What can Stockouts tell us about Inflation? : Evidence from Online Micro Data

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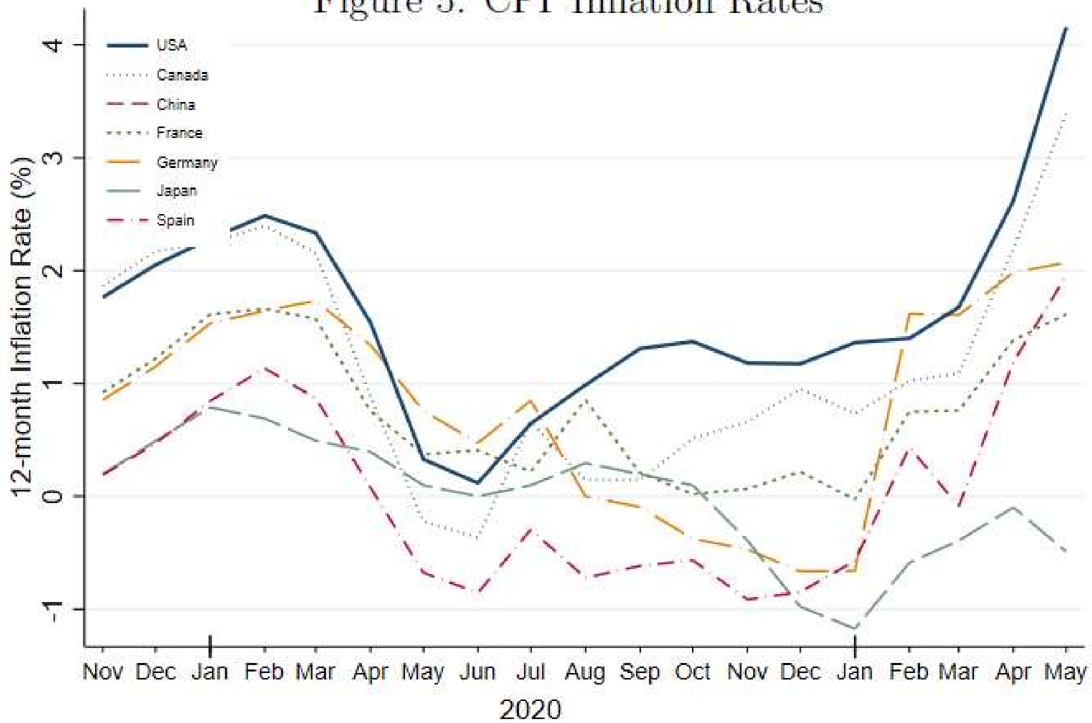
Motivation

- Inflation during Covid did not fall by much and has quickly rebounded

Figure 5: CPI Inflation Rates



- Did supply disruptions play an important role in these price dynamics?

Prices and Stockouts Data

- We use product data collected every day from the websites of large multi-channel retailers to measure inflation and shortages

<html>
<product> Leche Condensada </product>
<brand> Nestlé </brand>
<td price> $1.199 Uni </td>

	ID	ID2	PRODUCT	BRAND	SIZE	BULK PRICE	PRICE
1	3429	266235-ST	Leche Condensada	Leche Sur	Lata 395 grs.	xKilo:$1.744	689
2	3422	266231-ST	Leche Condensada	Nestlé	Descremada, Lata 395 grs.	xKilo:$2.023	799
3	995	619436-ST	Leche Condensada	Nestlé	Envase flexible 350 grs.	xKilo:$2.569	899
4	3804	399781-ST	Leche Condensada	Nestlé	Lata 397 grs.	xKilo:$1.761	699
5	11676	668674-ST	Leche Condensada	Nestlé	Pack 3 unidades, Lata 200 grs. c/u	xKilo:$1.998	1.199

Countries and Sectors

- We focus on 70 retailers in 7 countries that show out of stock information

	Products	Retailers	Coverage of all CPI Weights, (%)	Coverage of Goods CPI Weights, (%)
Canada	194,151	11	27	80
China	49,685	3	38	76
France	372,962	11	32	63
Germany	297,320	13	27	52
Japan	95,313	7	30	68
Spain	171,400	8	31	56
USA	777,554	17	21	62
All	1,958,385	70	29	65

