Mitigating international supply-chain risk with inventories and fast transport

Alessandria and Ruhl

New Directions in Transportation Economics Conference | May 2022

Part of a larger research agenda on int'l supply chains with Khan, Khederlarian, & Mix.

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 fixed transaction costs
  - Greater opportunity for disruption (choke points, policy)
- Firms manage global supply chains 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) in response to shocks (increases global spare capacity)

Goal 1: Understand use of inventories & delivery-modes to manage risks & reduce costs.

Goal 2: Develop data-consistent framework to study changes in environment (risks, policies).

Results

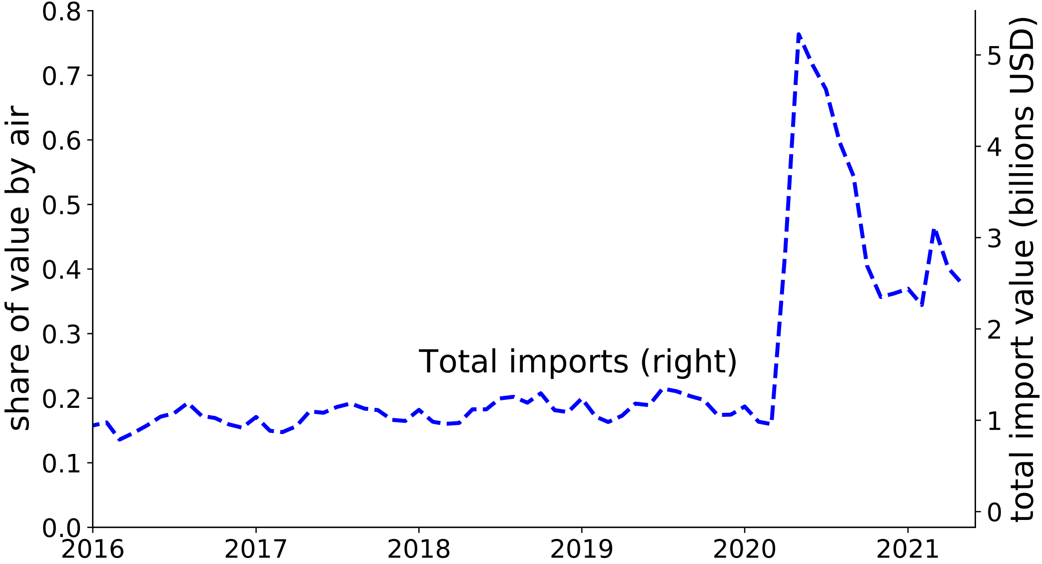
1. Air shipping leads to more frequent import shipments than sea
   - Goods sourced by air are managed like those sourced from NAFTA
   - More frequent shipments $\rightarrow$ smaller inventories at importers
   - Allows supply chains to stretch outside of North America
2. Exporters hold larger inventories
   - 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 following large shocks

Implication: Optimal ship & inventory decisions erode advantages of local suppliers.

