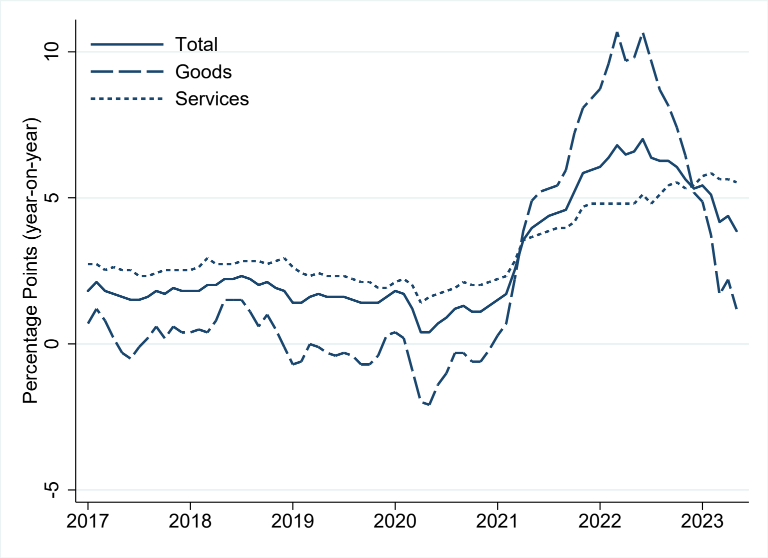
Supply Chain Constraints and Inflation

Diego Comin (Dartmouth College & NBER)
Robert C. Johnson (Notre Dame & NBER)
Callum Jones (Federal Reserve Board)

July 13, 2023
NBER Summer Institute

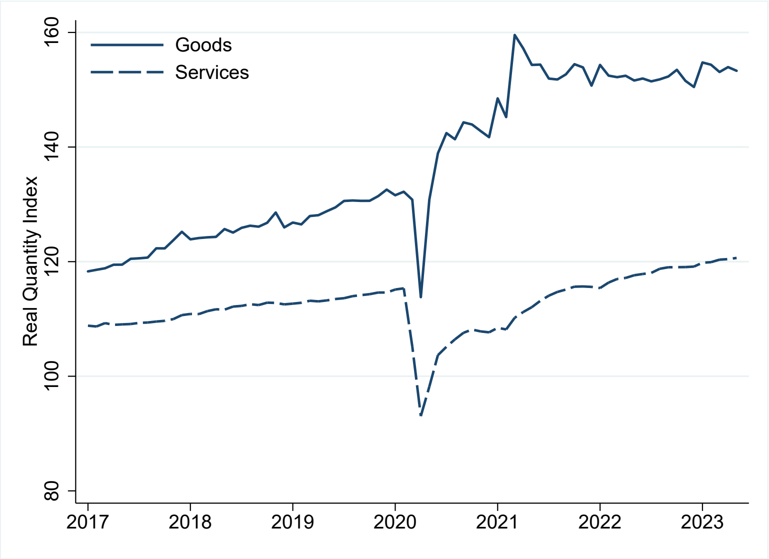
The views expressed are those of the authors and not necessarily those of the Federal Reserve Board or the Federal Reserve System.

US PCE Inflation



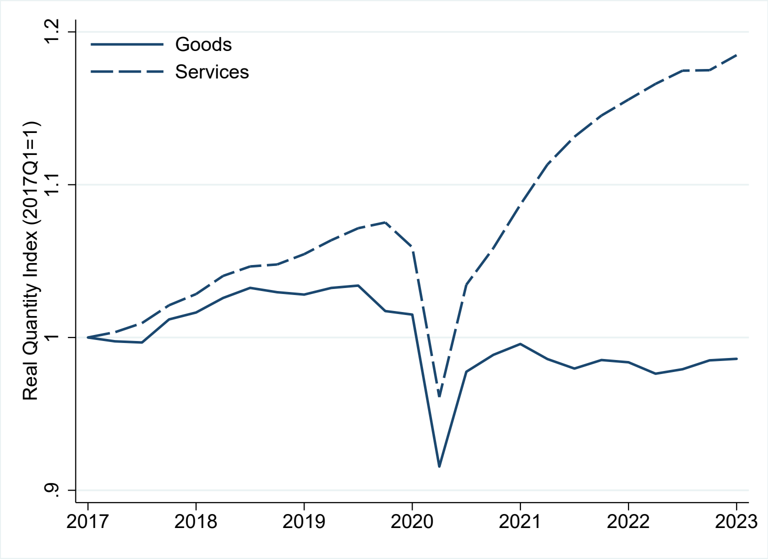
Source: Bureau of Economic Analysis & authors' calculations.

