The Aggregate Effects of Global and Local Supply Chain Bottlenecks: 2020–2022

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*Authors’ opinions only. Does not reflect views of Federal Reserve or World Bank.
Supply chain disruptions

- Getting inputs for sale or production has been hard since 2020.

- Confluence of factors
  - Production disruptions
  - Border closures
  - Reduced air freight capacity
  - Unexpected pace of recovery
  - Disease outbreaks at ports
  - Congestion effects

- Disruptions happening both internationally and domestically

- Lead time on inputs: 60 days → 100 days
  - Mix of longer lead times and longer shipping times.

- Firms lack buffer stocks to absorb these delays.
Domestic and foreign supplier delays (Census, Pulse survey)

In the last week, did this business have any of the following?

- Foreign supplier delays
- Domestic supplier delays
- Delays in delivery/shipping to customers

Last observation: March 28, 2022
Delays happening when inventory levels are low

Last observation: January 2022
And associated with rise in prices
The aggregate impact of supply disruptions

► How do supply disruptions/delays affect
  ► Aggregate production?
  ► Trade?
  ► Consumption?
  ► Employment?
  ► Prices?

► Standard “macro” frameworks ill-equipped to provide answers

► Model ingredients
  ► Firms can hold inventories, but at a cost (interest/depreciation)
  ► Fixed order costs
  ► Orders can be delayed
  ► Firm-level demand is uncertain
  ► Production/Consumption may be constrained by availability of goods.
  ► Not in our framework: endogenous delay
Findings

▶ Delays have been
  ◦ A drag on economic activity and trade
  ◦ Source of price increases
  ◦ Hidden by stimulus/shift in spending
  ◦ Worse because of lean inventories
  ◦ Starting to wane even if delays are still high (its the surprise that matters most)

▶ Effects arise from
  ◦ Delays $\rightarrow$ higher carrying costs
  ◦ Production disrupted from lack of inputs
  ◦ Uneven effects across firms - affect highest value, lean inventory products most
Production structure

- Two countries: home and foreign (*)

- The aggregate state is $\eta_t$ and the aggregate history is $\eta^t = (\eta_0, \ldots, \eta_t)$

- Two continua of retail/wholesale firms
  - Use “manufacturing inputs” to produce differentiated goods
  - Sell to the consumption good firm and manufacturing-good firm
  - One continuum buys domestic manufactures ($D$), one buys imported ($I$)
  - Fixed order cost, shipping delays, demand uncertainty vs. holding costs

- Representative consumption-good firm
  - Uses retail goods from $D$ and $I$ sector to produce consumption

- Representative manufactures firm
  - Uses retail goods from $D$ and $I$ sector and labor to produce
  - Sells to domestic retailers and foreign country import retailers

- Domestic & imported goods differ in fixed costs + ‘timeliness’
  - Global vs local supply chains.
Standard model elements

- Representative household chooses consumption, labor supply, and state-contingent debt
- Consumption-goods producers combine retail goods from D and I to produce C
- Manufacturing producers combine retail goods and labor to produce M

\[
C(\eta^t) = \left[ \left( \int_0^1 \nu_D(j, \eta^t) \frac{1}{\theta} c_D(j, \eta^t) \frac{\theta - 1}{\theta} \, dj \right)^{\frac{\theta}{\theta - 1} \frac{\gamma - 1}{\gamma}} \right]^{\frac{\gamma - 1}{\gamma}} + \tau_c^{\frac{1}{\gamma}} \left( \int_0^1 \nu_I(j, \eta^t) \frac{1}{\theta} c_I(j, \eta^t) \frac{\theta - 1}{\theta} \, dj \right)^{\frac{\theta}{\theta - 1} \frac{\gamma - 1}{\gamma}} \left[ \left( \int_0^1 \nu_I(j, \eta^t) \frac{1}{\theta} c_I(j, \eta^t) \frac{\theta - 1}{\theta} \, dj \right)^{\frac{\theta}{\theta - 1} \frac{\gamma - 1}{\gamma}} \right]^{\frac{\gamma - 1}{\gamma}}
\]

\[
M(\eta^t) = L^{1-\alpha}_p Y^\alpha_m
\]

