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

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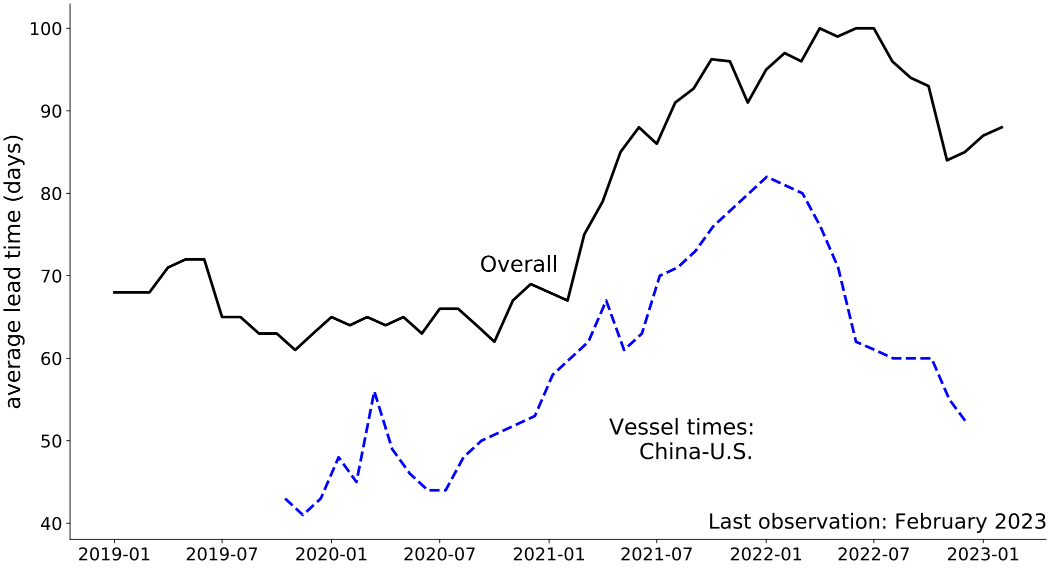
Bigger research agenda

- How do firms manage supply disruptions?
- How do supply disruptions affect GDP, employment, prices…
- Firms manage supply chains with
  - Inventory
  - Shipping mode choice
  - Supplier redundancy
- Need models with these features
- Our attempts
  - “The aggregate effects of global and local supply chain disruptions”
  - “Mitigating international supply-chain risk with inventories and fast transport”
  - “Supply-chain recessions”

Supply chain disruptions

1. Getting inputs for sale or production has been challenging since 2020
   - Confluence of factors
     - Unexpected pace of recovery
     - Production disruptions
     - Reduced air freight capacity
     - Congestion effects
   - Disruptions happening both internationally and domestically
   - Lead time on inputs: 65 days $\rightarrow$ 100 days
     - Mix of longer lead times and longer shipping times
2. Firms lack buffer stocks to absorb these delays
   - Consumer stockouts high globally (Cavallo & Kryvstov, 2021)
3. Not unique to COVID, supply delays common from 1950-1987

Delivery delays on production inputs



The aggregate impact of supply disruptions

- How do supply disruptions/delays affect aggregate
  - Employment?
  - Production?
  - Consumption?
  - Prices?
- Focus on 2020–22
- Standard “macro” frameworks ill-equipped to provide answers
- Model ingredients
  - Firms can hold inventories, but at a cost (interest, depreciation)
  - Fixed order costs
  - Delivery takes time and is uncertain (delays)
  - Firm-level demand is uncertain
- In model, production/consumption may be constrained by availability of goods

Findings

- Fit several shocks in model to match 2020–2022 data
- At its peak, international delays lead to
  - Production -12%
  - Consumption -7%
  - Consumer prices $+12\%$
- Effects arise from
  1. Delays $\rightarrow$ higher carrying costs
  2. Production disrupted from lack of inputs
- Uneven effects across firms: affect low-inventory products most

Roadmap

1. Model
2. Firms decision rules in steady state and during supply disruption
3. Experiments
   - Transitory delays
4. Fit the model to 2020–2022 data
   - Decompose the effects

Related Literature

- **Supply disruptions**

  Barrot and Sauvagnat (2016), Boehm, Flaaen and Pandalai-Nayar (2019), Carvalho et al (2020), Cavallo and Krystov (2021)

- **GE inventory models**

  Khan and Thomas (2007), Alessandria, Kaboski and Midrigan (2010, 2011, 2013), Iacoviello, Schiantarelli and Schuh (2011), Ortiz (2021), Carreras-Valle (2021)

- **Effect of timeliness on trade**

  Djankov, Freund and Pham (2010), Hummels and Schaur (2013), Clark, Kozlova and Schaur (2014), Feyrer (2019, 2021), Leibovici and Waugh (2019)

Model structure

- Two countries: home and foreign (*), complete markets
- 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’
  - Local and global supply chains

Households

- Choose consumption, labor supply, and state-contingent debt

$$\max \sum_t \sum_{\eta^t} \beta^t \pi(\eta^t) \left[\ln C(\eta^t) + \psi \ln(1 - L(\eta^t))\right]$$