Real Consumer Expenditure



Source: Bureau of Economic Analysis & authors' calculations.

Real Gross Output



Source: Bureau of Economic Analysis & authors' calculations.

Import Q Import P

Blame the Supply Chain

Gita Gopinath in the IMF's World Economic Outlook:

> *Pandemic outbreaks in* **critical links of global supply chains** *have resulted in longer-than-expected* **supply disruptions**, *further* **feeding inflation** *in many countries.*

Jerome Powell in The New York Times:

> *[Powell] noted that while demand was strong in the United States,* **factory shutdowns and shipping problems were holding back supply**... **pushing inflation above the Fed's goal**... *"[i]t is also frustrating to see the* **bottlenecks and supply chain problems**... *holding inflation up longer than we had thought," Mr. Powell said.*

Apple's finance chief in The Financial Times:

> **Supply constraints** *caused by Covid-related disruptions and industry-wide silicon* **shortages** *are impacting our ability to meet customer demand for our products.*

Constraints in the Global Supply Chain

1. Did supply chain constraints trigger the inflation surge?
   - What is the nature of the constraints?
     - Potentially-binding capacity constraints on firm output.
     - Related ideas in Fagnart et al. (1999), Álvarez-Lois (2006), Boehm and Pandalai-Nayar (2022).
     - Binding constraints produce non-linear outcomes.
   - Are constraints domestic or international in scope? Media/policy attention focused on import constraints.
2. What role for shocks to demand (including monetary policy) vs. supply in explaining inflation?
   - Did high demand exhaust existing capacity? Or, did negative supply-side shocks reduce capacity?
   - Did binding constraints amplify the impacts of other shocks?

Framework Overview

Multisector, New Keynesian, small open economy.

- Continuum of firms under monopolistic competition in each sector.
- Standard CES demand and production structure.
  - Representative consumer; separable consumption/leisure preferences. Nested CES preferences across sectors and home/foreign goods.
  - Firms use labor, home inputs, and foreign inputs to produce. And there are input-output linkages across sectors.
- Pricing assumptions:
  - Dollar invoicing for imports and exports.
  - Rotemberg adjustment costs for output prices.
  - Flexible wages [extension with wage rigidity to come].
- Complete international financial market.
- Taylor-type rule with inertia and policy shocks. [ZLB details later.]

The Twist: potentially binding constraints for foreign & domestic firms.

Pricing Problem for Home Firms

Suppress sector & end use notation for clarity.

Firm ω sets $P_t(\omega)$ to solve:

$$\max_{\{P_t(\omega)\}} \mathbf{E}_0 \sum_{t=0}^{\infty} \frac{S_{0,t}}{P_t} \left[\left(P_t(\omega) - MC_t(\omega) \right) Y_t(\omega) - \Phi(P_{t-1}(\omega), P_t(\omega)) \right]$$

$$\text{s.t.} \quad Y_t(\omega) = \left(\frac{P_t(\omega)}{P_{Ht}} \right)^{-\varepsilon} Y_t$$

$$\text{and} \quad Y_t(\omega) \leq \bar{Y}_t$$

with $\Phi(P_{t-1}(\omega), P_t(\omega)) \equiv \frac{\phi}{2} \left(\frac{P_t(\omega)}{P_{t-1}(\omega)} - 1 \right)^2 P_{Ht} Y_t$.

Pricing in Symmetric Equilibrium

Optimal Pricing:

$$0 = 1 - \varepsilon \left(1 - \frac{MC_t + \mu_t}{P_{Ht}}\right) - \phi \left(\Pi_{Ht} - 1\right) \Pi_{Ht} + E_t \left[\frac{S_{t,t+1}}{\Pi_{t+1}} \phi \left(\Pi_{Ht+1} - 1\right) \Pi^2_{Ht+1} \frac{Y_{t+1}}{Y_t}\right]$$

with $\Pi_{Ht} \equiv P_{Ht}/P_{H,t-1}$.

Complementary Slackness Condition:

$$\mu_t \left[\bar{Y}_t - Y_t\right] = 0$$

plus $\mu_t \geq 0$ and $Y_t \leq \bar{Y}_t$.

Slack constraint $\Rightarrow \mu_t = 0 \Rightarrow$ usual domestic price Phillips Curve holds.

