Shipping Time Volatility and Supply Chains: Evidence from U.S. Manufacturing Firms

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- Challenge: lack of comprehensive empirical measures of supply chain risk at the firm level

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- Preliminary findings: higher volatility of supply chains is associated with more suppliers (ext. margin) and lower imports (int. margin)
- We incorporate risky delivery times into standard model of input sourcing
  - Aim to assess whether benchmark model is consistent with our results

Literature review

- Most of literature on risk and trade has focused on the impact of risk on the output side (e.g. Ramondo et al 2013, Fillat and Garetto 2015, Esposito 2021, Baley et al 2020)
  - We focus on the input side
- Existing models of firm-level input sourcing typically abstract from supplier risk considerations — see e.g. Halpern et al 2015, Antras et al 2017, Blaum et al 2018
  - We add supply chain risk to the standard model of input sourcing
- Small literature that investigates how firms manage supply chain risk (Clark et al 2014, Gervais 2018, Huang 2019, Carreras-Valle 2021)
  - We provide a comprehensive measure of risk, firm-to-firm analysis, exogenous variation in risk from weather conditions, new facts
- Literature on supply chain disruptions (Boehm et al. 2019, Carvalho et al 2021, Antras and Chor 2021), and on shipping times and trade (Evans and Harrigan 2005, Hummels and Schaur 2013, Brancaccio et al 2019)
  - We focus on effect of supply chain risk

Empirical framework

Model of Shipping Times

- Shipping time for transaction s from a foreign country to the U.S.

$$T^{s}_{xhrtvf} = \left(\bar{\pi}_x + \bar{\alpha}_h + \bar{\gamma}_{rt} + \bar{\xi}_v + \bar{\delta}_f\right) + \pi_x + \alpha_h + \gamma_{rt} + \xi_v + \delta_f - \eta \bar{C}^s \quad (1)$$

  - x is foreign supplier, h is product, r is route, t is period, v is vessel, f is importer
  - bar variables denote deterministic components known by the importer, non-bar variables denote stochastic components
  - $\bar{C}^s$ are shipping charges

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- Shocks are mean zero and i.i.d.

- Population variance of shipping times is

$$\sigma^2_{xhrtvf} = \mathbb{V}(\pi_x) + \mathbb{V}(\alpha_h) + \mathbb{V}(\gamma_{rt}) + \mathbb{V}(\xi_v) + \mathbb{V}(\delta_f) \quad (2)$$

Construction of Shipping Times

- Longitudinal Firm Trade Transaction Database (LFTTD)
  - all import / export transactions since 1992
  - contains importer, foreign exporter, port of entry and departure, date of export and import, HS10 product codes, vessel identity, shipping charges

- Focus on manufacturing importers, arm's length, and ocean shipments

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- Shipping time of transaction s in days:

$$T^s_{xhrvtf} = \text{Date Import}_{xhrvtf}(s) - \text{Date Export}_{xhrvtf}(s),$$

where

  - Date import = date the goods are cleared by customs at port of entry
  - Date export = date the goods departed from the foreign port
  - Average shipping time is 17 days, standard deviation is 9 days

Factors affecting shipping times

Effect of extreme delays

Construction of the Risk Measure

- Estimate risk at supplier(x)-product(h)-route(r)-year(y) level.

1. Residualize shipping times wrt shipping charges, vessel fixed effects, buyer fixed effects, and quarter-year fixed effects:

$$T^s_{xhrvtf} = d_v + d_q + d_f - \eta \bar{C}^s + \epsilon^s_{xhrvtf}$$

2. Standard deviation of ϵ^s_{xhrvf} computed across all transactions within an estimation period (rolling 5-year windows) within x-h-r-y tuple

$$\widehat{StdTime}_{xhry-5,y-1} = \sqrt{\mathbb{V}\left(\epsilon^s_{xhrvtf}\right)}$$