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

Consumption-good producers

- Perfect competition + CRS $\rightarrow$ representative firm
- Combines domestic (D) and imported (I) varieties
- Variety-specific demand shocks ν

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

- Standard profit maximization yields

$$c_D(j,\eta^t) = \left(\frac{p_D(j,\eta^t)}{P_D(\eta^t)} \right)^{-\theta} \left(\frac{P_D(\eta^t)}{P_C(\eta^t)} \right)^{-\gamma} \nu_D(j,\eta^t) Y_c(\eta^t)$$

$$c_I(j,\eta^t) = \left(\frac{p_I(j,\eta^t)}{P_I(\eta^t)} \right)^{-\theta} \left(\frac{P_I(\eta^t)}{P_C(\eta^t)} \right)^{-\gamma} \nu_I(j,\eta^t) \tau_C Y_c(\eta^t)$$

Manufactures producers

- Perfect competition + CRS $\rightarrow$ representative firm
- Combines labor, domestic (D), and imported (I) varieties
- Variety-specific demand shocks ν (same as in consumption)

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

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

- Standard profit maximization yields demands: $m_D(j,\eta^t), m_I(j,\eta^t)$
- Price of the manufactured good: $p^m(\eta^t)$,

Retailers

- Two continua of monopolistic competitors: D, I (focus on a D firm)
- Firm j begins period with inventory $s_D(j)$, demand shock $\nu(j)$
  - Chooses order size $z_D(j)$ and prices $p_D(j)$
- If firm places an order: $z_D(j) > 0$
  - Pay fixed cost ϕ_D (units of labor)
  - With probability $1 - \mu_D$, order arrives at t; μ_D arrives at $t + 1$
  - μ_D allows us to vary average length of delivery lag
- For now: μ_D, μ_I are constants. Later: μ_D, μ_I are AR(1).
- Firm's state is $(\eta_t; s_t, \nu_t)$
- Timing: observe demand shock $\implies$ place order $\implies$ observe delivery $\implies$ set prices

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

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

- 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

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

Decision rules

- Inventories/ordering follow an "Ss rule"
  - Conditional on reordering

$$\mathop{\mathbb{E}}_{\nu',\mu'} Q(\eta'|\eta) V_1 \left(s', \nu'; \eta'\right) = p^m(\eta)$$

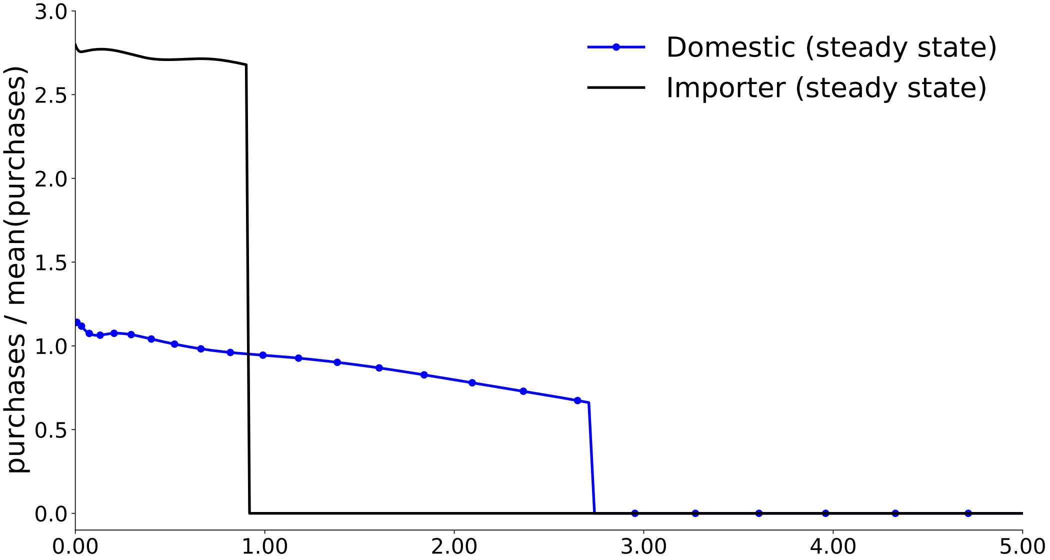
- Prices are a markup over the value of inventories

