Supply Chain Constraints and Inflation

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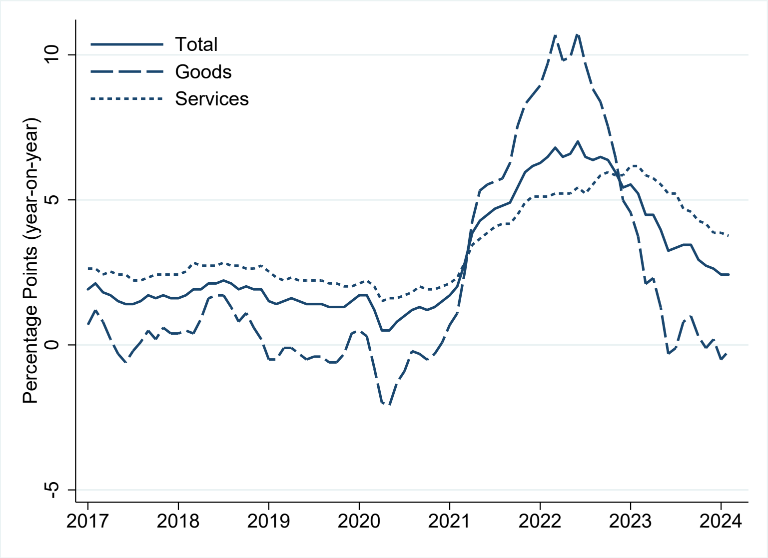
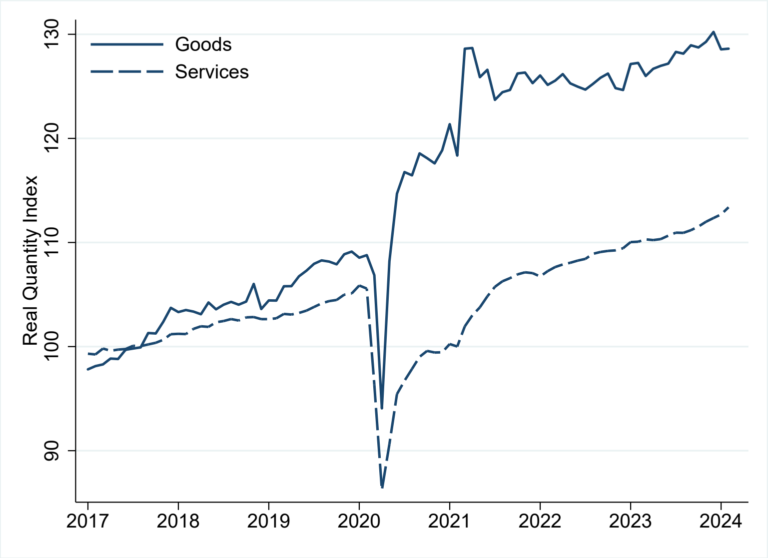
ASSA

US PCE Inflation



Source: Bureau of Economic Analysis & authors' calculations.

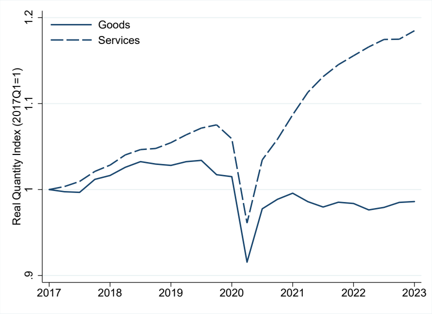
Real Consumer Expenditure



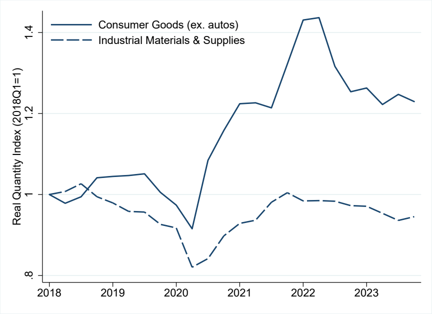
Source: Bureau of Economic Analysis & authors' calculations.

Production and Imports

(a) Real US Gross Output

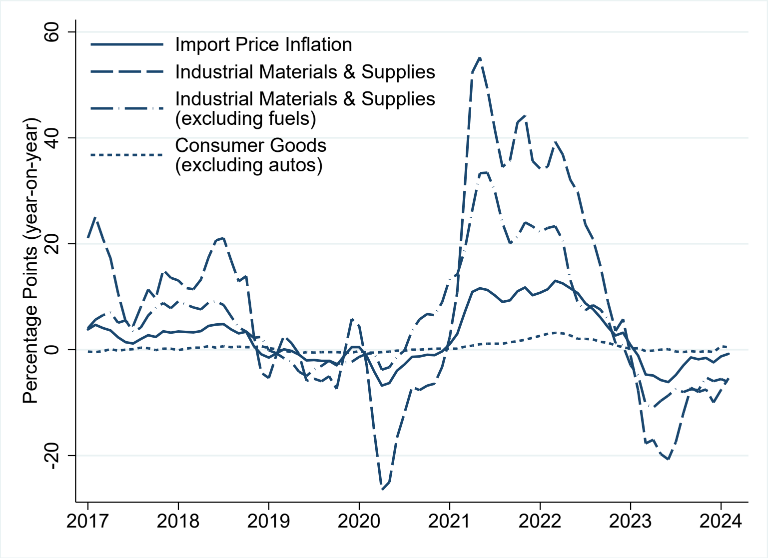


(b) Real Imports



Source: Bureau of Economic Analysis & authors' calculations.