\[
Y_m(\eta^t) = \left( \int_0^1 \nu_D(j, \eta^t) \frac{1}{\theta} m_D(j, \eta^t) \frac{\theta - 1}{\theta} \, dj \right)^{\frac{\theta}{\theta - 1} \frac{\gamma - 1}{\gamma}} + \tau_m^{\frac{1}{\gamma}} \left( \int_0^1 \nu_I(j, \eta^t) \frac{1}{\theta} m_I(j, \eta^t) \frac{\theta - 1}{\theta} \, dj \right)^{\frac{\theta}{\theta - 1} \frac{\gamma - 1}{\gamma}} \left[ \left( \int_0^1 \nu_I(j, \eta^t) \frac{1}{\theta} m_I(j, \eta^t) \frac{\theta - 1}{\theta} \, dj \right)^{\frac{\theta}{\theta - 1} \frac{\gamma - 1}{\gamma}} \right]^{\frac{\gamma - 1}{\gamma}}
\]
Retailers

- Two continua of monopolistic competitors: $D$, $I$ (focus on a $D$ firm)

- Firm $j$ begins period with inventory $s_D(j)$, demand shock $\nu(j)$, and chooses inputs $z_D(j)$ and prices $p_D(j)$

- If firm places an order: $z_D(j) > 0$
  - Pay fixed cost $\phi_D$ (in units of labor, numeraire)
  - With probability $1 - \mu_D$, order arrives at $t$; $\mu_D$ arrives at $t + 1$
  - vary $\mu_D$ to match avg. delivery lag

- Firm’s state is $(\eta_t; s_t, \nu_t)$

- Timing: observe demand shock $\Rightarrow$ place order $\Rightarrow$ observe delivery $\Rightarrow$ set prices

Recursive setup
Decision rules

- Prices are a markup over discounted **marginal** value of inventories

\[ p(s, \nu) = \frac{\theta}{\theta - 1} \mathbb{E}_{\nu'} Q(\eta' | \eta) V_1 (s', \nu'; \eta') \]

- Inventories follow an “Ss rule”
  - Only when a firm is ordering and it arrives on time is \( p(s, \nu) = \frac{\theta}{\theta - 1} p_m(\eta) \)
  - If it does not arrive, set stock-out price, i.e. \( p(s, \nu) \) s.th. \( c(p, \nu) + m(p, \nu) = s \)

Qualitatively consistent with evidence on firm-level response to supply disruptions.
Policy function: Ordering (median demand shock)
Policy function: Price (median demand shock)
Policy function: Price (median demand shock)

- Order arrived today (domestic)
- Order delayed (domestic)
- Order delayed (importer)

Inventory / mean(sales)

Price

Graph showing the policy function for price with different inventory levels and order statuses.
International delivery delays: Dynamics

- Start from steady state; unforeseen change in \( \mu_l \) from 0.5 to 1; perfect foresight afterward

\[
\mu_{l,t+1} = (1 - \rho_l) \mu_{l,ss} + \rho_l \mu_{lt}
\]

- \( \rho_l = 0.5 \) implies shock duration of two quarters

- Impulse increases average delivery time from 45 to 90 days
Policy function: Ordering (median demand shock)
International delivery delays

deviation from steady state

manufactures production
consumption
labor
days delay (right)
International delivery delays

- total inventory (eop)
- manufacturing inventory (eop)
- retail inventory (eop)
International delivery delays

- Consumption price ($P_c$)
- Manufactures-input price ($P_m$)
- Manufactures price ($p_m$)

deviation from steady state

consumption price ($P_c$)
manufactures-input price ($P_m$)
manufactures price ($p_m$)
International delivery delays - Two main mechanisms

1. Reduced supply for production & consumption today
   - If nothing arrives today → production & consumption limited to what is on hand (about 1 quarters worth of output)
   - Decreases demand for production labor, more so with complementary inputs.
   - Affects firms with the lowest inventories (unlike trade cost or productivity shock)

2. Higher replacement costs of inventories
   - Interest costs: (extra days/365) × r
   - Depreciation costs: (extra days/365) × δ
   - Fixed costs: more orders burns up resources
The role of input-output links