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

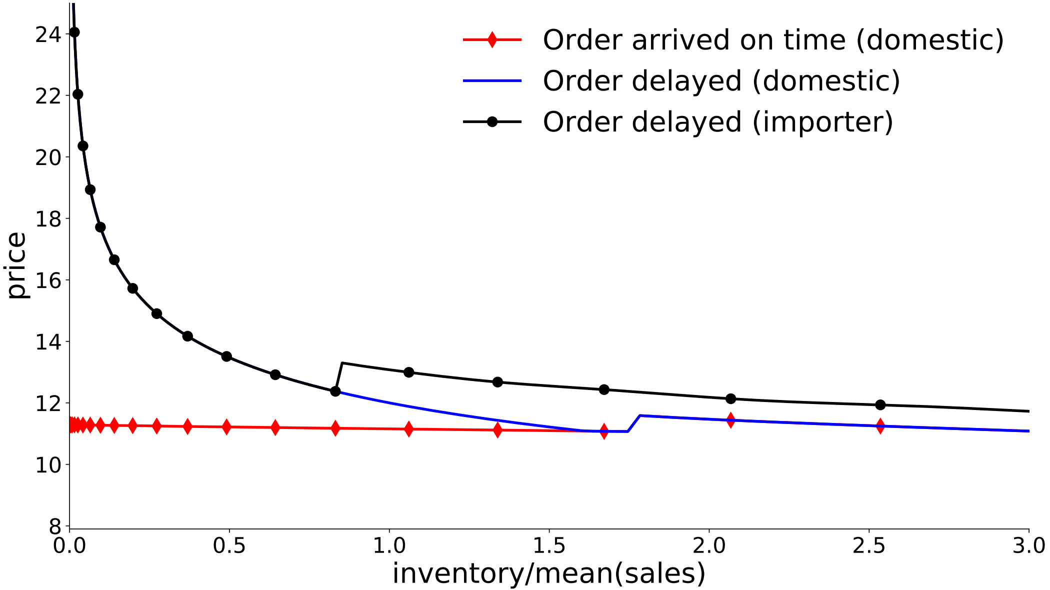
- If goods are delayed, set price to "stock out"

$$\max_p p \;\text{ s.t. } c(p, \nu) + m(p, \nu) = s$$

Policy function: Ordering (median demand shock)



Policy function: Price (median demand shock)



Feasibility (focusing on home country)

- Manufactures

$$M(\eta^t) = \int z_D(j, \eta^t) dj + \int z_I^*(j, \eta^t) dj$$

- Labor

$$L(\eta^t) = L_p(\eta^t) + \int \phi_D \mathbf{1}_{z_D(j,\eta^t)} dj + \int \phi_I \mathbf{1}_{z_I(j,\eta^t)} dj$$

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)

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

Three model specifications

1. Stationary steady state (calibration)
2. Dynamics of model with only international delay shock (highlight the mechanisms)
3. Dynamics of model with shocks to labor supply, delays, consumption (quantitative)

Assigned parameters

- Model period is one quarter

Parameters			Moments	
Discounting	β	$0.96^{0.25}$	Annual real rate	4%
Input cost share	α	0.6	Manufacturing GO/VA	2.8
International delay	μ_I	0.5	Authors' calculation	45 days
Frisch elasticity	ψ	2	Steady State Labor	1/3
Substitution within source	θ	4		
Substitution across source	γ	1.1		
IES	σ	1		

Jointly estimated

- Focus on the manufacturing and trade sector
- Inventory holdings and order frequency: $\delta, \mu_D, \sigma_\nu^2, \phi_D, \phi_I$ 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 quarters
- Elasticity of substitution between sources: $\gamma = 1.1$
- Trade preferences τ_c and τ_m chosen so that
  - import share matching U.S. data
  - share of consumption vs material imports from data

Jointly estimated

Parameters			Moments	
Home bias manufactures	τ_m	0.4	Imports in man.-input bundle	15%
Home bias consumption	τ_c	0.07	Manufactures' share of imp	80%
Depreciation	δ	0.045	Inventory-purchases ratio (dom)	1.1
Domestic delay	μ_D	23 days	Inventory-purchases ratio (imp)	2.4
Demand variance	σ_ν^2	1.5	Inventory-purchases ratio (agg)	1.3
Fixed order cost† (dom)	ϕ_D	2.5%	Order freq (dom)	50%
Fixed order cost† (imp)	ϕ_I	15%	Order freq (imp)	25%