Import Prices



Source: Bureau of Economic Analysis & authors' calculations.

Constraints in the 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.
     - Binding constraints produce non-linear outcomes.
     - Fagnart et al (1999), Álvarez-Lois (2006), Boehm & Pandalai-Nayar (2022).
   - Are constraints domestic or international in scope?
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 impact 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.

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 $u \in \{C, M\}$:

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

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

1. Binding constraints $\sim$ markup (cost-push) shocks.
   - Stable market structure (elasticity), change in pricing conduct.
   - Distinct from "capital utilization" approach to capacity. Details
   - Bernanke and Blanchard (2023) & Del Negro et al. (2022):
     - Cost-push shocks account for US inflation.
   - Markup channel is also consistent with resilience of profits. 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

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: $C_t(g) = \zeta_t(g) \left(\frac{P_t(g)}{P_t} \right)^{-\vartheta} C_t$
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 and Estimation

- Non-linearities due to occasionally binding constraints

  $\rightarrow$ construct piece-wise linear solution [Guerrieri and Iacoviello (2015)].

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

  Policy function depends on whether constraints bind today, and how long they are expected to bind (the duration).

- Estimate: shock process params, elasticities, Taylor rule coefficients.

- Treat duration of binding constraint as estimable parameter.

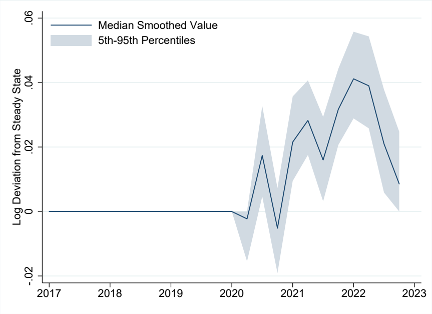
- $\Rightarrow$ Likelihood is a function of parameters and durations. Details
  - Check that the duration is consistent with the state and shocks.

Observables

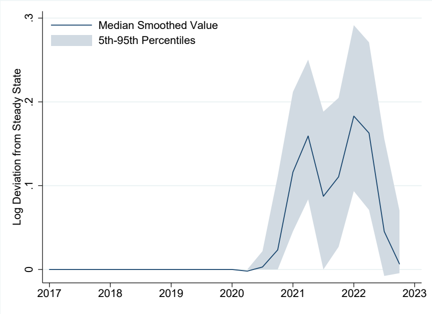
- Consumer inflation and expenditure by sector.
- Industrial production and aggregate nominal GDP.
- Value-added per worker by sector.
- Inflation and expenditure for imported goods inputs (ex. fuels).
- Inflation and expenditure for imported consumer goods.
- Shadow Fed Funds rate (Wu and Xia, 2016)
  - We have also explored explict ZLB constraint in our model, as in Kulish et al. (2017) and Jones et al. (2022).
- Sample: 1990:Q1 to 2022:Q4
- Model Fit

Capacity Multipliers

(a) Multiplier on Domestic Constraint



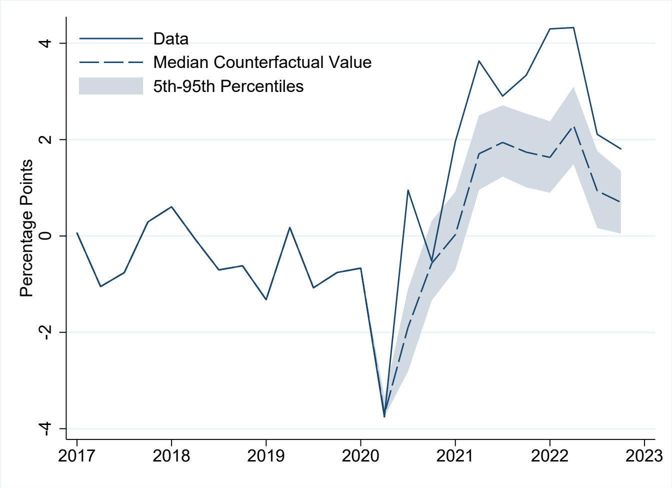
(b) Multiplier on Foreign Constraint



We plot reduced-form markup shocks in the domestic and import price Phillips Curves: $\left(\frac{\varepsilon}{\phi(s)}\frac{P_0}{P_{H0}(s)}\right)\hat{\tilde{\mu}}_t(s)$ and $\left(\frac{\varepsilon}{\phi(s)}\frac{P_0}{P_{uF0}(s)}\right)\hat{\tilde{\mu}}^*_{ut}(s)$.