Binding constraint $\Rightarrow Y_t = \bar{Y}_t \Rightarrow$ price determined by demand.

Phillips Curves

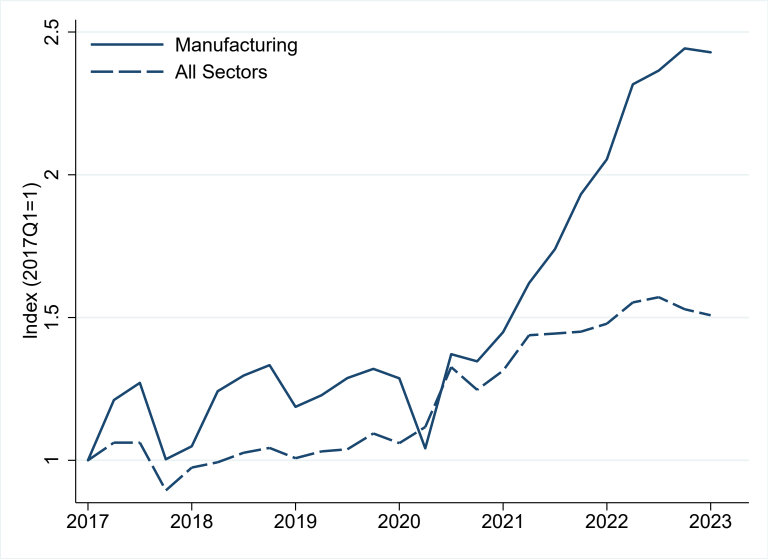
Adding notation: $s \in \{1, \ldots, S\}$ and $u \in \{C, M\}$:

$$\pi_{Ht}(s) = \frac{\varepsilon - 1}{\phi(s)}\left[\widehat{rmc}_t(s) - \widehat{rp}_{Ht}(s)\right] + \frac{\varepsilon}{\phi(s)}\hat{\hat{\mu}}_t(s) + \beta \mathbb{E}_t\left[\pi_{Ht+1}(s)\right]$$

$$\pi_{uFt}(s) = \frac{\varepsilon - 1}{\phi(s)}\left[\widehat{rmc}^*_t(s) + \hat{q}_t - \widehat{rp}_{uFt}(s)\right] + \frac{\varepsilon}{\phi(s)}\hat{\hat{\mu}}^*_{ut}(s) + \beta \mathbb{E}_t\left[\pi_{uFt+1}(s)\right]$$

1. Binding constraints $\sim$ markup (cost-push) shocks.
   - Del Negro et al. (2022): cost-push shocks account for US inflation.
   - Distinct from "capital utilization" approach to capacity. Details
   - Markup channel is also consistent with resilience of profits.
2. Prices tell us whether constraints bind, not why they bind.
   - Positive **demand** shocks vs. negative **capacity** shocks.
   - Both manifest as supply-side "markup shocks."
   - We need data on prices & quantities to pin down shocks. IRFs

Profits per Unit of Output



Nominal corporate profits (NIPA Table 6.16) per unit of gross output.
Source: Bureau of Economic Analysis & authors' calculations.

Framework, Final Details

Two sectors: goods and services.
Labor is homogeneous and mobile across sectors.
CES export demand for each sector's output.

Foreign consumption goods and inputs are distinct goods,
but are subject to the same cost shocks: $\widehat{rmc}_t^*(s)$.

Two potentially binding constraints:

1. Foreign input goods production capacity.
2. Domestic goods production capacity.

Monetary policy:

$$1 + i_t = (1 + i_{t-1})^{\varrho_i} \bar{\Pi}_t^{\omega(1-\varrho_i)} \left(Y_t / Y_0\right)^{(1-\varrho_i)\varrho_y} \Psi_t$$

Shocks

1. Demand shocks:
   - Time discount shock: $\mathbf{E}_0 \sum_{t=0}^{\infty} \beta^t \Theta_t \left[\frac{C_t^{1-\rho}}{1-\rho} - \chi \frac{L_t^{1+\psi}}{1+\psi} \right]$.
   - Goods-biased demand shock: $C_t(g) = \zeta_t(g) \left(\frac{P_t(g)}{P_t} \right)^{-\vartheta} C_t$, with $\zeta_t(g) + \zeta_t(s) = 1$.
2. Monetary policy shocks: Ψ_t.
3. Shocks to domestic and foreign capacity: $\bar{Y}_t(g), \bar{Y}^*_{Mt}(g)$.
4. Cost shocks:
   - Sector-level TFP: $Z_t(s)$.
   - Foreign real marginal cost: $\widehat{rmc}^*_t(s)$.

