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

Alberto Cavallo
Harvard Business School

Oleksiy Kryvtsov
Bank of Canada

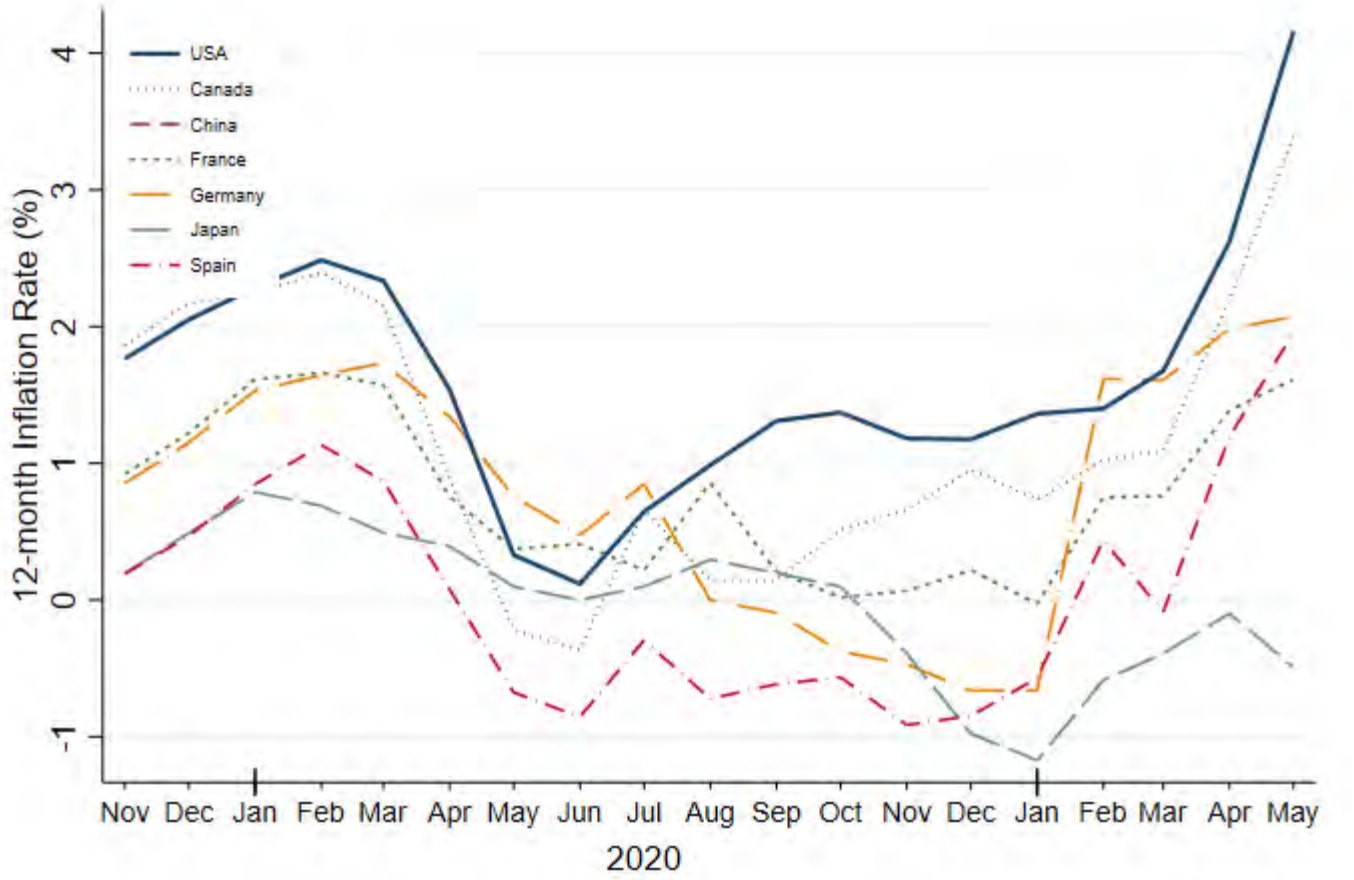
Danmarks Nationalbank, Deutsche Bundesbank and Norges Bank Conference
*Stabilization policies: Lessons from the COVID-19 crisis and prospects for future policy strategies*
13 December 2021

The views expressed here are ours, and they do not necessarily reflect the views of the Bank of Canada

# Motivation

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

*CPI Inflation Rates*




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

# Paper summary

- Analyze two high-frequency measures of consumer product shortages in 7 countries
  - temporary stockouts, discontinued products
- Widespread multi-fold rise in shortages in nearly all sectors early in the pandemic
- Over time, the composition of shortages evolved from many temporary stockouts to mostly discontinued products, concentrated in fewer sectors
- Product shortages have significant but transitory inflationary effects
- Inflationary effects can be associated with elevated cost of replenishing inventories

# Prices and stockouts micro data

- We use daily product data from The Billion Prices Project, currently collected by PriceStats
- Data scraped from websites of large multi-channel retailers that sell mostly offline


<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 |

- Sectors: Food & Beverages, Furnishings & Household, Health, Electronics, Other goods
- Not included: Alcohol & Tobacco, Apparel, Cars, Gasoline