Table 1: Data Coverage

Measuring Retail Supply Disruptions

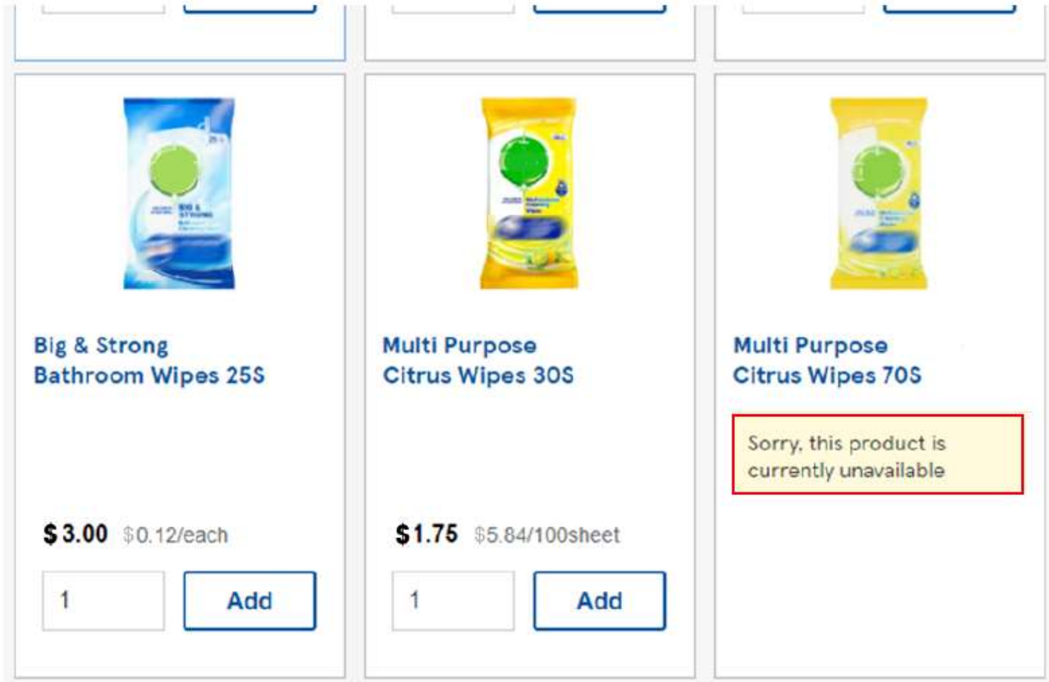


Figure 1: Identifying Stockouts on a Retailer's Website

- Temporary Stockouts (TOOS) $= \frac{\#\, out\ of\ stock_{t,j,c}}{\#\, total\ products_{t,j,c}}$

Measuring Retail Supply Disruptions

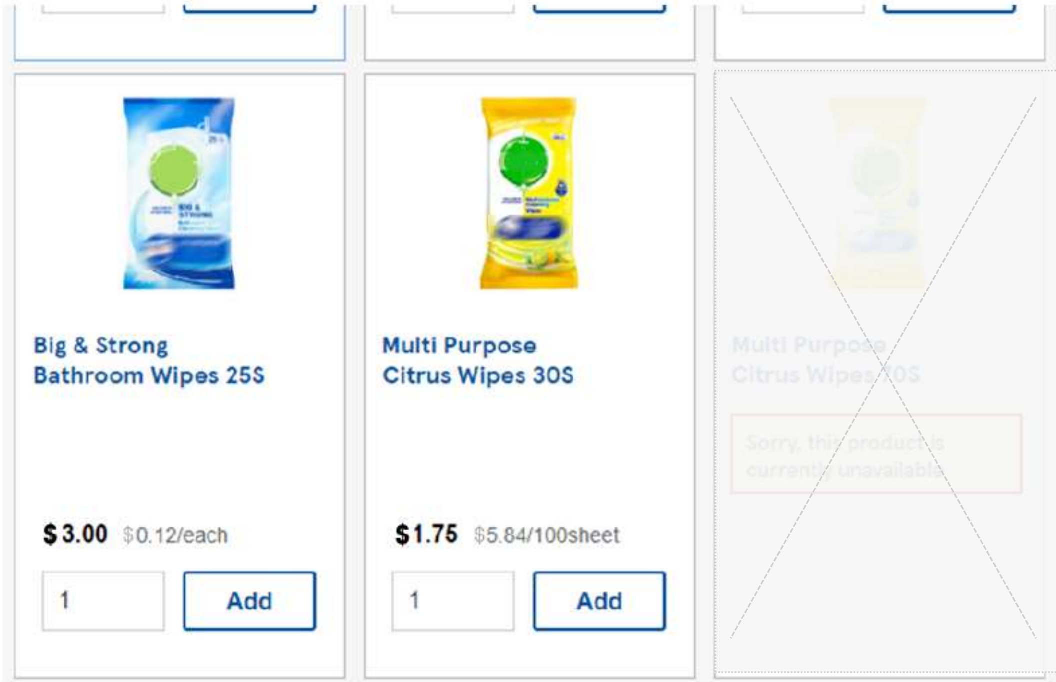


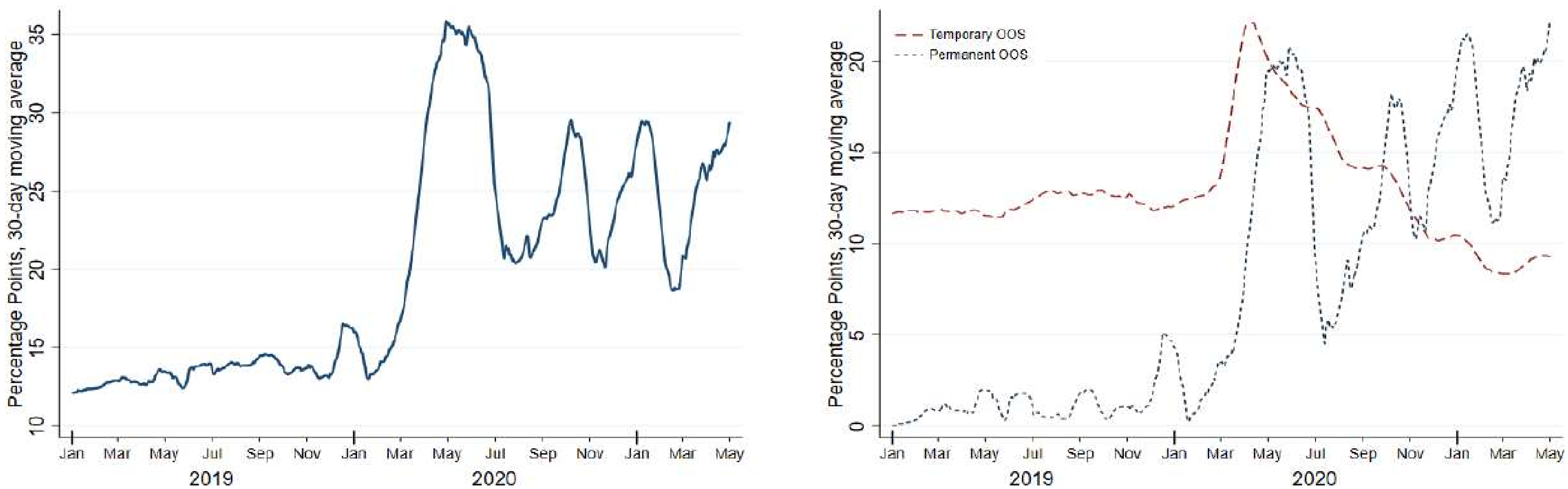
Figure 1: Identifying Stockouts on a Retailer's Website

