The Aggregate Effects of Global and Local Supply Chain Disruptions: 2020-2022*

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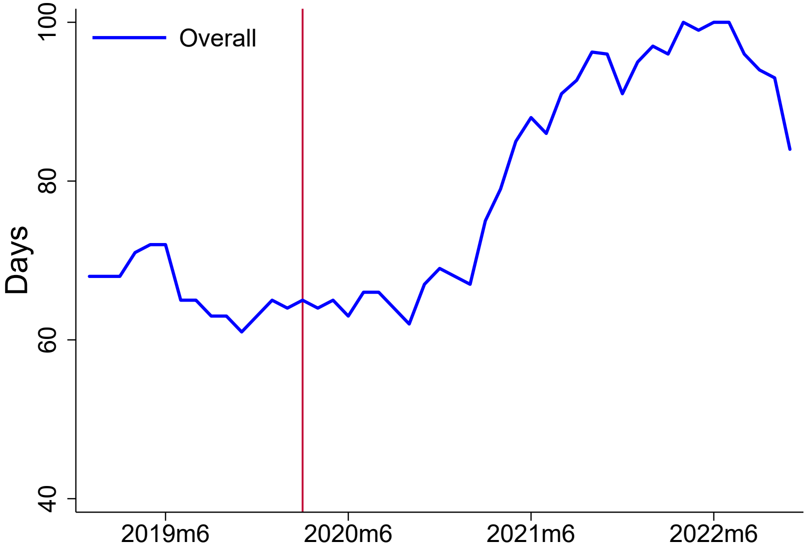
*Authors' opinions only. Does not reflect views of Federal Reserve or World Bank.

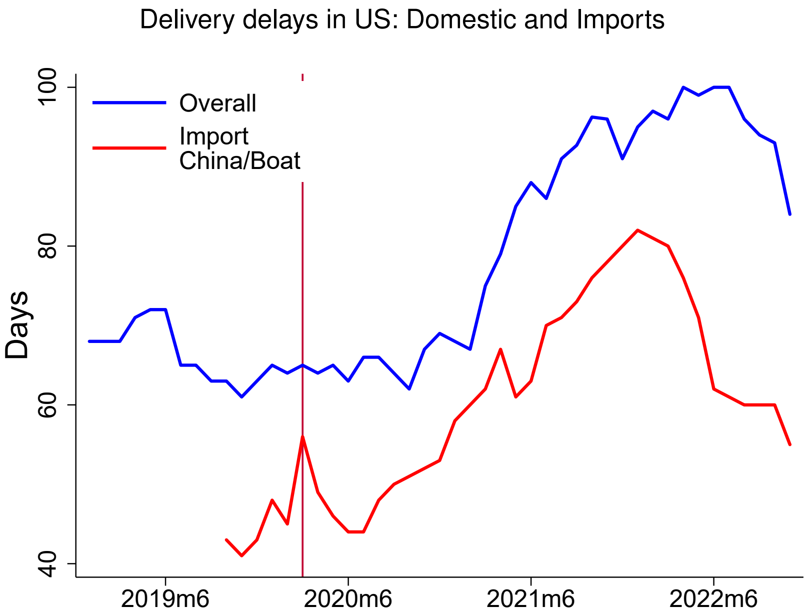
Introduction: Supply chain disruptions

- Getting inputs for sale or production has been hard since 2020.
  - Lead time on inputs: 60 days $\rightarrow$ 100 days
  - Disruptions global: domestic & int'l transactions; US & ROW
- Confluence of factors
  - Production disruptions (public health)
  - Border & Port closures
  - Reduced air freight capacity
  - Unexpected pace of recovery
  - Congestion effects
- Firms lack buffer stocks to absorb these delays.
  - Inventories low since start of COVID (key margin).
  - Consumer stockouts high globally (Cavallo & Kryvstov, 2022)
- Not unique to COVID, supply delays common from 1950-1987.

Delivery delays in US: Domestic and Imports

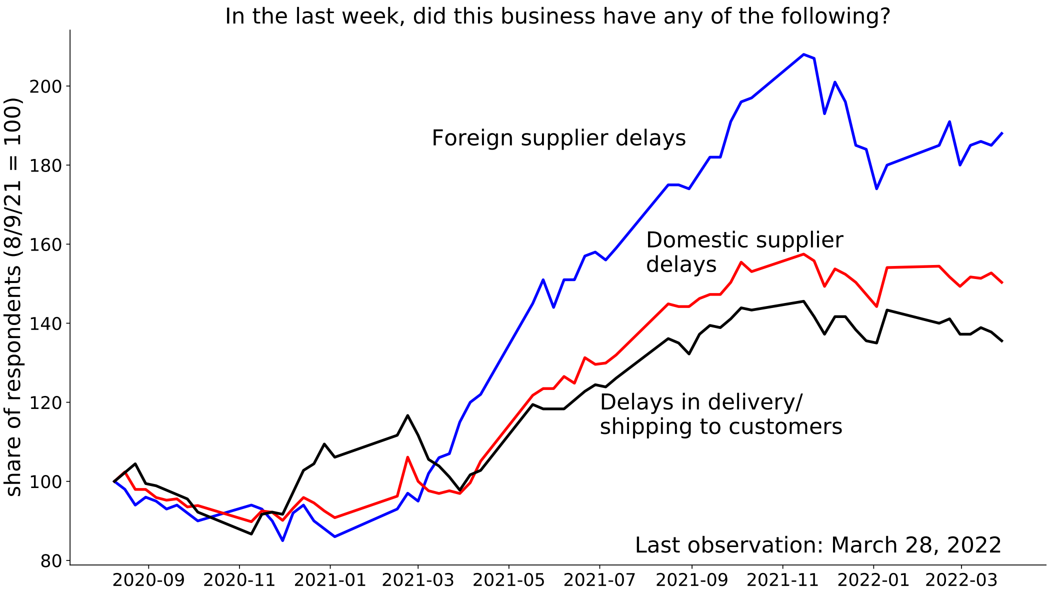


Source: Days (ISM), Shipping from China (Freightos) Last: September 2022.