# Measuring shortages in retail (date $t$, sector $j$, country $c$)

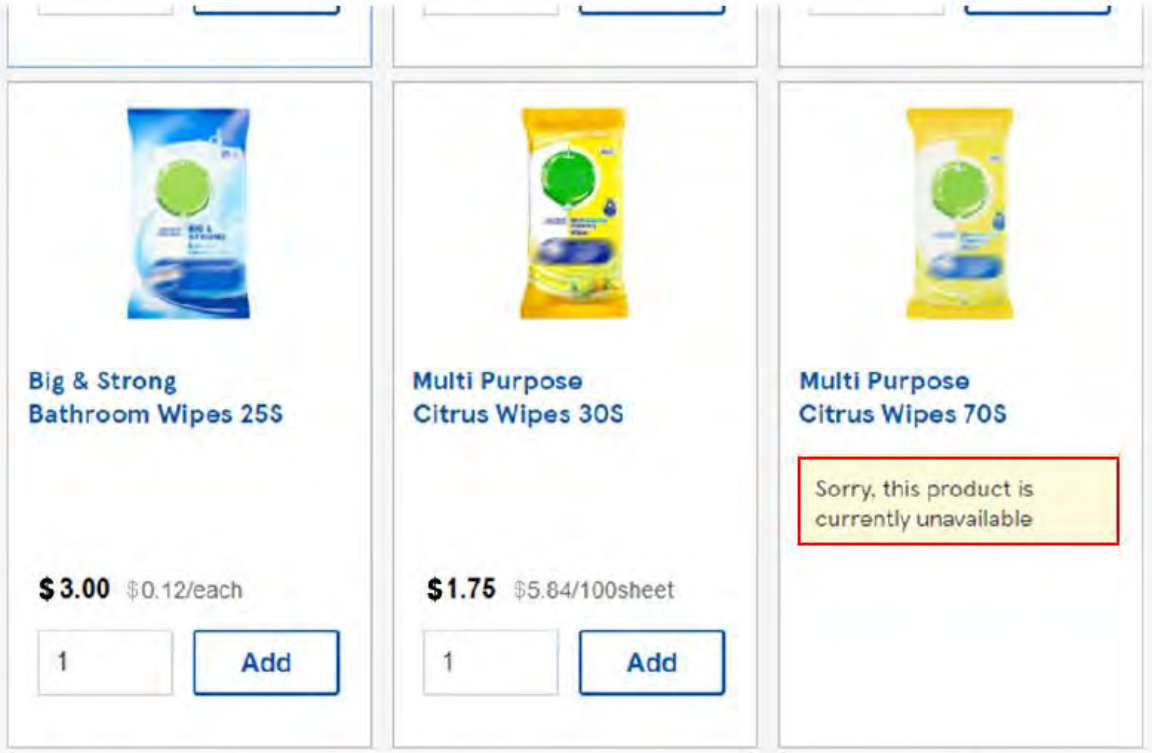



Figure 1: Identifying Stockouts on a Retailer's Website

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

# Measuring shortages in retail (date $t$, sector $j$, country $c$)

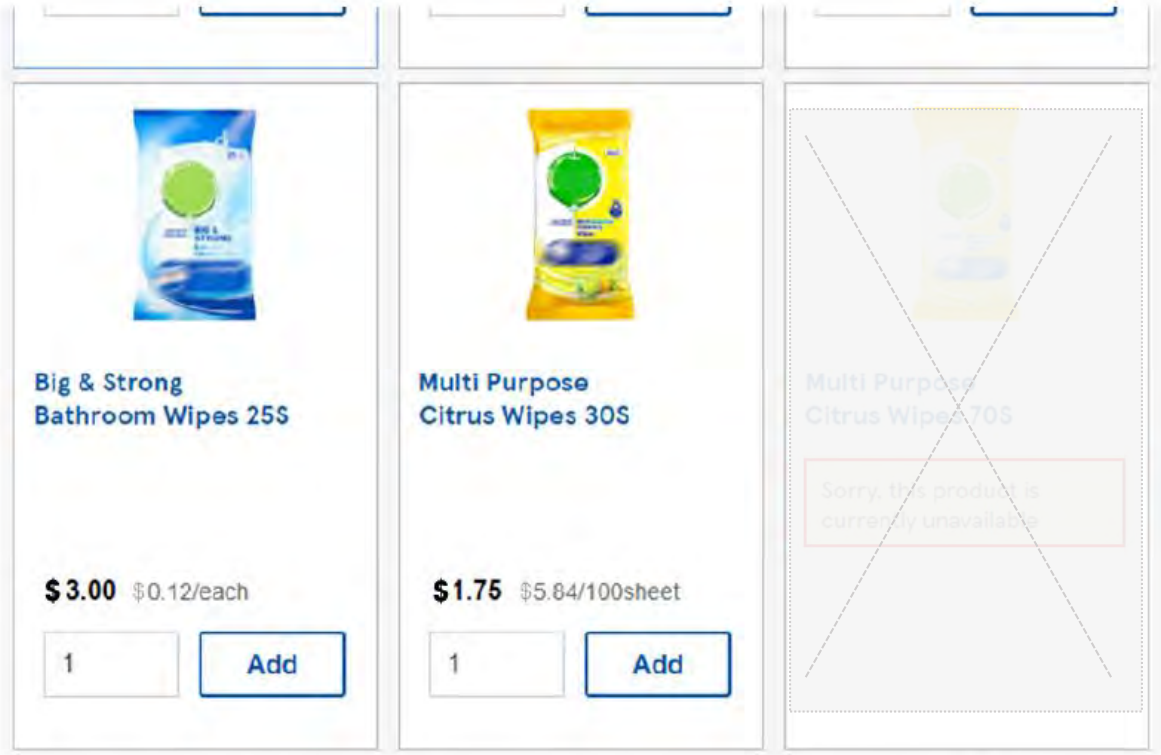



