Mitigating international supply-chain risk with inventories and fast transport

Alessandria and Ruhl

The Rise of Global Supply Chains | December 2021

Global supply chains

- Global supply chains allow for...
  - Greater opportunity for diversification of supply
  - Lower per-unit costs on inputs and finished goods
- ...but bring with them
  - Longer lead times and higher transaction costs
  - Greater opportunity for disruption (choke points, policy)
- Firms manage risk by
  - Holding inventories to economize on transaction costs and as risk-buffer
  - Using air freight to decrease lead time and ship more frequently
  - Switching modes (air, sea, ground) in response to shocks

Goal 1: Understand how firms use inventories and delivery-mode choice to manage risks and reduce costs of trade.

Goal 2: Develop framework for analysis of changes in environment (risks, policies).

[Part of a larger research agenda on international supply chains with Armen Khederlarian, Shafaat Khan, and Carter Mix.]

Results

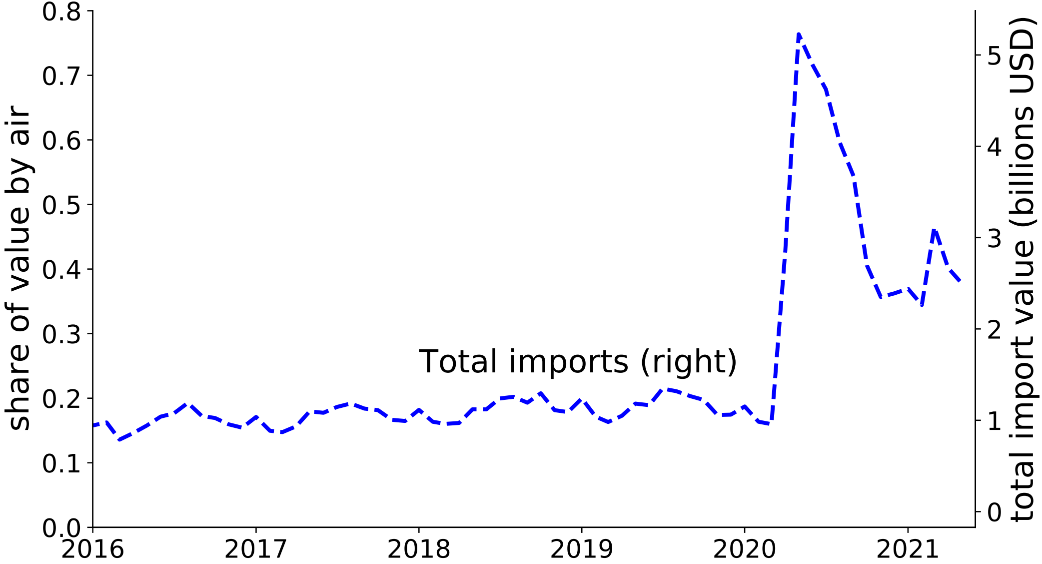
1. Air shipping leads to more frequent import shipments
   - Goods sourced by air behave like those sourced from NAFTA
   - Allowing supply chains to stretch outside of North America
   - More frequent shipments $\rightarrow$ smaller inventories at importers
2. Exporters hold larger inventories
   - Less so for exporters to NAFTA
   - Inventories help to absorb disruptions (complementary to air shipping)
3. Develop a quantitative model of shipping mode and inventory choice
   - Shipping times and transaction costs equivalent to tariffs of 13%-25%
   - Model value of air freight for large shocks

Implication:
Optimal shipping and inventory decisions erode the advantages of local supply chains.