Counterfactual: Slack Capacity Constraints

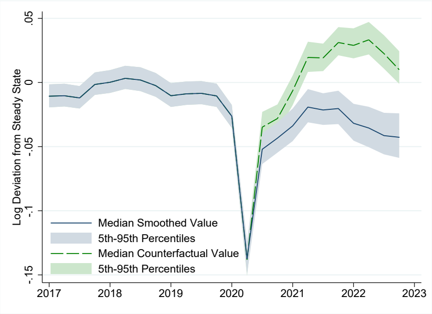
Aggregate Consumer Price Inflation



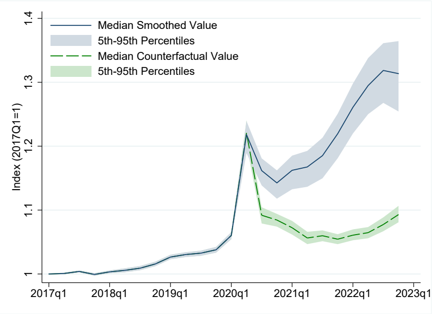
Note: Simulated values include measurement error, for comparability to data.

Counterfactual: Slack Capacity Constraints

(a) Goods Output



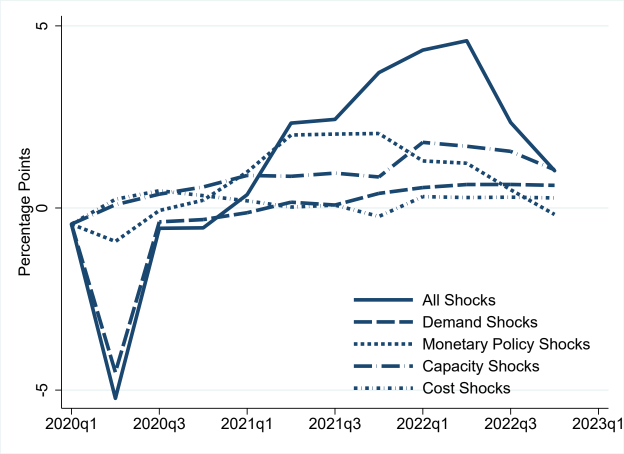
(b) Goods Profits Per Unit



Profits in the Data

Decomposition Consumer Price Inflation

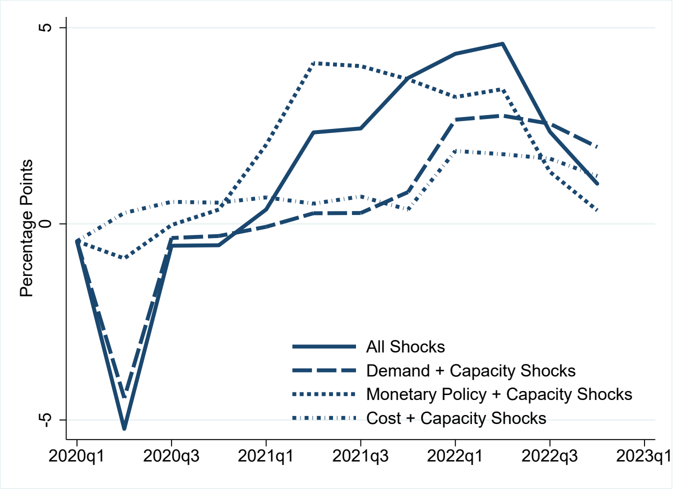
Individual Shocks



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.

Decomposition Consumer Price Inflation

Individual Shocks + Capacity Shocks



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

Extensions

- Remove energy from the domestic price indexes Energy Extension
- Labor supply shocks and constraints

Labor Supply Shocks and Constraints

Add three new features to enrich labor market:

1. **Wage rigidity** $\rightarrow$ Phillips Curve for wages.

$$\pi_{Wt} = \left(\frac{\epsilon_L - 1}{\phi_W}\right)\left[\widehat{mrs}_t - \widehat{rw}_t\right] + \left(\frac{\epsilon_L}{\phi_W}\frac{P_0}{W_0}\right)\hat{\tilde{\mu}}_{Lt} + \beta E_t\left(\pi_{Wt+1}\right)$$

   with $\widehat{mrs}_t = \hat{\lambda}_t + \psi \hat{l}_t - \rho \hat{c}_t$.

2. **Labor disutility shocks** $(\hat{\lambda}_t)$ $\rightarrow$ raise cost of labor supply, moving up the wage Phillips Curve.

3. **Labor supply constraints**: $L_t \leq \bar{L}_t$
   $\rightarrow$ when constraint binds $(\hat{\tilde{\mu}}_{Lt} > 0)$, wage Phillips Curve shifts up.