Figure 1: Identifying Stockouts on a Retailer's Website

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

# Measuring shortages in retail (date $t$, sector $j$, country $c$)

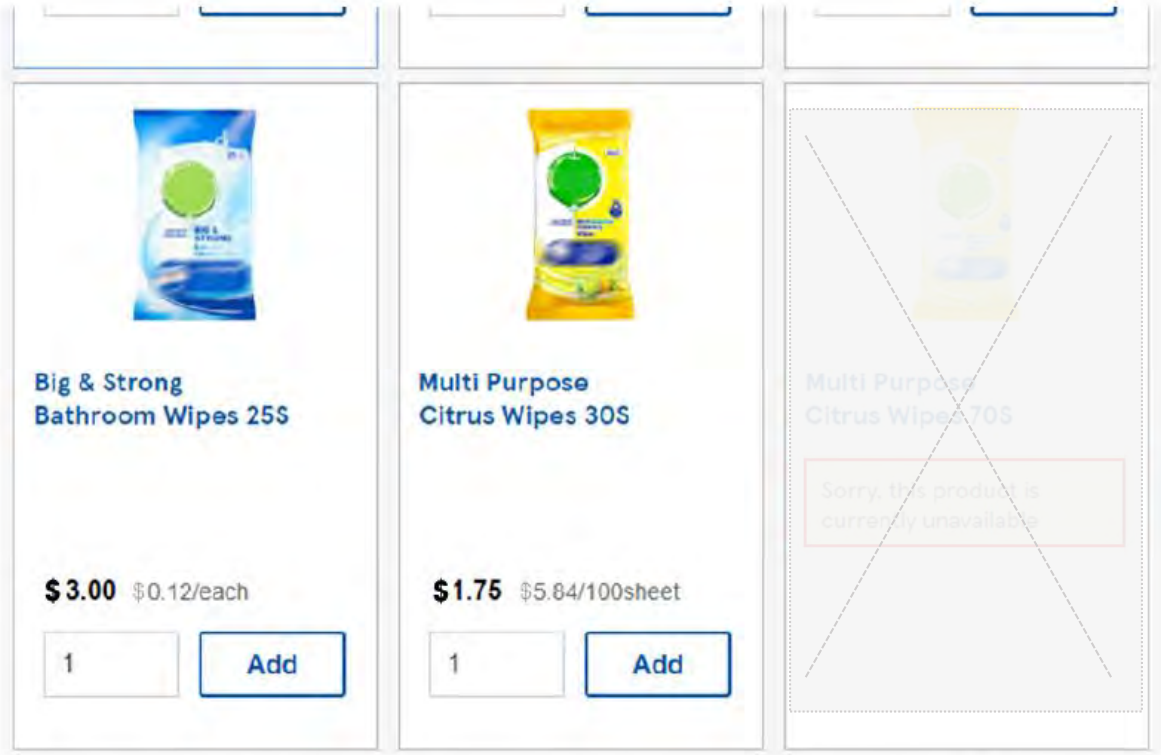
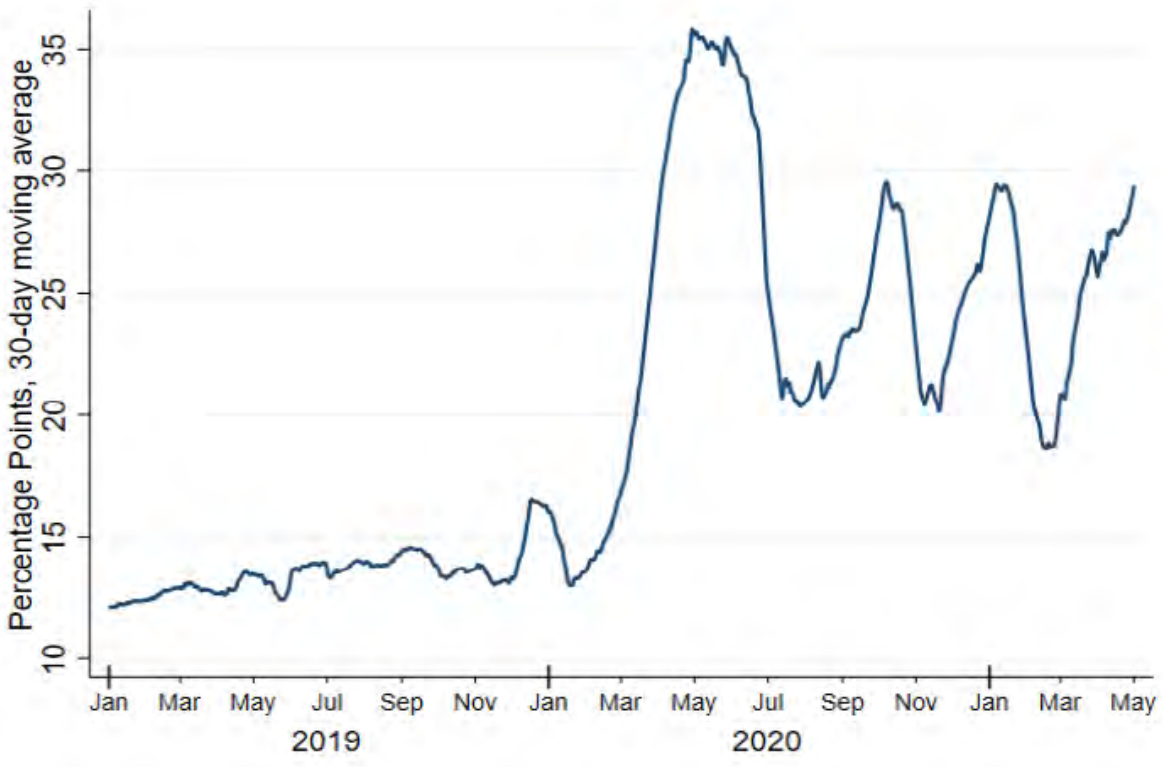