- Temporary Stockouts (TOOS) $= \frac{\#\, out\ of\ stock_{t,j,c}}{\#\, total\ products_{t,j,c}}$
- Permanent Stockouts (POOS) $= 1 - \frac{\#\, total\ products\ _{t,j,c}}{\#\, total\ products\ _{Jan-2020,j,c}}$

$$OOS_{t,c} = \prod_j w_{j,c} OOS_{t,j,c},$$

$$OOS = \{TOOS, POOS, AOOS\}$$

Stockout Dynamics in the US



(a) All Stockouts (b) Temporary and Permanent Stockouts

Figure 2: Stockouts in the United States, 2019–2021.

In the US, Stockouts are more persistent in Food and Electronics

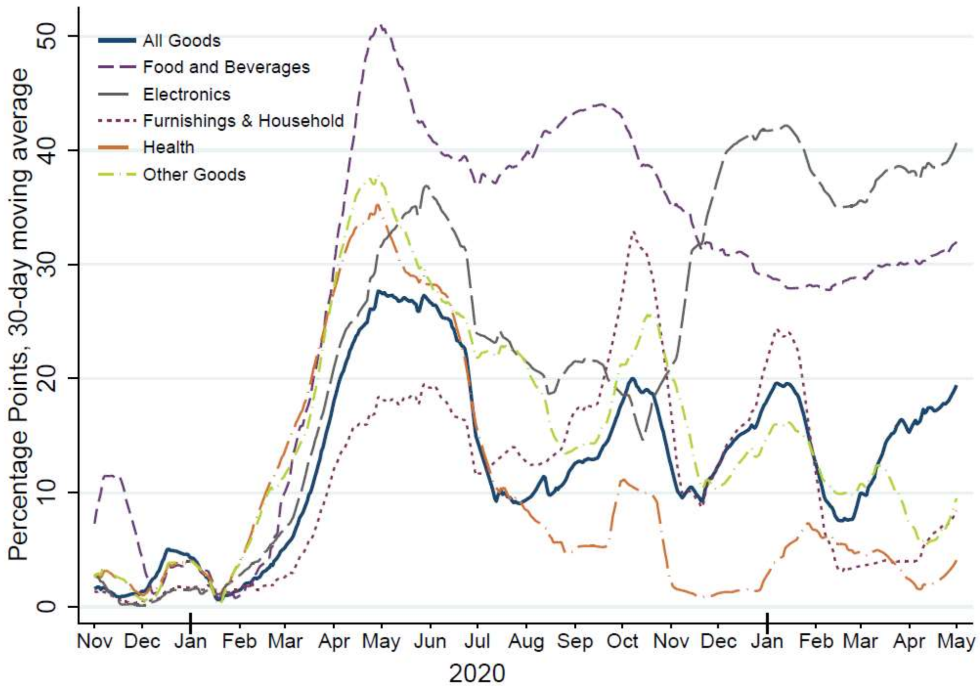


Figure 3: All Stockouts in U.S. Sectors

Changes in stockouts in the United States (2-digit categories)

L2 Category	Max Temp OOS	Max All OOS	Latest All OOS
Food	15	53	13
Non-alcoholic beverages	10	40	32
Other major durables for recreation and culture	9	81	81
Personal care	7	35	5
Goods and services for routine household maintenance	6	42	13
Audio-visual, photographic and information processing equipment	6	36	29
Other recreational items and equipment, gardens and pets	6	45	37
Medical products, appliances and equipment	5	25	-13
Tools and equipment for house and garden	5	62	62
Household appliances	5	32	23
Furniture and furnishings, carpets and other floor coverings	4	31	9
Glassware, tableware and household utensils	3	36	-6
Household textiles	2	21	-6
Personal effects n.e.c.	-1	29	-17

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- Most sectors experienced hike in OOS around Spring 2020 and came down since
- Large differences in latest OOS across sectors: food, consumer durables (high), pharma (low)

