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

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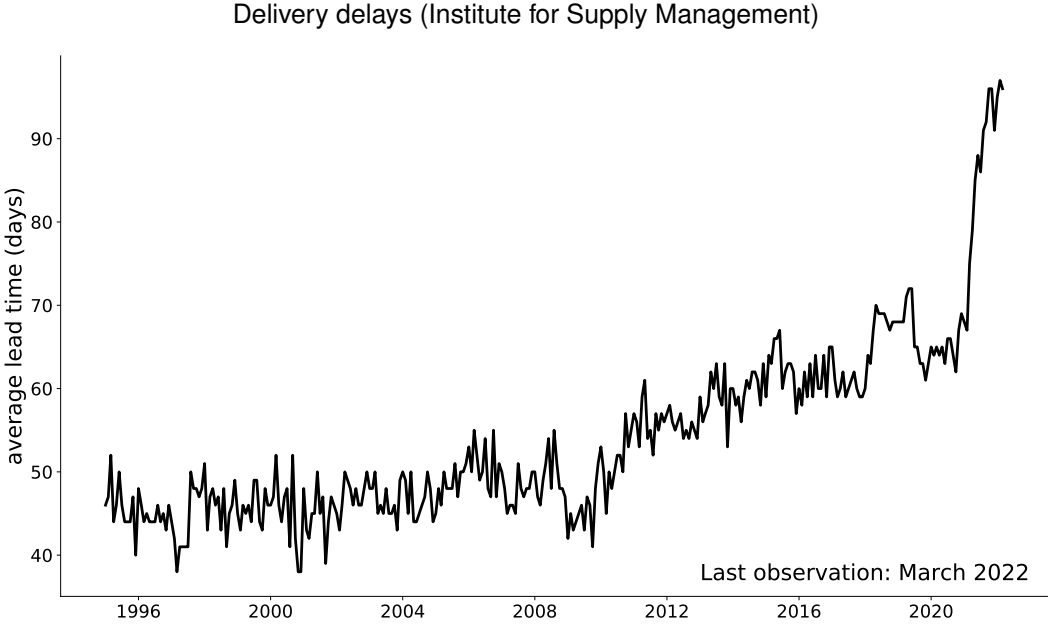
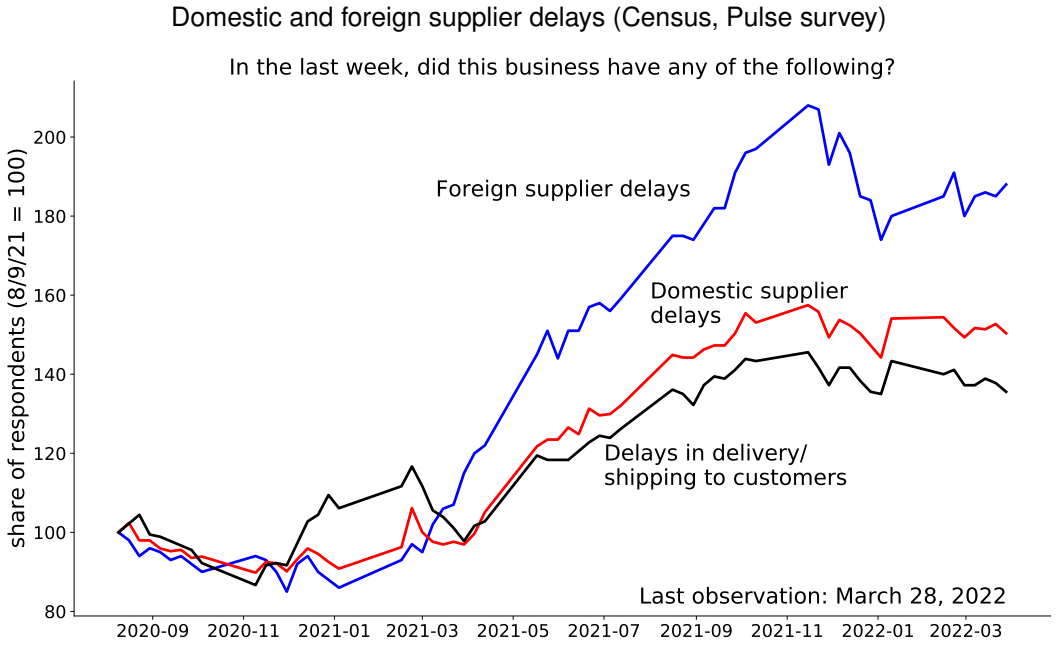
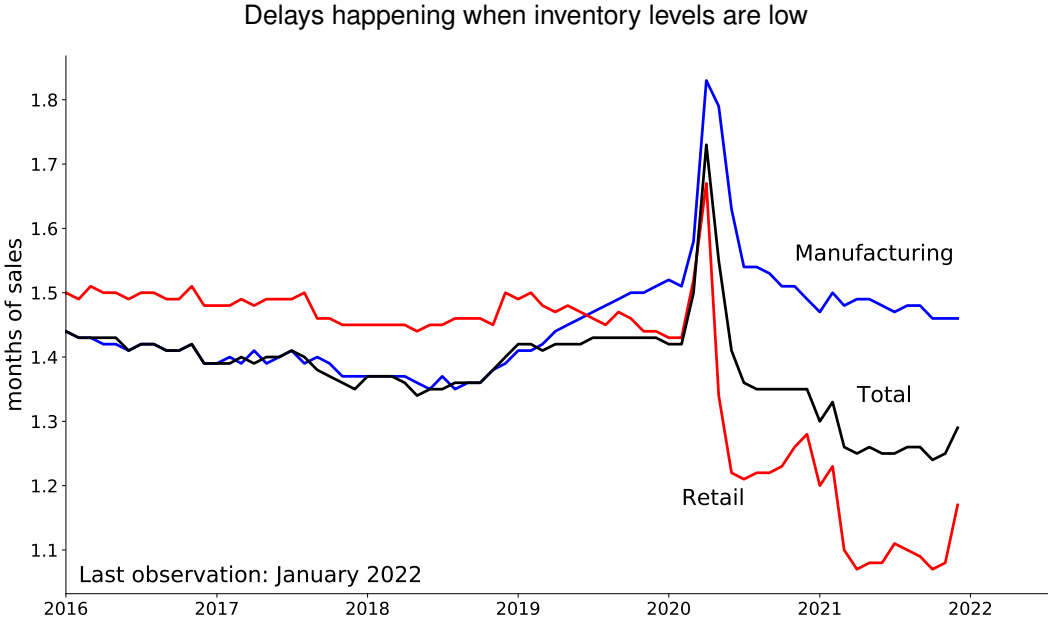
*Authors' opinions only. Does not reflect views of Federal Reserve or World Bank.