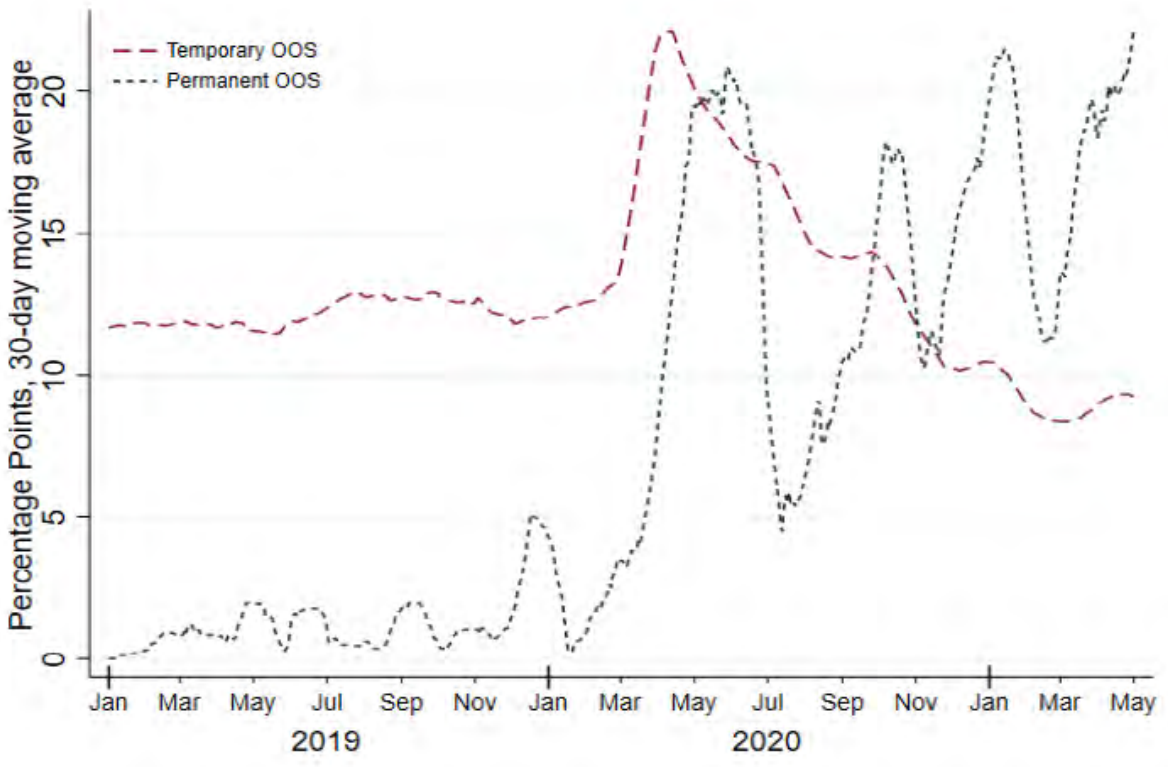

Figure 1: Identifying Stockouts on a Retailer's Website

- Temporary Stockouts $(TOOS_{t,j,c}) = \frac{\#\ out\ of\ stock_{t,j,c}}{\#\ total\ products_{t,j,c}}$
- Permanent Stockouts $(POOS_{t,j,c}) = 1 - \frac{\#\ total\ products\ _{t,j,c}}{\#\ total\ products\ _{Jan-2020,j,c}}$
- All Stockouts $(AOOS_{t,j,c}) = TOOS_{t,j,c} + POOS_{t,j,c}$