Within-sector differences for Food indicative of supply-chain disruptions

Category	Max Temp OOS	Max All OOS	Latest All OOS
Oils and fats	24	73	4
Food products n.e.c.	20	51	26
Fruits	17	55	-14
Bread and cereals	16	55	10
Meat	14	62	0
Equipment for sport, camping and open-air recreation	14	69	63
Fish and seafood	13	60	40
Coffee, tea and cocoa	13	46	22
Information processing equipment	12	41	39
Sugar, jam, honey, chocolate and confectionery	12	46	0
Non-durable household goods	11	41	15
Vegetables	11	51	10
Milk, cheese and eggs	11	61	-16
Major durables for indoor and outdoor recreation including musical instruments	10	79	78
Mineral waters, soft drinks, fruit and vegetable juices	9	49	30
Gardens, plants and flowers	9	48	-14
Major tools and equipment	8	31	30
Electrical appliances for personal care; other appliances, articles and products for personal care	8	35	1
Photographic and cinematographic equipment and optical instruments	7	55	41
Games, toys and hobbies	6	37	21
Pets and related products, veterinary and other services for pets	6	42	26
Pharmaceutical products	6	30	-10
Furniture and furnishings	6	35	-1
Glassware, tableware and household utensils	6	32	-4
Equipment for the reception, recording and reproduction of sound and picture	6	31	6
Major household appliances whether electric or not and small electric household appliances	5	32	1
Other medical products; therapeutic appliances and equipment	5	24	-15
Small tools and miscellaneous accessories	4	54	4
Household textiles	3	64	48
Carpets and other floor coverings	2	53	41
Recording media	2	24	10
Jewellery, clocks and watches	1	38	-23
Other personal effects	-1	34	-14

- Unprocessed Food OOS returned to pre-COVID levels

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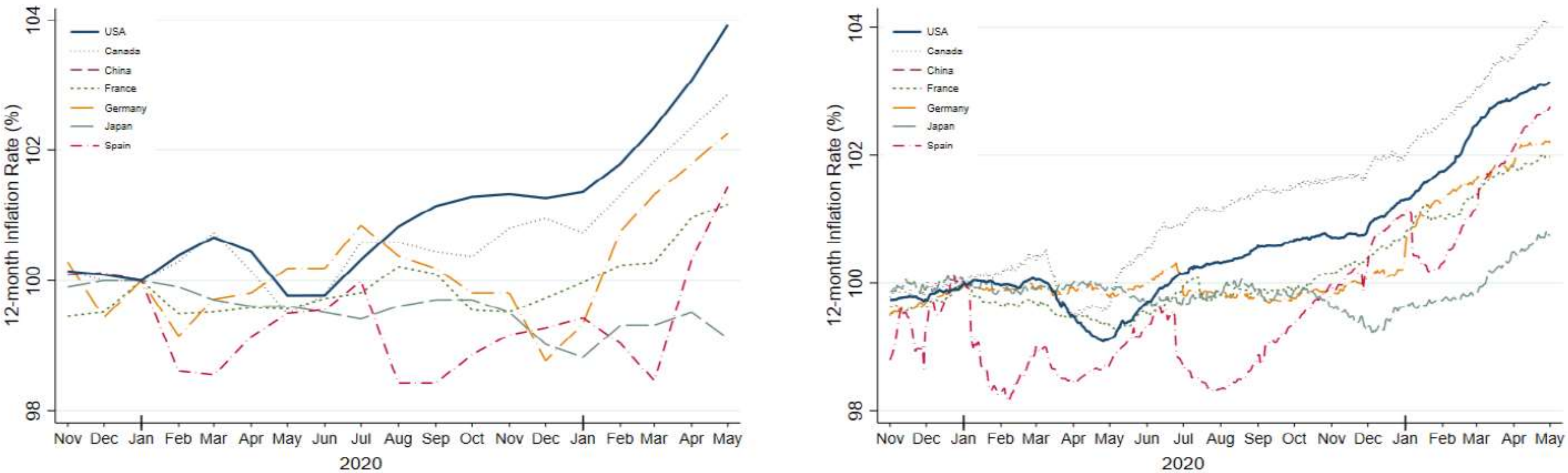
- Unprocessed Food OOS returned to pre-COVID levels
- Processed Food, Fish & Seafood OOS are still high

What is the impact on Inflation?



