State Dependence of Monetary Policy During Global Supply Chain Disruptions

Xiwen Bai [1] Jesús Fernández-Villaverde [2] Yiliang Li [3] Francesco Zanetti [4]

[1]Tsinghua University

[2]University of Pennsylvania

[3]University of International Business and Economics

[4]University of Oxford

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Introduction and Questions

- Global supply chains are central to modern production. Any major disruption –such as COVID-19 or a trade war– can generate *sharp* adjustments in domestic prices.

- Central banks have the mandate for price stability.

- **Question**

  Should monetary policy forcefully adjust its stance to address the sudden and sharp increase in prices arising from supply chain disruptions?

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Our paper

1. **Data** = New evidence linking global supply chain to transportation costs, spare capacity, imbalances in supply-demand, and prices increase.
2. **Theory** = A simple theoretical model to link supply chain disruptions to demand control.
3. **Empirical test of state-dependent efficacy of MP** = Test the interplay between supply chain disruptions and the changes in the effectiveness of monetary policy to control inflation and output.

Related Literature

- **Models with convex supply curves**: Michaillat and Saez (2015, 2022); ; Boehm and Pandalai-Nayar (2022); Ghassibe and Zanetti (2022).

- **State dependence of monetary policy**: Alpanda et al., 2021; Angrist et al., 2018; Benigno and Ricci, 2011; Berger et al., 2021; Bilbiie et al., 2023; Eichenbaum et al., 2022, 2025; Ikeda et al., 2024; Liu et al., 2019; Miyamoto et al., 2024; Tenreyro and Thwaites, 2016.

- **Implications of supply chain disturbances**: Bai et al., 2024; Balleer and Noeller, 2023; Benigno and Eggertsson, 2023; Blanchard and Bernanke, 2024;Comin et al., 2023; di Giovanni et al., 2022, 2023; Harding et al., 2023.

Road Map

Average Congestion Rate (ACR) from Bai et al. (2024)

- Supply chain: congestion at ports.

- Weighted average of congestion in universe of ports:

$$ACR_t = \sum_{p\in\mathscr{P}} \left[\frac{Delayed_{pt} + Undelayed_{pt}}{\sum_{p\in\mathscr{P}} \left(Delayed_{pt} + Undelayed_{pt}\right)} \cdot Congestion_{pt} \right]$$

- Webpage: `https://zhongjunma.github.io/port-congestion/congestion.html`

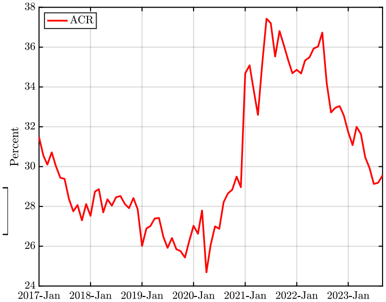

Figure 1: ACR for 2017:M1 – 2023:M9.

Fact I: Rise in Transportation Costs and Severance of Relationships

- Bai et al. (2024) ACR Index vs. HARPEX vs. Supply Disruptions Index (SDI, Smirnyagin and Tsyvinski, 2022)

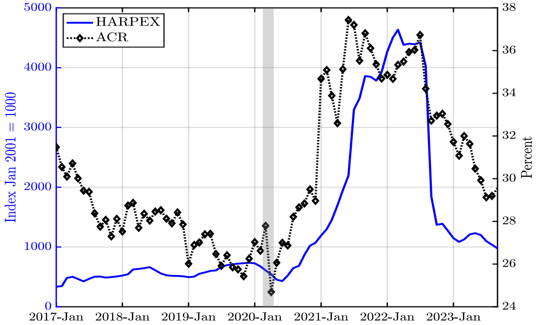

Figure 2: ACR vs. HARPEX

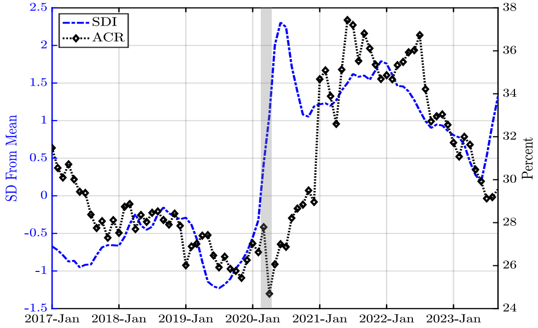

Figure 3: ACR vs. SDI

Fact II: Significant Imbalances in Supply and Demand for Good

- Global supply chain disruptions severely curtail the supply of goods in the US, resuting in:
  - Spare productive capacity for its major trading partners.
  - Excess demand in the US.