†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

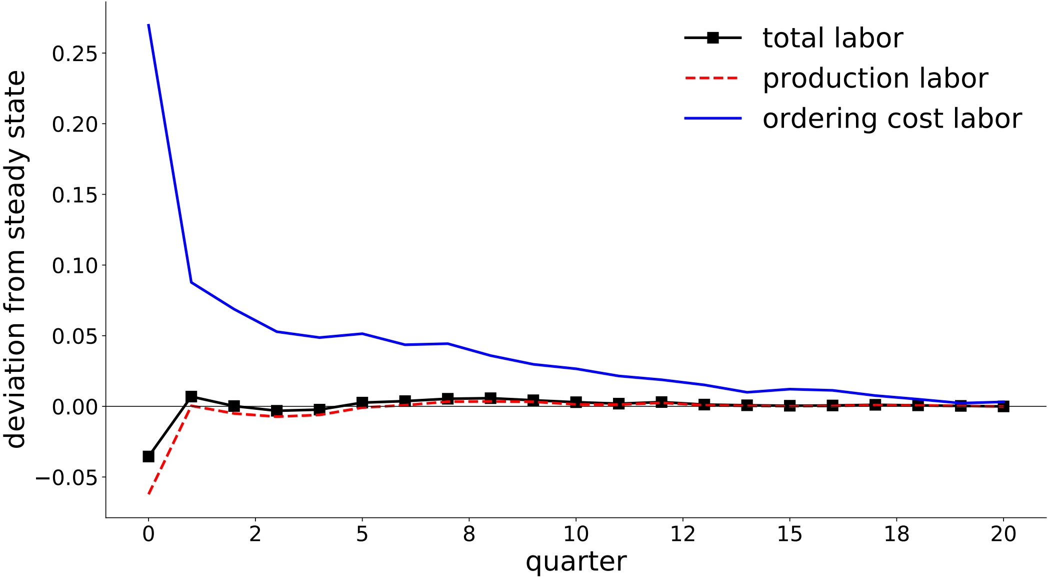
International delivery delays: Dynamics

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

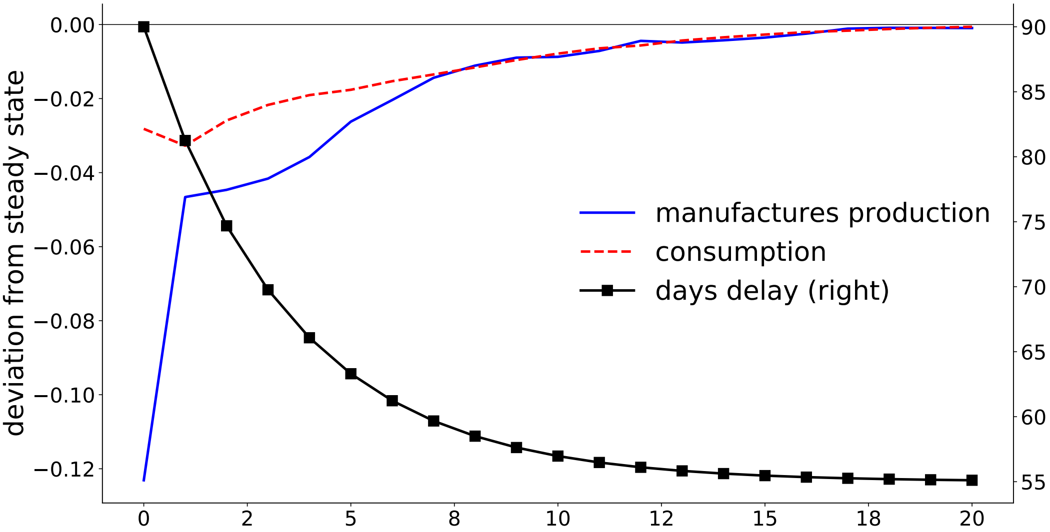
$$\mu_{I,t+1} = 0.5\mu_I^{ss} + \rho_I \mu_{It}$$

- Impulse increases average delivery time from 45 to 90 days

International delivery delays



International delivery delays



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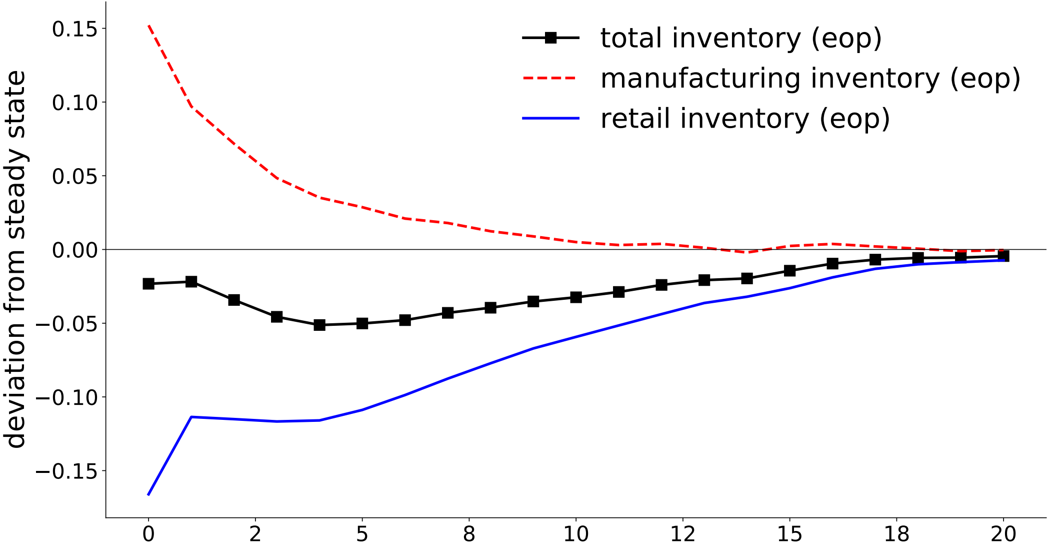