- Outputs of retail/wholesale sector are inputs into manufacturing
  - Delays to wholesalers disrupt manufacturing

- Shut down roundabout structure by making manufacturing only use labor
  - Shipping delays do not disrupt manufacturing production

- Keep Trade/GDP constant by increasing import share in consumption

- Roundabout production
  - Magnifies shock on production
  - Propagates shock over time through decumulation of intermediate inputs.
International delays and Roundabout structure

Manufacturing production

Consumption

deviation from steady state

quarter

international delays
international delays w/o roundabout

deviation from steady state

quarter

international delays
international delays w/o roundabout
Other factors

- Increase in spending on goods (taste, stimulus)
  - Temporarily more expansionary, offset effects of delays
  - Larger reduction in inventory, larger drag on recovery.

- Low inventory
  - More contractionary as more firms constrained by delays
Fitting Data with Delay shocks (in progress)

- Estimate sequence of shocks to global import delays ($\mu_I = \mu^*_I$) and US production delays ($\mu_D$) to match
  - Trade relative to Consumption of Goods
  - Trade Balance as share of sales
  - Working to introduce:
    - Other variables and shocks (IP, IP ROW, Stimulus, Inventories,...)
    - Measures of delays (PMI’s, Cavallo & Kryvstov, 21)

- Recovers reasonable series of delays.

- And suggests important role of delays in US & ROW IP dynamics.
Trade and Delays: Model & Data

**Trade**

**NX**

**Delays_imports**

**Delays_US**

Period 1 is 2019q4
Period 1 is 2019q4
Aggregate Evidence (AKKMR, 2021)

- VAR evidence for US from 1950-2020 (delay shocks more common from 50-87)
- LP cross country panel evidence from Suez-Canal closure in 1967 to 1975
- Both shocks show delays are contractionary and raise prices as in model
- Also consistent with elasticity of trade to time (Djankov, 2010)
Response to Days Shock

Days

IP

Prices

CI 90%
Summary

► Supply delays much more costly than cost shocks, particularly in SR.

► Mitigated by inventory levels at firm & aggregate level.
  ► Level of stocks quite different in 2020 than 2008.

► Can take time to clear

► Important policy consideration
  ► Need to introduce congestion effects to properly analyze appropriate policy.
Supporting Evidence

- Inflation and Delays 1950-1987
- Motor Vehicle production, sales, inventory & prices.
Delays and Inflation Highly Correlated

\[ \text{Inflation} \times \text{Delivery Days} = \text{Corr} = 0.67 \]
US Motor Vehicles

- Prime example of the effects of supply disruptions. Through January, relative to pre-COVID
- Production is constrained by inputs (-25%)
- Inventory is very low (-33%)
- Sales are now falling sharply (-25%)
- Prices are rising sharply (+7 to 20%)
  - Owing to an increases in markups
  - Cost of retail dealer services +350%
Motor Vehicle Price Dynamics

Price relative to CPI detrended

- Retail (New)
- Retail (New & Used)
- PPI
- Imports (New & Used)

Last date: October, 2021, Source: Census, Prices are relative to trend
Motor Vehicle Price Dynamics

![Motor Vehicle Price Dynamics Graph]

Last date: October, 2021, Source: Census, Prices are relative to trend
Motor Vehicle Quantity Dynamics

Last date: October, 2021, Source: Census
Retailer optimization (suppressing the aggregate state)

\[ V(s, \nu) = \max \left\{ V^N(s, \nu), J(s, \nu) - \phi W \right\} \]

- Value of not placing an order

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

\[ \text{s.t. } s \geq c(p, \nu) + m(p, \nu) \]

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

- Value of placing an order (within period; no primes)

\[ J(s, \nu) = \max_{z} -p^m z + (1 - \mu)V^N(s + z, \nu) + \mu V^O(s, \nu, z) \]

- Value when order but it does not arrive

\[ V^O(s, \nu, z) = \max_{p, c, m} \pi(c(p, \nu), m(p, \nu)) + \mathbb{E}_{\nu'} QV(s', \nu') \]

\[ \text{s.t. } s \geq c(p, \nu) + m(p, \nu) \]

\[ s' = (1 - \delta)(s + z - c(p, \nu) - m(p, \nu)) \]