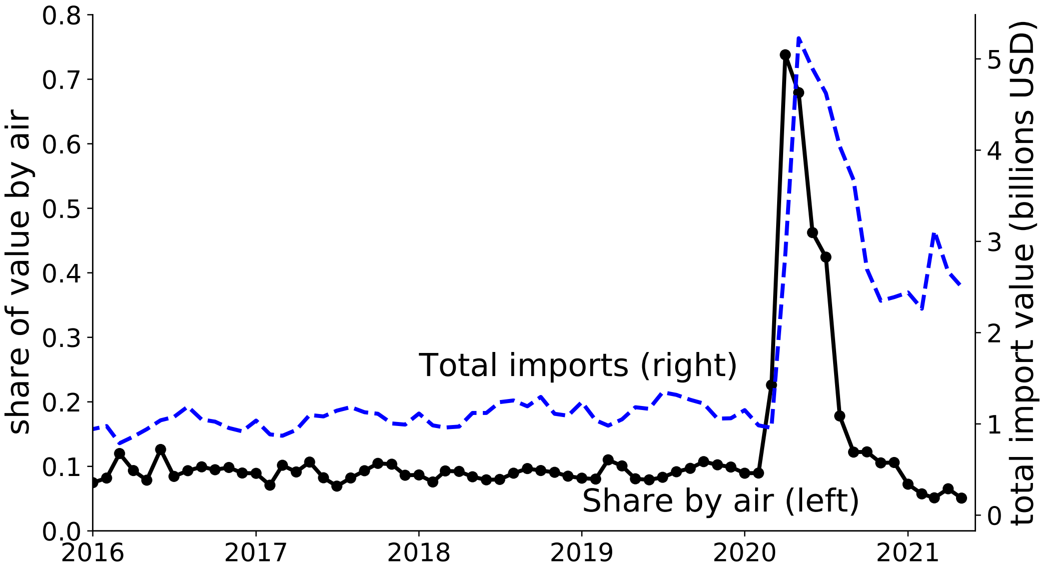
Outline

- Evidence from aggregate shocks
  - Unanticipated shocks – mode substitution
  - Anticipated shocks – precautionary stockpiling
- Evidence on inventory management and trade
  - Simple model to set ideas
  - Study U.S. trade data and show
    - Frequency, size of shipments depend on source & delivery mode
    - Substantial differences in inventory holdings by mode
  - Industry data: Trade involves substantial inventory stockpiles
- Structural Model
  - Industry model of firms facing stochastic demand & inventory management frictions
  - Study response to shocks with & without mode substitution choice
  - Recover trade frictions & risk by industry

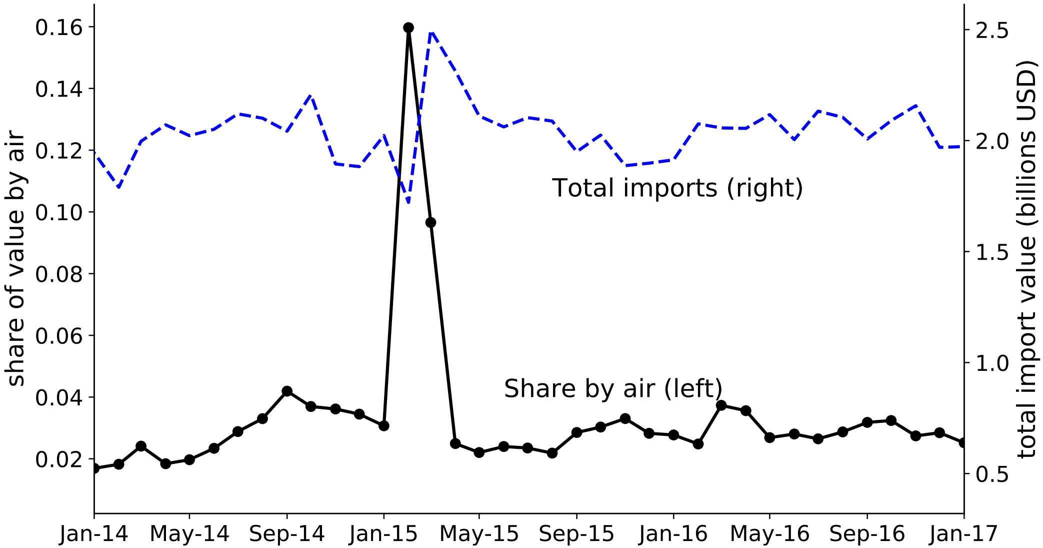
Mode substitution: PPE during the early covid pandemic



Mode substitution: PPE during the early covid pandemic



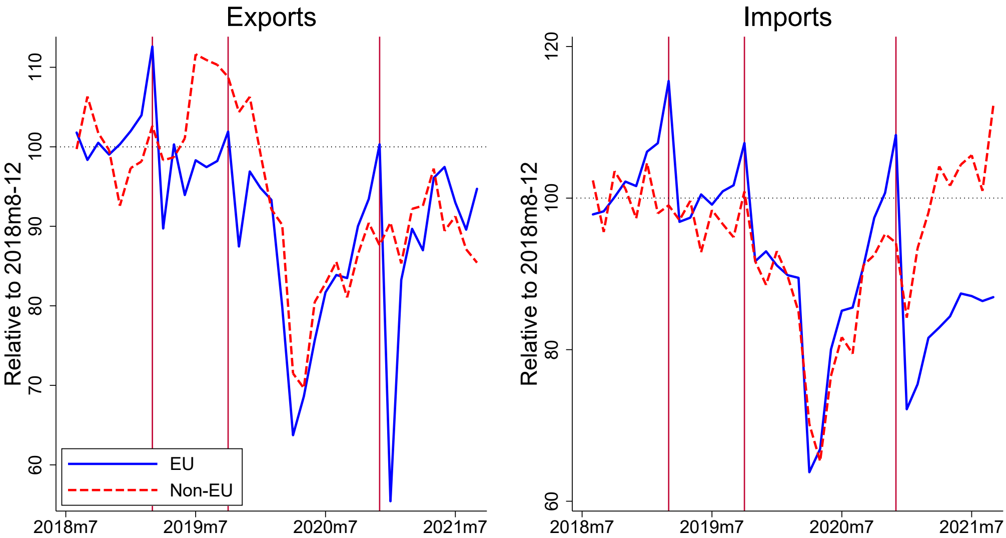
Mode substitution: West Coast ports labor relations