Supply chain disruptions

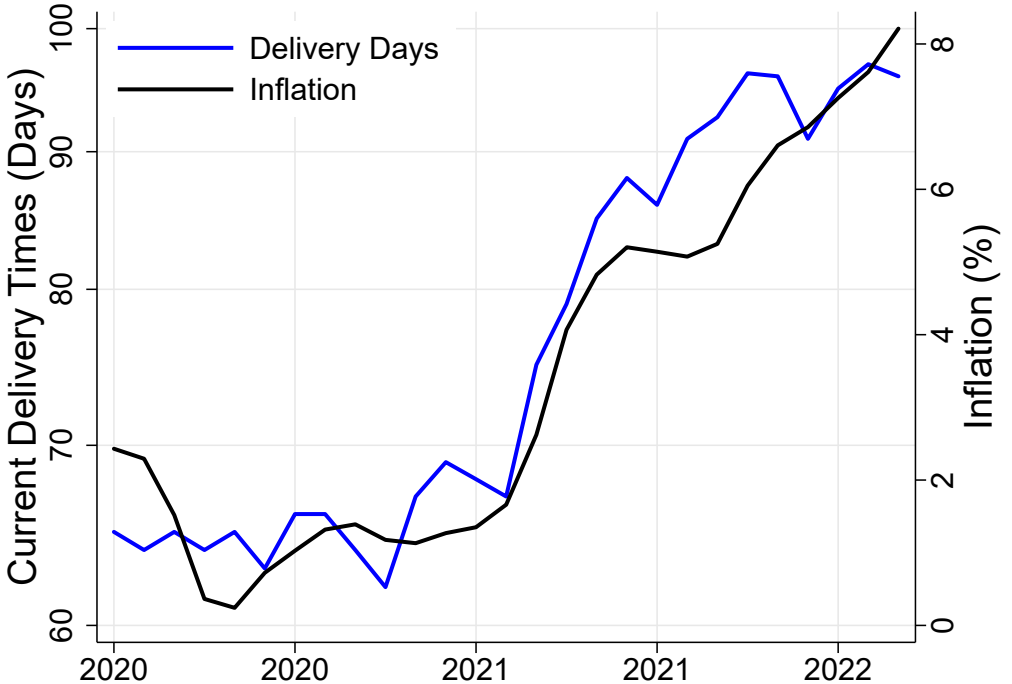
- Getting inputs for sale or production has been hard since 2020.
- Confluence of factors
  - Production disruptions
  - Border closures
  - Reduced air freight capacity
  - Unexpected pace of recovery
  - Disease outbreaks at ports
  - Congestion effects
- Disruptions happening both internationally and domestically
- Lead time on inputs: 60 days $\rightarrow$ 100 days
  - Mix of longer lead times and longer shipping times.
- Firms lack buffer stocks to absorb these delays.