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

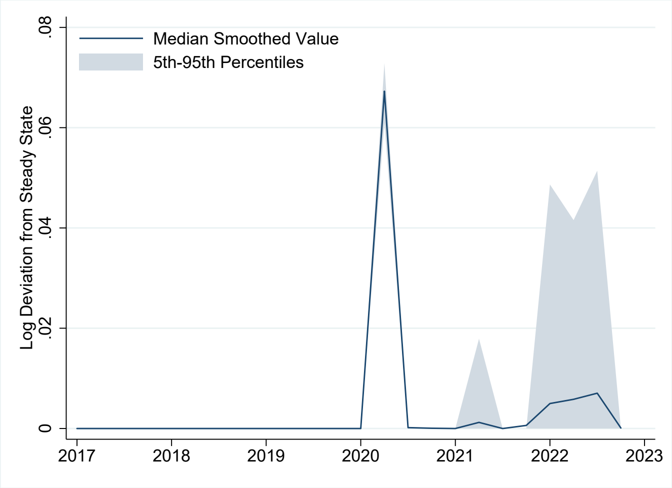
Key questions

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

Three questions:

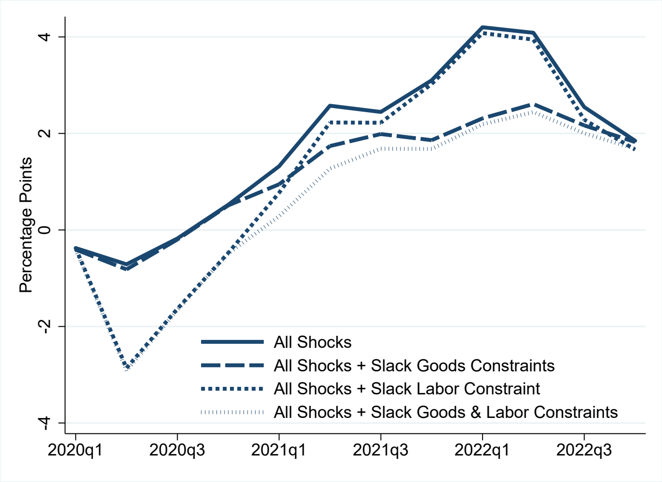
1. Did labor supply constraints bind? And what impact on inflation?
2. How important were labor supply shocks in the inflation surge?
3. How does adding labor market shocks alter quantitative impact of goods capacity constraints and policy shocks?

Multipliers on the Labor Constraint



Binding labor constraint helps explain lack of deflation in 2020.

Counterfactuals



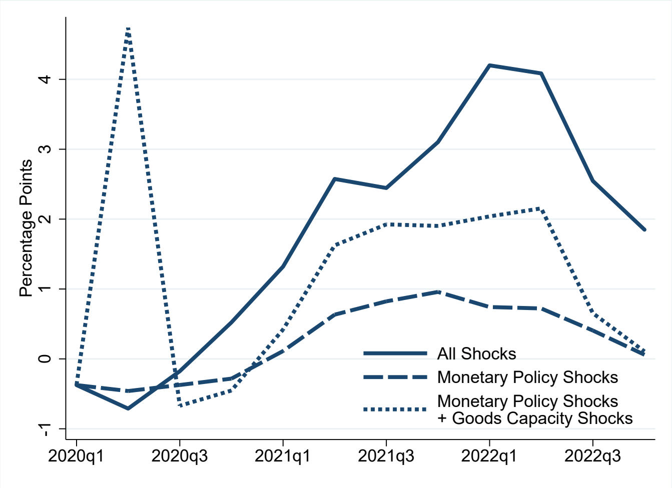
Note: Median values across 1000 simulations.

C1: Goods constraints are slack.

C2: Labor constraint is slack.

C3: Goods and labor constraints are slack.

Counterfactual: Policy & Capacity Shocks



Median values across 1000 simulations.

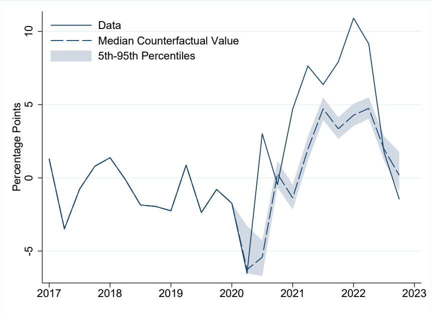
Concluding Remarks

- 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.
- Next: optimal policy & mistakes with capacity constraints.