Exogenous variables follow AR(1) process.

Note: no labor market shocks; more to come in an extension.

Solution Method

Non-linearities due to occasionally binding constraints
$\rightarrow$ construct piece-wise linear solution [Guerrieri and Iacoviello (2015)].

General Solution:

$$X_t = P\left(X_{t-1}, \varepsilon_t; \theta\right) X_{t-1} + D\left(X_{t-1}, \varepsilon_t; \theta\right) + Q\left(X_{t-1}, \varepsilon_t; \theta\right) \varepsilon_t$$

Policy function depends on whether the constraint is binding.

Looking forward to estimation, re-write the solution:

$$X_t = J(\mathbf{D}_t, \theta) + Q(\mathbf{D}_t, \theta) X_{t-1} + G(\mathbf{D}_t, \theta)\varepsilon_t$$

- $\mathbf{D}_t = [d_t, d_{Mt}]$ is # of periods each constraint binds from date t.
- Given guess for $\mathbf{D}_t$, one can solve for time-varying coefficients in policy matrices. Then verify path of X_t is consistent with the guess.

Estimation

- Calibrate subset of parameters, estimate the remainder.
- Structural parameters to be estimated:
  - Stochastic process for exogenous variables: shock variance, AR coeffs.
  - Capacity levels (mean for periods w/ potentially-binding constraints).
  - Elasticities of substitution between home and foreign goods, separately for consumption and inputs.
  - Parameters of monetary policy rule.
- Treat durations of binding constraints ($\mathbf{D}_t$) as estimable parameters.
  - Kulish et al. (2017), Kulish and Pagan (2017), Jones et al. (2022).
  - We extend this work by imposing equilibrium constraints on durations.
  - Allow constraints to potentially bind from 2020:Q2 onward.

Estimation Details

- The likelihood, $\mathcal{L}(\theta, \mathbf{D}|Y^{\text{obs}})$ is a function of both the structural parameters (θ) and the sequence of durations ($\mathbf{D} = \{\mathbf{D}_t\}_{t=1}^{T}$).
- We set priors over structural parameters and independent priors over durations to construct the posterior.
- For each proposed draw, we check that durations are consistent with rational expectations equilibrium.
  - Draw proposed durations and parameters.
  - Construct time-varying policy matrices for those parameters.
  - Kalman-filter data and construct smoothed shocks.
  - For each date τ, project endogenous variables forward given duration (d_τ) and smoothed shock ($\tilde{\varepsilon}_\tau$), assuming no future shocks.
  - Reject the draw if constraints are violated.
    Otherwise, accept it and evaluate the likelihood.
  - We accept about 25% of parameter/duration draws.

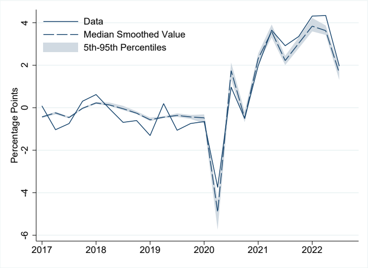
Observables

Data for 1990:Q1 to 2022:Q3

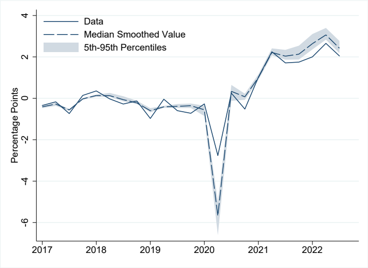
- Consumer inflation and expenditure by sector.
- Industrial production and aggregate nominal GDP.
- Value-added per worker by sector.
- Inflation and expenditure for imported goods inputs (ex. fuels).
- Inflation and expenditure for imported consumer goods.
- Shadow Fed Funds rate:
  - We use updated Wu and Xia (2016) shadow rate as the policy rate.
  - We have also explored explict ZLB constraint in our model, as in Kulish et al. (2017) and Jones et al. (2022).