- Index of import-weighted total spare capacity of major U.S. trading partners (Mexico, Canada, China, Germany, and Japan):

$$SpareCapacityDollar_t = \sum_{i \in \mathscr{C}} \left[\frac{Import_{i,t}}{\sum_{i \in \mathscr{C}} Import_{i,t}} \cdot \left(\frac{1}{CapacityUtilization_{i,t}} - 1 \right) \cdot IndustrialProduction_{i,t} \right], \tag{1}$$

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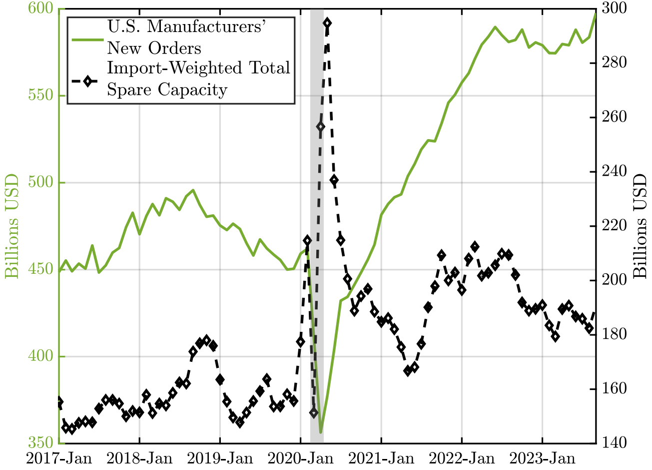

Figure 4: Imbalances in the Supply and Demand for Goods

Fact III: Tightening of Product Market and Surge in Goods Prices

- The imbalance arising from curtailed global supply and local demand for goods (Fact II).
- The imbalance leads to a tightening of the product market and a significant increase in goods prices.
- Measure of product market tightness:

$$Tightness_t = \frac{ManufactureNewOrder_t}{SpareCapacityDollar_t}. \tag{2}$$

Fact III: Tightening of Product Market and Surge in Goods Prices

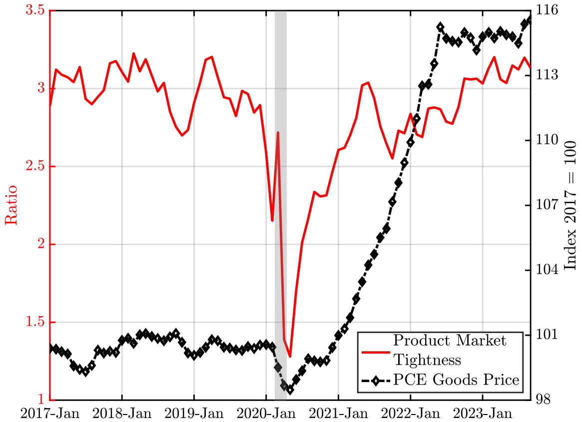

Figure 5: Co-Movements Between Goods Prices and Product Market Tightness

Road Map

Key Model Features

- Based on empirical analysis, we need a model that:
  - Separation between producers and retailers with transportation costs (Fact I).
  - Tension between demand and supply reflected in the tightness of the goods market (Fact II).
  - Link between tightness and prices (Fact III).
- Framework: Search and matching frictions in the goods market as in Michaillat and Saez (2015), Ghassibe and Zanetti (2022), and Bai et al. (2024)

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A Model of Congestion and Spare Capacity: Agents

- Producers:
  - Produce goods with a capacity determined by labor inputs (l) and face stochastic transportation costs
  - Supply goods to retailers, yet matching frictions prevent full capacity utilization
- Retailers:
  - Buy goods by visiting producers at a cost, not all visits would result in a match due to matching frictions
  - Sell goods to the representative household
- Representative household. Consumes, supplies labor inputs inelastically, and holds money
- Monetary policy. Sets quantity of money, influencing demand for goods

Matching between Producers and Retailers

- Matching function:

$$m = A(x_U^{-\xi} + i_U^{-\xi})^{-\frac{1}{\xi}},$$

where x_U and i_U: the number of unmatched producers and retailers

- Product market tightness θ:

$$\theta = \frac{i_U}{x_U}.$$

- Transaction probabilities for producers and retailers:

$$f(\theta) = \frac{m}{x_U} = A(1+\theta^{-\xi})^{-\frac{1}{\xi}},\ q(\theta) = \frac{m}{i_U} = A(1+\theta^{\xi})^{-\frac{1}{\xi}}.$$