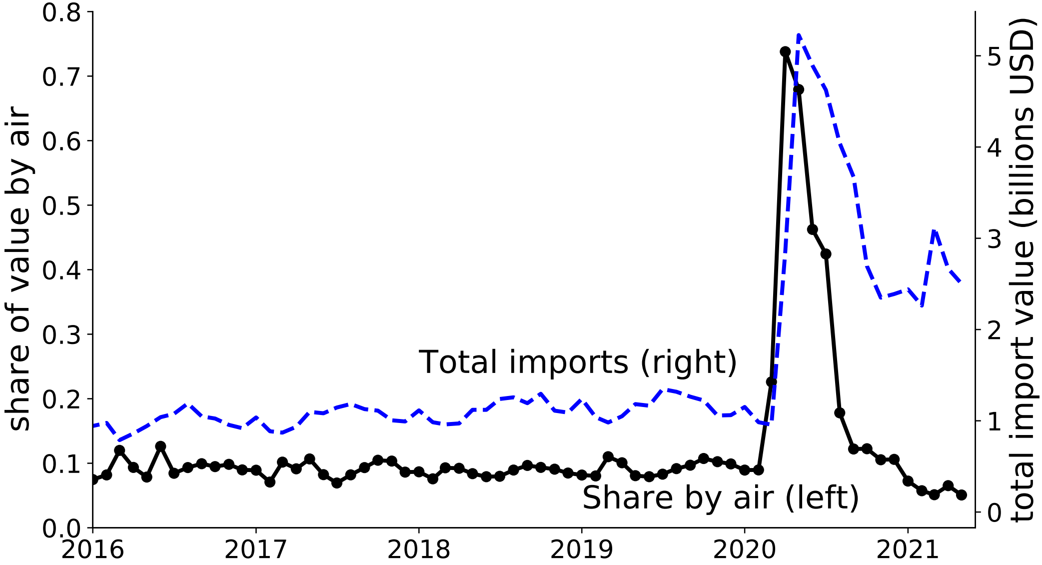
Outline

- Evidence from aggregate shocks
  - Unanticipated shocks – mode substitution
  - Anticipated shocks – precautionary stockpiling
- Evidence on order/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 (ongoing)

Mode substitution: PPE during the early covid pandemic

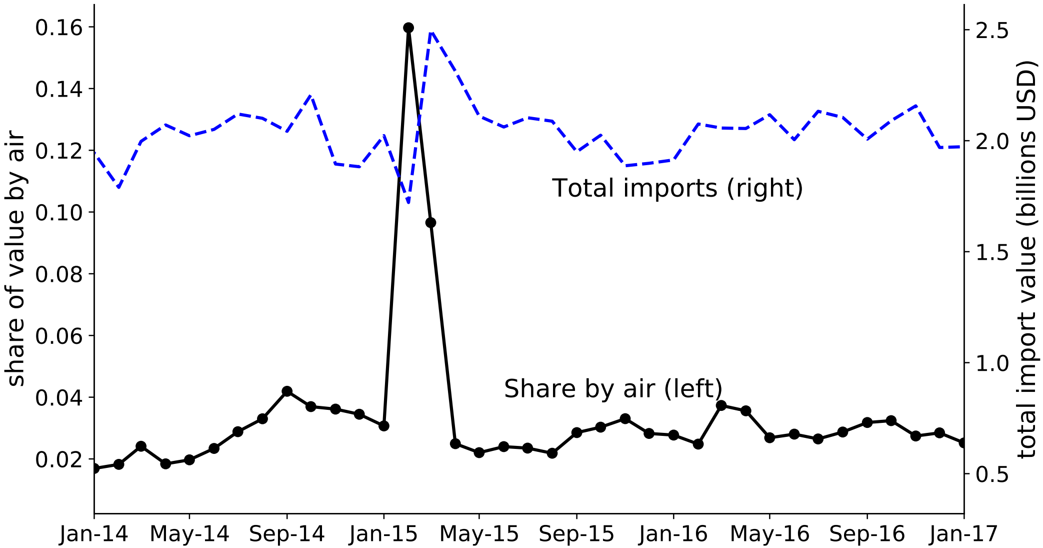


Mode substitution: PPE during the early covid pandemic



**** Currently Operation Fly Formula**

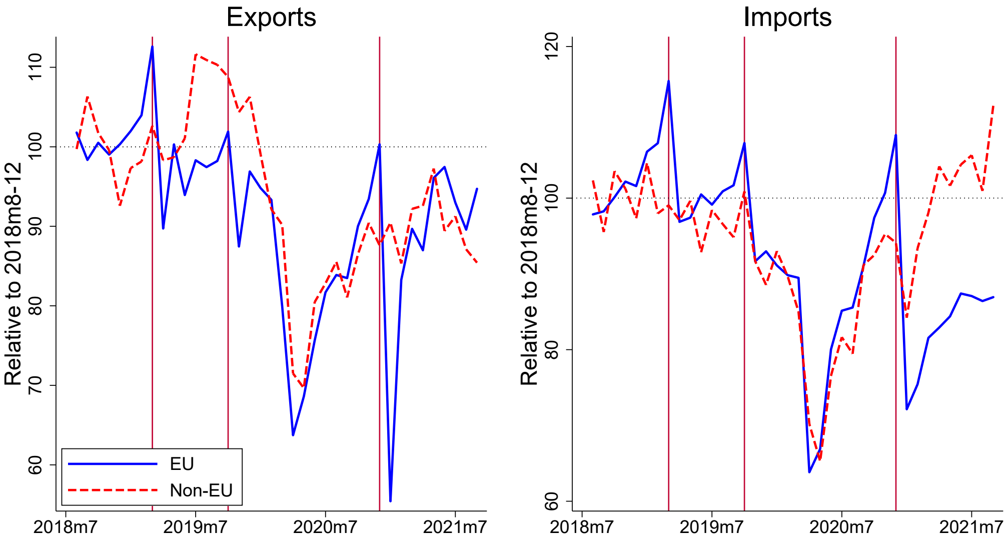
Mode substitution: West Coast ports labor relations (Auto parts from Asia)



