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 → 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
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

Exports

Imports
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 \( h_{ij} \)
- \( \tau_{ij}^m \) is marginal cost including shipping; \( f_{ij}^m \) is fixed order costs
- Decides how much to order (\( Q \)) and how many orders (\( D/Q \))

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

- Given a mode, the key tradeoff is
  - Ordering costs → fewer, larger orders; more inventory
  - Inventory cost → 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 (+)

\[
\frac{I_{ij}^m}{sales_{ij}^m} = \frac{Q_{ij}^m}{2D_{ij}^m} = \sqrt{\frac{f_{ij}^m}{2h_{ij} D_{ij}^m}}
\]

- 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

Low per-order cost

High per-order cost
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

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

- \( V = \text{value}; \ w = \text{avg. weight}; \ \text{air, land} = \text{share of trade by mode} \)
  - 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
<table>
<thead>
<tr>
<th></th>
<th>log($N$)</th>
<th>log($V$)</th>
<th>log($w$)</th>
<th>land share</th>
<th>air share</th>
<th>Canada</th>
<th>Mexico</th>
<th>dep rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.611***</td>
<td>0.610***</td>
<td>0.647***</td>
<td>0.652***</td>
<td>0.657***</td>
<td>0.654***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.016)</td>
<td>(0.016)</td>
<td>(0.017)</td>
<td>(0.017)</td>
<td>(0.001)</td>
<td>(0.002)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.0638***</td>
<td>-0.0640***</td>
<td>-0.0567***</td>
<td>-0.0602***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.005)</td>
<td>(0.005)</td>
<td>(0.008)</td>
<td>(0.008)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.763***</td>
<td>0.613***</td>
<td>0.273*</td>
<td>0.345**</td>
<td>0.372***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.139)</td>
<td>(0.139)</td>
<td>(0.116)</td>
<td>(0.104)</td>
<td>(0.013)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.523***</td>
<td>0.512***</td>
<td>0.603***</td>
<td>0.583***</td>
<td>0.490***</td>
<td>0.500***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.037)</td>
<td>(0.038)</td>
<td>(0.045)</td>
<td>(0.042)</td>
<td>(0.007)</td>
<td>(0.007)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.277**</td>
<td>0.385***</td>
<td>0.345**</td>
<td>0.345**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.094)</td>
<td>(0.068)</td>
<td>(0.057)</td>
<td>(0.057)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.157</td>
<td>0.246***</td>
<td>0.196***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.082)</td>
<td>(0.061)</td>
<td>(0.052)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.00558***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.000)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adj. R-squared</td>
<td>0.753</td>
<td>0.753</td>
<td>0.814</td>
<td>0.819</td>
<td>0.870</td>
<td>0.860</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HS FE</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Country FE</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>NAFTA</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
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 → 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)
The value of air shipping and inventories

- Vary air-freight price holding fixed costs same: $\tau^a/\tau^s$

- 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

- Inventory-purchase ratio: 4.2 months
- Tariff equivalent: 1.9 months

Share of value by air vs. inventory-purchase ratio and tariff equivalent.
The value of air shipping and inventories

- Vary air-freight price holding fixed costs same: $\frac{\tau^a}{\tau^s}$

- 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?

<table>
<thead>
<tr>
<th></th>
<th>air share</th>
<th>tariff</th>
</tr>
</thead>
<tbody>
<tr>
<td>air freight expensive</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>air freight cheap</td>
<td>1</td>
<td>13</td>
</tr>
</tbody>
</table>
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

- Shock sales
- Air imports
- Stock (t)
- Imports (t+1)

- Bi-modal
- Sea only
- Sea only adjusted
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),
- Delivery Risk and trade: Clark et al. (2014)
- Trade Policy and stockpiling: Khan and Khederlarian (2020) and Alessandria et al. (2019)
### Table A1: Number of transactions conditioning on transport mode

<table>
<thead>
<tr>
<th></th>
<th>Pure Boat</th>
<th>Pure Air</th>
<th>Pure Either</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>log(V)</td>
<td>0.549***</td>
<td>0.519***</td>
<td>0.537***</td>
<td>0.604***</td>
</tr>
<tr>
<td></td>
<td>(149.57)</td>
<td>(156.47)</td>
<td>(218.79)</td>
<td>(114.34)</td>
</tr>
<tr>
<td>airshare</td>
<td>0</td>
<td></td>
<td>0.388***</td>
<td>(.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(.731)</td>
<td>(7.31)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Adj. R-squared</th>
<th>HS FE</th>
<th>HS-Mode FE</th>
<th>Country FE</th>
<th>NAFTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>log(V)</td>
<td>65,744</td>
<td>0.703</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>79,980</td>
<td>0.706</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>145,724</td>
<td>0.707</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>16,431</td>
<td>0.828</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>No</td>
</tr>
</tbody>
</table>