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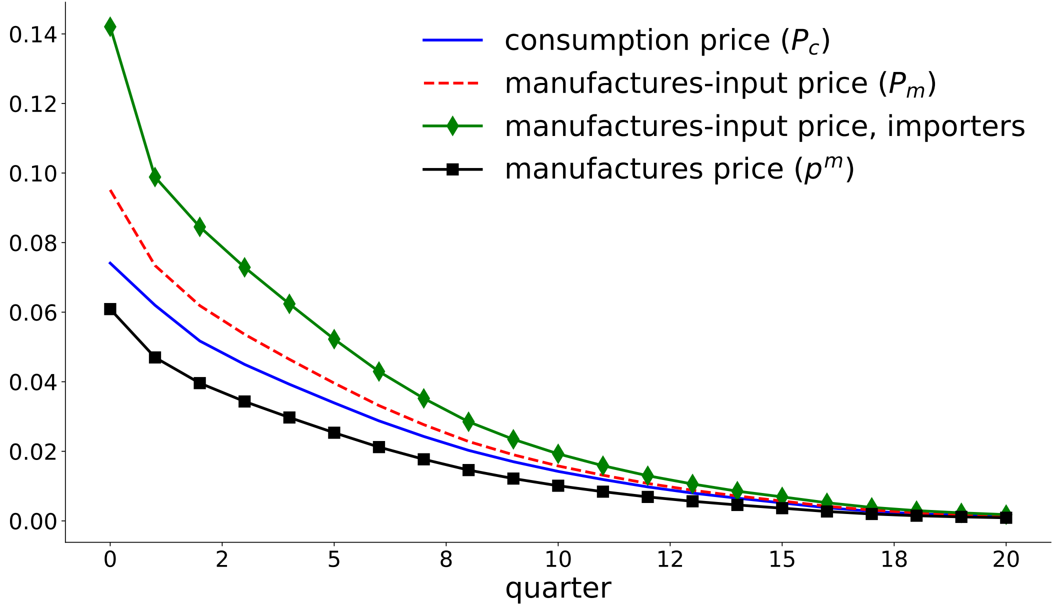
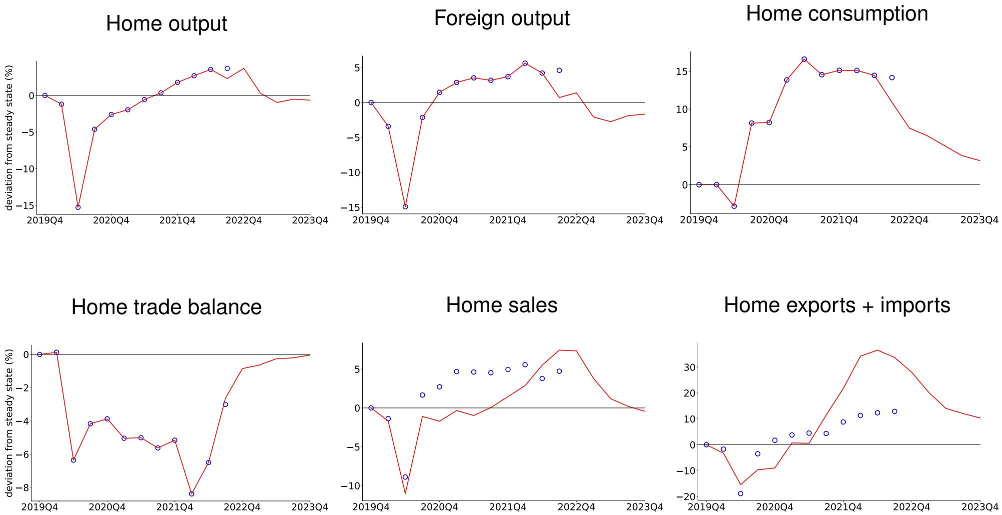


Fitting the model to the data

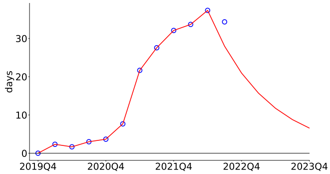
- 2019Q4–2022Q2
- Shocks: international delays; domestic delays (x2); consumption stimulus (x2); labor supply (x2)
  - Restrict delay shocks to be symmetric
  - Stimulus, labor supply shocks asymmetric
- Targets: production (x2); domestic delays (x2); international delays; home consumption; trade balance
- Everything effects everything, but
  - Labor supply (x2) $\rightarrow$ output in US and ROW
  - Stimulus (x2) $\rightarrow$ US consumption & trade balance