- Tightness enhancing for producers: $f'(\theta) > 0$, but detrimental for retailers $q'(\theta) < 0$

Transportation Cost

- Producers pay an idiosyncratic transportation cost
- In each period, producers draw the transportation cost z from a log-normal distribution $G(z)$:

$$G(z) \equiv \Phi\left(\frac{\log z - \gamma}{\sigma}\right),$$

  where $\Phi(\cdot)$: standard normal CDF.
- There exists a reservation transportation cost $\bar{z}$, above which matches are not profitable
- All matches with a draw of transportation cost $z > \bar{z}$ are severed, whereas those with $z \leq \bar{z}$ continue.

Value Functions Producer and Retailer

- Value functions for **matched and unmatched producer**:

$$X_M(z) = r(z) - z + \beta \mathbb{E}_{z'} \Big[\max \Big(X_M(z'), X_U \Big) \Big], \quad (3)$$

$$X_U(z') = \beta f(\theta) \mathbb{E}_{z'} \Big[\max \Big(X_M(z'), X_U \Big) \Big] + \beta \Big(1 - f(\theta) \Big) X_U \quad (4)$$

where $r(z)$: wholesale price; z: transportation cost; β: discount factor; z': draw of transportation cost at the beginning of the next period.

- Value functions for **matched and unmatched retailer**:

$$I_M(z) = p - r(z) + \beta \mathbb{E}_{z'} \Big[\max \Big(I_M(z'), I_U \Big) \Big], \quad (5)$$

$$I_U = -\rho + \beta q(\theta) \mathbb{E}_{z'} \Big[\max \Big(I_M(z'), I_U \Big) \Big] + \beta \Big(1 - q(\theta) \Big) I_U, \quad (6)$$

where p: retail price of goods; ρ: unitary cost per visit. **Free entry**: $I_U = 0$.

Wholesale Price $r(z)$: Nash Bargaining

- The wholesale price $r(z)$ splits the total surplus of the match. We assume Nash bargaining
- The total surplus from matching is:

$$S(z) = X_M(z) - X_U + I_M(z) - I_U.$$

- Nash bargaining: share η to the producer ($1 - \eta$ to the retailer). In equilibrium:

$$\eta\big(I_M(z) - I_U\big) = (1-\eta)\big(X_M(z) - X_U\big).$$

- The wholesale price is:

$$r(z) = \eta(p + \rho\theta) + (1-\eta)z.$$

Match Separation, Creation, and Capacity

- Match separation. Cut-off transportation cost $\bar{z}$ above which match severed:

$$S(\bar{z}) = 0.$$

- Match creation. The free entry condition $I_U = 0$ determines the creation of new matches:

$$\frac{\rho}{q(\theta)} = (1-\eta)\beta\mathbb{E}_{z'} S(z') = 0. \tag{7}$$

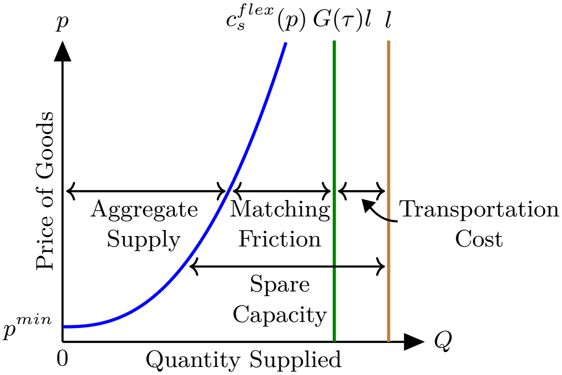
- Economic capacity: $x_M + x_U = 1$. Thus, number of matched producers in equilibrium:

$$x_M^{eqm}(\bar{z}, \theta) = \frac{f(\theta)G(\bar{z})}{1 - G(\bar{z}) + f(\theta)G(\bar{z})}.$$

Aggregate Supply

- Aggregate supply = capacity × number of matched producers

$$c_s(\bar{z},\theta) = x_M^{eqm}(\bar{z},\theta)\cdot l = \frac{f(\theta)G(\bar{z})}{1-G(\bar{z})+f(\theta)G(\bar{z})}\cdot l = c_s^{flex}(p). \tag{8}$$