(a) Official CPIs

(b) Online Price Indices

Figure 5: CPI and Online Inflation Rates

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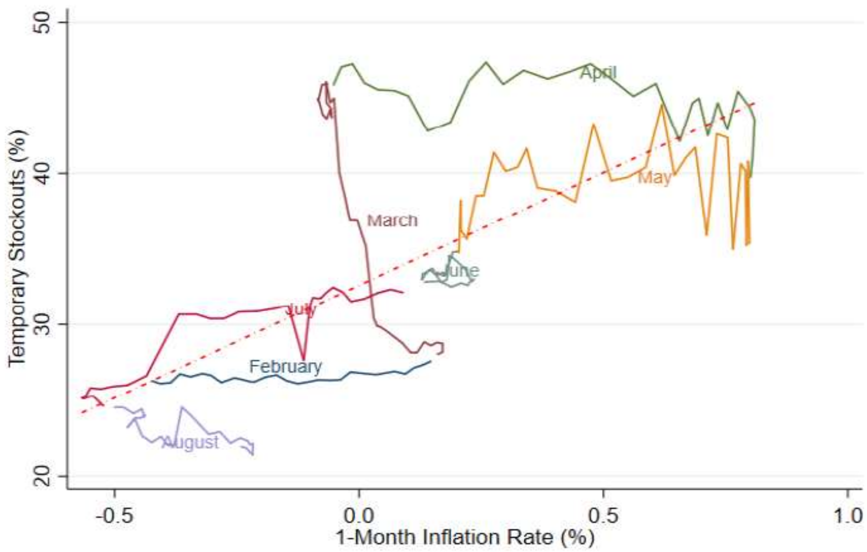
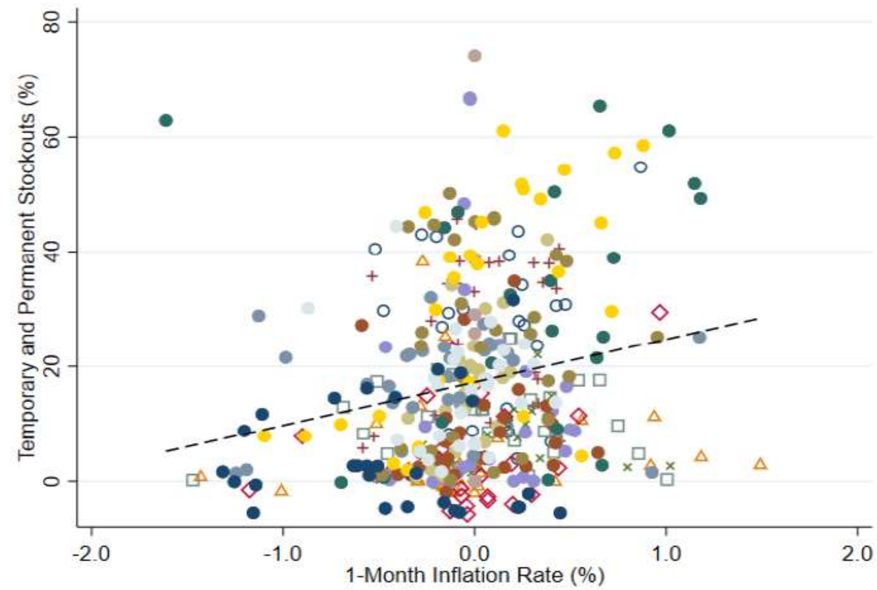


(a) Food and Beverages



(b) 2-digit Sectors

Figure 6: U.S. Inflation and Stockouts

Impact on Inflation : Correlations

	All Goods	Food & Bev.	Household	Health	Electronics	Other Goods
Monthly inflation						
OOS (%)	0.001 (0.000)	0.006 (0.000)	-0.005 (0.001)	-0.006 (0.001)	-0.004 (0.000)	-0.001 (0.001)
Obs.	16,892	5,357	3,896	974	5,204	1,461
Annual inflation						
OOS (%)	0.029 (0.001)	0.004 (0.001)	0.015 (0.001)	-0.039 (0.004)	0.023 (0.001)	-0.091 (0.003)
Obs.	16,856	5,346	3,888	972	5,192	1,458

Table 2: Impact of Stockouts on Contemporaneous Inflation Rates in the United States

- Increase OOS from 10% to 30% increases year-on-year inflation by 0.58% in U.S.
- Differences in contemporaneous correlations monthly vs annual → suggest the relationship is dynamic

Impact on Inflation

	All Goods	Food & Bev.	Household	Health	Electronics	Other Goods
Annual inflation						
OOS (%)	0.029	0.004	0.015	-0.039	0.023	-0.091
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Impact on Inflation: Dynamic Estimation

- We estimate the response of inflation to a stockout disturbance at the 3-digit level (for now assumed to be an exogenous shock)

- The stockout shock is estimated as the residual of an AR(1) process for the weekly stockout rate

$$OOS_{jt} = c_j + \beta_j OOS_{jt-1} + \epsilon_{jt}.$$

- We then estimate the impulse responses to the stockout shock using a liner projection method:

$$X_{j,t+h} - X_{j,t-1} = c^{(h)} + \sum_{l=0}^{L} \beta_l^{(h)} \epsilon_{t-l} + \sum_{n=1}^{N} \delta_n^{(h)} X_{j,t-n} + D_j + error_{j,t}^{(h)}$$