Risk exposure and import demand

- Assess relationship between exposure to supply chain risk and import behavior

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- Main specification:

$$\ln(Y_{fhy}) = \beta_1 \ln(\widehat{StdTime}_{fhy-5,y-1}) + \beta_2 X_{fhy} + \gamma_h + \gamma_y + \epsilon_{fhy} \quad (3)$$

  - Y_{fhy}: Number of suppliers, value imported
  - $\widehat{StdTime}_{fhy-5,y-1}$: weighted average of risk across all routes of the main supplier for a given 10-digit product
  - X_{fhy}: Controls such as avg. shipping time, unit value, inventories

Risk exposure and import demand: Preliminary results

	Number of Suppliers		Imports per Supplier		Total Imports	
	(1)	(2)	(3)	(4)	(5)	(6)
Std Time	.0178***	.0065*	−.0397***	−.0301***	−.0218*	−.0236**
	(.0048)	(.0037)	(.0105)	(.0088)	(.0125)	(.0104)
Importer FE	–	Y	–	Y	–	Y
Product FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Observations	287,000	287,000	287,000	287,000	287,000	287,000

Notes: Number of observations has been rounded to the nearest 1000 as per U.S. Census Bureau Disclosure Guidelines. Standard errors are clustered at the firm level.

Refining the Risk Measure

- Our measure contains many sources of risk:
  - port delays
  - weather conditions along the route
  - number of intermediate stops
  - supplier's ability to comply with regulation

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- Our measure contains many sources of risk:
  - port delays
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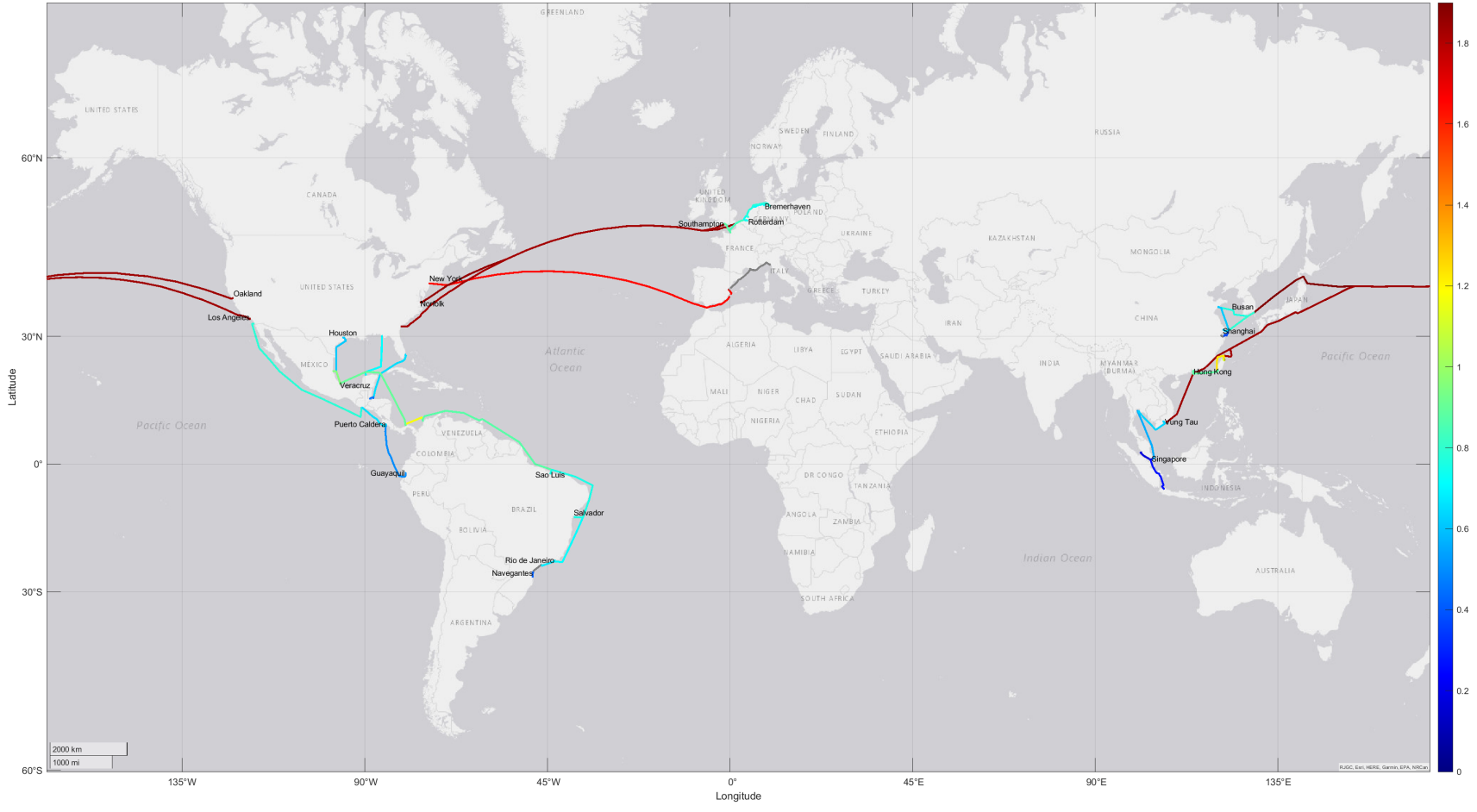
  - supplier's ability to comply with regulation
- Focus on variation induced by weather, which is arguably not anticipated when orders are made