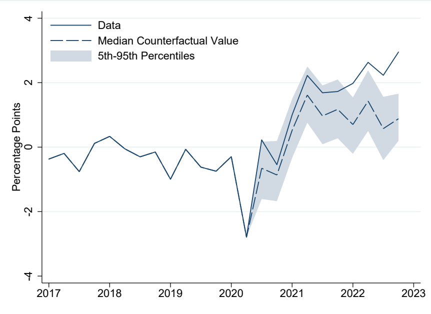
Appendix

Counterfactual: Slack Capacity Constraints

(a) Goods Inflation

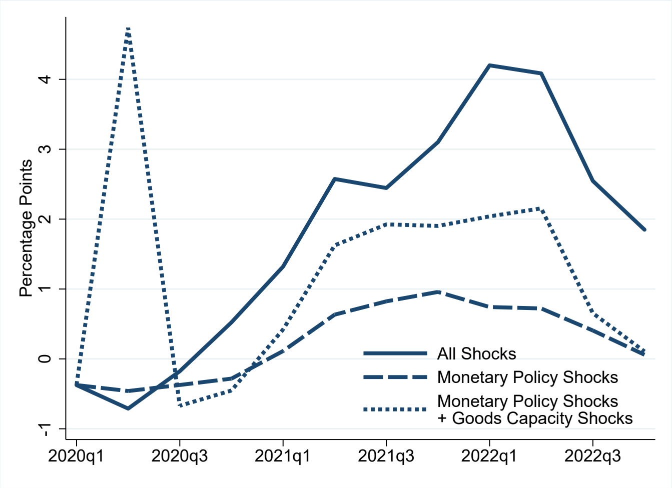


(b) Services Inflation



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

Counterfactual: Policy & Capacity Shocks



Median values across 1000 simulations.

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*.

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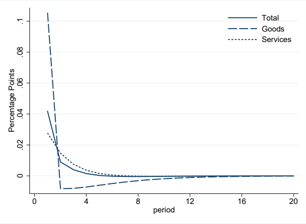
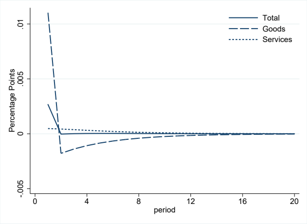
Demand vs. Capacity Shocks

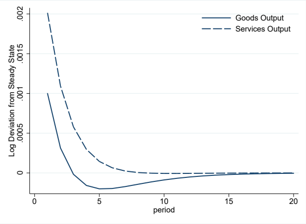
(a) Demand Shock: Inflation



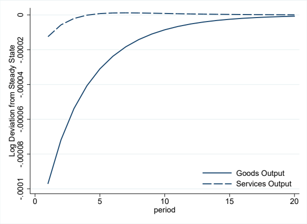
(b) Capacity Shock: Inflation



(c) Demand Shock: Output

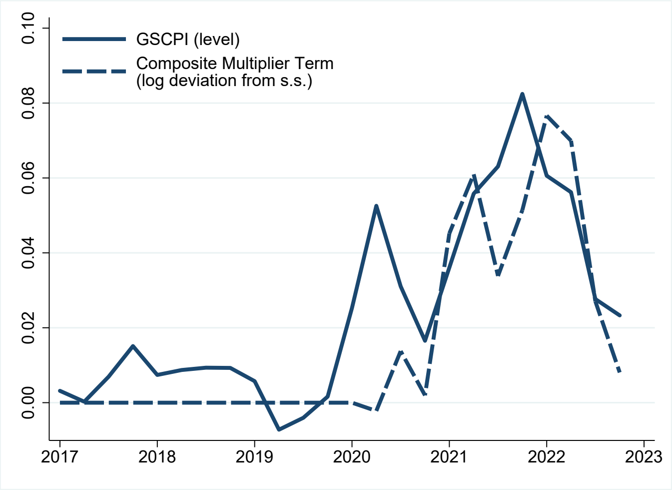


(d) Capacity Shock: Output



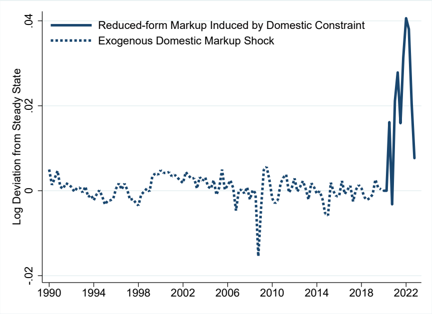
Positive demand shock causes domestic constraint to bind in (a) & (c).
Negative domestic capacity shock causes constraint to bind in (b) and (d).

GSCPI versus Multipliers

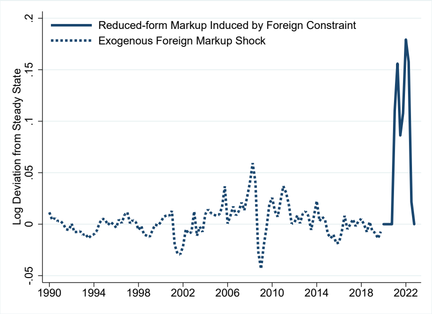


Markup Shocks v Multipliers

(a) Domestic Markup Shock



(b) Foreign Markup Shock



Estimate on 1990:Q1 to 2019:Q4 data, with exogenous markup shocks.

Compare smoothed markup series to μ_t and μ_t^* shifters.