Delivery delays (Institute for Supply Management)
average lead time (days)
90
80
70
60
50
40
1996
2000
2004
2008
2012
2016
2020
Last observation: March 2022


Domestic and foreign supplier delays (Census, Pulse survey)
In the last week, did this business have any of the following?
share of respondents (8/9/21 = 100)
200
180
160
140
120
100
80
Foreign supplier delays
Domestic supplier delays
Delays in delivery/ shipping to customers
Last observation: March 28, 2022
2020-09
2020-11
2021-01
2021-03
2021-05
2021-07
2021-09
2021-11
2022-01
2022-03


Delays happening when inventory levels are low
months of sales
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
2016
2017
2018
2019
2020
2021
2022
Manufacturing
Total
Retail
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 η_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

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

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

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

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 $\Longrightarrow$ place order $\Longrightarrow$ observe delivery $\Longrightarrow$ set prices

Recursive setup

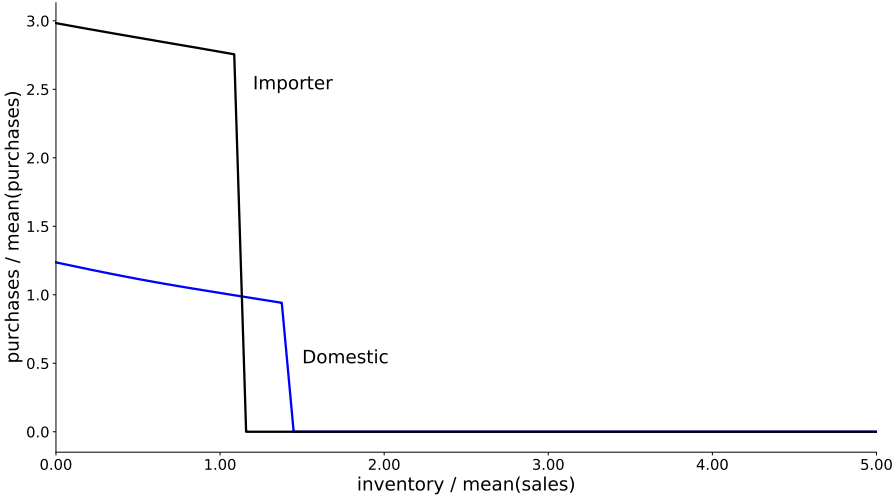
Decision rules

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

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

- 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)



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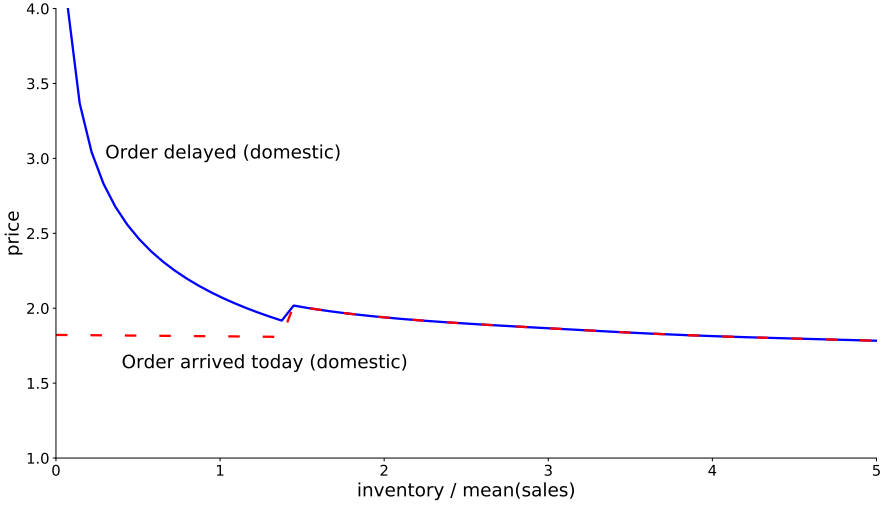

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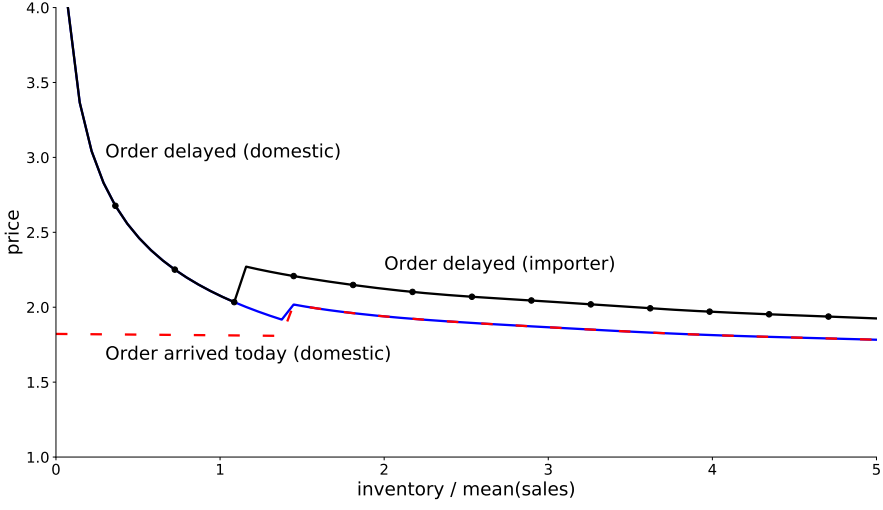


