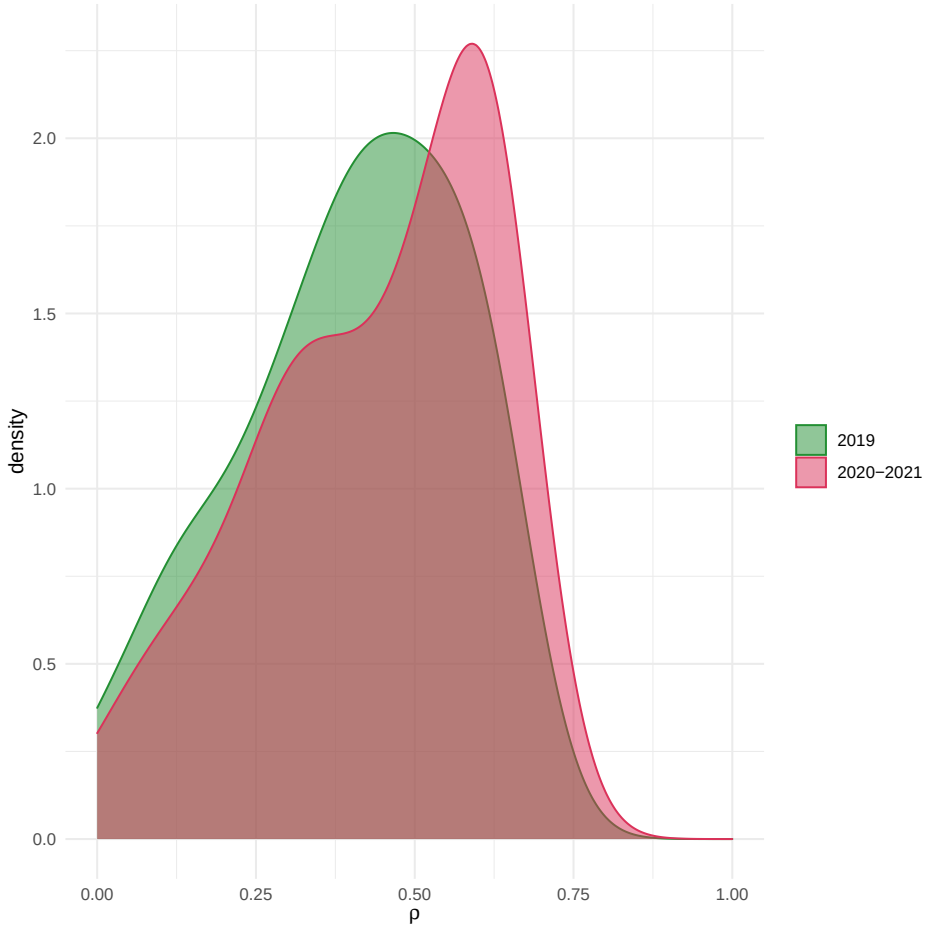
# Sensitivity to Shocks

- Ports are inherently prone to disruptions
  - Using model simulations, consider a 1% demand shock to arrivals




- Same shock has different impact depending on congestion

# Stability of US Ports




- Model implies index of port utilization, $\rho_{jt} \equiv \frac{\lambda_{jt} T_{jt}}{K_{jt}}$
  - as $\rho \to 1$, port infrastructure gets overwhelmed and queue explodes
- Less slack post 2020

# Avoiding the COVID Disruptions

- How much would we need to adjust inputs to eradicate the increase in time at port during COVID (until fall 2021)?

| | |
|---|---|
| change in TT (%) | 25% |
| Required change in L (%) | 23% |
| Required change in K (%) | 40% |

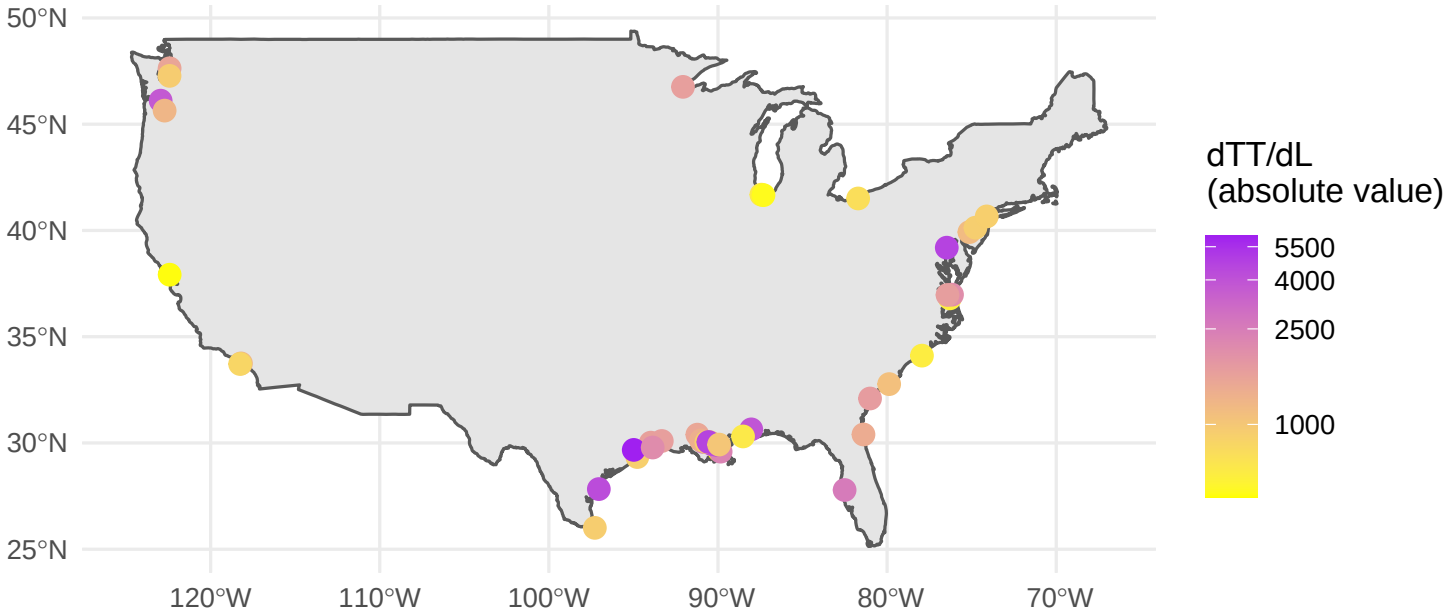
- Both substantial impact (high elasticities)
  - But different mechanisms: $K$ matters only when congested