Stockpiling in advance of disruptions/cost shocks

- Firms also can use inventories to adjust to changes in trade policy.
- In advance of tariff cuts from NAFTA, firms reduce imports and run down stocks (Khan and Khederlarian, 2019)
- In advance of possible tariff increases, firms increase imports and build up stocks (Alessandria et al., 2019)
- Evident in the case of Brexit around two proposed dates & actual date.
  - Booms and busts in EU/UK trade in UK/non-EU trade

Inventory adjustment: Stockpiling in advance of disruptions/cost shocks



A simple inventory management model

- i = product, j = source country, m =mode (air, sea)
- Firm faces **certain** annual demand of D_{ij}^m
- Holds inventories at cost h_{ij}
- τ_{ij}^m is marginal cost including shipping; f_{ij}^m is fixed order costs
- Decides how much to order (Q) and how many orders (D/Q)

$$\min_{Q_{ij}^m} \quad \tau_{ij}^m D_{ij}^m + f_{ij}^m \frac{D_{ij}^m}{Q_{ij}^m} + h_{ij} \frac{Q_{ij}^m}{2},$$

- Given a mode, the key tradeoff is
  - Ordering costs $\rightarrow$ fewer, larger orders; more inventory
  - Inventory cost $\rightarrow$ more, smaller orders; less inventory

Model solutions

- Frequency of orders depends on sales $(+)$, depreciation (+), order costs $(-)$

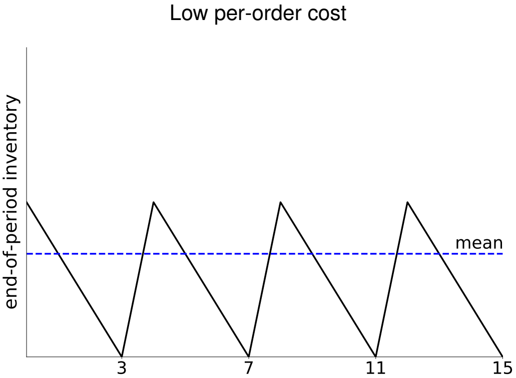
$$N_{ij}^{m} = \frac{D_{ij}^{m}}{Q_{ij}^{m}} = \sqrt{\frac{h_{ij}}{2f_{ij}^{m}} D_{ij}^{m}}$$

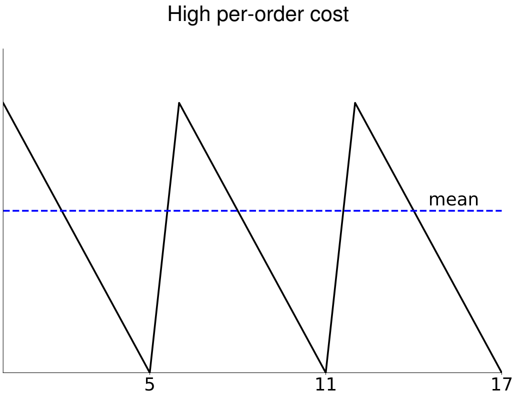
- Inventory-sales ratio depends on sales $(-)$, depreciation $(-)$, order costs $(+)$

$$\frac{I_{ij}^{m}}{\text{sales}_{ij}^{m}} = \frac{Q_{ij}^{m}}{2D_{ij}^{m}} = \sqrt{\frac{f_{ij}^{m}}{2h_{ij}D_{ij}^{m}}}$$

- Suppose $f^{\text{land}} < f^{\text{air}} < f^{\text{sea}}$
  - Land and air shipments more frequent than sea
  - Goods shipped by land or air held in smaller inventories

Inventory dynamics





Order frequency in the data

- Frequency of orders depends on sales (+), depreciation (+), order costs ($-$)

$$N_{ij}^m = \frac{D_{ij}^m}{Q_{ij}^m} = \sqrt{\frac{h_{ij}}{2f_{ij}^m} D_{ij}^m}$$

- Consider three shipping methods: land, air, sea

$$\log(N_{ijt}) = \beta_0 \log(V_{ijt}) + \beta_2 \text{air}_{ijt} + \beta_3 \text{land}_{ijt} + \beta_1 \log(w_{jt}) + c_{it} + c_{jt} + \epsilon_{ijt},$$