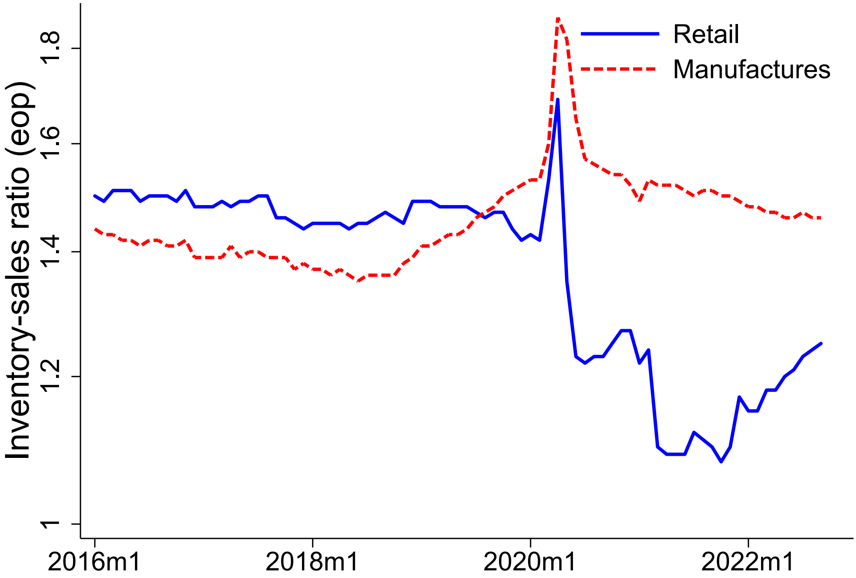


Source: Days (ISM), Shipping from China (Freightos) Last: September 2022.

Domestic and foreign supplier delays (Census, Pulse survey)

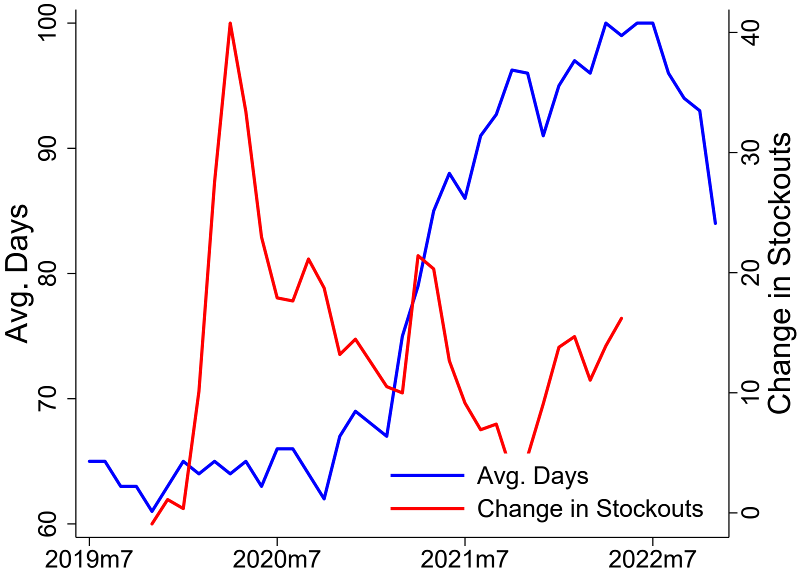


Delays happening with low inventory



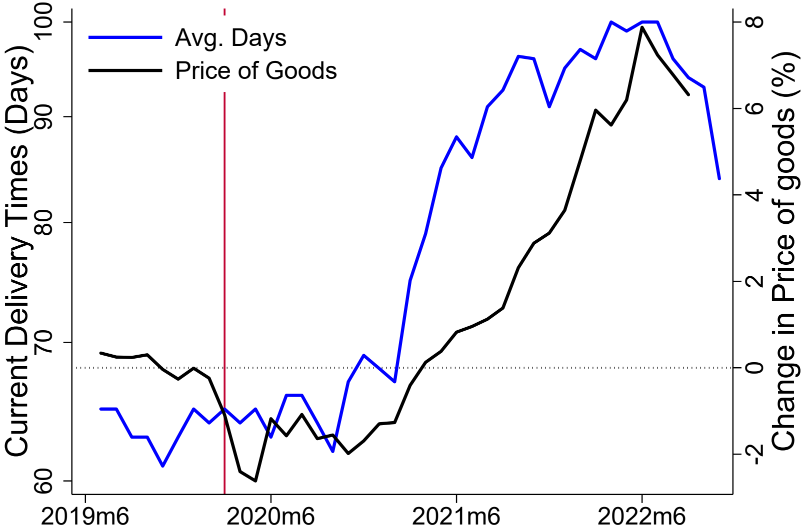
Last date: 8/22, Source: Census

Leading to More Stockouts



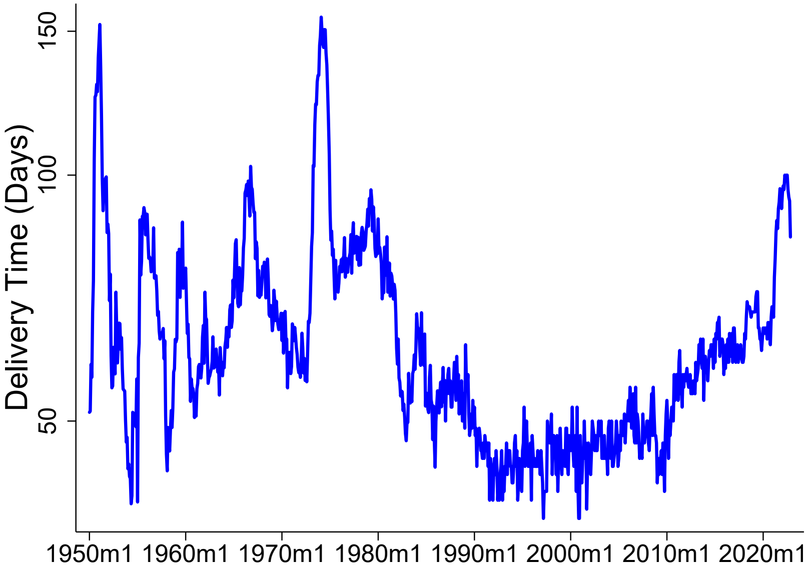
Source: Cavallo & Kryvstov(2021)

And a large increase in prices



Source: Days (ISM), Prices (BLS) Last date: 8/22.
Price of goods deflated by hourly earnings in Manufacturing and detrended with HP10^5.