Household

- The household supplies labor inelastically and derives utility from consumption c and real money holdings m/p:

$$u\left(c, \frac{m}{p}\right) = \frac{\chi}{1+\chi} c^{\frac{\epsilon-1}{\epsilon}} + \frac{1}{1+\chi}\left(\frac{m}{p}\right)^{\frac{\epsilon-1}{\epsilon}},$$

- The budget constraint:

$$pc + m \leq \mu + \underbrace{pc_s^{flex}(p) - \int_0^{\tau} z' c_s^{flex}(p) dG(z')}_{\text{Profits of Producers \& Retailers}} + \underbrace{\int_0^{\tau} z' c_s^{flex}(p) dG(z')}_{\text{Profits of Shipping Firms}}$$

$$= \mu + \underbrace{p\left[\frac{f\left(\theta(p)\right) G(\tau)}{1 - G(\tau) + f\left(\theta(p)\right) G(\tau)} l\right]}_{\text{Total profits}}$$

where μ is the endowment of nominal money.

- Aggregate demand: $c_d(p) = \chi^{\varepsilon} \dfrac{\mu}{p}$. Monetary policy: μ

Aggregate Demand

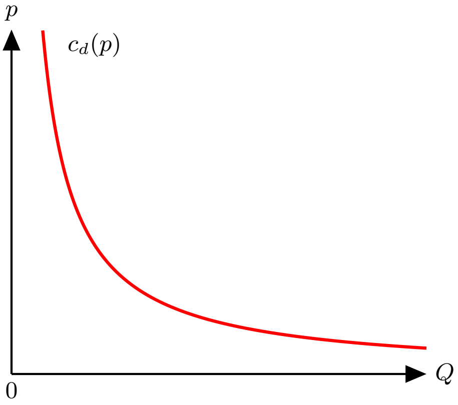


Figure 6: Money Supply ↓ or Taste for Consumption ↓.

Equilibrium

Definition 1 (Equilibrium)

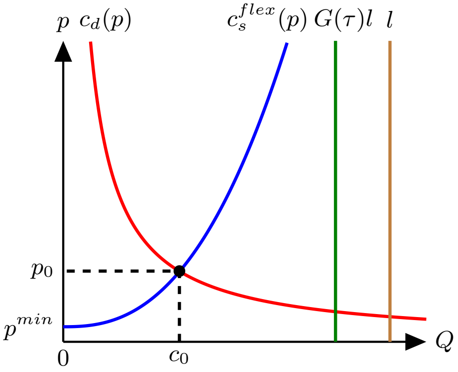
$$c_s^{flex}(p) = c_d(p)$$

- Equilibrium:

$$\frac{f(\theta)G(\bar{z})}{1 - G(\bar{z}) + f(\theta)G(\bar{z})} l = \chi^{\epsilon} \frac{\mu}{p},$$

where θ is given by:

$$\theta(p) = \frac{1-\eta}{\eta\rho}\left(p - \tau + \beta \int_0^{\tau} G(z')dz'\right)$$



Equilibrium Dynamics: Contractionary Monetary Policy ($\mu \downarrow$)

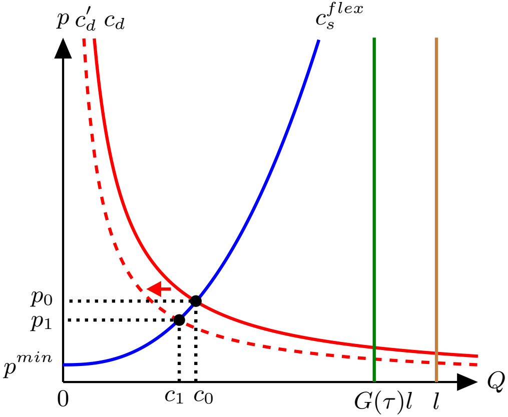


Figure 7: Money Supply $\mu \downarrow$

Equilibrium Dynamics: An Adverse Shock to the Supply Chain

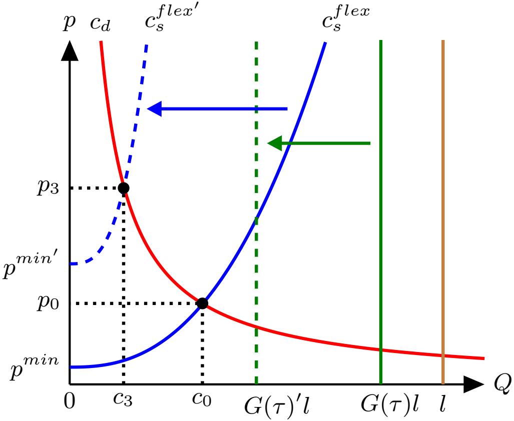


Figure 8: Scale Parameter of the Log-normal Distribution of Transportation Costs $\gamma \uparrow$