Model Fit: Inflation

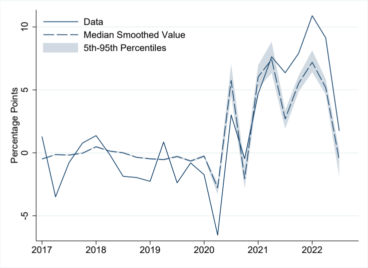
(a) Aggregate Consumer Inflation



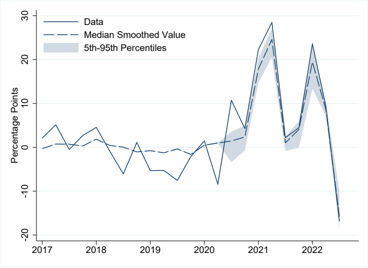
(b) Consumer Services Inflation



(c) Consumer Goods Inflation

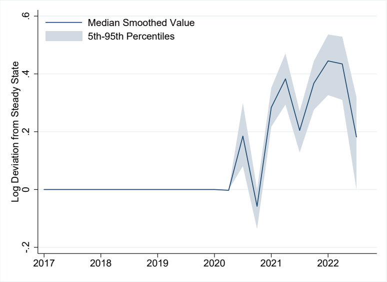


(d) Inflation for Imported Goods Inputs11d

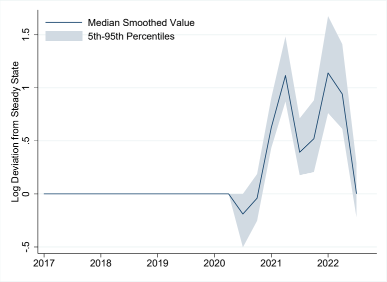


Capacity Multipliers

(a) Multiplier on Domestic Constraint (μ_t)

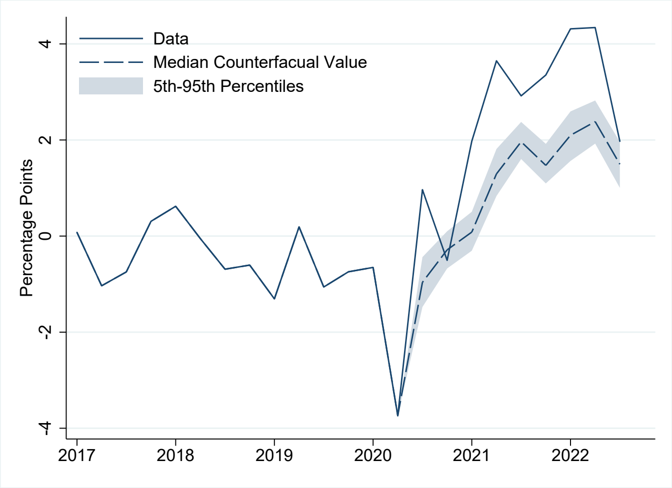


(b) Multiplier on Foreign Constraint (μ_t^*)



Counterfactual: Slack Capacity Constraints

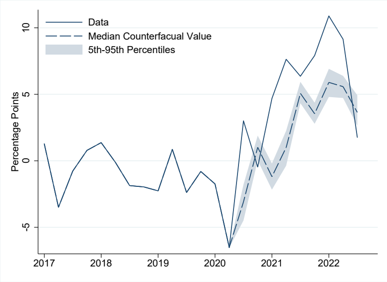
Aggregate Consumer Price Inflation



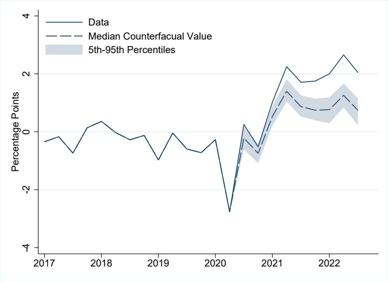
Note: Simulated values include measurement error, for comparability to data.

Counterfactual: Slack Capacity Constraints

(a) Goods Inflation



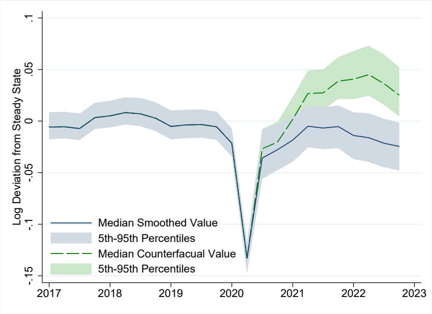
(b) Services Inflation



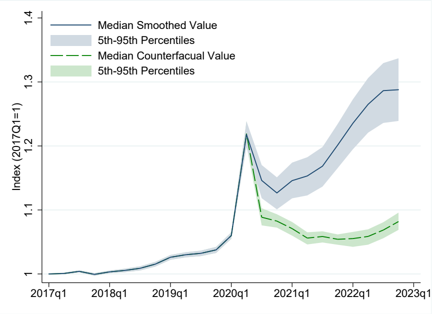
Note: Simulated values include measurement error, for comparability to data.