And delays have happened before



The aggregate impact of supply disruptions

- How do supply disruptions/delays affect
  - Aggregate production?
  - Trade?
  - Consumption?
  - Employment?
  - Prices?
- What was the effect in 20-22? And what will the effect be going forward?
- Standard “macro” or “trade” 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 inputs available (stockouts)

Findings

- Delays have been
  - A drag on economic activity and trade
  - Source of price increases
  - Mitigated/magnified by stimulus/shift in spending
  - Worse because of lean inventories
- 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
- Fitting exercise:
  - Delays were a big drag on output & source of price increases
  - As supply disruptions dissipate, will unwind effects on output/prices but not enough to offset effects of waning stimulus.

Outline

- Model description
- Firms' decision rules in steady state and after supply chain disruptions
- Effect of delays on aggregate economy
- Fitting exercise and counterfactuals
- Confirming evidence
  - US VAR from 1950-2020
  - Suez canal closure/opening 67/75
  - Cross-industry evidence from COVID

Production structure

- Two countries: home & foreign ($*$)
- Aggregate: state (η_t); history ($\eta^t = (\eta_0, \ldots, \eta_t)$)
- Two continua of retail firms in each country
  - Use “manufacturing inputs” to produce differentiated goods
  - One continuum buys domestic manufactures (*D*), one buys imported (*I*)
  - Sell to the consumption good firm and manufacturing-good firm
  - 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

$$u(C,L) = \frac{C^{1-\sigma}}{1-\sigma} - \chi \frac{L^{1+\frac{1}{\psi}}}{1+\frac{1}{\psi}}$$

$$P_c(\eta^t)C(\eta^t) + \sum_{\eta^{t+1}} Q(\eta^{t+1}|\eta^t)B(\eta^{t+1}) = B(\eta^t) + W(\eta^t)L(\eta^t) + \Pi(\eta^t)$$

- Consumption-goods producers combine retail goods from D and I to produce C

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

- Manufacturing producers combine retail goods and labor to produce M

$$M(\eta^t) = L_p^{1-\alpha} Y_m^{\alpha}$$

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

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 ϕ_D (in units of labor, numeraire)
  - With probability $1 - \mu_D$, order arrives at t; μ_D arrives at $t + 1$
  - vary μ_D to match avg. delivery lag
- Firm's state is $(\eta_t; s_t, \nu_t)$
- Timing: observe demand shock $\implies$ place order $\implies$ observe delivery $\implies$ set prices
- Analogous optimization for home importers, foreign domestic and foreign import sectors

Recursive setup

Decision rules

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

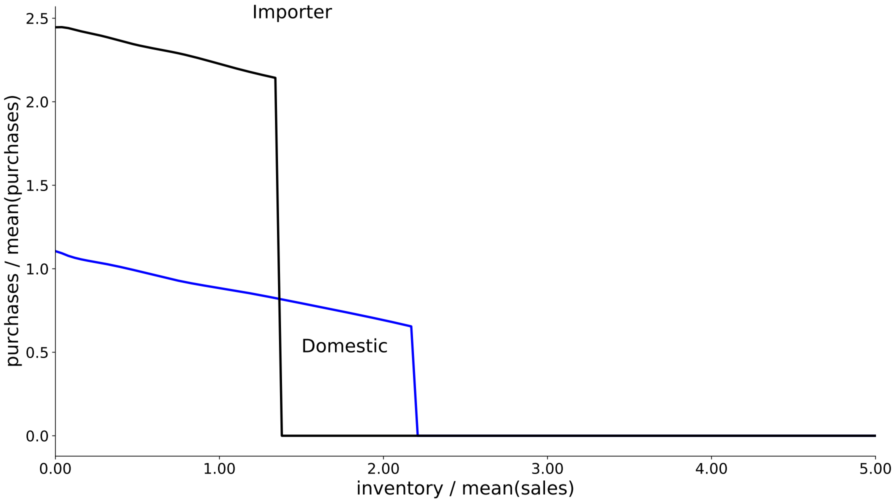
$$p(s,\nu) = \frac{\theta}{\theta-1}(1-\delta)\mathop{\mathbb{E}}_{\nu'} Q(\eta'|\eta) V_1\left(s', \nu'; \eta'\right)$$

- Ordering behavior
  - s,S policy: Order when inventories hit s, restock up to S
  - Low inventory/high demand firms order inputs
  - If it does not arrive, set stock-out price, i.e. $p(s,\nu)$ s.th. $c(p,\nu) + m(p,\nu) = s$

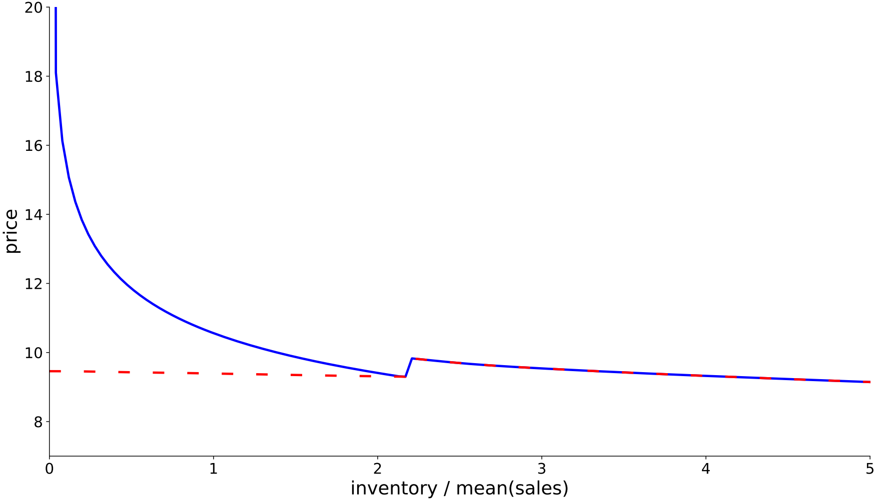
    Qualitatively consistent with evidence on firm-level response to supply disruptions.