- V =value; w =avg. weight; air, land = share of trade by mode
  - Monthly U.S. imports (HS 10 level); consider a product-source pair
  - Product depreciation rates (h) from insurance adjusters at HS6 level
  - Cross-section (2005), but robust to pooling

Frequency of transactions, shipping mode, and depreciation

	log(N)					
log(V)	0.611***	0.610***	0.647***	0.652***	0.657***	0.654***
	(0.016)	(0.016)	(0.017)	(0.017)	(0.001)	(0.002)
log(w)	-0.0638***	-0.0640***	-0.0567***	-0.0602***		
	(0.005)	(0.005)	(0.008)	(0.008)		
land share	0.763***	0.613***	0.273*	0.345**	0.372***	
	(0.139)	(0.139)	(0.116)	(0.104)	(0.013)	
air share	0.523***	0.512***	0.603***	0.583***	0.490***	0.500***
	(0.037)	(0.038)	(0.045)	(0.042)	(0.007)	(0.007)
Canada		0.277**	0.385***	0.345***		
		(0.094)	(0.068)	(0.057)		
Mexico		0.157	0.246***	0.196***		
		(0.082)	(0.061)	(0.052)		
dep rate				0.00558***		
				(0.000)		
Adj. R-squared	0.753	0.753	0.814	0.819	0.870	0.860
HS FE	No	No	No	Yes	Yes	Yes
Country FE	No	No	Yes	Yes	Yes	Yes
NAFTA	Yes	Yes	Yes	No	Yes	Yes

Results

- Model fits data well
  - Shipment frequency grows with trade
  - Faster modes (land, air) have more transactions holding volume constant
  - Less storable goods are shipped more often
  - Shipments fall with weight
- Suggests that per-shipment costs are greatest in sea freight

Takeaways

1. Goods shipped by quicker modes are shipped more frequently

2. Allows importers to hold smaller inventories

A stochastic model of inventory management

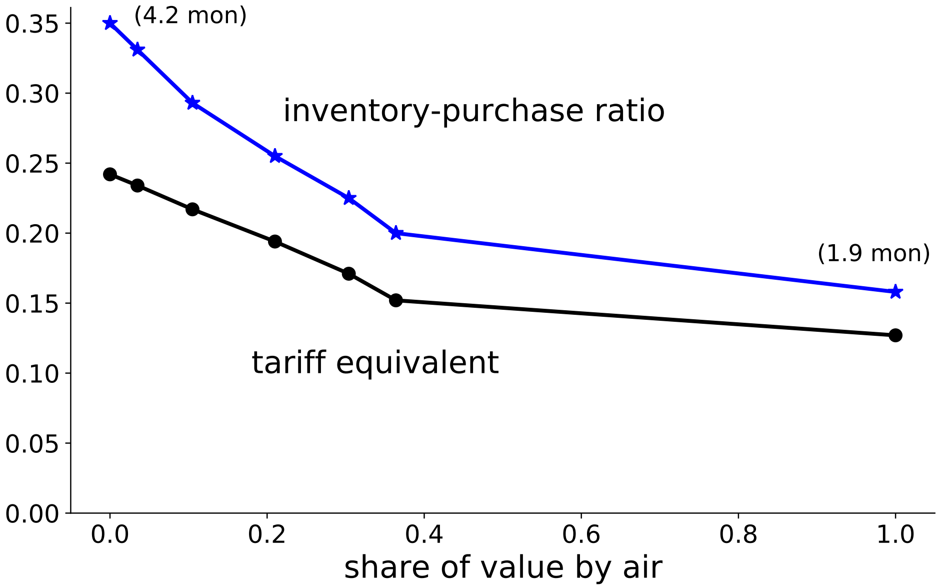
- simple model + uncertainty + shipping time
- Firms: Buy inputs from abroad
  - Idiosyncratic demand shocks
  - Set prices, choose shipping mode (sea or air)
- Imported inputs take time to ship
  - Shipping by sea takes longer than shipping by air
  - Shipping by sea is cheaper than shipping by air
- Stochastic demand + time to ship $\rightarrow$ firms hold inventories
  - Inventories are costly (depreciation/spoilage, interest costs)
  - Inventories economize on transactions costs
  - Inventories allow firms to meet high demand rather than stockout and miss sales (precautionary)

[jump to model details]

The value of air shipping and inventories

- Vary air-freight price holding fixed costs same: τ^a/τ^s
- Increasing air freight premium
  - Reduces sales & transactions
  - Increases inventories: 1.9 months $\rightarrow$ 4.2 months
  - Fewer, larger shipments but firm sales more stable