Stockpiling in advance of disruptions/cost shocks

- Firms also use inventories to adjust to changes in trade policy.
- In advance of tariff cuts from NAFTA, firms reduce imports & run down stocks (Khan and Khederlarian, 2019)
- In advance of possible tariff increases, firms increase imports & 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 ($-$)

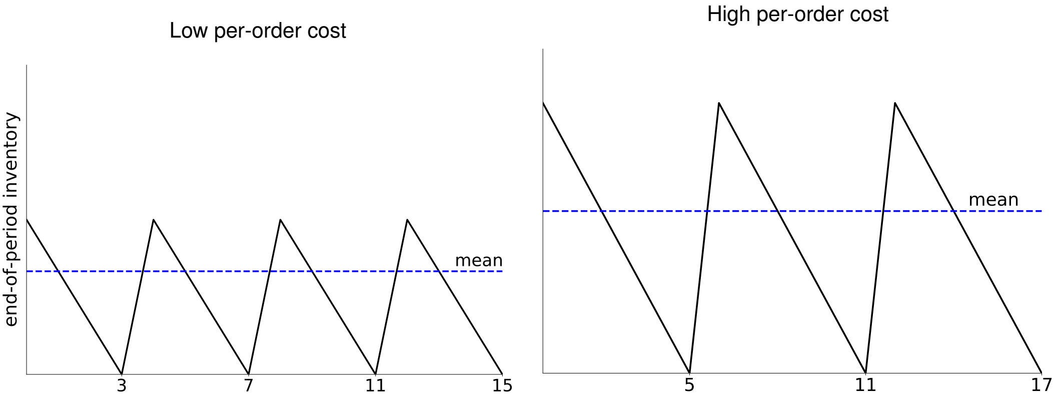
$$N_{ij}^m = \frac{D_{ij}^m}{Q_{ij}^m} = \sqrt{\frac{h_{ij}}{2f_{ij}^m} D_{ij}^m}$$

- 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

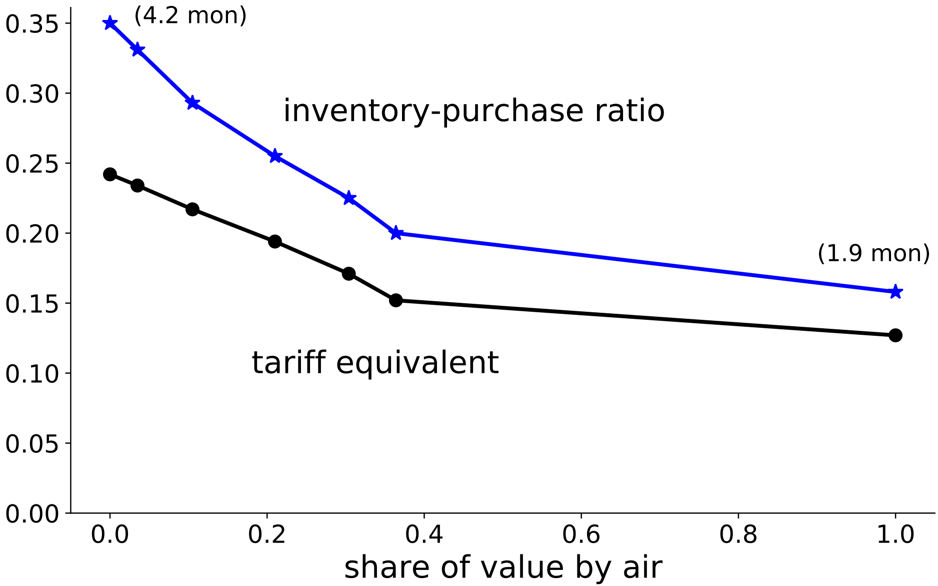
- simple model + uncertainty + shipping time
- Firms: Buy inputs from abroad
  - Idiosyncratic demand shocks (risk)
  - Set prices, choose shipping mode (sea or air)
- Imported inputs take time to ship
  - Shipping by sea takes longer than shipping by air
  - Shipping by sea is cheaper than shipping 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
- Reducing air freight premium
  - Raises sales & transactions
  - Lowers inventories: 4.2 months $\rightarrow$ 1.9 months
  - More, smaller shipments but firm sales less stable