# Stockout dynamics in the United States

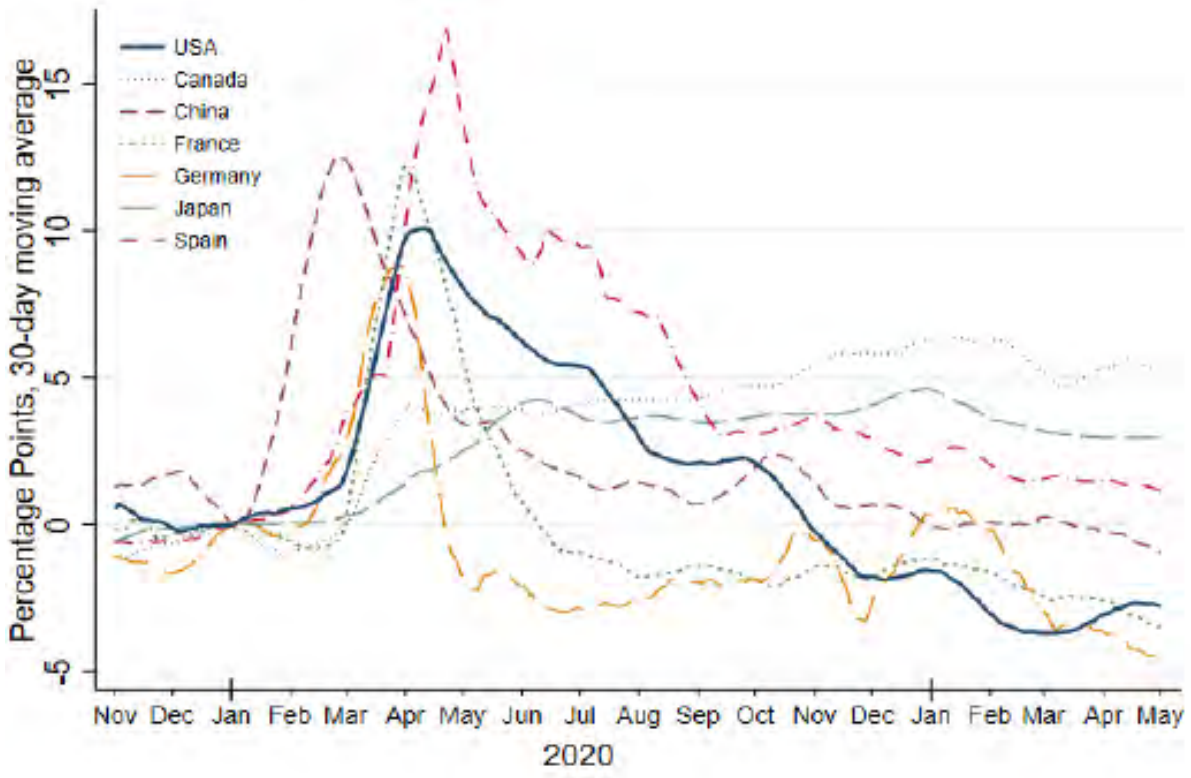



(a) All Stockouts

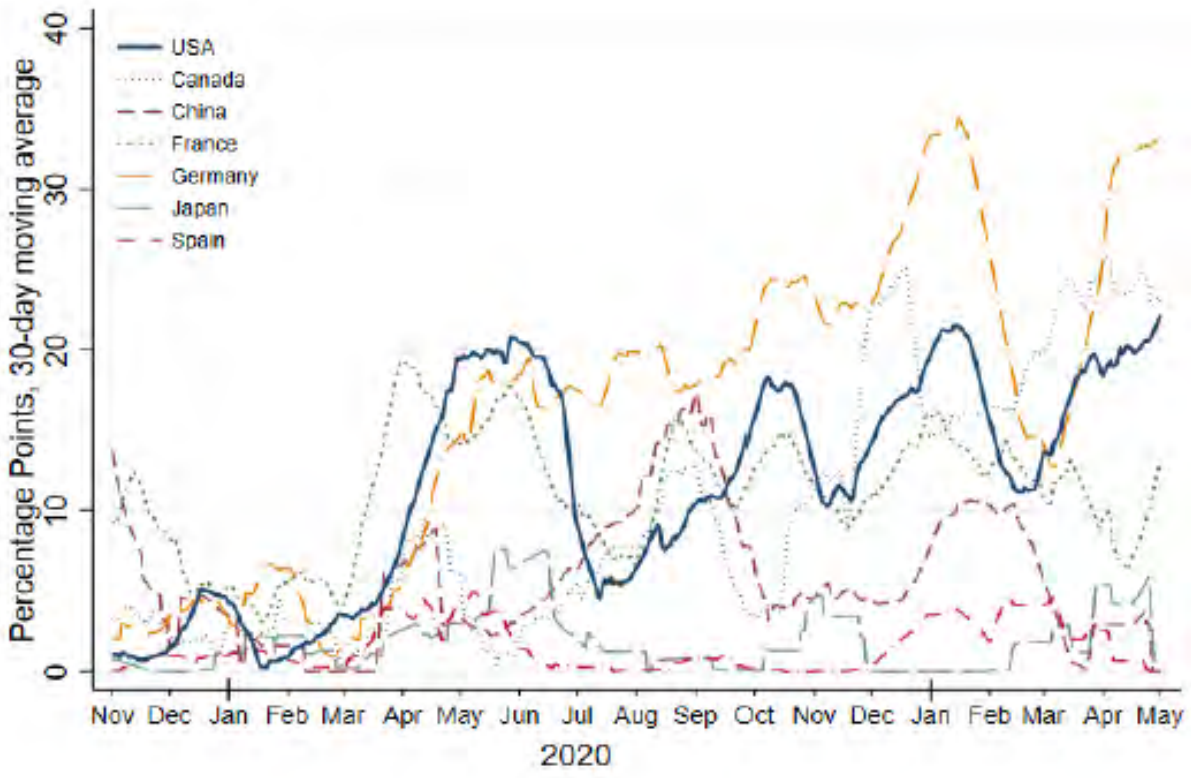



(b) Temporary and Permanent Stockouts

# Stockout dynamics in 7 countries

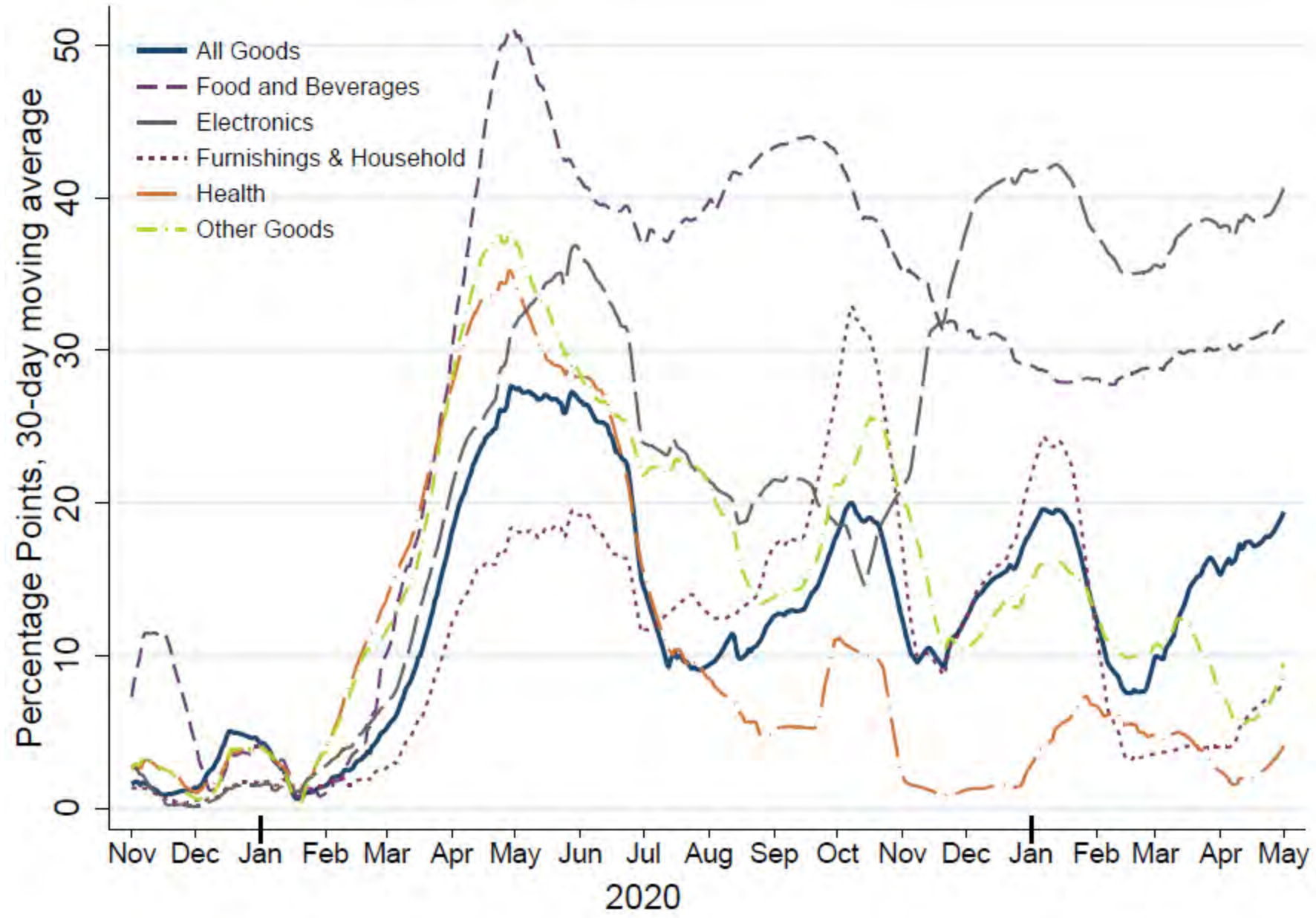



(a) Temporary Stockouts




(b) Permanent Stockouts

# In the United States, stockouts are more persistent in Food and Electronics



# 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 |

"Latest" = May 2021

- Unprocessed Food OOS below pre-COVID levels

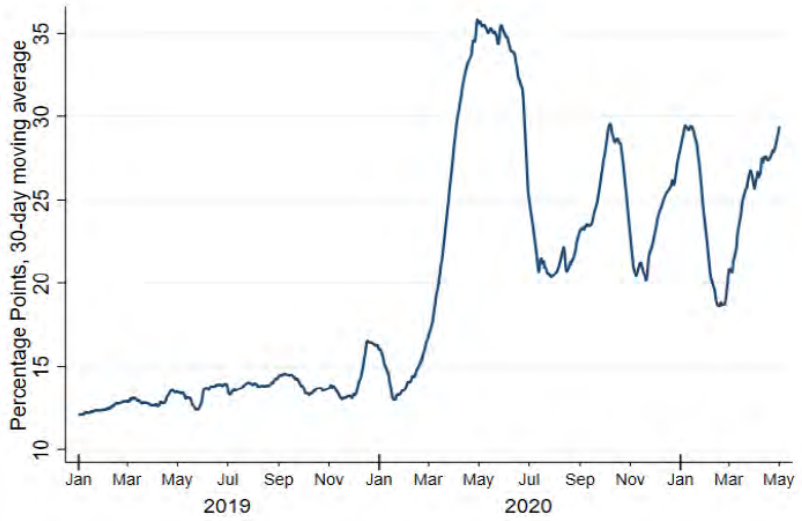
# Within-sector differences for Food indicative of supply-chain disruptions