Response to changes in air freight prices



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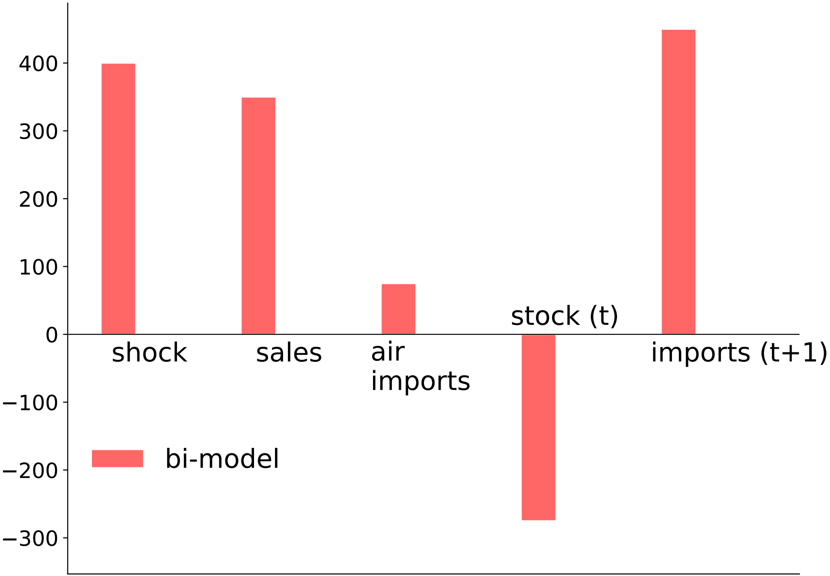
- Tariff-equivalent of shipping costs and time
  - Counterfactual world: No shipping time or cost, but tariff on imports
  - What tariff makes the counterfactual world as profitable as the multi-modal world?

	air share	tariff
air freight expensive	0	25
air freight cheap	1	13

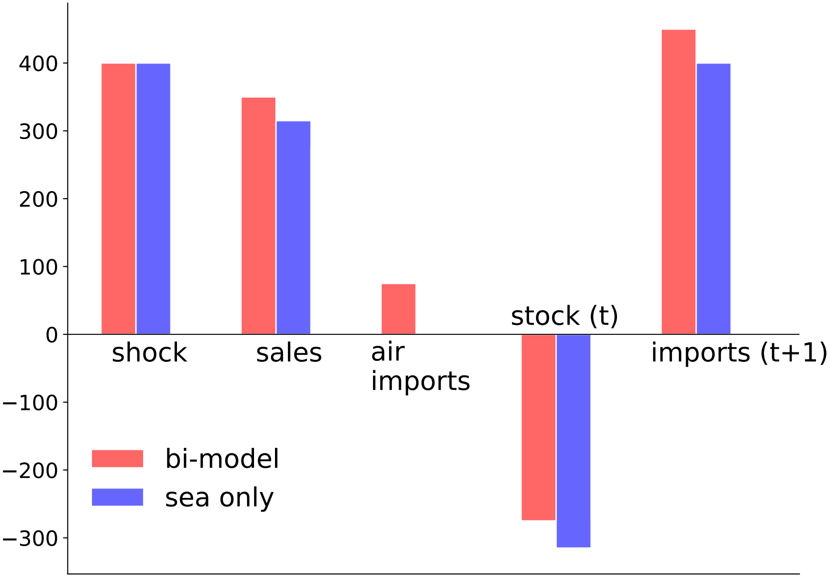
Responding to large shocks

- In the spirit of COVID's affect on PPE (more quantitative work to do)
- Compare the dynamics in the model with and without mode substitution.
  - Model with sea and air freight
  - Model with only sea freight
  - Model with only sea freight, but with the same inventory levels as the bi-modal model