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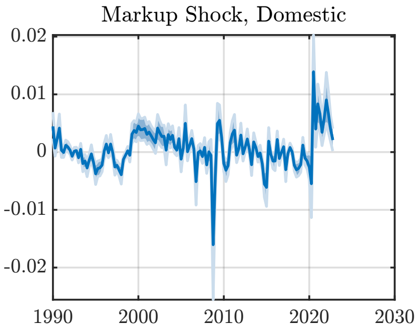
Exogenous Markup Shocks During Pandemic

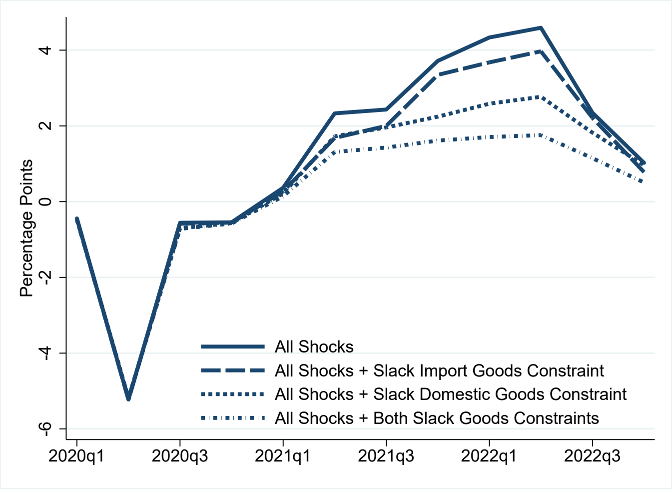


Estimate on 1990:Q1 to 2019:Q4 data, with exogenous markup shocks.

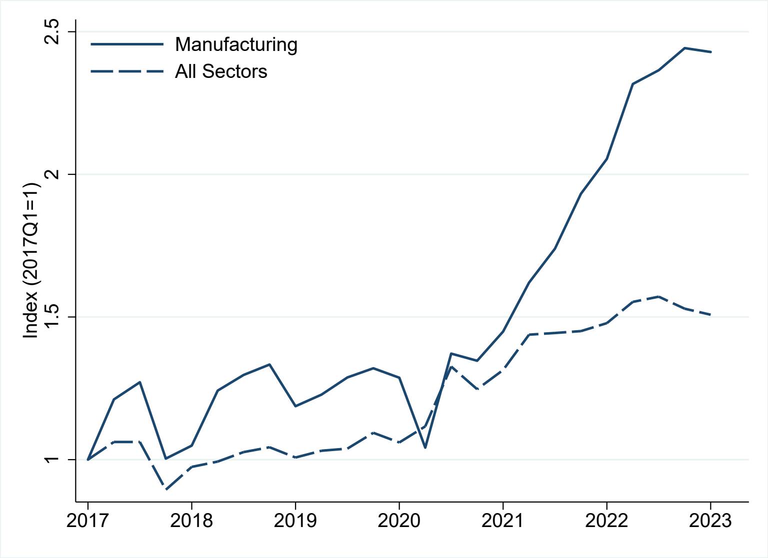
Filter data through 2022:Q4 under assumption of no binding capacity constraints.

Decomposition Consumer Price Inflation

Domestic vs. Import Constraints



Profits per Unit of Output



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

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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.

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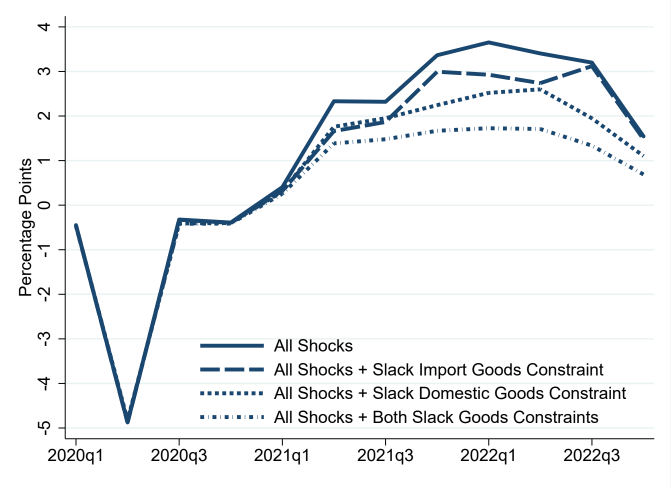
Energy Shocks

Energy prices rise (late 2021), then fall (late 2022).
We removed oil/fuels from the import price index.
Now, remove from domestic price indexes, and re-estimate.



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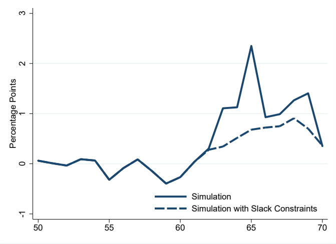
Estimation on Simulated Data

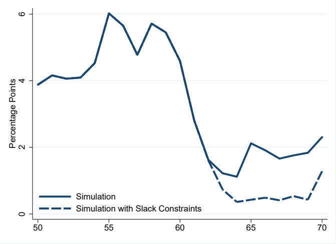
- Simulate a 70 period path using OccBin
- Engineer monetary expansion in last 10 quarters of simulation
- OccBin gives duration of endogenously binding constraints