Response to changes in air freight prices



The value of air shipping and inventories

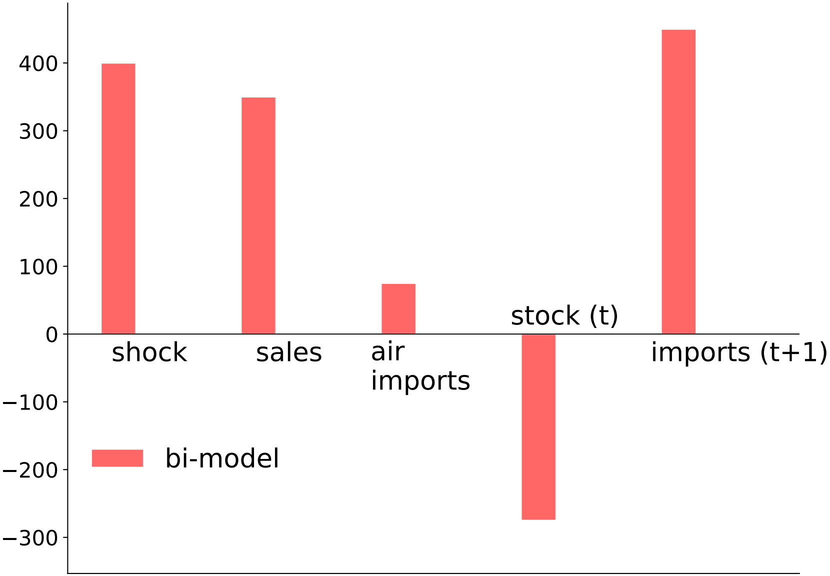
- Vary air-freight price holding fixed costs same: τ^a/τ^s
- Increasing air freight premium
  - Reduces sales & transactions
  - Increases inventories: 1.9 months $\rightarrow$ 4.2 months
  - Fewer, larger shipments but firm sales more stable
- Tariff-equivalent of shipping costs and time
  - Counterfactual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

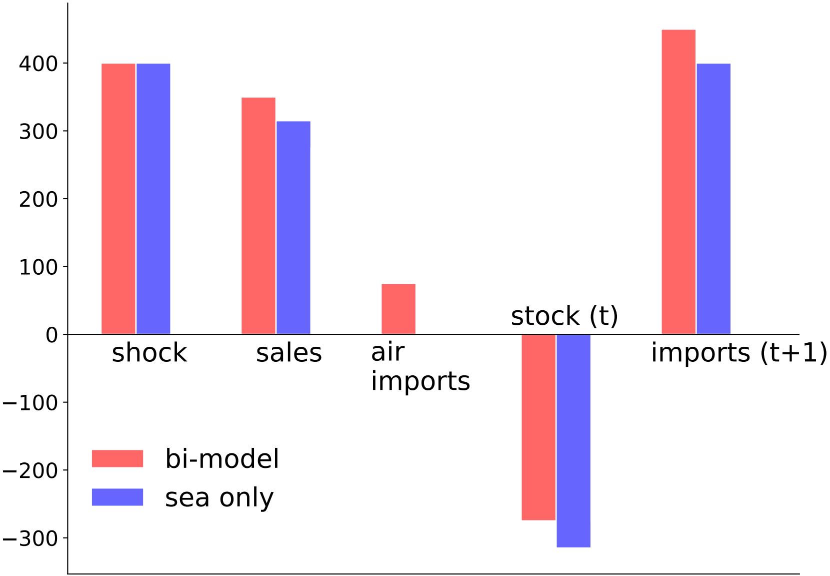
Responding to large, transitory shock

- In the spirit of covid's effect 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