Identification restrictions for monetary policy shock

Table 1: Comparative Statics

Contractionary Shock To:	Effects On:					
	Consumption (or Output)	Price	Product Market Tightness	Wholesale Price	Matching Cost	Spare Capacity
	c	p	θ	r	$\frac{AG(\tau)}{1-(1-A)G(\tau)} l - c$	$l - c$
Monetary policy ($\mu \downarrow$)	$-$	$-$	$-$	$-$	$+$	$+$
Productive Capacity ($l \downarrow$)	$-$	$+$	$+$	$+$	$-$	$-$
Supply Chain ($\gamma \uparrow$)	$-$	$+$	Undetermined	Undetermined	Undetermined	$+$
Supply Chain ($A \downarrow$)	$-$	$+$	$+$	$+$	Undetermined	$+$

Historical Decomposition (HD) of U.S. Goods Inflation

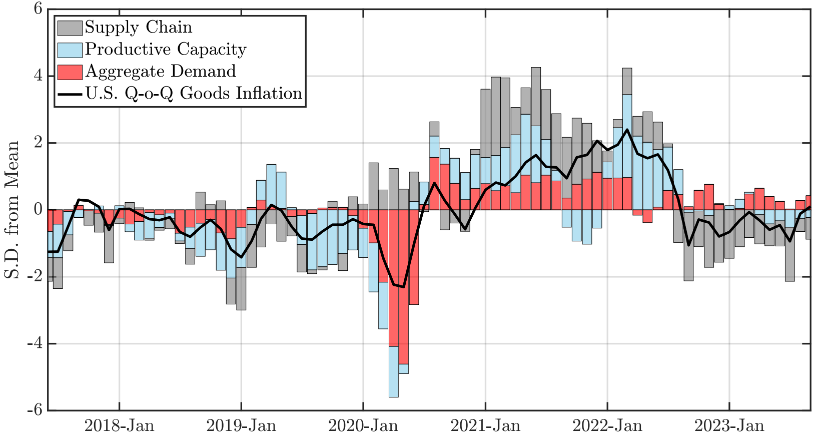


Figure 9: Cumulative Historical Contribution of Each Shock to U.S. Quarter-On-Quarter Goods Inflation.

Road Map

Theory: Supply chain disruptions and the state dependence of monetary policy

- The model shows that with supply chain disruptions:
  - Scarcity in retailing market → contraction in goods supply
  - Increase product market tightness → steepening of the supply curve

- Intuition
  - Output is curtailed and with scarsity in the retailing market the price of goods includes increasing search costs.

⇒ Contractionary monetary policy exerts large influence on prices with less influence on output during supply chain disruptions.

Graphical Representation: State-dependence of Monetary Policy Shocks

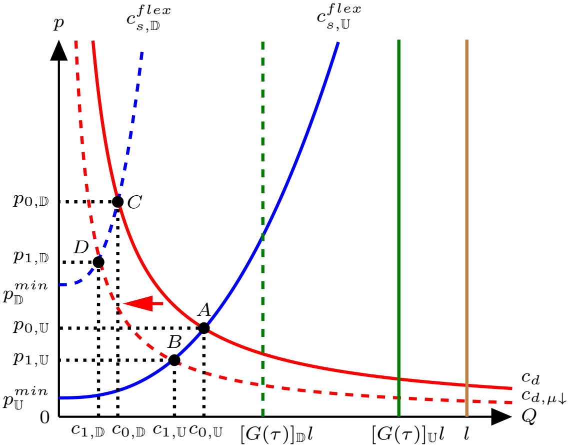


Figure 10: State-Dependent Effects of a Contractionary Monetary Policy Shock: Theoretical Prediction.