| 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 |

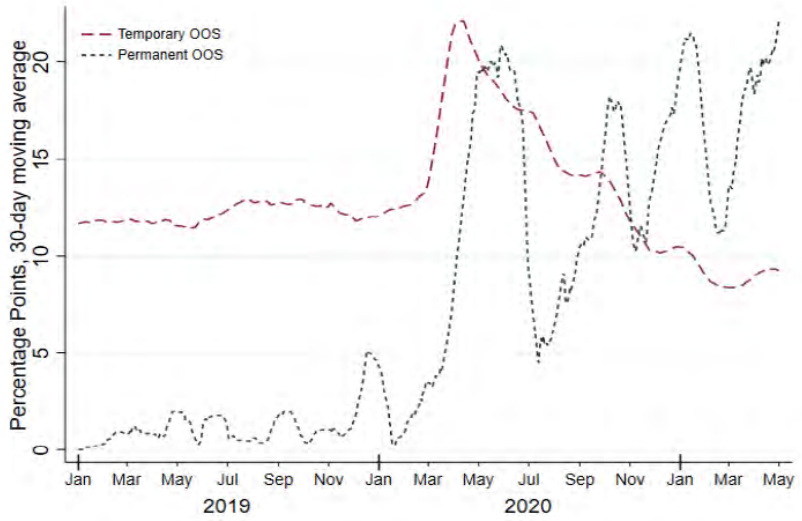
"Latest" = May 2021

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

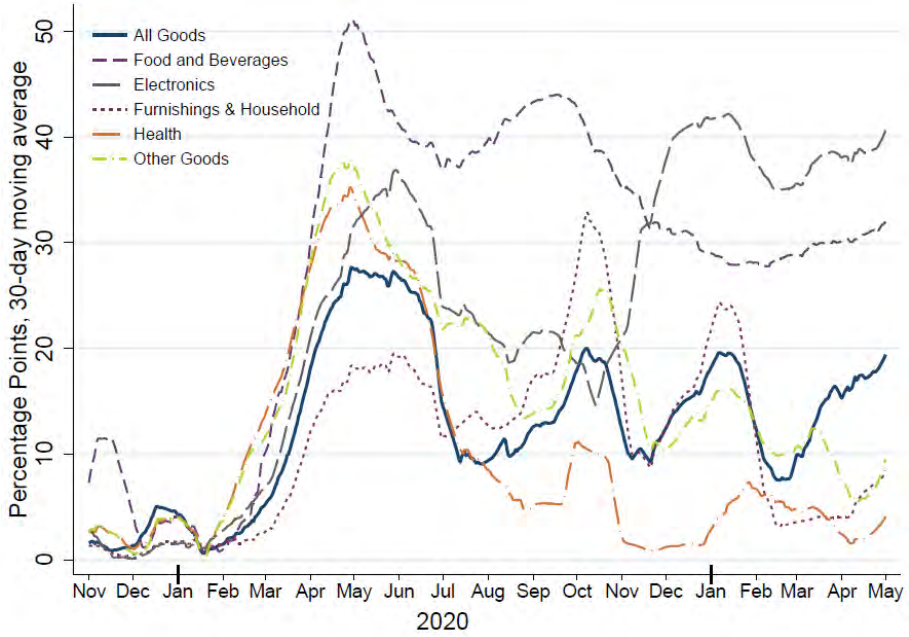
# Summary on shortages



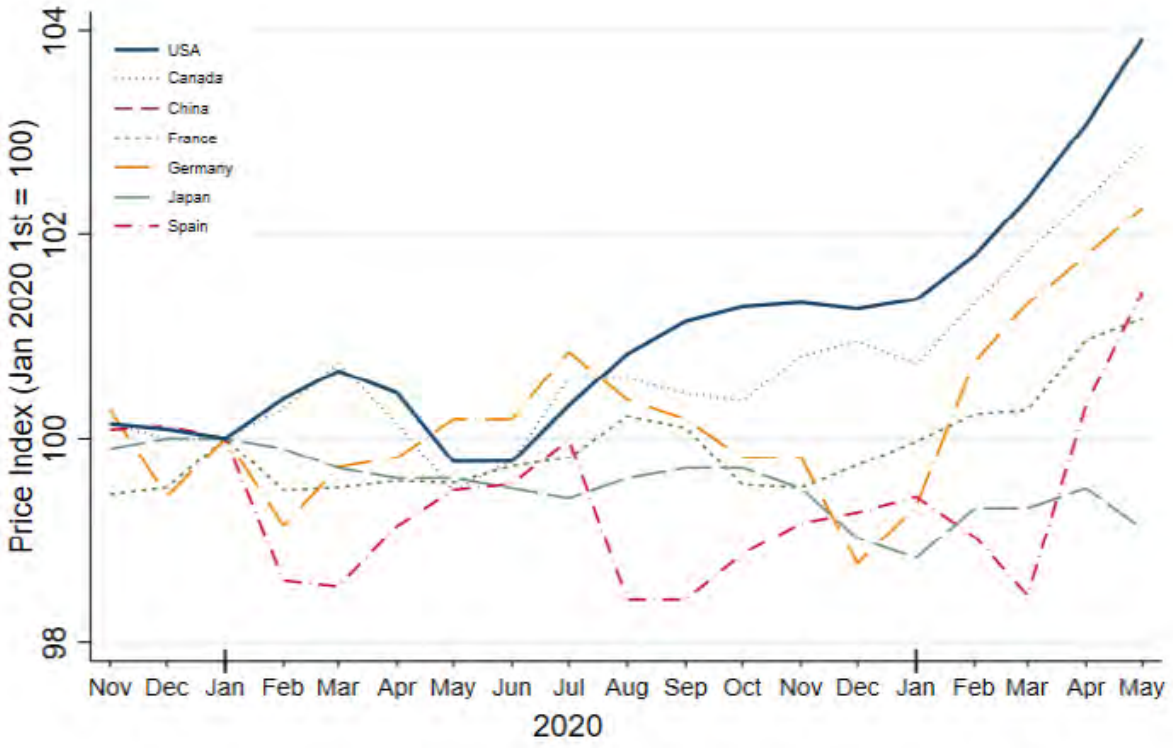

(a) All Stockouts



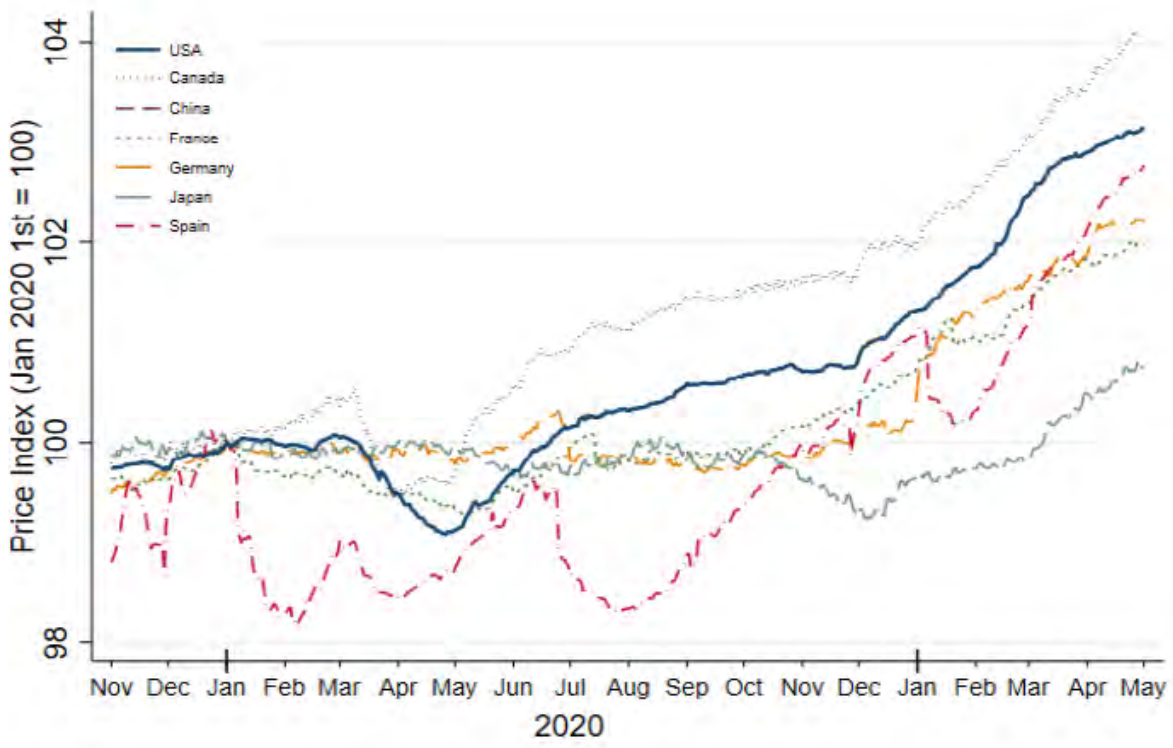

(b) Temporary and Permanent Stockouts