$$T^s_{xhrvtf} = \left(\bar{\pi}_x + \bar{\alpha}_h + \bar{\gamma}_{rt} + \bar{\xi}_v + \bar{\delta}_f\right) + \pi_x + \alpha_h + (Weather^s_{rt} + \tilde{\gamma}_{rt}) + \xi_v + \delta_f - \eta \bar{C}^s$$

Measuring Weather Along a Route

- Using LFTTD, compute route for each transaction from origin port to U.S. port
  - e.g., La Spezia - Barcelona - New York
- Find shortest ocean distance for each segment from Eurostat's SeaRoute program
  - about 20,000 segments, e.g., La Spezia - Barcelona
- Obtain daily average weather for each coordinate on each route
  - 6 variables: wave, swell, tide (height and direction)
- Compute average weather for each trip segment
  - e.g., if La Spezia (11/6) and Barcelona (11/11), average over these 6 days
- Compute average across all segments of a trip

Major Routes and their Weather Volatility



Shipping Time Volatility Induced by Weather

1. Residualize shipping times with vessel and season fixed effects, plus realized weather

$$T^s_{xhrvtf} = d_v + d_q + d_f + \beta \cdot Weather^s_{rt} - \eta \bar{C}^s + \epsilon^s_{xhrvtf}$$

2. Estimate risk at supplier(x)-product(h)-route(r)-year(y) level:
   - Standard deviation of $\hat{\beta} \cdot Weather^s_{rt}$ computed across all transactions within an estimation period (rolling 5-year windows)

$$\widehat{StdTime}^W_{xhrt} = \sqrt{\mathbb{V}\left(\hat{\beta} \cdot Weather^s_{rt}\right)}.$$

Towards a Theoretical Framework

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- Key departure from literature: shipping time and thus input qualities are stochastic.

A model of input sourcing with supply chain risk

- Assume production uses labor, domestic input, and a CES aggregator of foreign inputs:

$$\tilde{y} = \varphi l^{1-\gamma} \left((x_D)^{\frac{\varepsilon-1}{\varepsilon}} + \left(\sum_{i=1}^{N} (\alpha_i x_i)^{\frac{\kappa-1}{\kappa}} \right)^{\frac{\kappa}{\kappa-1}\frac{\varepsilon-1}{\varepsilon}} \right)^{\gamma\frac{\varepsilon}{\varepsilon-1}}$$

  where N is number of foreign suppliers, α_i is the stochastic input quality

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- Hummels and Schaur 2013:

$$\alpha_i = e^{-\tau \cdot days_i}$$

  where τ is a time valuation parameter that translates time in transit into effective input quality.