Calibration

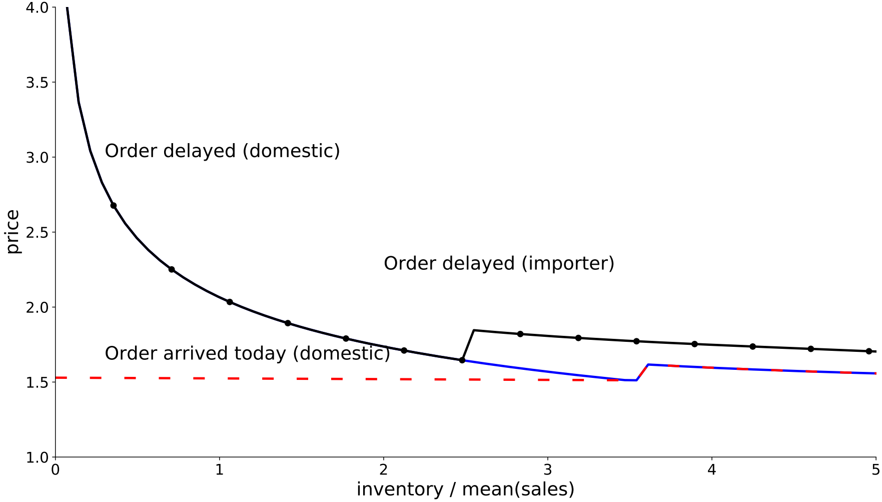
Policy function: Ordering (median demand shock)



Policy function: Price
(median demand shock)



Policy function: Price
(median demand shock)



Inventories

- For accounting split inventories across manufacturing and retail.
- Retail inventory (on the shelf)

$$I_r(\eta^t) = \int \left[s_D(j,\eta^t) - c_D(j,\eta^t) - m_D(j,\eta^t) + (1-\mu_D) z_D(j,\eta^t) \right] dj$$
$$+ \int \left[s_I(j,\eta^t) - c_I(j,\eta^t) - m_I(j,\eta^t) + (1-\mu_I) z_I(j,\eta^t) \right] dj$$

- Manufacturing inventory (on the ship)

$$I_m(\eta^t) = \int \mu_D \, z_D(j,\eta^t) dj + \int \mu_I \, z_I(j,\eta^t) dj$$

Calibration - Goods producing sector

- Elasticity of substitution between sources: $\gamma = 1.1$

- Inventory holdings and order frequency: $\delta, \mu_D, \mu_I, \phi_D, \phi_I$ chosen so that
  - importing firms hold larger inventories than domestic firms ($\approx$ 2x)
  - importing firms order less frequently ($\approx$ half)
  - imported goods arrive with 0.5 quarter delay on average
  - importers order every 4 quarters on average
  - aggregate inventories to purchases ratio of 1.3

- Trade preferences τ_c and τ_m chosen so that
  - import share matching U.S. data
  - share of consumption vs material imports from data
  - gross output to VA in mfr

Assigned parameters

- Model period is one quarter

Parameters			Moments	
Discounting	β	$0.96^{0.25}$	Annual real rate	4%
Input cost share	α	0.64	Manufacturing GO/VA	2.8
International delay	μ_I	0.6	Authors' calculation	55 days
Frisch elasticity	ψ	2	Steady State Labor	1/3
Substitution within source	θ	4		
Substitution across source	γ	1.1		
IES	σ	0.5		

Jointly estimated

Parameters			Moments	
Home bias manufactures	τ_m	0.425	Imports-to-IP	30%
Home bias consumption	τ_c	0.165	Manufactures' share of imp	74%
Depreciation	δ	0.055	Inventory-purchases ratio (dom)	1.0
Domestic delay	μ_D	35 days	Inventory-purchases ratio (imp)	2.1
Demand variance	σ_ν^2	1.5	Inventory-purchases ratio (agg)	1.31
Fixed order cost† (dom)	ϕ_D	1.5%	Order freq (dom)	60%
Fixed order cost† (imp)	ϕ_I	19.7%	Order freq (imp)	30%

†Expressed as share of average revenue.

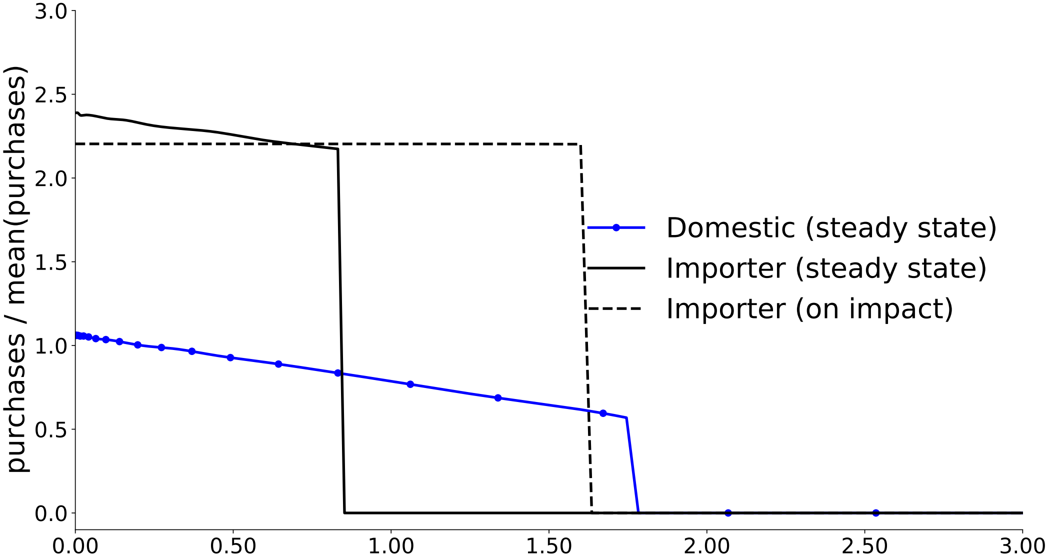
- Home biases largely determine import ratios
- Higher δ hold smaller inventories; higher μ hold larger inventories
- Different ϕ drive different order frequency