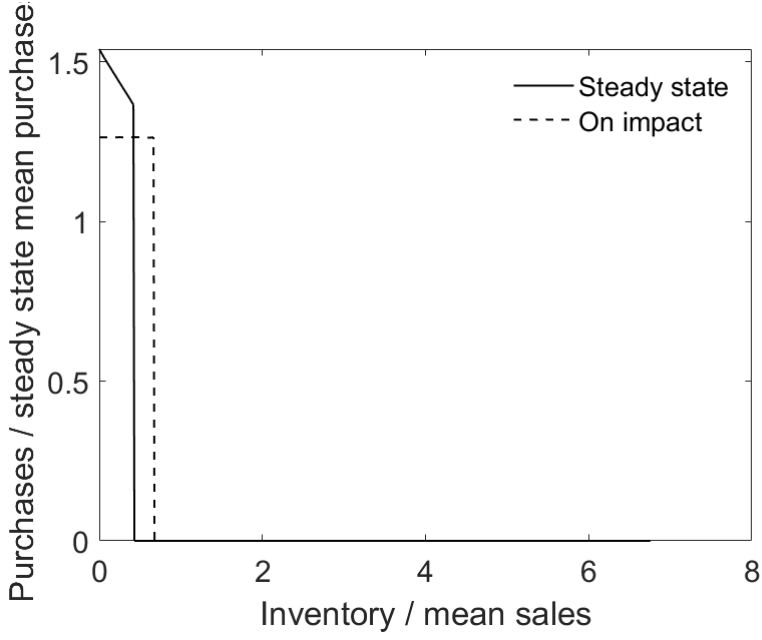
International delivery delays: Dynamics

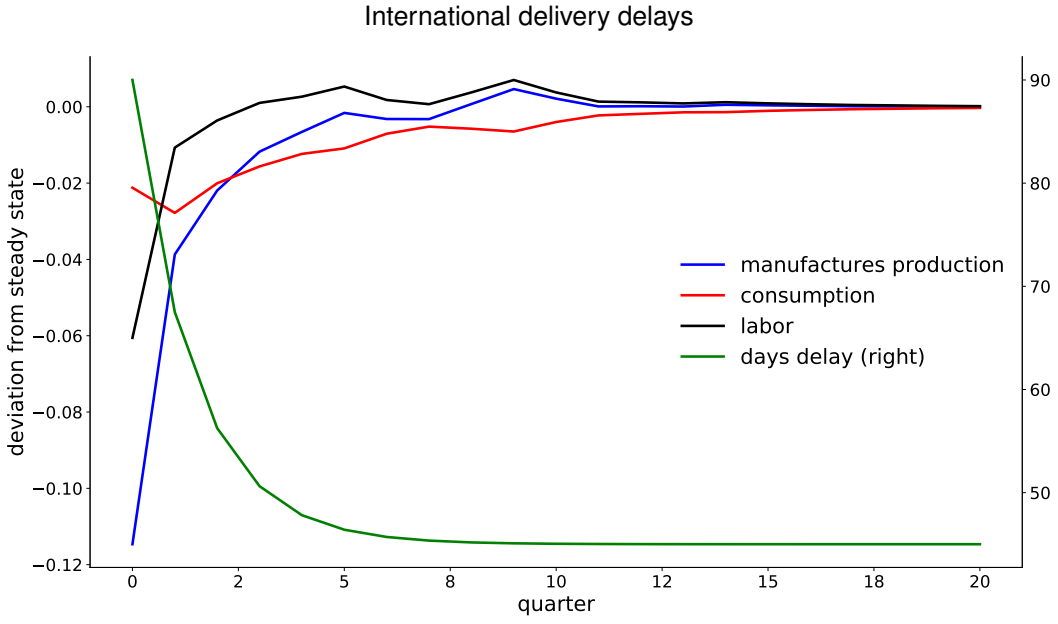
- Start from steady state; unforeseen change in μ_I from 0.5 to 1; perfect foresight afterward

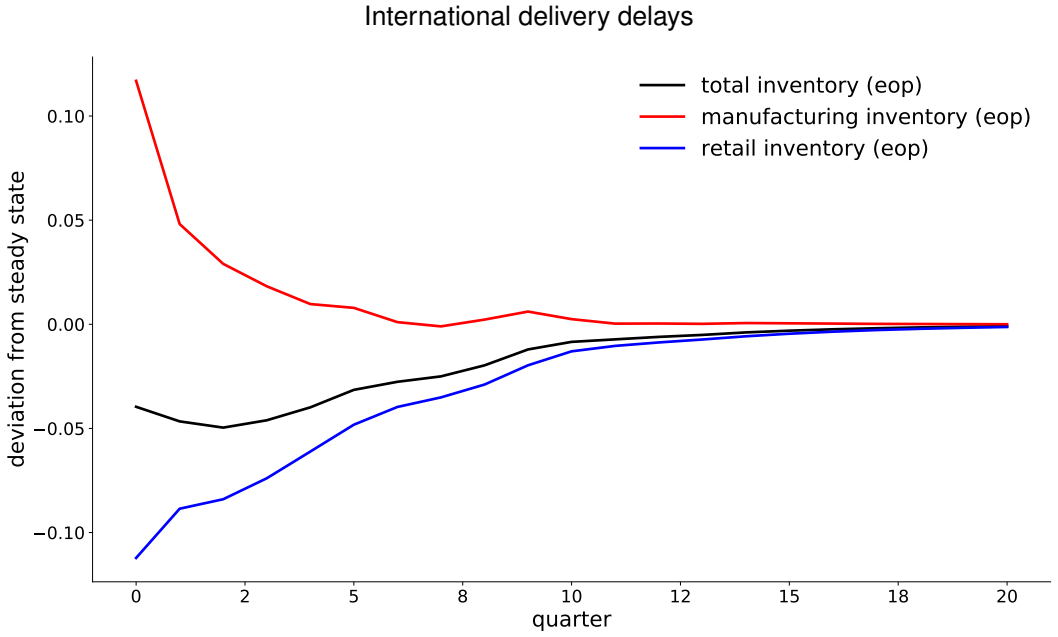
$$\mu_{I,t+1} = (1 - \rho_I)\mu_I^{ss} + \rho_I \mu_{It}$$