Empirics: State-Dependence of Monetary Policy. A TVAR Model

- TVAR model with parameters varying between disrupted ($\mathbb{D}$) and undisrupted ($\mathbb{U}$) states.
- Average Congestion Index (ACI) from Bai et al. (2024) indicator for identifying global supply chain disturbances.
- The TVAR model can be written as:

$$\boldsymbol{y}_t = I_t \left[\sum_{l=1}^{L} \boldsymbol{B}'_{\mathbb{D},l} \boldsymbol{y}_{t-l} + \boldsymbol{C}'_{\mathbb{D}} \boldsymbol{\omega}_t + \boldsymbol{\Sigma}_{\mathbb{D}}^{1/2} \boldsymbol{\varepsilon}_t \right] + (1 - I_t) \left[\sum_{l=1}^{L} \boldsymbol{B}'_{\mathbb{U},l} \boldsymbol{y}_{t-l} + \boldsymbol{C}'_{\mathbb{U}} \boldsymbol{\omega}_t + \boldsymbol{\Sigma}_{\mathbb{U}}^{1/2} \boldsymbol{\varepsilon}_t \right], \tag{9}$$

- Switches between the regimes are governed by the indicator variable $I_t \in \{0, 1\}$:

$$I_t = \begin{cases} 1, & \text{if } ACR_{t-1} > \overline{ACR}; \\ 0, & \text{if } ACR_{t-1} \leq \overline{ACR}. \end{cases}$$

- **Restriction on a contractionary monetary policy shock**: negative response of real GDP, PCE goods price, and import price, as well as to a positive response of spare capacity and FFR at horizon

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IRFs to a Contractionary Monetary Policy Shock

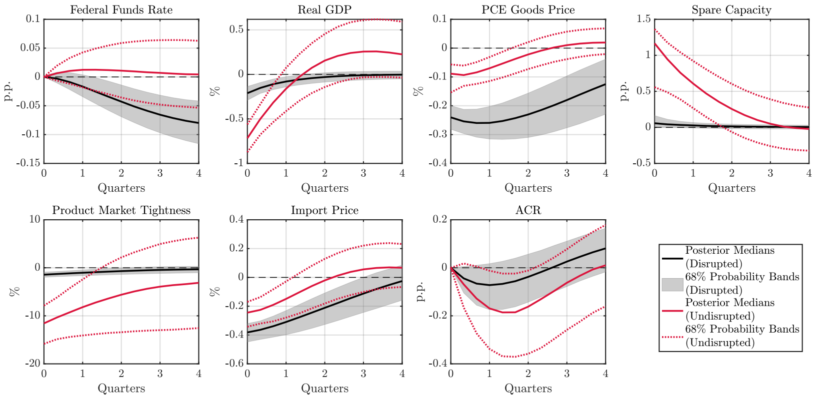


Figure 11: State-Dependent Effects of a Contractionary Monetary Policy Shock: Empirical Validation.

- Results robust to the Local Projection method

Road Map

Conclusion

- We studied –theoretically and empirically– the state dependence of monetary policy in controlling price increases during global supply chain disruptions.
  - Theory: supply chain disturbances curtail output and steepen the supply curve.
  - Empirics: TVAR or LP corroborate the theory.

- Monetary tightening can tame inflation at reduced costs of real activity during times of supply chain disruption.

Thank you!

Additional Slides

- Since $X_M(z) + I_M(z)$ is strictly decreasing in z on $(0, +\infty)$, there exists a cut-off transportation cost $\bar{z}$ above (below) which both sides choose to sever (continue) their match, and at $\bar{z}$, the total surplus is:

$$S(\bar{z}) = 0.$$

- Hence, we define the match separation condition as a function of price p, reservation transportation cost $\bar{z}$, and product market tightness θ, defined for all $p \in (0, +\infty)$, $\bar{z} \in (0, +\infty)$, and $\theta \in [0, +\infty)$, satisfying:

$$\mathbb{F}(p, \bar{z}, \theta) = p - \bar{z} + \Big(1 - \eta f(\theta)\Big)\beta \mathbb{E}_{z'} S(z') = 0, \tag{1}$$

where the expected surplus in $t + 1$ is defined by $\mathbb{E}_{z'} S(z') = \displaystyle\int_0^{\bar{z}} S(z') dG(z')$.