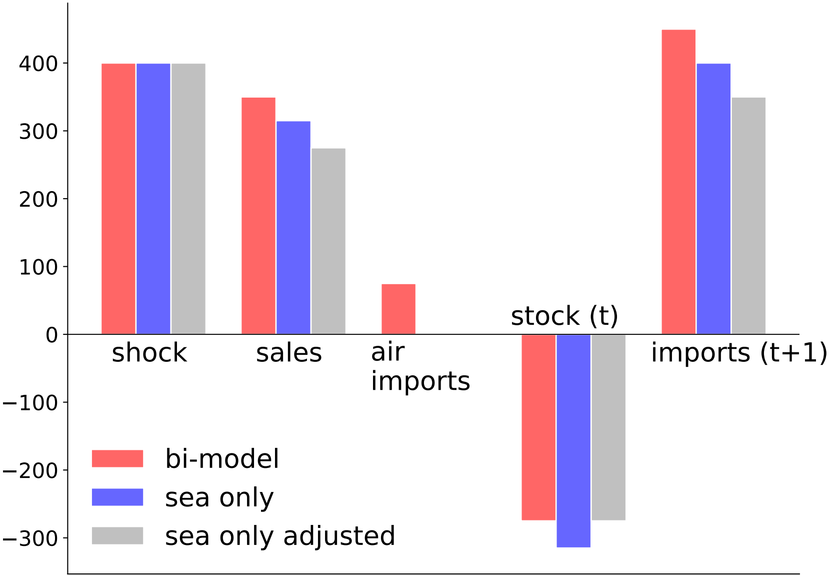
A large shock: Bi-modal shipping



A large shock: Sea only



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



Takeaways

- Firms use inventories AND shipment modes to prepare/adjust to shocks
- Speeding up trade increases resources in short-run, option not available domestically.
  - Extra cost to reshoring!
- Inventory & mode-substitution model is a valuable building block for studying aggregate shocks & policy responses.

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, ν)
- 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

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

Compensating Differentials

- Let

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

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

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

References

Alessandria, George, Joseph P. Kaboski, and Virgiliu Midrigan (2010). "The Great Trade Collapse of 2008–09: An inventory adjustment?" *IMF Economic Review* 58 (2), pp. 254–294.

Alessandria, George, Shafaat Y. Khan, and Armen Khederlarian (2019). "Taking stock of trade policy uncertainty: Evidence from China's pre-WTO accession." NBER Working Paper 25965.

Baumol, W. J. and H. D. Vinod (1970). "An Inventory Theoretic Model of Freight Transport Demand." *Management Science* 16 (7), 413–421.

Clark, Don P., Valentina Kozlova, and Georg Schaur (2014). "Supply Chain Uncertainty in Ocean Transit as a Trade Barrier." Working paper.

Heise, Sebastian et al. (2015). "Tariff Rate Uncertainty and the Structure of Supply Chains." Working paper.

Hornok, Cecília and Miklós Koren (2015a). "Per-shipment costs and the lumpiness of international trade." *The Review of Economics and Statistics* 97 (2), pp. 525–530.

Hornok, Cecília and Miklós Koren (2015b). "Administrative barriers to trade." *Journal of International Economics* 96. 37th Annual NBER International Seminar on Macroeconomics, S110–S122.

Hummels, David L. and Georg Schaur (2010). "Hedging price volatility using fast transport." *Journal of International Economics* 82 (1), pp. 15–25.

— (2013). "Time as a Trade Barrier." *American Economic Review* 103 (7), pp. 2935–59.

Khan, Shafaat Y. and Armen Khederlarian (2019). "How trade responds to anticipated tariff changes: Evidence from NAFTA." Unpublished manuscript.

References

Khan, Shafaat Y. and Armen Khederlarian (2020). "Inventories, input costs and productivity gains from trade Liberalizations." Unpublished manuscript.

Kropf, Andreas and Philip Sauré (2014). "Fixed costs per shipment." *Journal of International Economics* 92 (1), pp. 166–184.

Nadais, Ana (2017). "Are international fixed ordering costs higher than domestic? An inventory approach." Unpublished manuscript.