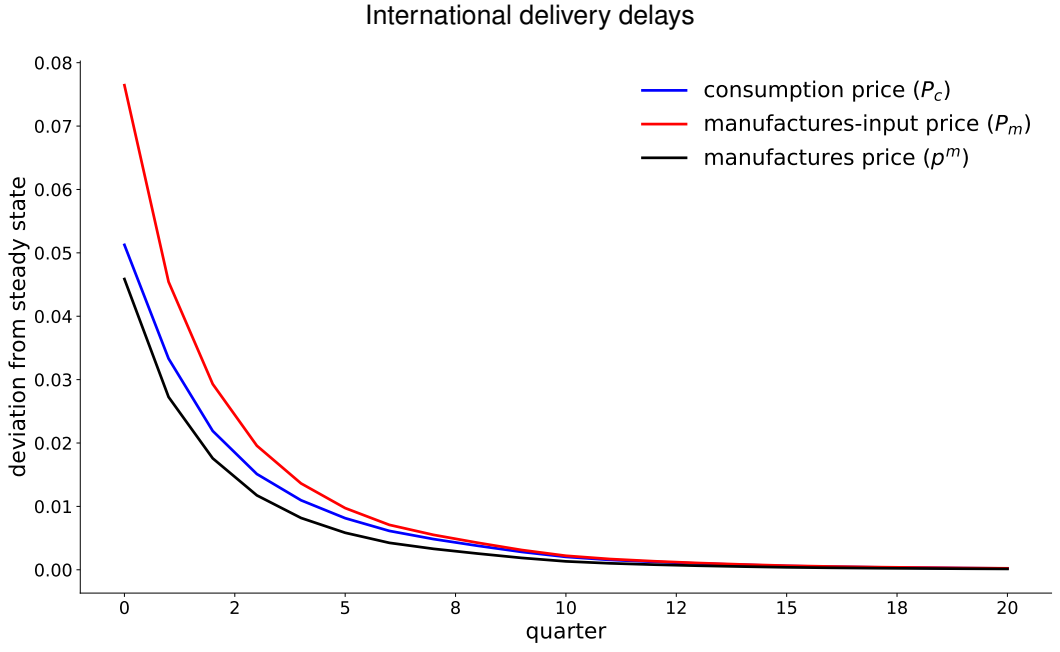
- $\rho_I = 0.5$ implies shock duration of two quarters
- Impulse increases average delivery time from 45 to 90 days

Policy function: Ordering (median demand shock)




International delivery delays
deviation from steady state
quarter
manufactures production
consumption
labor
days delay (right)
0.00
−0.02
−0.04
−0.06
−0.08
−0.10
−0.12
0
2
5
8
10
12
15
18
20
90
80
70
60
50


International delivery delays
total inventory (eop)
manufacturing inventory (eop)
retail inventory (eop)
deviation from steady state
0.10
0.05
0.00
−0.05
−0.10
0
2
5
8
10
12
15
18
20
quarter


International delivery delays
consumption price (P_c)
manufactures-input price (P_m)
manufactures price (p^m)
deviation from steady state
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
2
5
8
10
12
15
18
20
quarter

International delivery delays - Two main mechanisms

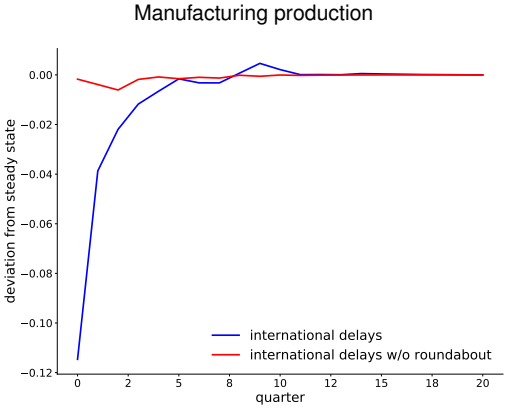
1. Reduced supply for production & consumption today
- If nothing arrives today $\rightarrow$ production & consumption limited to what is on hand (about 1 quarters worth of output)
- Decreases demand for production labor, more so with complementary inputs.
- Affects firms with the lowest inventories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