# Input Misallocation

# Input Misallocation

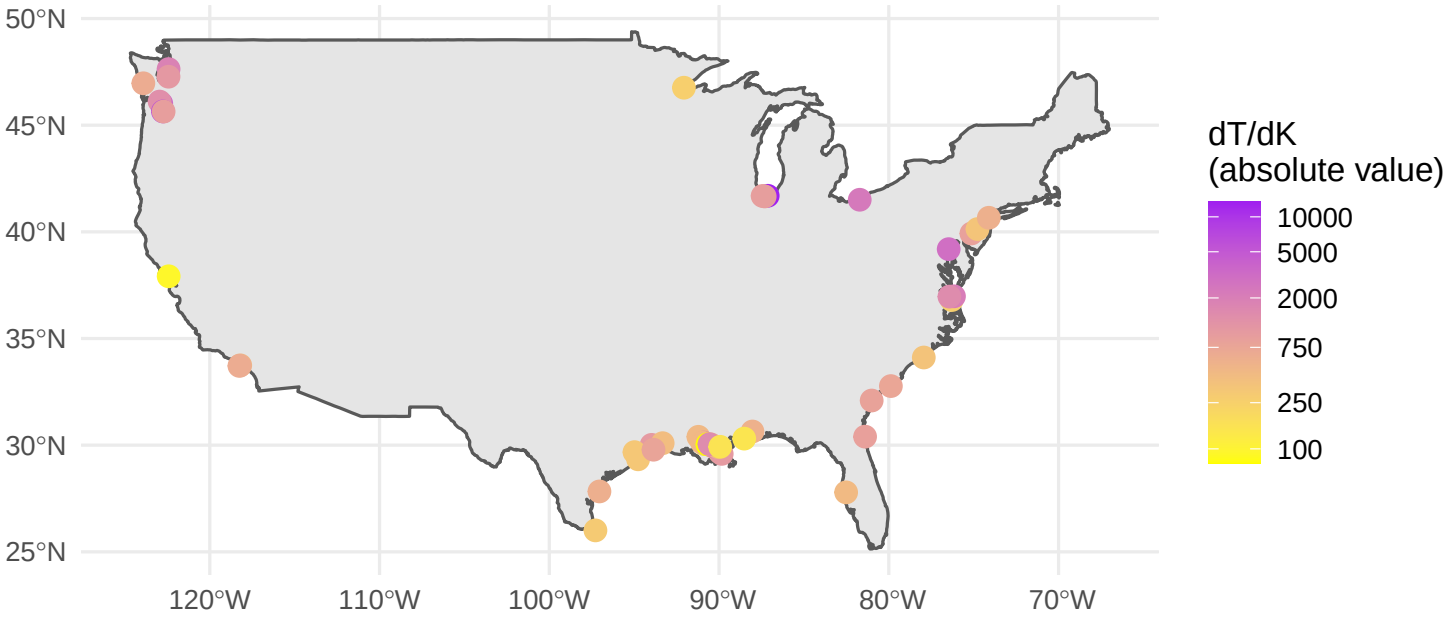
- More generally, what is the optimal input allocation ($L$ and $K$)? ▸ frictions
  - Can current inputs be redistributed to improve total time at port?
- Compute marginal worker contribution to total time at port
- Are marginal contributions equalized across ports? ▸ derivation
  - Restuccia and Rogerson, 2008; Hsieh and Klenow, 2009

# Marginal Worker Contribution




- Dispersion persists within region
- No wage dispersion within region
- Robust when restrict to coal ports

# Marginal Infrastructure Contribution



# Reallocation

- Within each macro-region, divide ports between below and above median marginal worker contribution
- Reallocate one worker from below-median to above-median port

| | Great Lakes | East Coast | West Coast | Gulf |
|---|---|---|---|---|
| change in TT (hours) | -14,715 | -7,091 | -14,715 | -13,937 |
| (% change) | -25.4 | -7.11 | -12.85 | -7.88 |

# Where should the workers be reallocated?

| | $\lvert dTT/dL \rvert$ (log) |
|---|---|
| port productivity, $\omega$ (log) | $3.08^{**}$ |
| | (1.40) |
| port utilization, $\rho$ (log) | $1.41^{**}$ |
| | (0.35) |
| Area FE | Yes |
| N | 53 |

- Reallocation:
  - From Newark to Baltimore: higher congestion
  - From Baton Rouge to Houston: more productive, more ships

# Conclusion

- Estimate a port production function
  - rich data & technology model based on queueing theory
- Findings:
  - substantial port productivity dispersion
  - ports inherently prone to disruptions
  - relative importance of labor and capital for avoiding disruptions
  - evidence of sizeable misallocation of inputs in US ports