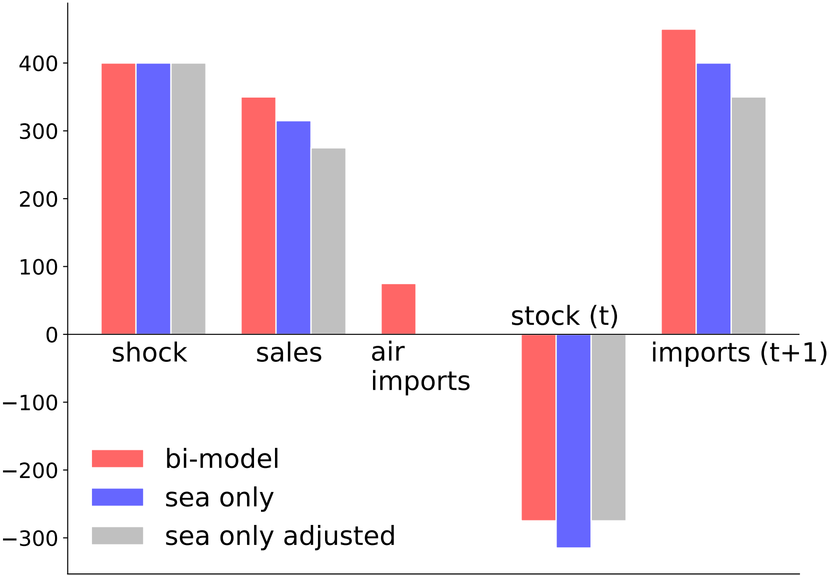
A large shock: Bi-modal shipping



A large shock: Sea only



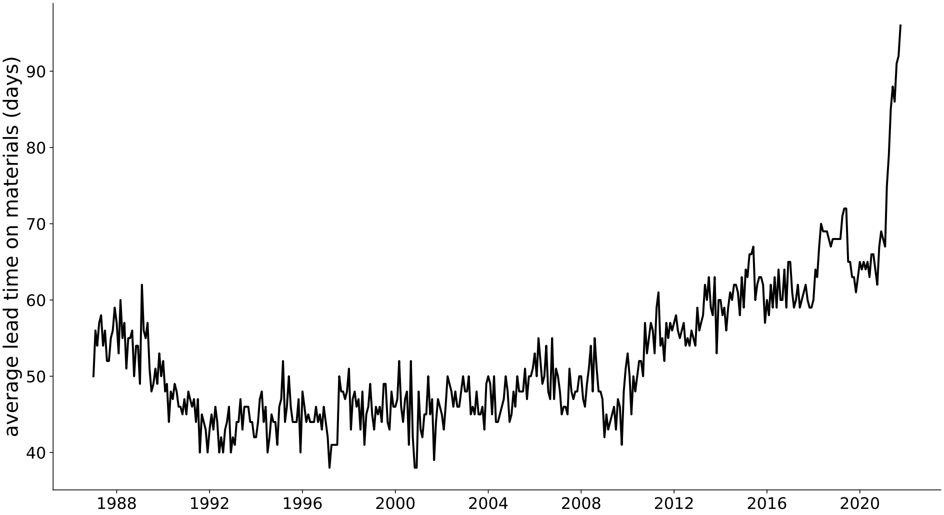
A large shock: Sea only, bi-modal inventory levels



Further directions

- Empirical
  - Document lifecycle of shipment mode (product & destination)
  - Relate to sales volatility.
  - What are the commodity fixed effects? Holding costs, volatility?
- Modeling
  - Estimate industry heterogeneity in risks, shipping technology, and holding costs.
  - Modelling supply constraints
  - Extend to allow for time-to-ship or stochastic availability: in progress Alessandria, Khan, Khederlarian, Mix, Ruhl (2021)

Modelling delays - ISM



Appendix

Related Literature

- Inventories and Trade: Alessandria et al. (2010), Nadais (2017),
- Mode choice in Trade: Baumol and Vinod (1970), Hummels and Schaur (2010), Hummels and Schaur (2013)
- Delivery Risk and trade: Clark et al. (2014)
- Shipment margin: Kropf and Sauré (2014), Hornok and Koren (2015a), Hornok and Koren (2015b), Heise et al. (2015)
- Trade Policy and stockpiling: Khan and Khederlarian (2020) and Alessandria et al. (2019)

Table A1: Number of transactions conditioning on transport mode

	log(N)			
	Pure Boat	Pure Air	Pure Either	Mixed
log(V)	0.549***	0.519***	0.537***	0.604***
	(149.57)	(156.47)	(218.79)	(114.34)
airshare			0	0.388***
			(.)	(7.31)
N	65,744	79,980	145,724	16,431
Adj. R-squared	0.703	0.706	0.707	0.828
HS FE	Y	Y	N	Y
HS-Mode FE	N	N	Y	N
Country FE	Y	Y	Y	Y
NAFTA	Yes	Yes	Yes	No

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A2: Number of transactions and the lumpiness of trade

	log(N)	
log(V)	0.657***	0.502***
	(443.60)	(235.43)
airshare	0.490***	0.400***
	(71.47)	(69.53)
land	0.372***	0.177***
	(28.44)	(15.77)
HH-dist		-0.562***
		(-73.15)
HH-time		-1.346***
		(-136.14)
N	267986	267986
Adj. R-squared	0.870	0.903

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Exporters and inventories

- Match industry inventory levels with trade
- Estimate, for 334 industries (j) in 2016

$$\log(I_{jt}) = \beta_0 \log(V_{jt}) + \beta_1 \log(exs_{jt}) + \beta_2 \text{air}_{jt} + \beta_3 \text{nafta}_{jt} + \alpha_{jt} X_{jt} + \epsilon_{ijt}.$$