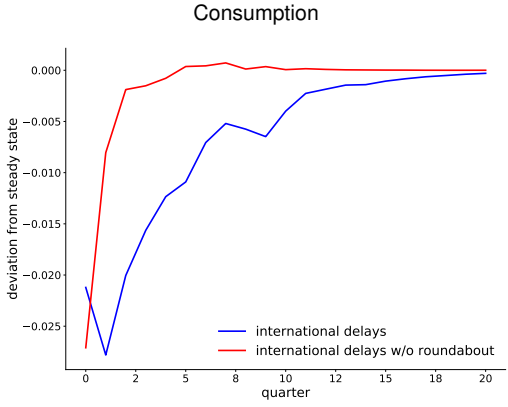
2. Higher replacement costs of inventories
- Interest costs: (extra days$/365$) $\times$ r
- Depreciation costs: (extra days$/365$) $\times$ δ
- Fixed costs: more orders burns up resources

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





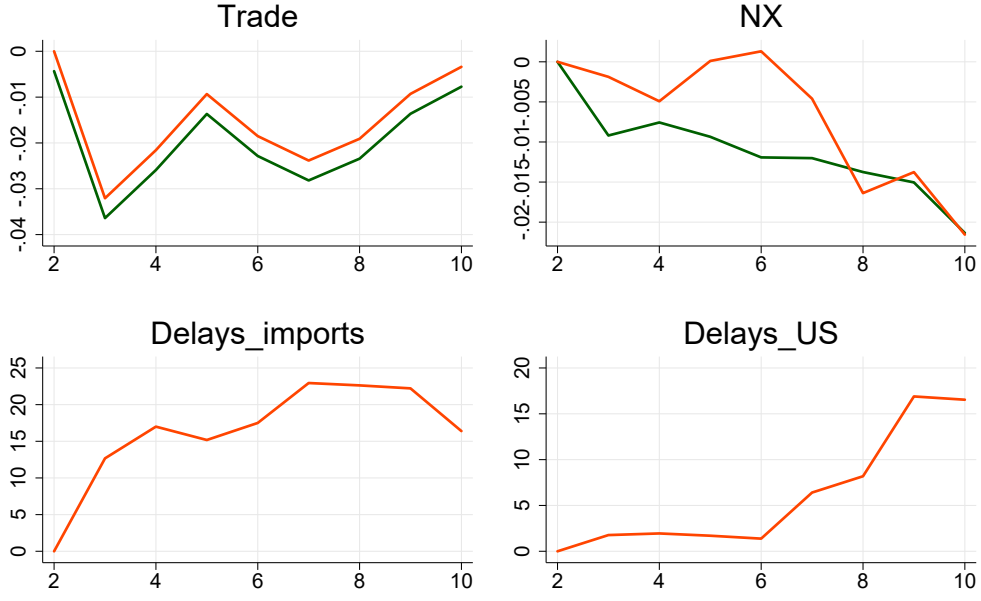
Other factors

- 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)

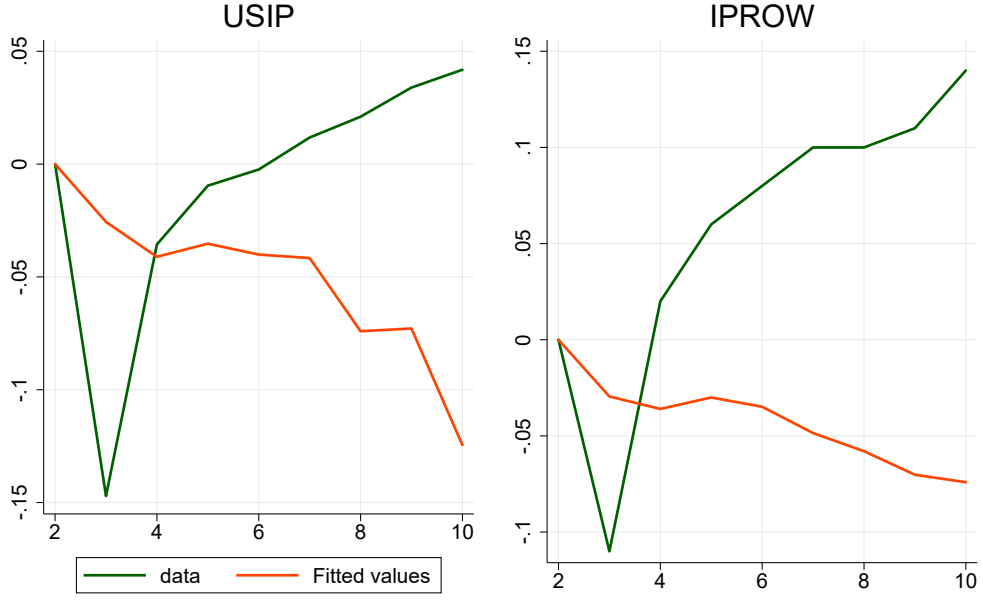
- Estimate sequence of shocks to global import delays (μ_I=μ_I^*) and US production delays (μ_D) to match
  - Trade relative to Consumption of Goods
  - Trade Balance as share of sales
  - Working to introduce:
    - Other variables and shocks (IP, IP ROW, Stimulus, Inventories,...)
    - Measures of 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