$t$ statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Table A2: Number of transactions and the lumpiness of trade

<table>
<thead>
<tr>
<th></th>
<th>log($N$)</th>
<th>log($V$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>log($V$)</td>
<td>0.657***</td>
<td>0.502***</td>
</tr>
<tr>
<td></td>
<td>(443.60)</td>
<td>(235.43)</td>
</tr>
<tr>
<td>airshare</td>
<td>0.490***</td>
<td>0.400***</td>
</tr>
<tr>
<td></td>
<td>(71.47)</td>
<td>(69.53)</td>
</tr>
<tr>
<td>land</td>
<td>0.372***</td>
<td>0.177***</td>
</tr>
<tr>
<td></td>
<td>(28.44)</td>
<td>(15.77)</td>
</tr>
<tr>
<td>HH-dist</td>
<td>-0.562***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-73.15)</td>
<td></td>
</tr>
<tr>
<td>HH-time</td>
<td>-1.346***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-136.14)</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>267986</td>
<td>267986</td>
</tr>
<tr>
<td>Adj. R-squared</td>
<td>0.870</td>
<td>0.903</td>
</tr>
</tbody>
</table>

$t$ 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

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

- \(exs = \) 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

<table>
<thead>
<tr>
<th></th>
<th>Inventory (EOY)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \log(V) )</td>
</tr>
<tr>
<td></td>
<td>( 0.841^{***} ) (0.024)</td>
</tr>
<tr>
<td></td>
<td>( 0.820^{***} ) (0.026)</td>
</tr>
<tr>
<td></td>
<td>( 0.837^{***} ) (0.033)</td>
</tr>
<tr>
<td></td>
<td>( 0.832^{***} ) (0.032)</td>
</tr>
<tr>
<td></td>
<td>( 0.820^{***} ) (0.031)</td>
</tr>
<tr>
<td>establishments</td>
<td>( 0.0534^{**} ) (0.026)</td>
</tr>
<tr>
<td></td>
<td>( 0.0686^{**} ) (0.028)</td>
</tr>
<tr>
<td></td>
<td>( 0.0492^{*} ) (0.028)</td>
</tr>
<tr>
<td></td>
<td>( 0.0614^{**} ) (0.028)</td>
</tr>
<tr>
<td>export-shipment ratio</td>
<td>( 0.954^{***} ) (0.157)</td>
</tr>
<tr>
<td></td>
<td>( 0.495^{***} ) (0.176)</td>
</tr>
<tr>
<td></td>
<td>( 0.517^{***} ) (0.170)</td>
</tr>
<tr>
<td>land (NAFTA) share</td>
<td>( -0.489^{***} ) (0.109)</td>
</tr>
<tr>
<td></td>
<td>( -0.218^{*} ) (0.111)</td>
</tr>
<tr>
<td>air share</td>
<td>( 0.306^{***} ) (0.099)</td>
</tr>
<tr>
<td></td>
<td>( 0.189^{*} ) (0.100)</td>
</tr>
<tr>
<td>materials</td>
<td>( -1.663^{***} ) (0.229)</td>
</tr>
<tr>
<td>finished</td>
<td>( -0.705^{***} ) (0.200)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>N</th>
<th>334</th>
<th>334</th>
<th>333</th>
<th>333</th>
<th>319</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adj. R-squared</td>
<td>0.783</td>
<td>0.786</td>
<td>0.807</td>
<td>0.825</td>
<td>0.847</td>
</tr>
</tbody>
</table>
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 $\phi^s$ or air $\phi^f$
  - $\tau$ is air shipping premium
- Firm's state is $(s, \nu)$
- 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**

\[ V^n(s, \nu) = \max_{p} \pi(d(p, \nu)) + \mathbb{E}_{\nu'} QV(s', \nu') \]

s.t. \( s \geq d(p, \nu) \)

\[ s' = (1 - \delta)(s - d(p, \nu)) \]

- **Value of placing an order**

\[ V^a(s, \nu) = \max_{p, m^f, m^s} \pi(d(p, \nu)) - p^m(\tau^f m^f + m^s) - \text{costs} + \mathbb{E}_{\nu'} QV(s', \nu') \]

s.t. \( s \geq d(p, \nu) + m^f \)

\[ s' = (1 - \delta)(s - d(p, \nu) + m^f + m^s) \]

\[ \text{costs} = \phi^f I_{m^f > 0} + \phi^s I_{m^s > 0} \]
Compensating Differentials

Let

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

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

The value of \( \tau \) 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


References