Simulation

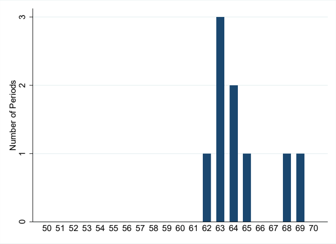
(a) Inflation



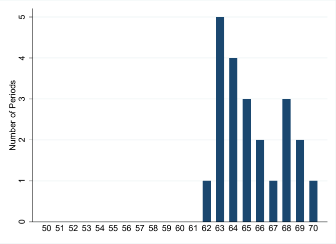
(b) Interest Rate



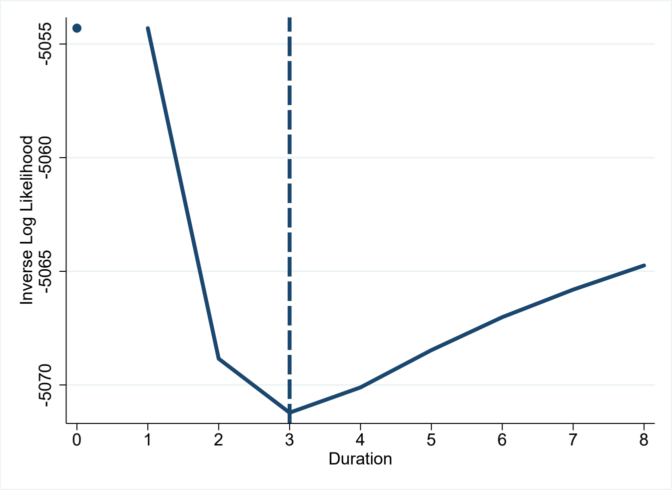
(c) Domestic Duration



(d) Foreign Duration

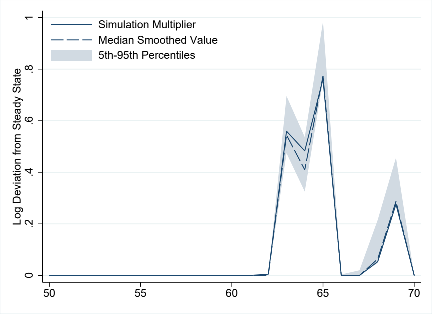


Likelihood for Foreign Duration in Period 65

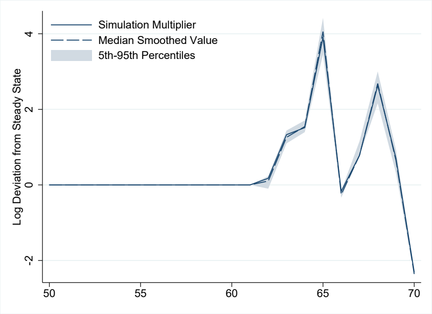


Smoothed Multipliers

(a) Domestic Multiplier



(b) Foreign Multiplier



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Consumers

$$U\left(\{C_t, L_t\}_{t=0}^{\infty}\right) = \mathbf{E}_0 \sum_{t=0}^{\infty} \beta^t \Theta_t \left[\frac{C_t^{1-\rho}}{1-\rho} - \chi \frac{L_t^{1+\psi}}{1+\psi}\right]$$

$$\text{with} \quad C_t = \left(\sum_s \zeta_t(s)^{1/\vartheta} C_t(s)^{(\vartheta-1)/\vartheta}\right)^{\vartheta/(\vartheta-1)}$$

$$C_t(s) = \left(\sum_s \gamma(s)^{1/\epsilon(s)} C_{Ht}(s)^{(\epsilon(s)-1)/\epsilon(s)} + \right.$$
$$\left. (1-\gamma(s))^{1/\epsilon(s)} C_{Ft}(s)^{(\epsilon(s)-1)/\epsilon(s)}\right)^{\epsilon(s)/(\epsilon(s)-1)}$$

Domestic Firms

$$Y_t(s,\omega) = Z_t(s,\omega)A(s)\left(L_t(s,\omega)\right)^{1-\alpha(s)}\left(M_t(s,\omega)\right)^{\alpha(s)}$$

$$M_t(s,\omega) = \left(\sum_{s'}\left(\alpha(s',s)/\alpha(s)\right)^{1/\kappa} M_t(s',s,\omega)^{(\kappa-1)/\kappa}\right)^{\kappa/(\kappa-1)}$$

$$M_t(s',s,\omega) = \left[\xi(s',s)^{\frac{1}{\eta(s')}} M_{Ht}(s',s,\omega)^{\frac{\eta(s')-1}{\eta(s')}} + \right.$$
$$\left.(1-\xi(s',s))^{\frac{1}{\eta(s')}} M_{Ft}(s',s,\omega)^{\frac{\eta(s')-1}{\eta(s')}}\right]^{\frac{\eta(s')}{\eta(s')-1}},$$