Counterfactual: Slack Capacity Constraints

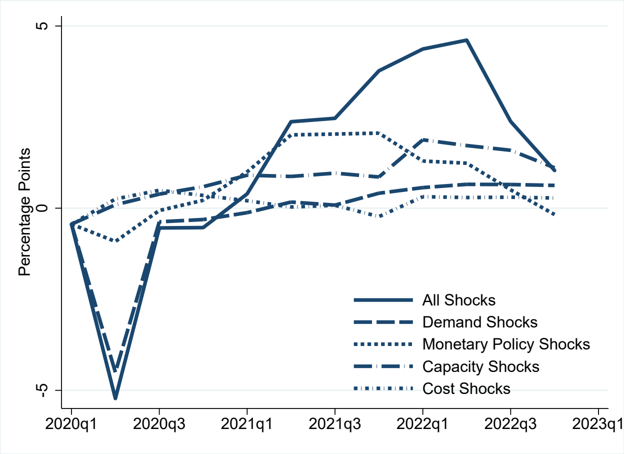
(a) Goods Output



(b) Goods Profits Per Unit

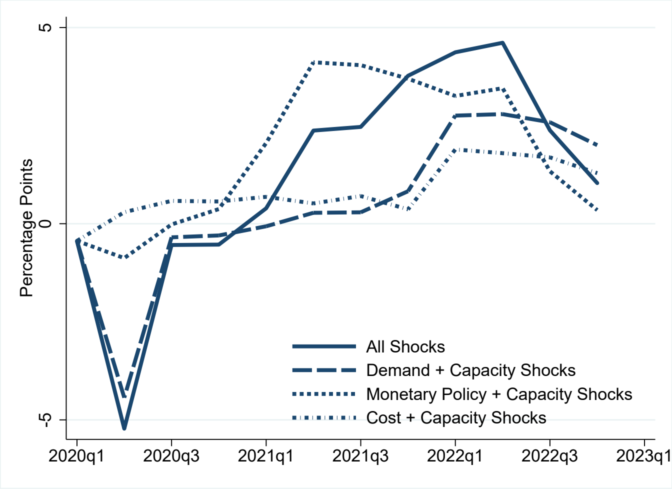


Historical Decomposition Consumer Price Inflation



Set excess capacity to 5% for domestic goods, 10% for imported inputs.
Draw parameters & filter data for smoothed shocks.
Introduce shocks one-by-one and solve model with potentially binding constraints.
Repeat 1000 times and plot median across simulations.

Historical Decomposition Consumer Price Inflation



Repeat the same exercise, now combining capacity and non-capacity shocks. Negative capacity amplify the impact of monetary policy shocks in 2021-2022.

Labor Supply Shocks and Constraints

Add three new features to enrich labor market:

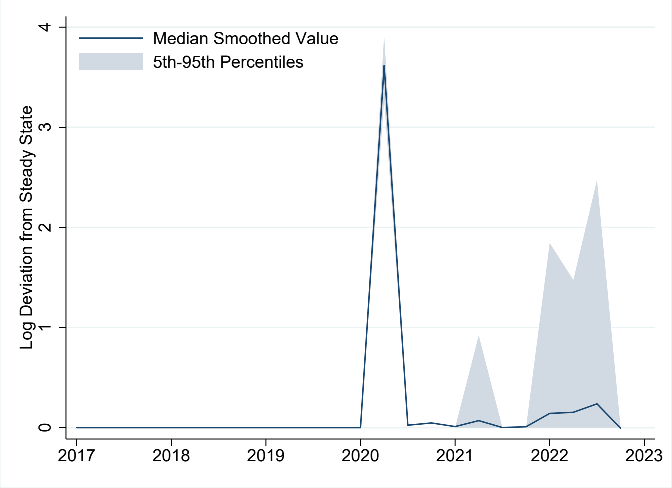
1. Wage rigidity $\rightarrow$ Phillips Curve for wages.
2. Labor disutility shocks $\rightarrow$ raise cost of labor supply, moving up the wage Phillips Curve.
3. Labor supply constraints: $L_t \leq \bar{L}_t$ $\rightarrow$ shift the wage Phillips Curve.

Re-estimate model, adding data on real wages and hours worked.