  - *exs* = exports-shipment ratio
  - *air* = share of exports by air
  - *nafta* = share of exports to Mexico/Canada
  - X_{jt} = other controls, including number of establishments

- Data sources
  - U.S. exports (Census)
  - County Business Patterns (Census)
  - NBER-CES database (NBER)
  - Annual Survey of Manufactures (Census)

Inventories and export shipments

	Inventory (EOY)				
$\log(V)$	0.841***	0.820***	0.837***	0.832***	0.820***
	(0.024)	(0.026)	(0.033)	(0.032)	(0.031)
establishments		0.0534**	0.0686**	0.0492*	0.0614**
		(0.026)	(0.028)	(0.028)	(0.028)
export-shipment ratio			0.954***	0.495***	0.517***
			(0.157)	(0.176)	(0.170)
land (NAFTA) share				-0.489***	-0.218*
				(0.109)	(0.111)
air share				0.306***	0.189*
				(0.099)	(0.100)
materials					-1.663***
					(0.229)
finished					-0.705***
					(0.200)
N	334	334	333	333	319
Adj. R-squared	0.783	0.786	0.807	0.825	0.847

Results

- Industries that export more hold more inventory, consistent with larger per-shipment costs
- Inventory levels are lower when trade with NAFTA is important
- Inventory levels are higher for products that are likely to be shipped by air (not expected)

Takeaways

1. Higher shipping costs lead exporters to hold higher inventories
2. Inventories provide a buffer to draw down in response to shocks

Firms

- Continuum of monopolistic competitors
- Firm j begins period with inventory $s(j)$, demand shock $\nu(j)$

$$d(p, \nu) = p(j)^{-\theta} \nu(j)$$

- Chooses inputs ordered by boat $m^s(j)$ or air $m^f(j)$ [can do both]
- If firm places an order: $m(j) > 0$
  - Cost of ocean shipping ϕ^s or air ϕ^f
  - τ is air shipping premium
- Firm's state is (s_t, ν_t)
- Timing: observe demand $\rightarrow$ place order(s) $\rightarrow$ observe delivery $\rightarrow$ set prices