Endogenous variables

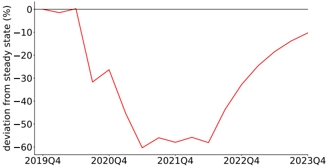


Exogenous shocks

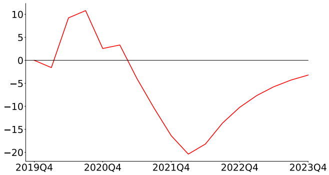
Home domestic delays



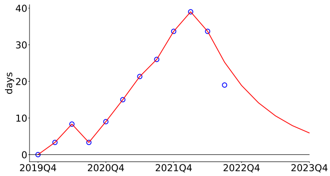
Home stimulus



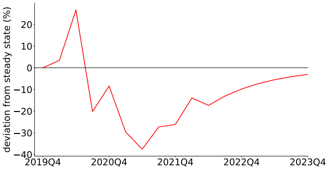
Home disutility of labor



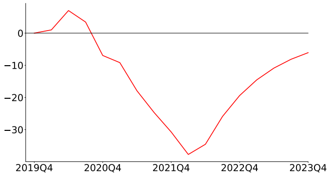
Import delays



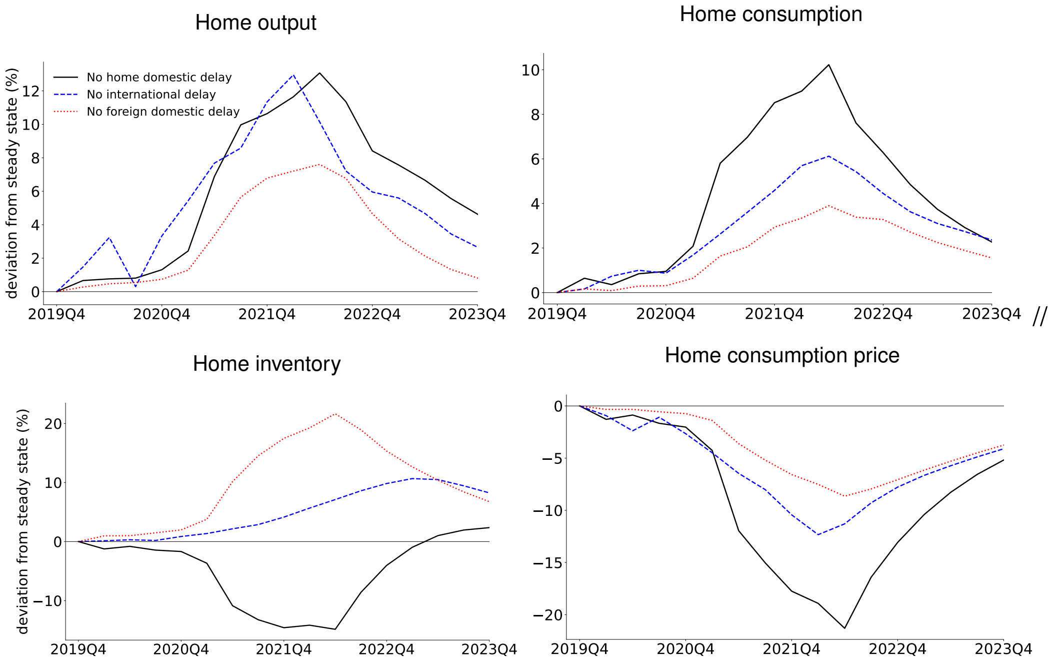
Foreign stimulus



Foreign disutility of labor



The effect of delays

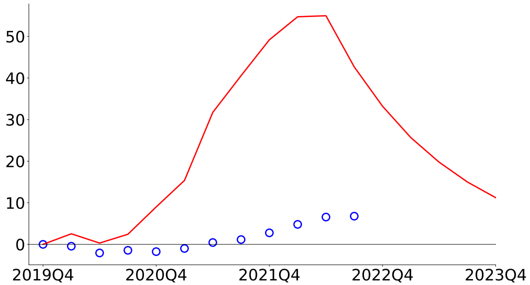


A few more things…

1. Prices
2. Expectations

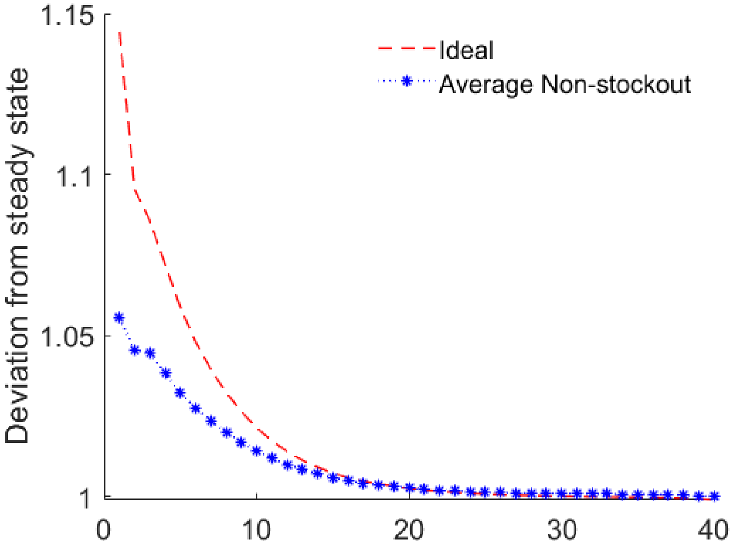
Misses

- Timing assumption: Firms change price after observing arrival



- Prices improved by setting prices before delivery
  - Minimal effect on quantities since sales still constrained by inventory
  - Current prices capture ”shadow price” of consumption.