Match Creation

- The free entry condition $I_U = 0$ determines the creation of new matches:

$$\mathbb{H}(\bar{z}, \theta) = \frac{\rho}{q(\theta)} - (1-\eta)\beta \mathbb{E}_{z'} S(z') = 0, \tag{2}$$

  where $\mathbb{E}_{z'} S(z') = \int_0^{\bar{z}} S(z') dG(z')$

- Surplus of retailers generates incentives for new matches and tightness
- Transportation costs diminish expected surplus thus decreasing new matches and tightness

Equilibrium tightness

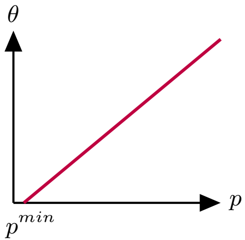
- The equilibrium level of tightness is obtained by conditions for match separation (1) and match creation (2) simultaneously hold:

$$\mathbb{F}(\bar{z}, \theta, p) = \mathbb{H}(\bar{z}, \theta) = 0 \tag{3}$$

- In equilibrium, it yields:

$$\theta(p, \bar{z}) = \frac{1-\eta}{\eta\rho}\Big(p - \bar{z} + \beta \int_0^{\bar{z}} G(z')dz'\Big), \tag{4}$$

- For a given $\bar{z}$, tightness increases with retail price p and it falls with supply chain shock (i.e., shift to the right of distribution of transportation costs)



Aggregate supply

- The total capacity in the economy:

$$x_M + x_U = 1$$

- law of motion for the number of matched producers at the beginning of the next period:

$$x'_M = G(\bar{z})x_M + f(\theta)G(\bar{z})x_U,$$

- number of unmatched producers at the beginning of the next period:

$$x'_U = \Big[1 - f(\theta) + f(\theta)\big(1 - G(\bar{z})\big)\Big]x_U + \big(1 - G(\bar{z})\big)x_M.$$

- Thus, the equilibrium the number of matched producers x_M^{eqm} equal to:

$$x_M^{eqm}(\bar{z}, \theta) = \frac{f(\theta)G(\bar{z})}{1 - G(\bar{z}) + f(\theta)G(\bar{z})}.$$

Aggregate Supply (cont.)

- Aggregate supply = number of matched producers × capacity

$$c_s(\bar{z},\theta) = x_M^{eqm}(\bar{z},\theta)\cdot l = \frac{f(\theta)G(\bar{z})}{1-G(\bar{z})+f(\theta)G(\bar{z})}\cdot l, \tag{5}$$

where recall the equilibrium tightness:

$$\theta(p,\bar{z}) = \frac{1-\eta}{\eta\rho}\Big(p-\bar{z}+\beta\int_0^{\bar{z}} G(z')dz'\Big) \tag{6}$$

- Equilibrium indeterminacy of search models. Two equations (5)-(6), and three unknowns: $\{\bar{z},\theta,p\}$
- We assume flexible prices and fixed reservation transportation cost ($\bar{z}=\tau$). Thus, the aggregate supply is:

$$c_s^{flex}(p)$$

Aggregate Supply (cont.)

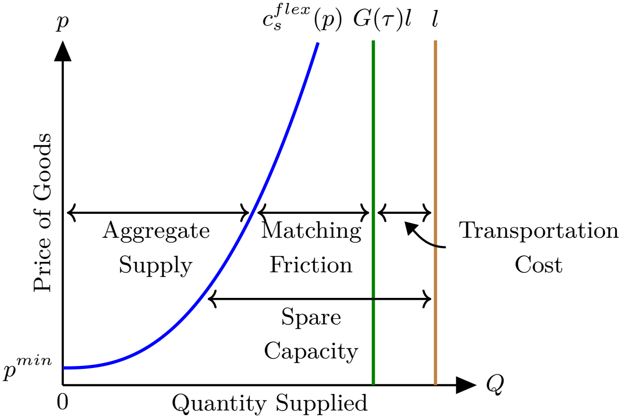


Figure A.1: Aggregate Supply and Spare Capacity

Drivers of U.S. Goods Inflation

Table 1: Cumulative Historical Contribution of Each Shock to U.S. Goods Inflation.[1]