back

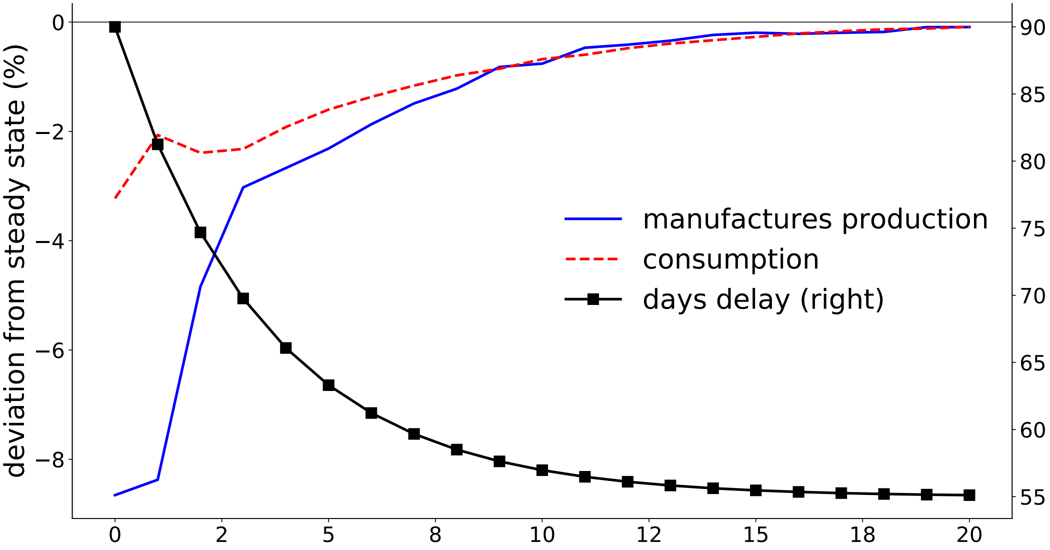
International delivery delays: Dynamics

- Start from steady state; unforeseen change in import deliveries from 55 to 90 days; perfect foresight afterward
$$\mu_{I,t+1} = (1 - \rho_I)\mu_I^{ss} + \rho_I \mu_{It}$$
- $\rho_I = 0.75$ implies shock duration of 4 quarters
- Symmetric global import delays
- Domestic delays have similar flavor

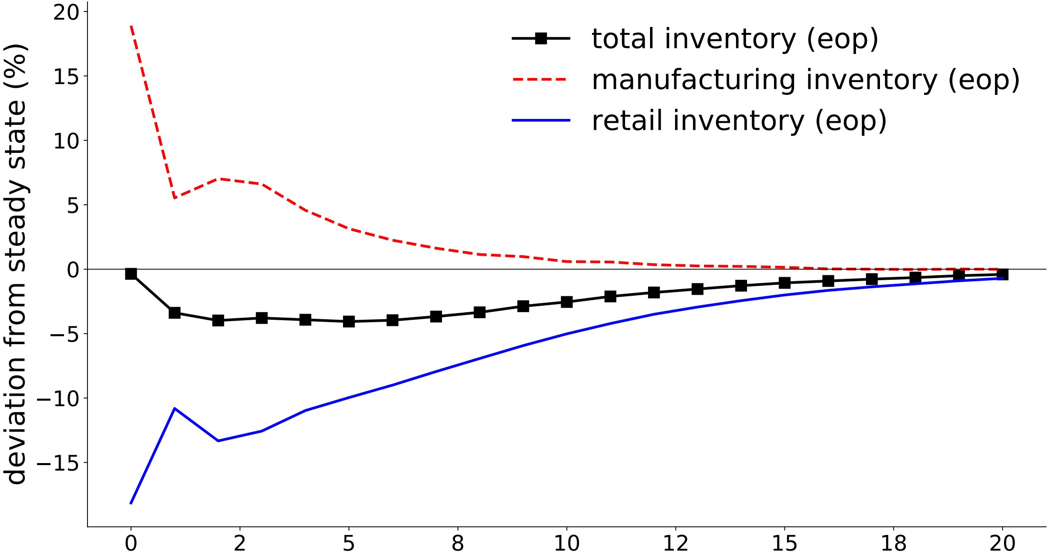
Policy function: Ordering (median demand shock)



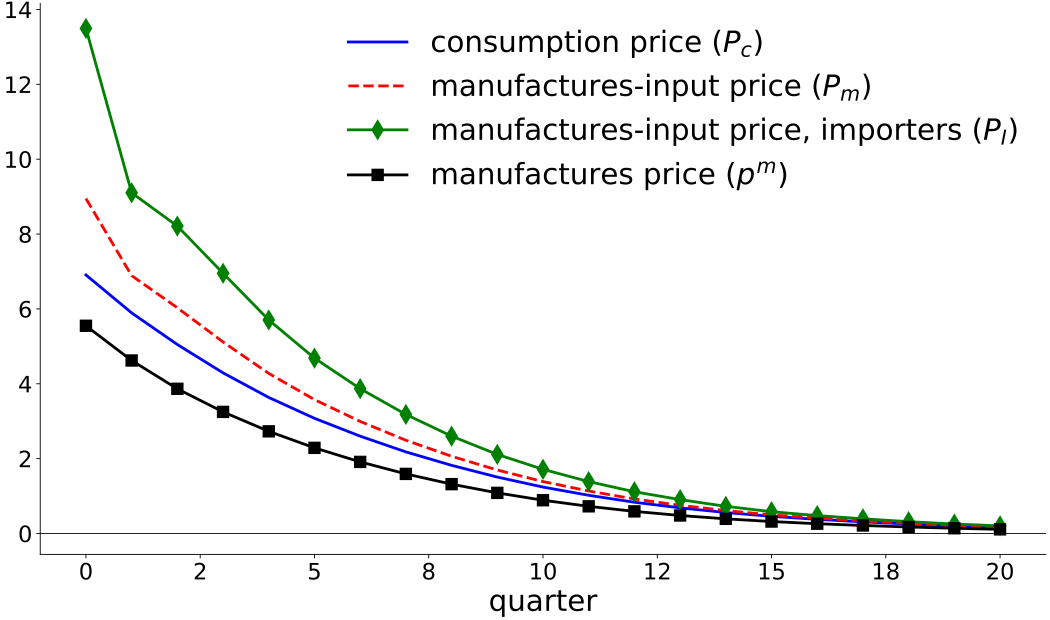
International delivery delays - Aggregates