$\beta_l^{(h)}$ provides the impulse response at horizon h

Inflation Response to Stockout Shocks

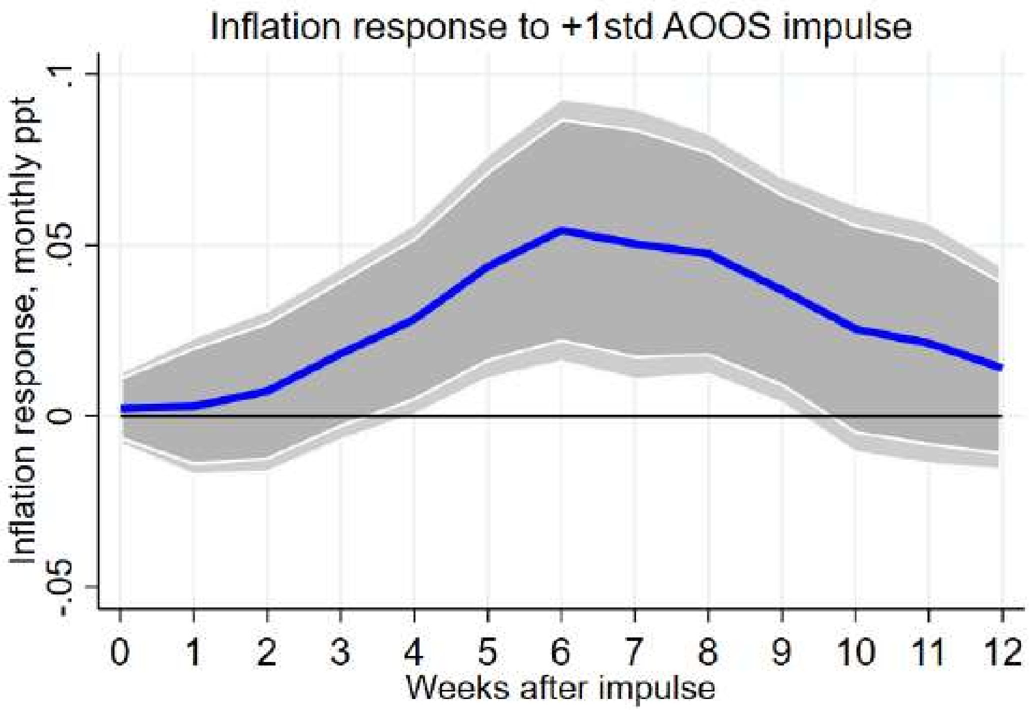


Figure 7: Inflation Response to Stockout Shocks in 3-digit U.S. sectors.

Estimation of Underlying Replacement Cost

- Stockouts are endogenous, and like prices, depend on the cost of supplying goods
- Challenge: production/replacement cost are unobserved
- Model of monopolistic firm with inventories (build on Kryvtsov and Midrigan (2013))
  - Inventories help firm to manage incidence of stockouts
  - Inventories help firm to smooth production costs
- Model predicts a relationship between firm s price, cost, and probability of stockout
- Use this relationship to estimate cost at sector level using weekly OOS and price data
- Re-asses the simultaneous impact of this cost shock on both stockouts and inflation

What can prices and OOS tell us about costs?

- **Model of monopolistic firm with inventories (Kryvtsov–Midrigan 2013)**
  - stockout-avoidance motive for holding inventories
  - FOC relates firm's OOS to firm's price and cost of replenishing inventories
  - replacement cost is correlated with lagged OOS
- **Idea:**
  - aggregate FOC for firms within consumption sector
  - GMM estimation with moment conditions derived from aggregate FOC
  - weekly data for sector-level OOS and price

Monopolistic retail firm i in sector j

- Buy $q_{jt}(i)$ goods at price P^I_{jt}, convert them into their specific variety i
- Inventory stock available for sale: $z_{jt}(i) = z_{0jt}(i) + q_{jt}(i)$
- Set price $P_{jt}(i)$ and face demand: $v_{jt}(i) \left(\frac{P_{jt}(i)}{P_{jt}}\right)^{-\theta} C_{jt}$
  - $v_{jt}(i)$ i.i.d. demand shocks with c.d.f. F
- Choose $P_{jt}(i)$ and stock $z_{jt}(i)$ before learning $v_{jt}(i)$
  - sell $y_{jt}(i) = \min\left(v_{jt}(i)\left(\frac{P_{jt}(i)}{P_{jt}}\right)^{-\theta} C_{jt}, z_{jt}(i)\right)$
  - stock out if $v_{jt}(i) \geq v^*_{jt}(i)$, where $v^*_{jt}(i) = \left(\frac{P_{jt}(i)}{P_{jt}}\right)^{\theta} \frac{z_{jt}(i)}{C_{jt}}$
  - price adjustment constraints (e.g., Calvo with parameter ξ_j)

Inventory decision

- Choose sequences of prices $\{P_{jt}(i)\}$ and inventories $\{z_{jt}(i)\}$ to maximize

$$E_t \sum_{\tau=0}^{\infty} \xi_j^{\tau} Q_{t,t+\tau} \cdot \left[P_{jt}(i) y_{jt+\tau}(i) - P^I_{jt+\tau} \left(q_{jt+\tau}(i) + \frac{\phi}{2} (q_{jt+\tau}(i) - q_j)^2 \right) \right]$$

  subject to above conditions, initial stock, and law of motion

$$z_{0jt+1}(i) = (1 - \delta_z) \left(z_{jt}(i) - y_{jt}(i) \right)$$

- Cost of replacing one unit of stock:

$$\Omega_{jt}(i) = P^I_{jt} \left(1 + \phi(q_{jt}(i) - q_j)\right)$$

- Order size $q_{jt}(i)$ decreasing initial stock $z_{0jt}(i) \Longrightarrow$ firm that experienced a stockout in period $t-1$ will face higher costs $\Omega_{jt}(i)$ in period t

FOC for inventories

- Optimal inventory (relative to av. sales), $v_{jt}^{*}(i) = \left(\frac{P_{jt}(i)}{P_{jt}^{I}}\right)^{\theta} \frac{z_{jt}(i)}{C_{jt}}$:

$$\underbrace{1 - F\left(v_{jt}^{*}(i)\right)}_{\text{prob. stockout}} = \frac{1 - (1-\delta_z)\frac{E_t[Q_{t,t+1}\Omega_{jt+1}(i)]}{\Omega_{jt}(i)}}{\underbrace{\frac{P_{jt}(i)}{\Omega_{jt}(i)}}_{\text{markup}} - (1-\delta_z)\underbrace{\frac{E_t\left[Q_{t,t+1}\Omega_{jt+1}(i)\right]}{\Omega_{jt}(i)}}_{\Delta\text{replacement cost}}} \quad (1)$$

- Probability of stockouts decreases in markup and in expected change in replacement cost

- Key property: if we directly observe stockouts, we can analyze condition (1) without information about $v_{jt}^{*}(i)$ or F.