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- Caveat: exogenous matching between importers and suppliers
  - Why are U.S. importers matched to suppliers of different risk?

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  - If not, how much risk aversion needs to be introduced into profit function?
- Caveat: exogenous matching between importers and suppliers
  - Why are U.S. importers matched to suppliers of different risk?
- Embed firm's problem in general equilibrium trade model and look at welfare

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QUESTION 9

What have you done and/or planned to do to mitigate the effects of supply disruptions?

Please check all that apply

	Business Leaders Survey	Empire State Manufacturing Survey
	Percentage of Respondents	Percentage of Respondents
Build extra inventories	43.1	58.1
Make do without some inputs	35.8	11.0
Switch to existing backup supplier(s)	25.8	41.2
Find new suppliers	42.4	58.8
Source more goods from U.S. as opposed to foreign suppliers	7.3	11.8
Acquire upstream suppliers	0.7	2.2
Other	12.6	10.3

FRB New York Survey 2021

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QUESTION 7

Which of these, if any, have contributed to the disruptions in 2020 and thus far in 2021?

Please check all that apply

	Business Leaders Survey		Empire State Manufacturing Survey	
	Thus Far in 2021	In 2020	Thus Far in 2021	In 2020
Shipping delays (at the ports)	29.1	36.4	34.6	42.7
Trucking delays	39.1	43.1	41.2	47.8
Rail delays	7.3	8.6	2.9	2.9
Air delays	11.3	11.9	10.3	17.7
Domestic suppliers shut down or have limited supplies	50.3	66.2	60.3	76.5
Foreign suppliers shut down or have limited supplies	30.5	46.4	30.9	44.9
Other	7.3	8.6	8.1	6.6

Factors affecting Shipping Times

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Dep. Var.: Shipping Times	(1)	(2)	(3)	(4)	(5)	(6)
Quarter 2				−.0181***		
				(.0023)		
Quarter 3				−.0164***		
				(.0025)		
Quarter 4				−.0031		
				(.0022)		
Log of number of vessels					.0097**	
					(.0044)	
Log of total imports						.0066***
						(.0015)
R^2	.424	.582	.608	.608	.676	.676
Country FE	Y	–	–	–	–	–
Country-port FE	–	Y	Y	Y	–	–
Product FE	–	–	Y	Y	Y	Y
Cty-port-quarter FE	–	–	–	–	Y	Y
Observations (thousands)	10,480	10,480	10,480	10,480	10,480	10,480

Notes: Number of observations has been rounded to the nearest 1000 as per U.S. Census Bureau Disclosure Guidelines. Standard errors are clustered at the firm level.

Effect of Extreme Shipping Delays

- Compute for each year the log deviation from the average shipping time for each importer-exporter-HS10-country-port of entry combination.
- Compute the value of transactions whose shipping time is larger than the 99th percentile of deviations in the data ("extreme delays").
- Aggregate this variable at the importer-year level and scale it by the importer's total production costs.

Effect of Extreme Shipping Delays

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	(1)	(2)	(3)	(4)
Dependent Variable:	Sales	Profits	Payroll	Employees
Fraction Delayed	-1.526^{***}	-1.044^{***}	$-.5160^{***}$	$-.5840^{***}$
	(.2740)	(.3140)	(.1510)	(.1910)
Importer FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Observations	142,000	142,000	142,000	142,000

Notes: Number of observations has been rounded to the nearest 1000 as per U.S. Census Bureau Disclosure Guidelines. Standard errors are clustered at the firm level.