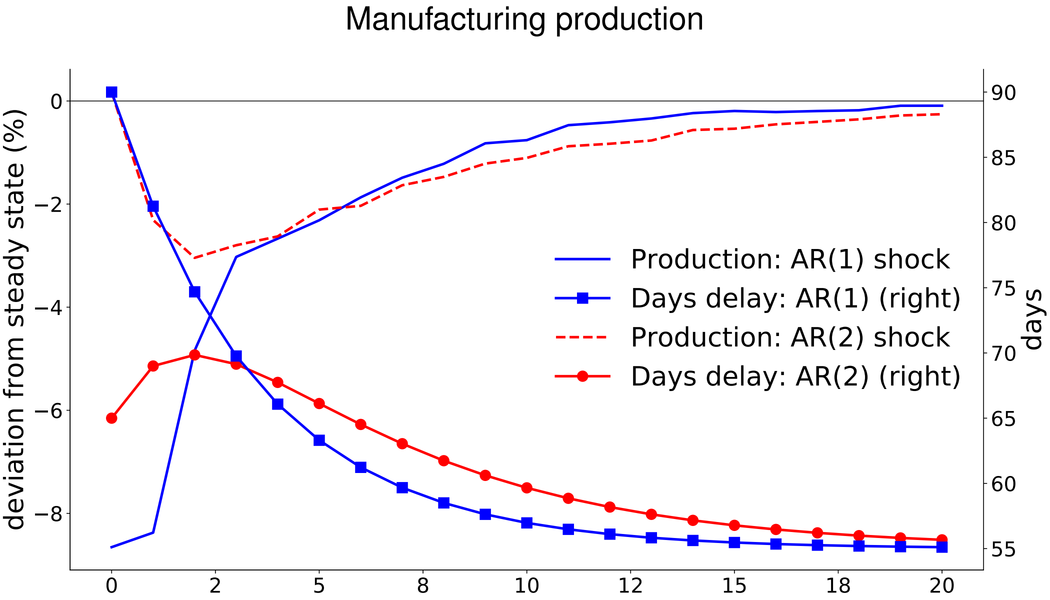
Impulse response: Consumption prices



The role of expectations

- Aggregate effects depend on the size and persistence of delays
- Hard to discipline in current environment—we chose AR(1)
- Historically, US delays are hump-shaped (AKKRS, 2022; 1950-1990)
- Hump-shaped shocks can be expansionary in the short run
  - Precautionary stockpiling (order toys for Xmas sooner)

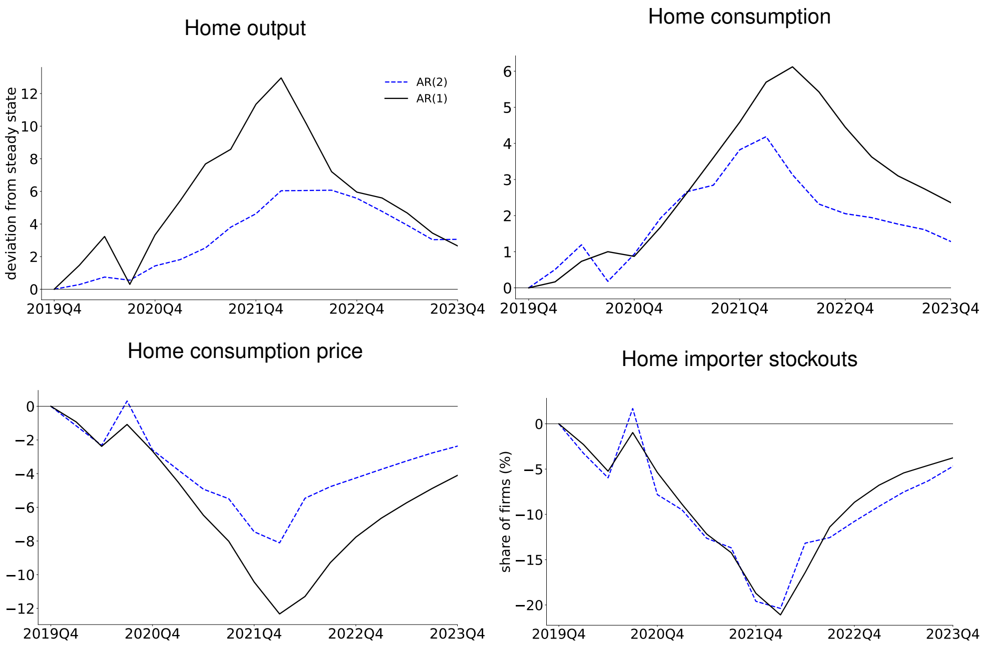
International delivery delay AR(1) v. AR(2)



Quantitative implications: AR(2) vs AR(1)

- Redo fitting with AR(2) import delay shocks.
- Firms see that delays will get worse, and adjust
- Compare counterfactual effects:
  - Most effects about 1/3 smaller
  - Slightly different timing

The effect of import delays: AR(1) v AR(2)



Summary

- Develop a GE model of time to restock
- Large aggregate effects of changing the speed of trade
- Supply delays much more costly than cost shocks
- Mitigated by inventory levels at firm & aggregate level
- For policy, need to introduce congestion effects (in progress)