International delivery delays - Inventories



International delivery delays - Prices



Delivery delays - Two main mechanisms

1. Reduced supply for production & consumption today
   - If nothing arrives today $\rightarrow$ 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) $\times$ r
   - Depreciation costs: (extra days$/$365) $\times$ δ
   - Fixed costs: more orders burns up resources

Costs vs. time

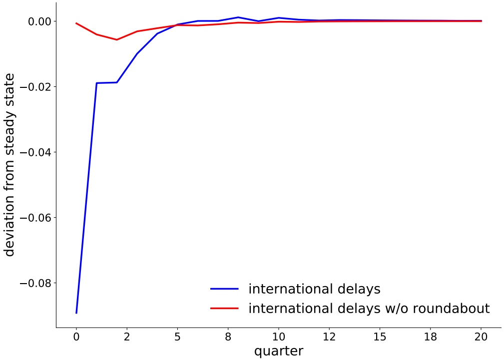
- Consider an increase in shipping costs equivalent to extra carrying costs of delay.
- Cost shocks less contractionary because they do not constrain the orders of high-demand low-inventory firms.
- Consistent with high willingness to pay very large trade costs to accelerate trade.

The role of input-output links

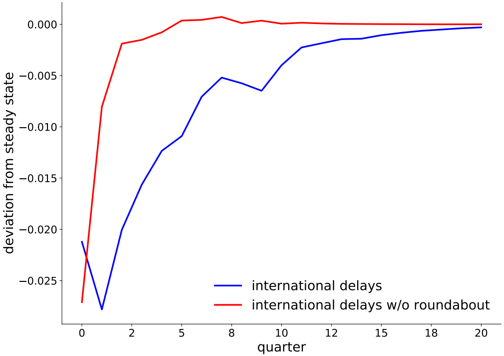
- Outputs of retail/wholesale sector are inputs into manufacturing
  - Delays to wholesalers disrupt manufacturing
- Shut down roundabout structure by making manufacturing only use labor
  - Shipping delays do not disrupt manufacturing production
- Keep Trade/GDP constant by increasing import share in consumption
- Roundabout production
  - Magnifies shock on production
  - Propagates shock over time through decumulation of intermediate inputs.

International delays and Roundabout structure

Manufacturing production



Consumption



Other factors

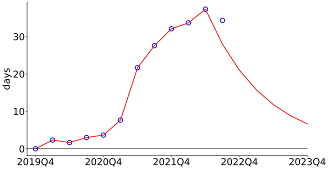
- Low inventory
  - More contractionary as more firms constrained by delays
- Increase in spending on goods (taste, stimulus)
  - Temporarily more expansionary, offset effects of delays
  - Larger reduction in inventory, larger drag on recovery.

Data Fitting Exercise

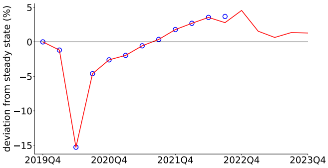
- Apply model with 3 types of shocks:
  1) Restocking delays 2) Labor supply and 3) Stimulus
- Sequence of unanticipated shocks with AR coefficient of 0.75.
- Allow delay shocks to be symmetric and other shocks asymmetric
- Fit to
  - Delays: import & domestic
  - Industrial production: US & RoW
  - Trade balance: US
  - Consumption of goods: US