# What is the impact on inflation?




(a) Official CPIs




(b) Online Price Indices

# Estimation of responses to stockouts shocks, United States

- 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 in sector *j*

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

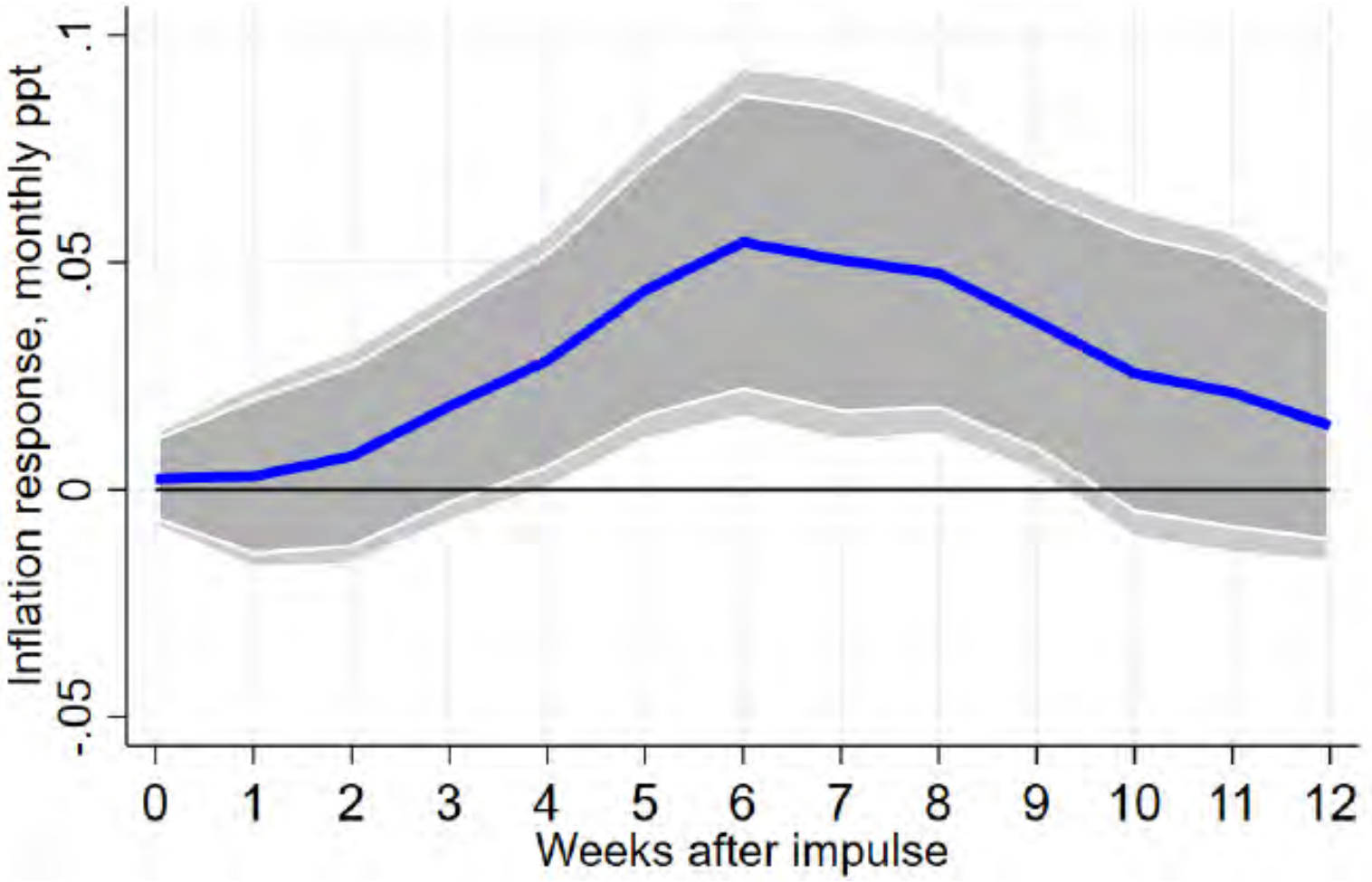
- Estimate impulse responses to the stockout shock using linear projections (Jordà, 2005):