Market Clearing

$$Y_t(s) = C_{Ht}(s) + \sum_{s'} M_{Ht}(s, s') + X_t(s) + \frac{\phi(s)}{2} \left(\frac{P_t(s)}{P_{t-1}(s)} - 1 \right)^2 Y_t(s)$$

$$Y^*_{Ct}(s) = C_{Ft}(s) + \frac{\phi(s)}{2} \left(\Pi_{CFt}(s) - 1 \right)^2 Y^*_{Ct}(s)$$

$$Y^*_{Mt}(s) = \sum_{s'} M_{Ft}(s, s') + \frac{\phi(s)}{2} \left(\Pi_{MFt}(s) - 1 \right)^2 Y^*_{Mt}(s)$$

Param	Value	Reference/Target
ψ	2	Labor supply elasticity of 0.5
ρ	2	Intertemporal elasticity of substitution of 0.5
β	.995	Annual risk-free real rate of 2%
ϑ	0.5	Elasticity of substitution across sectors in cons.
ε	4	Elasticity of substitution between varieties
κ	0.3	Elasticity of substitution for inputs across sectors
$\sigma(s)$	1.5	Export demand elasticity
ϕ	35.468	To yield first order equivalence to Calvo pricing, with average price duration of 4 quarters .

- We use data on labor productivity growth in manufacturing and total (private sector) labor productivity growth from the Bureau of Labor Statistics.
- We assume that labor productivity growth in manufacturing coincides with goods labor productivity (growth in real value added per worker) in the model
- Also matching aggregate (economy-wide) labor productivity growth in the model.
- Use data on import price inflation for consumption goods, and we proxy input price inflation in the model using data on import price inflation for imported industrial materials (excluding fuels).
- We use data for consumer goods (except food and automotive) to proxy for consumption imports
- We construct proxies for imported inputs (excluding fuels) by removing the subcategory of petroleum and products from industrial materials and supplies using standard chain index formulas and auxiliary NIPA data on the sub-categories of imports.

Solution Method

General Solution:

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

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 $\mathbf{D}_t$, 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.
  - Excess steady-state capacity for domestic goods (5%) and foreign goods inputs (10%).
  - Sufficiently high so that constraints are slack prior to 2020.
  - Calibrated level isn't important; magnitude of capacity shocks adjusts.

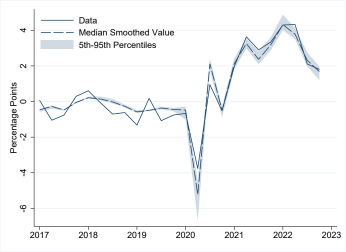
- Structural parameters θ to be estimated:
  - Stochastic process for exogenous variables: shock variance, AR coeffs.
  - Elasticities of substitution between home and foreign goods, separately for consumption and inputs.
  - Parameters of monetary policy rule.

- 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.

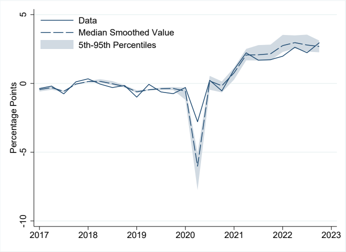
- Likelihood a function of parameters and durations $\mathcal{L}(\theta, \mathbf{D} | Y^{\text{obs}})$

Model Fit: Inflation

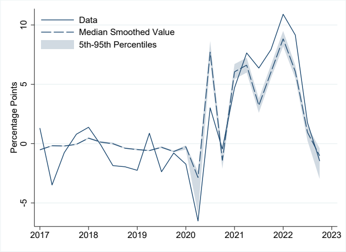
(a) Aggregate Consumer Inflation



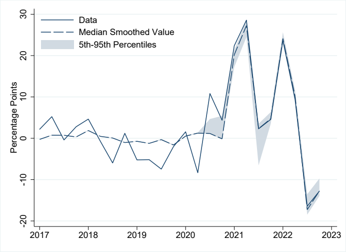
(b) Consumer Services Inflation



(c) Consumer Goods Inflation



(d) Inflation for Imported Inputs



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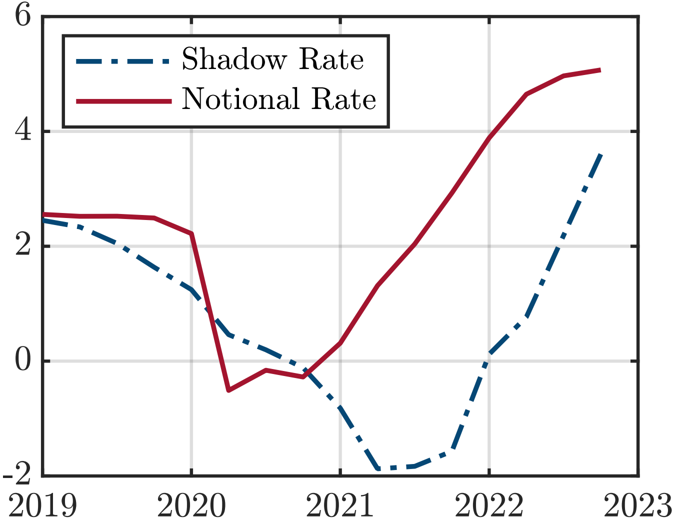
Shadow and Notional Federal Funds Rate



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