Fitting Exercise - Matched Moments

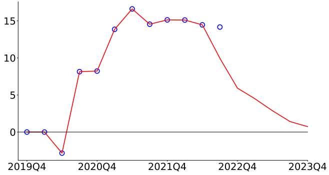
(a) Domestic delays



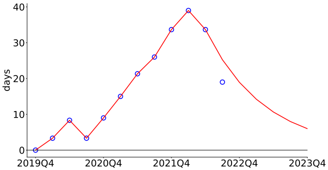
(b) Industrial Production - US



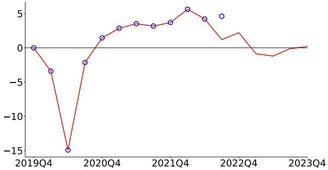
(c) Goods Sales - US



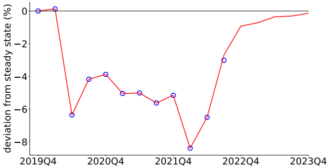
(d) Import delays



(e) Industrial Production - Rest

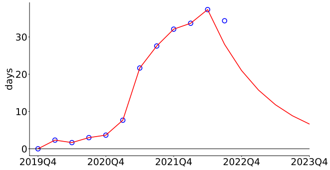


(f) Trade Balance - US

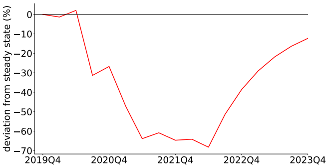


Fitting Exercise - Recovered Shocks

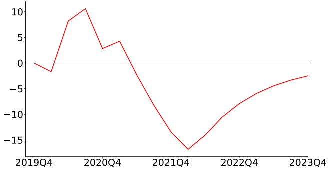
(a) Domestic delays



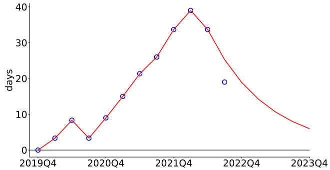
(b) Home stimulus



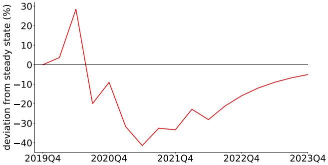
(c) Home disutility of labor



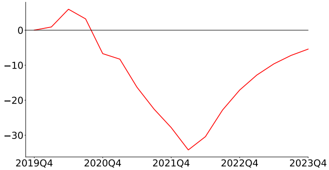
(d) Import delays



(e) Foreign stimulus

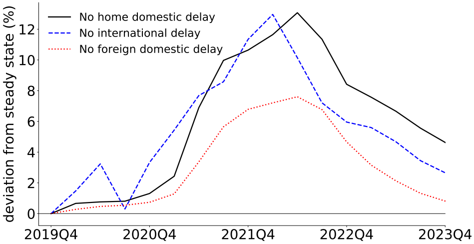


(f) Foreign disutility of labor

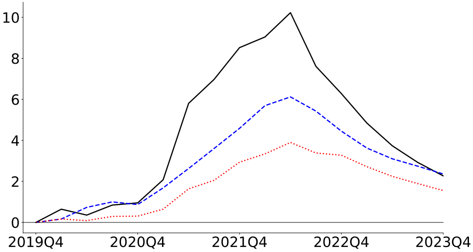


Fitting Exercise - Counterfactuals

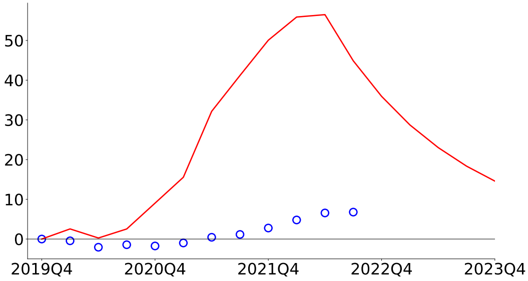
(a) Output



(b) Consumption

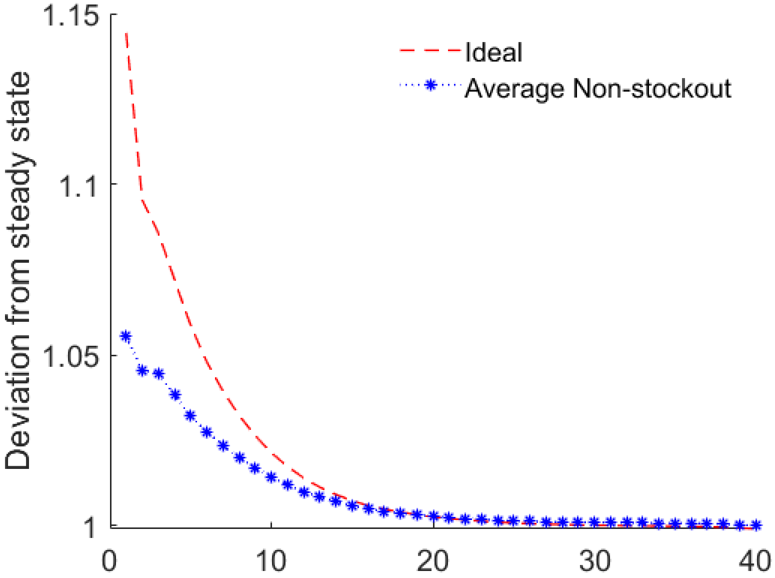


Miss I: Prices

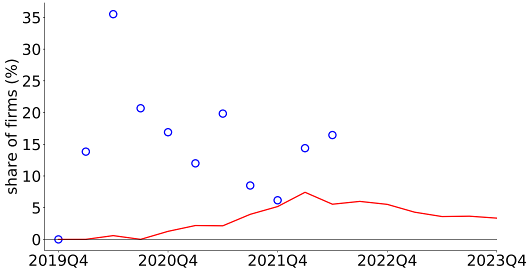


- Follow BLS convention using ”in-stock” prices”
  - Model captures ”shadow price” of consumption.
- Including labor in retailing (PPI effects 2x CPI)
- Setting prices before delivery
  - No effect on quantities, sales constrained by inventory

Non-Stockout Prices



Miss II: Stockouts



- Stockouts require combination of
  - Increase in uncertainty
  - Earlier restocking delays.

Caveat - expectations

- The agg. effects of delays will depend on the size and persistence.
- Hard to discipline in current environment
- Historically, hump-shaped (AKKMS, 2022) in US from 1950-1990.
- Hump-shaped shocks can be expansionary in SR
  - Precautionary stockpiling (order toys for Xmas sooner)
- With AR(2) shocks, most effects ~half as big.

Evidence: Aggregate and Industry

- 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
- Panel VAR with 3 digit NAICS with Census Pulse survey
- Delays reduce output and raise prices as in model

Summary

- Model
  - Allows for changes in lead times
  - Captures extensive & intensive margin response to delays
  - Delay shocks are more costly than cost shocks
  - Delays are more costly under the post-pandemic global conditions
- Disruption effects take time to clear
- Inventories were a key adjustment margin in COVID
  - Very different inventory situation from Great Recession.