Three questions:

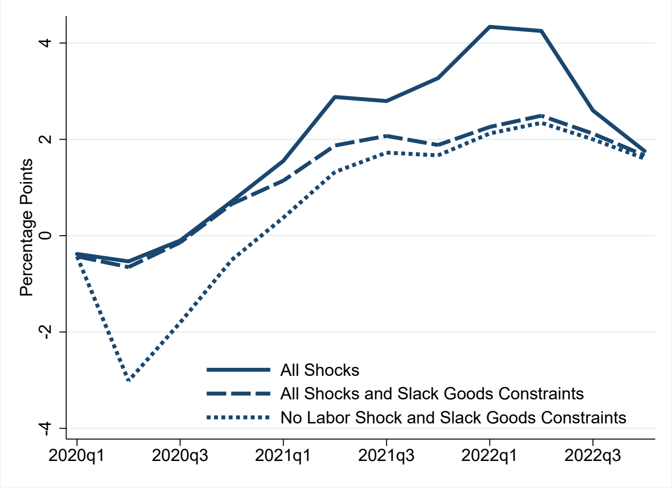
1. Did labor supply constraints bind? And what impact on inflation?
2. How important were labor supply shocks in the inflation surge?
3. How does adding labor market shocks alter quantitative impact of goods capacity constraints and policy shocks?

Multipliers on the Labor Constraint



Binding labor constraint helps explain lack of deflation in 2020.

Counterfactuals



Note: Median values across 1000 simulations.

C1: Goods constraints are slack.

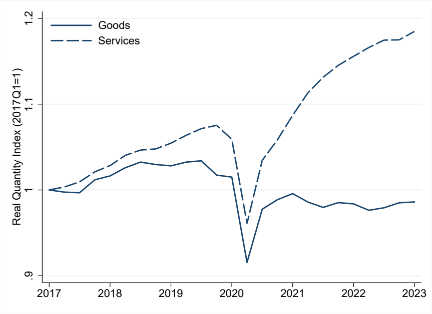
C2: Goods constraints are slack & no labor supply (disutility) shock.

Concluding Remarks

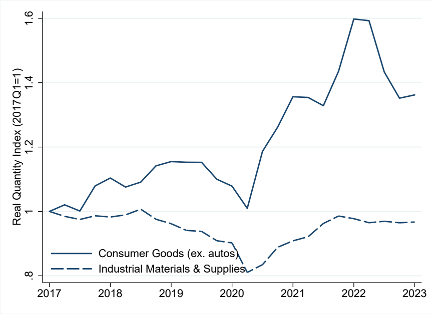
- We have developed a quantitative framework to study inflation that places capacity constraints at center stage.
- Binding constraints introduce a wedge in the Phillips Curve relationship between inflation and real marginal costs.
- Quantitatively, we find that binding capacity constraints explain about half of the rise in US inflation during 2021-2022.
- Why do constraints bind? Increases in demand, triggered by loose monetary policy, plus negative capacity shocks.

Production and Imports

(a) Real Gross Output



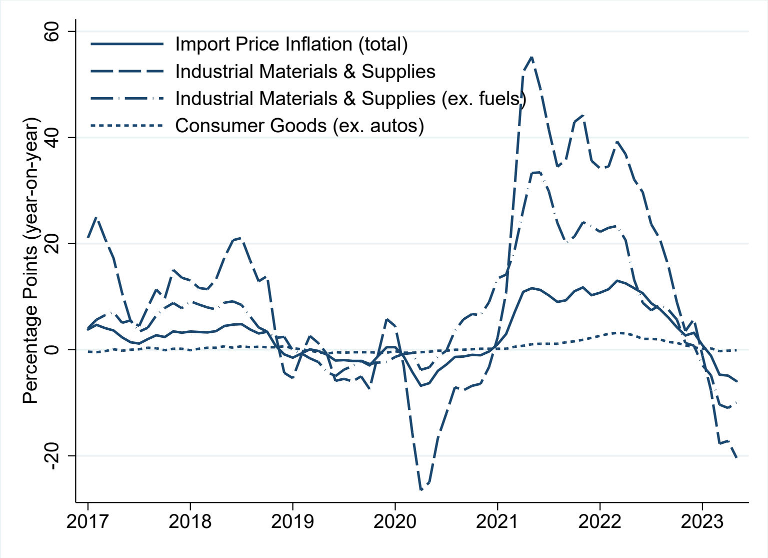
(b) Real Imports



Source: Bureau of Economic Analysis & authors' calculations.

Back

Import Prices



Source: Bureau of Economic Analysis & authors' calculations.