Stockouts in sector j

Integrate FOC (1) over i:

$$p_{jt}\left(OOS_{jt} + COV_{jt}\right) = \omega_{jt} - \left(1 - OOS_{jt}\right)\left(1 - \delta_z\right)R_t^{-1}\pi_t E_t\left[\omega_{jt+1}\right] \tag{2}$$

where

$$OOS_{jt} = \int \left(1 - F(v_{jt}^*(i))\right) di$$ fraction of stockouts

$$COV_{jt} = cov\left(OOS_{jt}(i), \frac{P_{jt}(i)}{\int_i P_{jt}(i)di}\right)$$ covariance between stockouts and prices

$$p_{jt} = \frac{\int_i P_{jt}(i)di}{P_{t-1}}$$ real price in sector j

$$\omega_{jt} = \frac{\int_i \Omega_{jt}(i)di}{P_{t-1}}$$ (unobserved) real replacement cost j

$$R_t = E_t\left[Q_{t,t+1}\right]^{-1}$$ risk-free rate, and

$E_t\left[Q_{t,t+1}\omega_{jt+1}\right] \approx R_t^{-1}E_t\left[\omega_{jt+1}\right]$

Estimation of process for cost ω_{jt}

- Assume replacement costs depend on recent stockouts:

$$\omega_{jt} = a_j + b_j OOS_{jt-1} + \varepsilon_{jt}$$

- Plug in (2) to obtain :

$$G(p_{jt}, OOS_{jt}, OOS_{jt-1}, COV_{jt}, R_t, \pi_t; a_j, b_j, \delta_z) = \varepsilon_{jt}$$

- Estimate key paremter b_j and residuals ε_{jt} using two-step GMM
  - calibrate a_j and δ_z using observations before COVID pandemic

- Instruments: $\boldsymbol{Z_t} = [OOS_{jt-1}, OOS_{jt-2}, p_{jt-1}, p_{jt-2}, p_{jt-3}, \boldsymbol{X_{t-1}}, \boldsymbol{X_{t-2}}]'$
  - $\boldsymbol{X_t} = [\Delta \text{Operational Challenges}_t, \Delta \text{Stringency Index}_t, \ \Delta \# \text{ Infected}_t]'$

U.S. Data

- Weekly data: November 1, 2019–April 30, 2021 (79 weeks)
- Compute $p_{jt}, OOS_{jt}, COV_{jt}$ from PriceStats micro data
- π_t is average inflation across sectors, R_t is 3-month T-bill rate
- Calibrate: $\delta_z = 0.0046\%$ (2% monthly rate), a_j using obs before COVID
- Two measures of OOS_t : temporary and temporary+discountinued

Estimation Results

$$\omega_{jt} = a_j + b_{jt} OOS_{jt-1} + \varepsilon_{jt}$$

1-digit sectors	Temporary out-of-stock				All out-of-stock			
	bj	First-stage F-statistic		Hansen's J-stat	bj	First-stage F-statistic		Hansen's J-stat
	(st.dev.)	price	OOS	p-value	(st.dev.)	price	OOS	p-value
Food & Bev	0.05*** (0.00)	15.56	237.52	0.68	0.04*** (0.00)	13.10	13.31	0.61
Household	0.43*** (0.02)	60.12	163.94	0.82	0.18*** (0.02)	50.62	7.15	0.57
Health	0.09*** (0.00)	10.97	96.43	0.86	0.05*** (0.00)	11.93	16.50	0.73
Electronics	0.52*** (0.02)	34.04	11.05	0.82	0.17*** (0.00)	27.34	12.97	0.78
Other Goods	0.02*** (0.01)	6.53	38.92	0.65	0.04*** (0.00)	7.24	7.59	0.97

Table 4: Estimation Results for the United States.

- Eg. Coefficient of 0.43 implies that an increase in the stockout rate from 10% to 20% increases the replacement cost by 2.2% on annualized terms.
- Model predicts OOS and P are negatively correlated → cost estimates higher in sectors where both variables increase

Cumulative Change in Replacement Costs

1-digit sectors	Data			Estimated Cost	
	Price Index %	TOOS ppt	AOOS ppt	TOOS %	AOOS %
	(1)	(2)	(3)	(4)	(5)
Food & Bev	0.80	-14.15	23.27	-0.41	1.33
Household	0.71	1.16	5.09	0.73	2.01
Health	-1.14	-2.18	-0.02	-1.17	-0.77
Electronics	-1.12	3.83	33.69	1.99	4.19
Other Goods	-2.38	-0.11	4.60	-0.54	-0.71

Table 5: Cumulative Changes in Stockouts, Prices and Estimated Replacement Costs between January 2020 and April 2021, United States.