Retailer optimization (suppressing aggregate state)

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

- Value of not placing an order

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

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

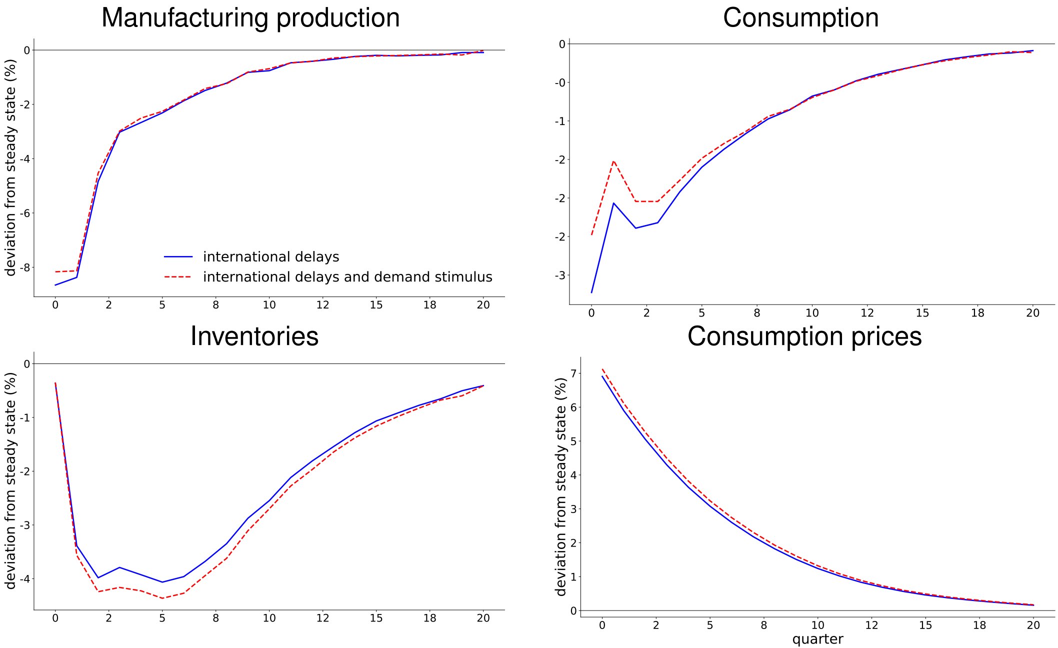
$$J(s,\nu) = \max_z\ -p^m z + (1-\mu)V^N(s+z,\nu) + \mu V^O(s,\nu,z)$$

- Value when order but it does not arrive

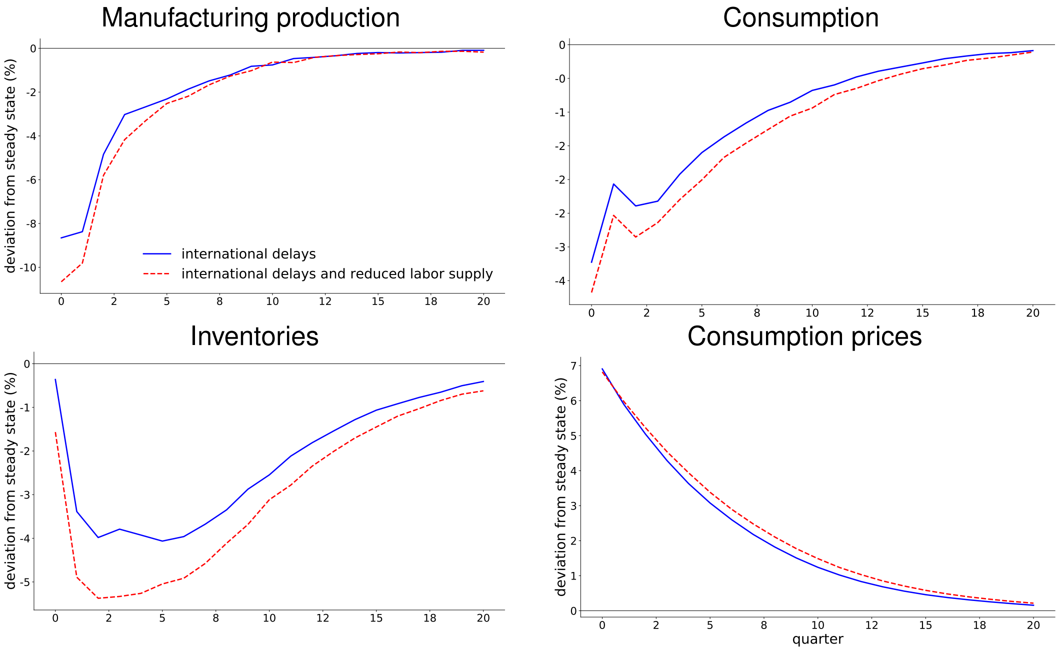
$$\begin{aligned} V^O(s,\nu,z) = \max_p \pi(c(p,\nu), m(p,\nu)) + \mathop{\mathbb{E}}_{\nu'} QV(s',\nu') \\ \text{s.t.}\ \ s \geq c(p,\nu) + m(p,\nu) \\ s' = (1-\delta)(s + z - c(p,\nu) - m(p,\nu)) \end{aligned}$$

Back

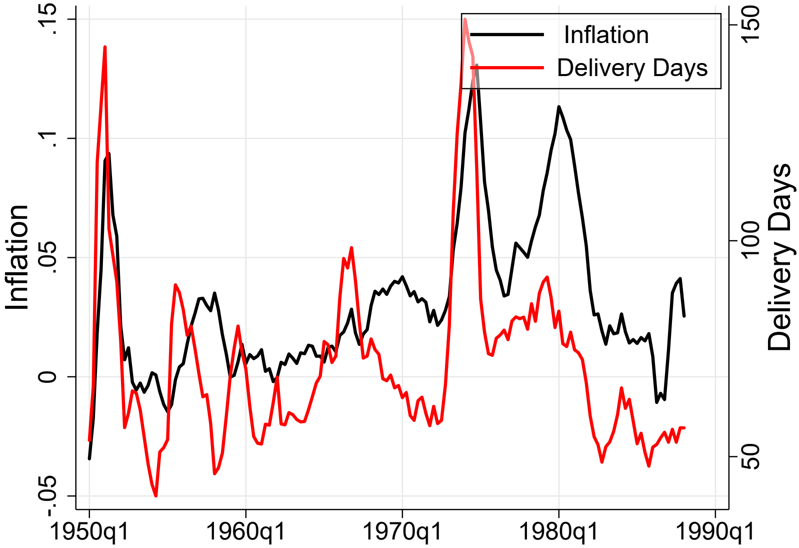
International delivery delays w/ stimulus



International delivery delays w/ low labor supply



Delays and Inflation Highly Correlated



Corr = 0.67