Period 1 is 2019q4

Trade and Delays: Model & Data

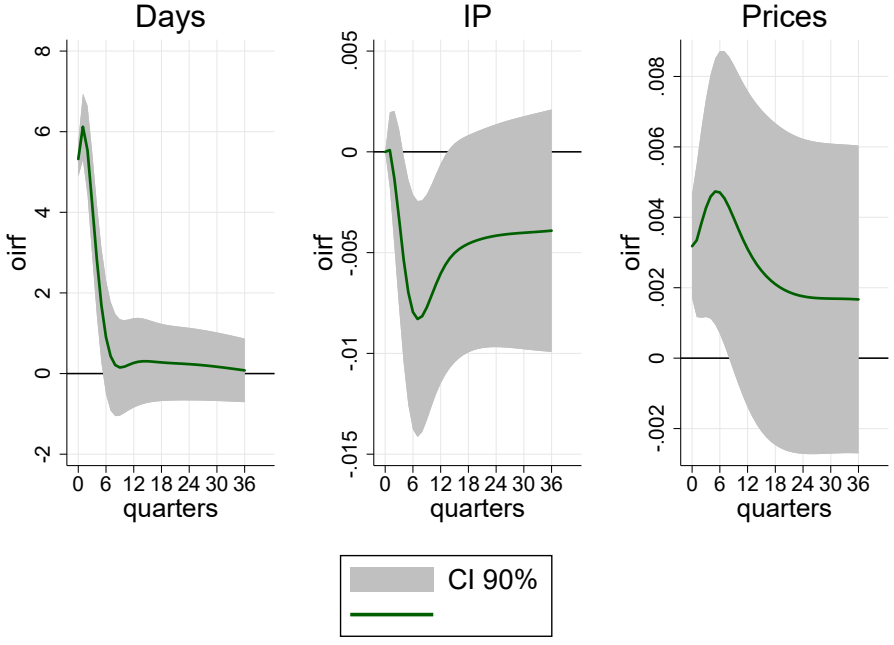


Period 1 is 2019q4

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



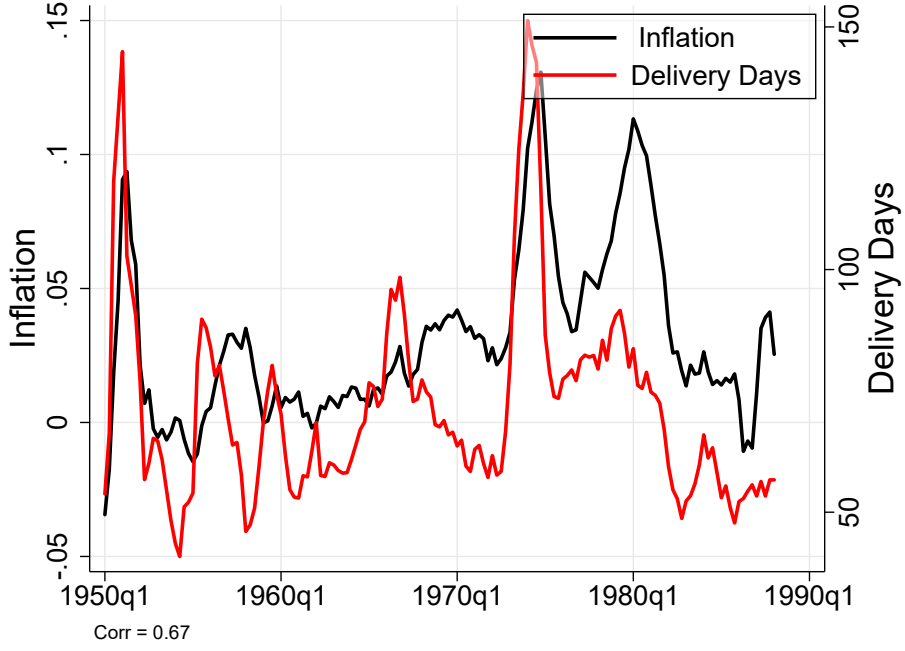
Summary

- 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.