Back

Contrast with Capacity (Capital) Utilization

Recall Greenwood, Hercowitz and Huffman (1988):

$$Y_t = Z_t(U_t K_t)^\alpha L_t^{1-\alpha}$$
$$K_t = I_t + (1-\delta(U_t))K_{t-1}$$
$$\widehat{rmc}_t = -\widehat{z}_t + \alpha(\varepsilon_\delta * \hat{u}_t + \widehat{rq}_t) + (1-\alpha)\widehat{rw}_t$$
$$\pi_{Ht}(s) = \frac{\varepsilon - 1}{\phi(s)}\left[\widehat{rmc}_t(s) - \widehat{rp}_{Ht}(s)\right] + \frac{\varepsilon}{\phi(s)} + \beta \mathbb{E}_t\left[\pi_{Ht+1}(s)\right]$$

Capital utilization $(\hat{u}_t) \rightarrow \widehat{rmc}_t(s) \rightarrow \pi_{Ht}(s)$.

Our approach to capacity works through markups, conditional on *rmc*.
It *changes the structural relation* between π and *rmc*.

Back

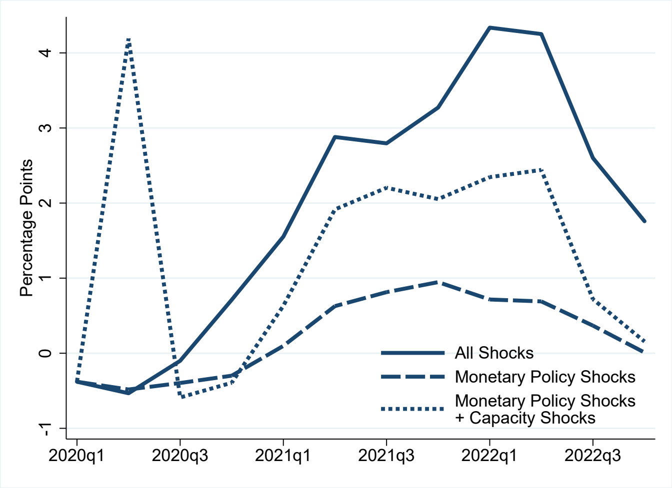
Shocks to Demand vs. Capacity

Positive Demand Shock vs. Negative Domestic Constraint Shock

Demand and capacity shocks have similar effects on inflation, but they have opposite effects on output.

Back

Counterfactual: Policy & Capacity Shocks



Median values across 1000 simulations.

Back

References I

Álvarez-Lois, Pedro P., "Endogeneous Capacity Utilization and Macroeconomic Persistence," *Journal of Monetary Economics*, 2006, *53*, 2213–2237.

Boehm, Christoph E. and Nitya Pandalai-Nayar, "Convex Supply Curves," *The American Economic Review*, 2022, *112* (12), 3941–3969.

Del Negro, Marco, Aidan Gleich, Shlok Goyal, Alissa Johnson, and Andrea Tambalotti, "Drivers of Inflation: The New York Fed DSGE Model's Perspective," Liberty Street Economics from Federal Reserve Bank of New York (No 20220301): https://libertystreeteconomics.newyorkfed.org/2022/03/drivers-of-inflation-the-new-york-fed-dsge-models-perspective/ 2022.

Fagnart, Jean-François, Omar Licandro, and Franck Portier, "Firm Heterogeneity, Capacity Utilization, and the Business Cycle," *Review of Economic Dynamics*, 1999, *2*, 433–455.

Greenwood, Jeremy, Zvi Hercowitz, and Gregory Huffman, "Investment, Capacity Utilization, and the Real Business Cycle," *American Economic Review*, 1988, *78* (3), 402–17.

Guerrieri, Luca and Matteo Iacoviello, "OccBin: A Toolkit for Solving Dynamic Models with Occasionally Binding Constraints Easily," *Journal of Monetary Economics*, 2015, *70*, 22–38.

References II

Jones, Callum, Mariano Kulish, and Daniel M. Rees, "International Spillovers of Forward Guidance Shocks," *Journal of Applied Econometrics*, 2022.

Kulish, Mariano and Adrian Pagan, "Estimation and Solution of Models with Expectations and Structural Changes," *Journal of Applied Econometrics*, 2017, *32*, 255–274.

__ , James Morley, and Tim Robinson, "Estimating DSGE Models with Zero Interest Rate Policy," *Journal of Monetary Economics*, 2017, *88*, 35–49.

Wu, Jing Cynthia and Fan Dora Xia, "Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound," *Journal of Money, Credit and Banking*, 2016, *48* (2-3), 253–291.