Inflation Response to Cost Shocks

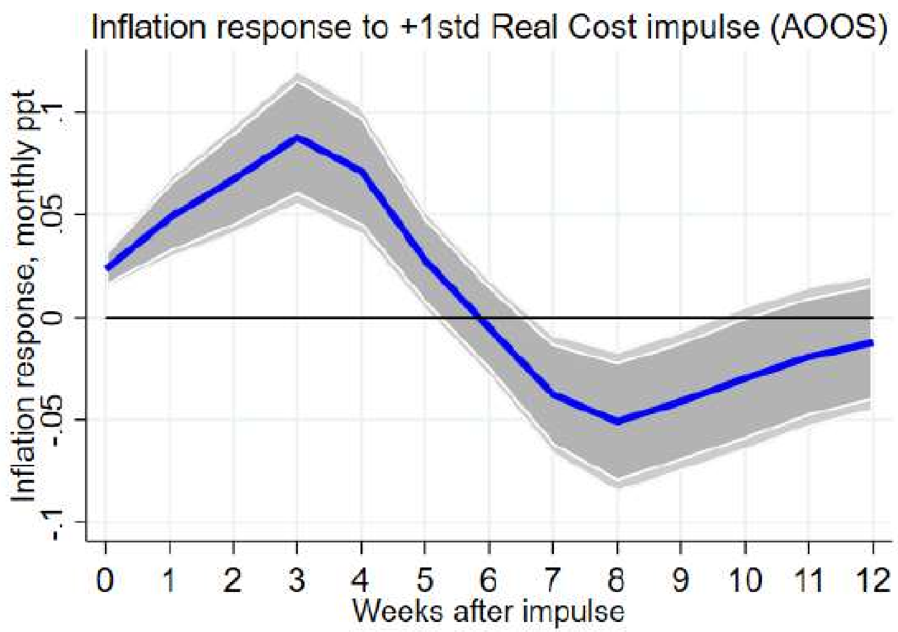
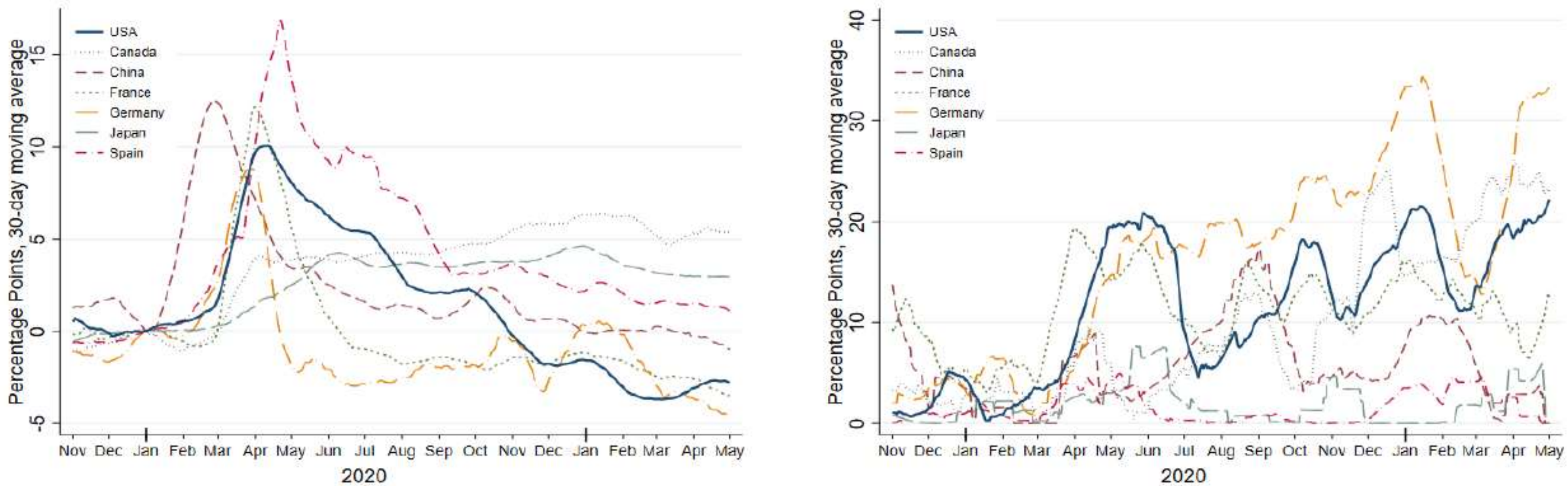


Figure 8: Responses to Real Replacement Cost Shocks in 3-Digit U.S. Sectors.

- Accounting for the endogeneity of stockouts makes the inflation response faster, stronger, and more transitory

Stockout Dynamics in other Countries



(a) Temporary Stockouts

(b) Permanent Stockouts

Figure 4: Temporary and Permanent Stockouts in 7 Countries

Stockouts and Inflation in other Countries

	USA	Canada	China	Germany	Spain	France	Japan
Annual inflation							
OOS (%)	0.029	0.027	0.011	0.011	-0.006	-0.011	-0.039
	(0.001)	(0.003)	(0.002)	(0.002)	(0.001)	(0.003)	(0.003)
Obs.	16,856	17,120	14,094	15,552	16,302	17,010	16,454

Table 3: Impact of Stockouts on Annual Inflation Rates By Country

Key results and takeaways

- We document a widespread increase in shortages during the Pandemic
- The composition and visibility of shortages changes over time → from temporary stockouts affecting nearly all categories to permanently discontinued goods concentrated in fewer sectors
- Inflation impact is:
  - significant and peaks after a couple of months
  - concentrated in categories and countries where the stockouts have been more persistent
    - US Sectors: Consumer Durables, Electronics, and Food
    - Countries: US, Canada, Germany
  - transitory and disappears after 2-3 months.
- Covid inflation outlook will depend on how quickly shortages dissipate