Time vs. carrying costs

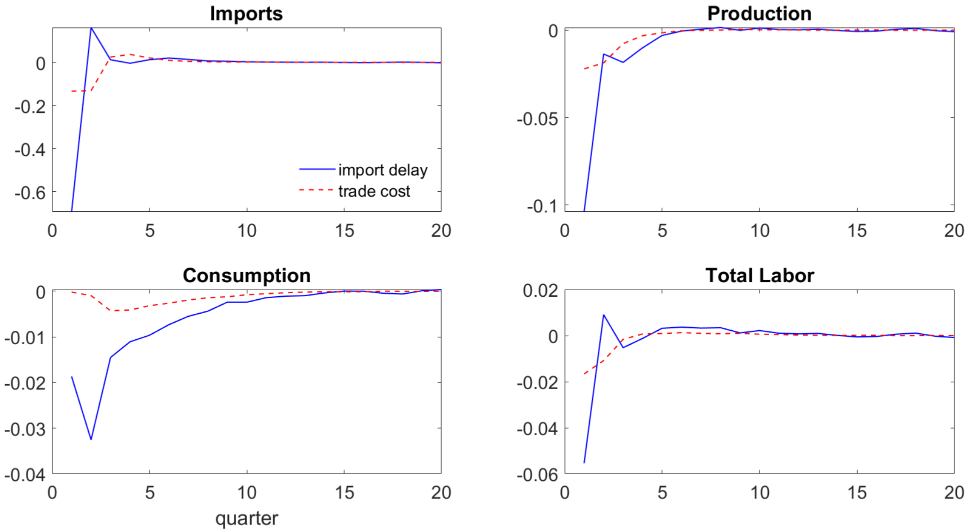
- Consider an increase in shipping costs equivalent to extra carrying costs of delay
- Cost shocks less costly because they do not constrain the orders of high-demand low-inventory firms
- Explains willingness to pay very large trade costs to accelerate trade

International delivery delays

- Two main mechanisms at work

1. (Time) Reduced supply for production and consumption today
   - If nothing arrives today $\rightarrow$ production & consumption limited to inventory
   - Decreases demand for production labor
   - Affects firms with lowest inventories most (different from trade cost)
2. (Cost) Higher carrying costs of inventories
   - Interest costs: (extra days$/$365) $\times$ r
   - Depreciation costs: (extra days$/$365) $\times$ δ
   - Fixed costs: more orders burns up resources

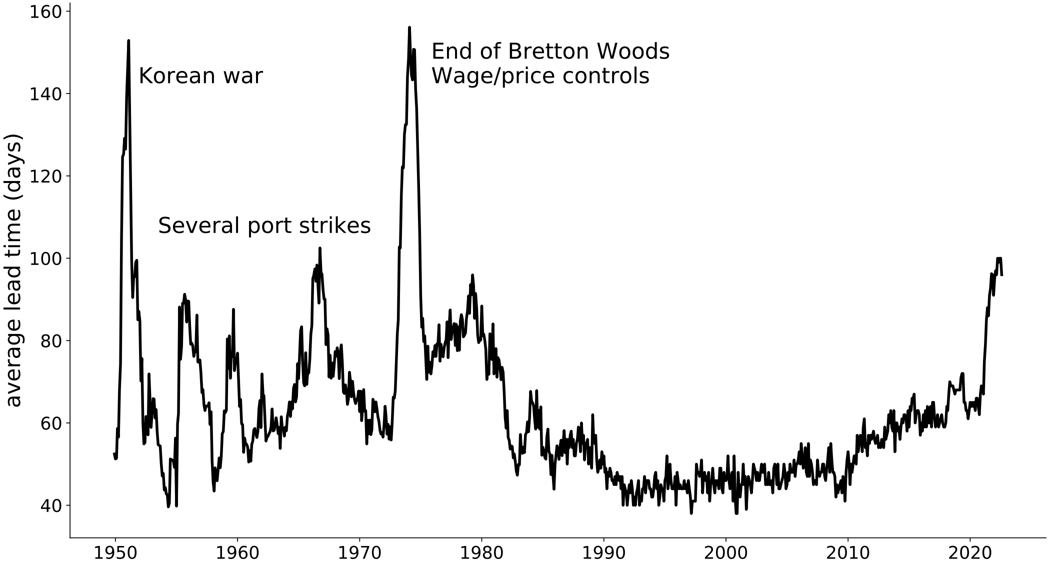
Time vs. carrying costs



Delays are common

- Delays have been important in the past, too
- Consider VAR evidence from 1950–2020
  - Delays more common 1950–1987
- Part of “Supply-chain recessions” with Alessandria, Khan, Khederlarian, and Mix

Delivery delays on production inputs



Some VAR evidence

- Consider VAR with 3 blocks
- Real: IP, Sales, Inventory, Employment, ISM Delays
- Nominal: Wages, Price of Goods/Wage
- Int'l: Trade, Export-Import Ratio, Terms of trade, Price of Traded goods
- Real variables, then delays, then prices (robust to ordering)
- Consider impulse from delays and orthogonalized response of system

Effects of a delay shock