Firm optimization

$$V(s,\nu) = \max\{V^a(s,\nu),\ V^n(s,\nu)\}$$

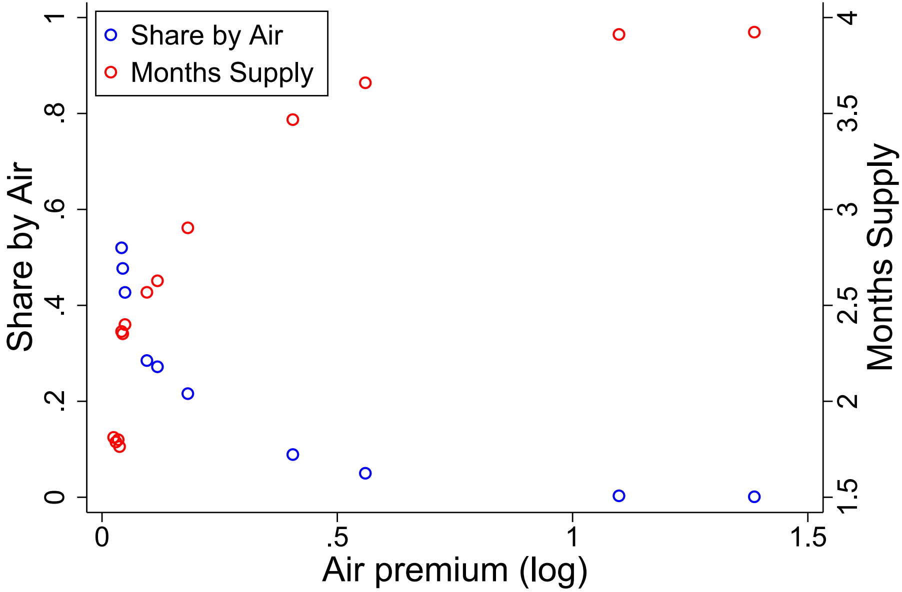
- Value of not placing an order

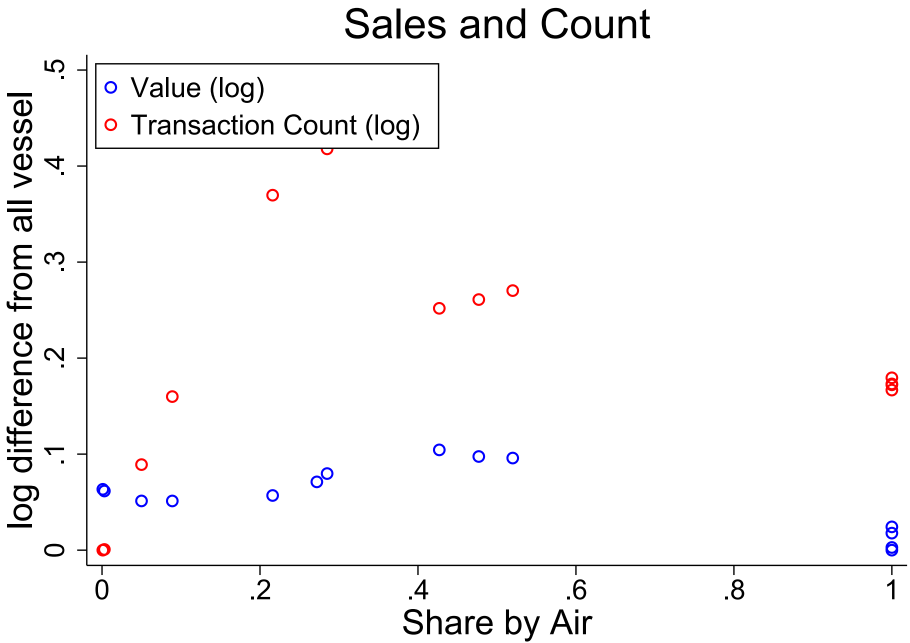
$$\begin{aligned} V^n(s,\nu) = \max_p\ & \pi(d(p,\nu)) + \mathop{\mathbb{E}}_{\nu'} QV(s',\nu') \\ \text{s.t. } & s \geq d(p,\nu) \\ & s' = (1-\delta)(s - d(p,\nu)) \end{aligned}$$

- Value of placing an order

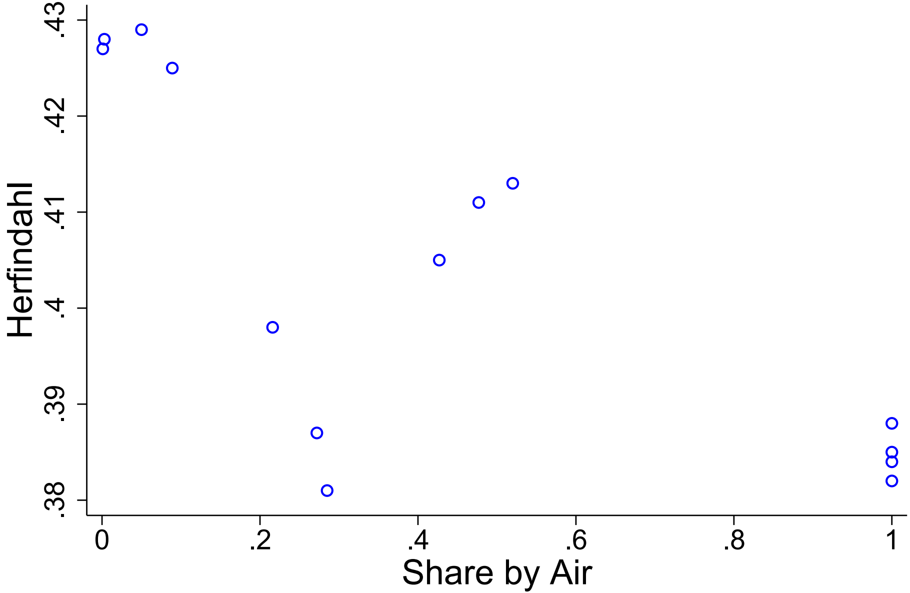
$$\begin{aligned} V^a(s,\nu) = \max_{p,m^f,m^s} & \pi(d(p,\nu)) - p^m(\tau^f m^f + m^s) - \text{costs} + \mathop{\mathbb{E}}_{\nu'} QV(s',\nu') \\ \text{s.t. } & s \geq d(p,\nu) + m^f \\ & s' = (1-\delta)(s - d(p,\nu) + m^f + m^s) \\ & \text{costs} = \phi^f I_{m^f>0} + \phi^s I_{m^s>0} \end{aligned}$$

Air Share & Inventory-Sales Ratio




Sales and Count
Value (log)
Transaction Count (log)
log difference from all vessel
0
.1
.2
.3
.4
.5
0
.2
.4
.6
.8
1
Share by Air

Concentration Falls with Air Shipments



Compensating Differentials

- Let

$$V^f(\tau) = \max_{p_t} E_0 \sum_{t=0}^{\infty} \left(p_t - (1+\tau)\, p^m\right) e^{v_t} p_t^{-\theta}$$

denote the expected value of an importer that faces an ad-valorem tariff τ on imports but no other trade frictions.

- The value of τ that delivers that same expected value as in the economy with no tariffs, but with the shipping lags and fixed transactions costs is implicitly defined as

$$V^f(\tau) = EV(0, \nu),$$

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