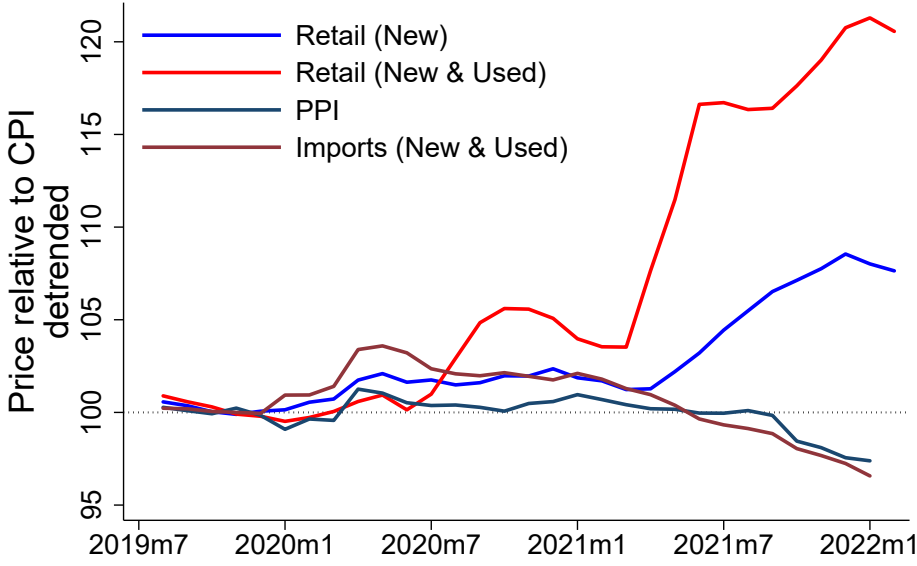
Delays and Inflation Highly Correlated



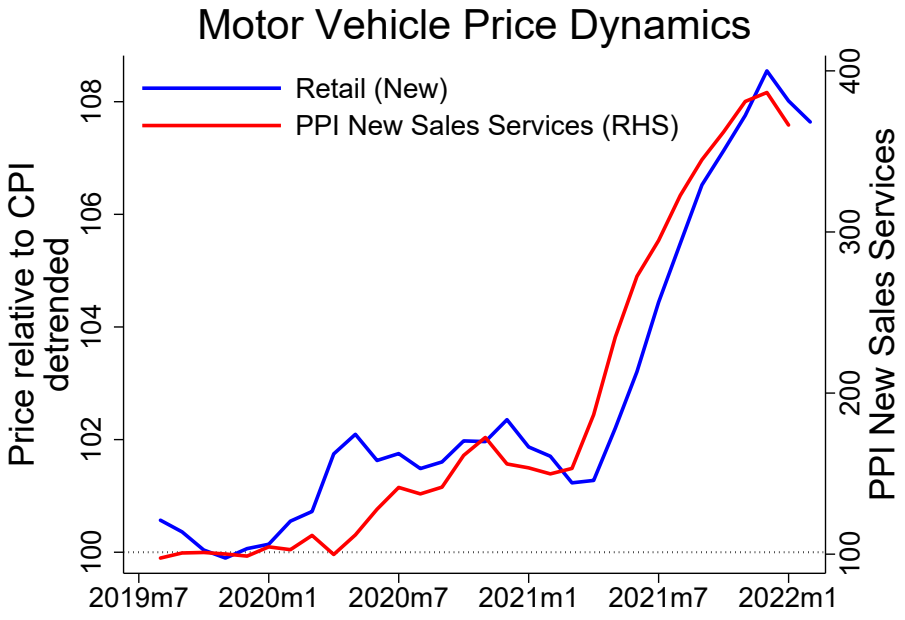
US Motor Vehicles

- 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



Last date: October, 2021, Source: Census, Prices are relative to trend



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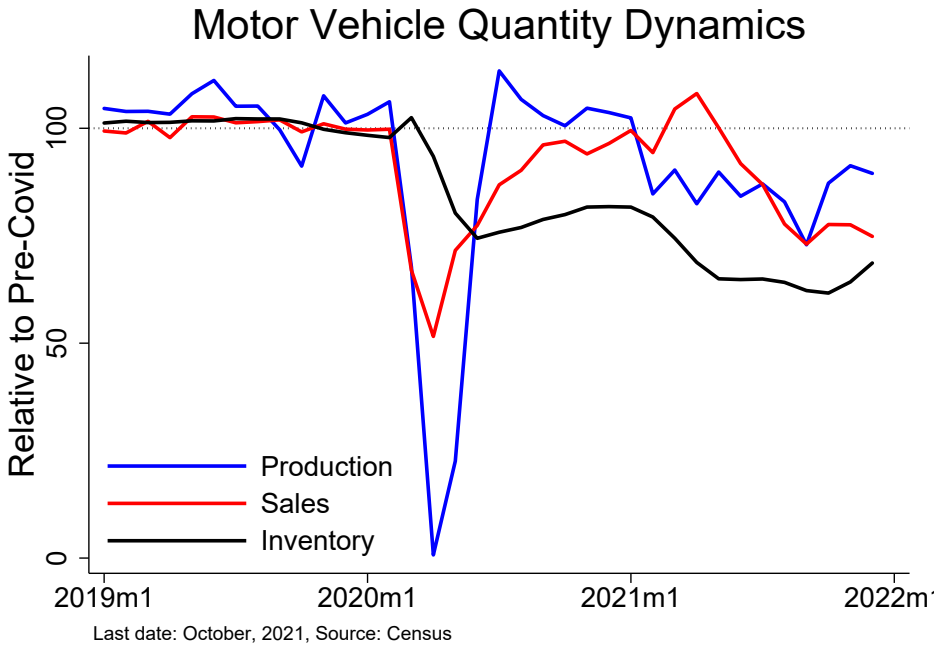
Motor Vehicle Quantity Dynamics
Relative to Pre-Covid
0
50
100
Production
Sales
Inventory
2019m1
2020m1
2021m1
2022m
Last date: October, 2021, Source: Census

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

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

- 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

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