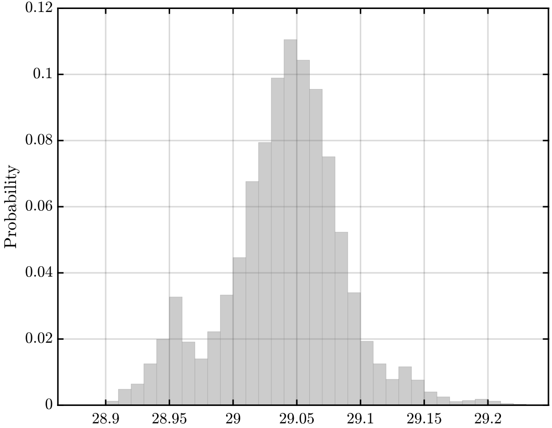
Date	U.S. Goods Inflation (Percent)	Cumulative Historical Contribution: Aggregate Demand (Percent)	Productive Capacity (Percent)	Supply Chain (Percent)
Apr-Dec 2017	-0.04	-0.33	-0.39	-0.30
Jan-Dec 2018	-0.02	-0.59	-1.08	-0.07
Jan-Dec 2019	0.37	-0.04	-0.78	-0.22
Jan-Dec 2020	-0.12	**−1.01**	0.13	0.18
Jan-Dec 2021	8.16	0.96	0.67	**1.11**
Jan-Dec 2022	4.67	0.40	**1.56**	-0.32
Jan-Sep 2023	1.21	0.36	-0.19	-0.36

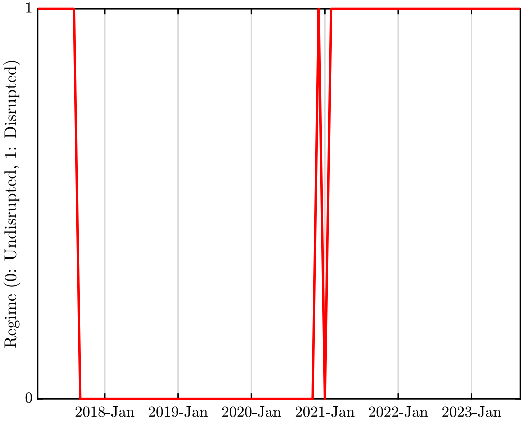
[1] Each line represents the U.S. goods inflation rate, calculated as the growth of the PCE goods price index, along with the cumulative historical contributions of shocks to aggregate demand, productive capacity, and the supply chain to U.S. goods inflation for each sample year from 2017 to 2023. Note that 2017 and 2023 are not fully represented years due to a lack of data.

Estimation TVAR

- We include one lag in the TVAR model, and our results are robust to different lag structures (i.e., two or three lags) and looser priors.
- We retain the same sample period from January 2017 to September 2023, and all the series are seasonally adjusted except for the FFR.
- Real GDP, GDP deflator, and import price enter the TVAR in log percent, whereas the FFR, unemployment, and ACR enter in percent.
- We compute the identified set of IRFs using a Bayesian approach.
- We also estimate LPs.

Posterior of $\overline{ACR}$ and regime switches





- Consider the following LP equation:

$$
\begin{aligned}
y_{i,t+k} = & I_t \left[\boldsymbol{\beta}'_{\mathbb{D},i,k,0} \boldsymbol{y}_t + \sum_{l=1}^{L} \boldsymbol{\beta}'_{\mathbb{D},i,k,l} \boldsymbol{y}_{t-l} + \boldsymbol{C}'_{\mathbb{D},i,k} \boldsymbol{\omega}_t \right] \\
& + (1 - I_t) \left[\boldsymbol{\beta}'_{\mathbb{U},i,k,0} \boldsymbol{y}_t + \sum_{l=1}^{L} \boldsymbol{\beta}'_{\mathbb{U},i,k,l} \boldsymbol{y}_{t-l} + \boldsymbol{C}'_{\mathbb{U},i,k} \boldsymbol{\omega}_t \right] + u_{i,k,t},
\end{aligned}
$$

  where I_t serves as a dummy variable indicating whether the supply chain is disrupted.

- The regime of supply chain disruptions is defined based on whether the one-month lag of the ACR index exceeds its median level over the sample period.

ACR and sample median for I_t

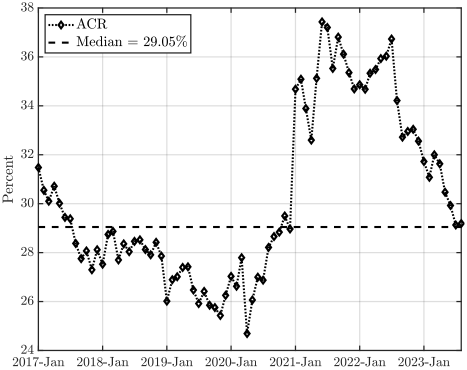


Figure A.2: ACR and Its Sample Median

IRFs to a contractionary monetary policy shock (LPs)