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

$X_{j,t}$ is monthly inflation rate or the stockouts rate, $D_j$ are sector fixed effects

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

# Sector inflation response to +1std AOOS impulse, 3-digit U.S. sectors




- The change in inflation rate is gradual, significant, and transitory
- Doubling weekly stockouts from 10% to 20% increases monthly inflation by 0.10 ppt

# Estimation of underlying replacement cost

- Stockouts are endogenous, and like prices, depend on the cost of supplying/replacing 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 the cost shock on both stockouts and inflation

# Stockouts in sector $j$

Derived from the first-order condition for firm's inventory decisoin:

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

where

$$OOS_{jt}=\int \Psi'(v_{jt}(i))di \qquad \text{fraction of stockouts}$$

$$COV_{jt}=cov\left(\Psi'(v_{jt}(i)),\frac{P_{jt}(i)}{P_{jt}}\right) \qquad \text{covariance between stockouts and prices}$$

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

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

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

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

# Stockouts in sector $j$

Derived from the first-order condition for firm's inventory decisoin:

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

- $OOS_{jt}$ and $p_{jt}$ are conditionally negatively correlated $\Longrightarrow$ model predicts higher cost $\omega_{jt}$ in sectors where both variables increase

- Assume replacement costs depend on recent stockouts:

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

- In response to limited product availability retailers
  - buy extra inventory
  - spend more time tracking or replacing vendors
  - spend more time managing trucks
  - spend more time searching for subs for out-of-stock products
  - reduce price discounts

# Cumulative Change in Nominal Replacement Costs, Jan 2020 Apr 2021

| 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 |

- *OOS* and *P* are conditionally negatively correlated → model predicts cost estimates higher in sectors where both variables increase

# Cumulative Change in Nominal Replacement Costs, Jan 2020 Apr 2021

| 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 |

- Similar AOOS increase, but prices increased in Household, so estimated cost is +2% vs -0.71%

# Cumulative Change in Nominal Replacement Costs, Jan 2020 Apr 2021

| 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 |

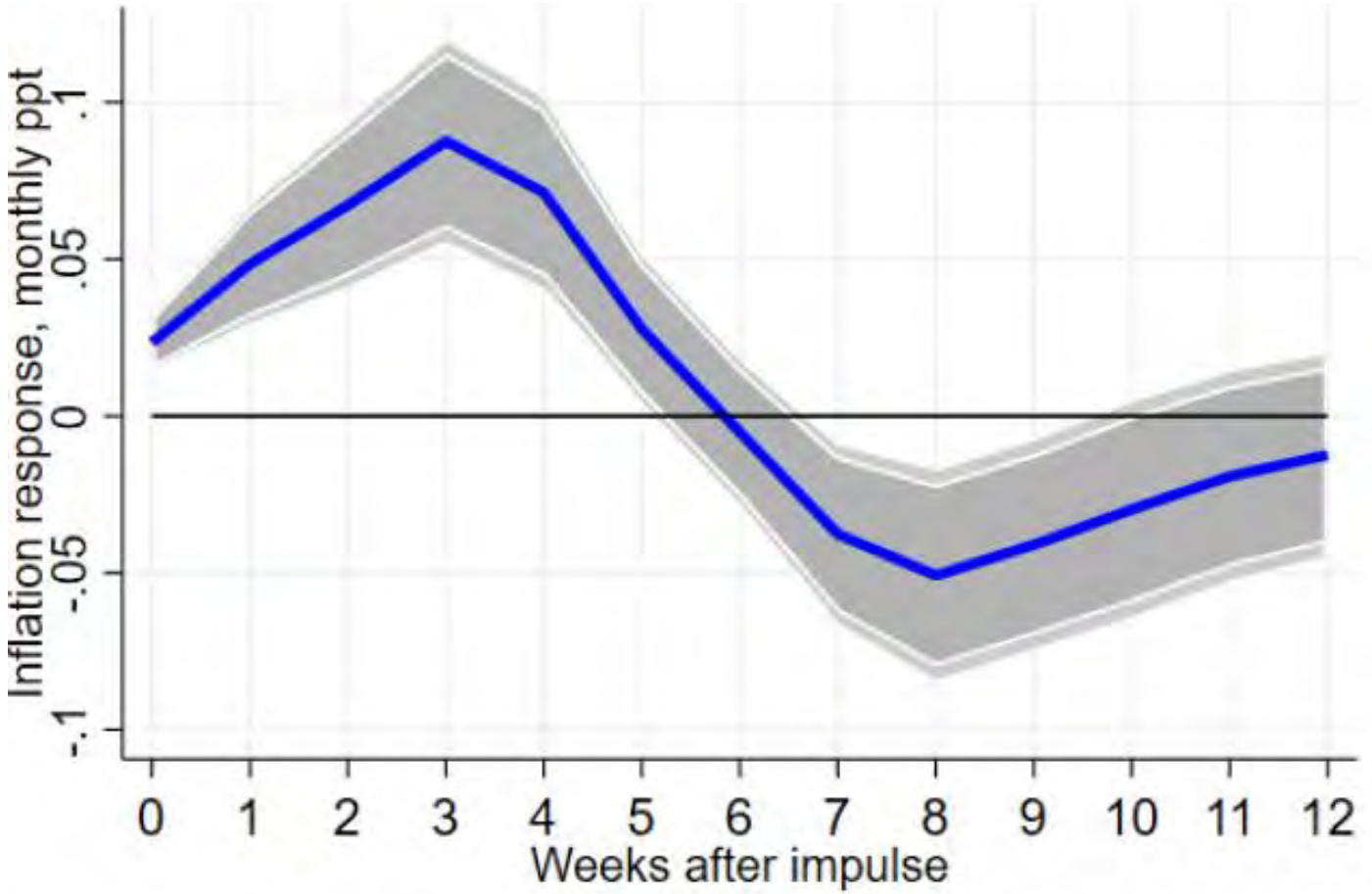
- Important to distinguish temporary vs permanent stockouts (e.g., Food and Beverages)

# Cumulative Change in Nominal Replacement Costs, Jan 2020 Apr 2021

| 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 |

- Largest increase in costs in Electronics, Household goods, Food and Beverages

# Inflation response to +1std real cost impulse, 3-digit U.S. sectors

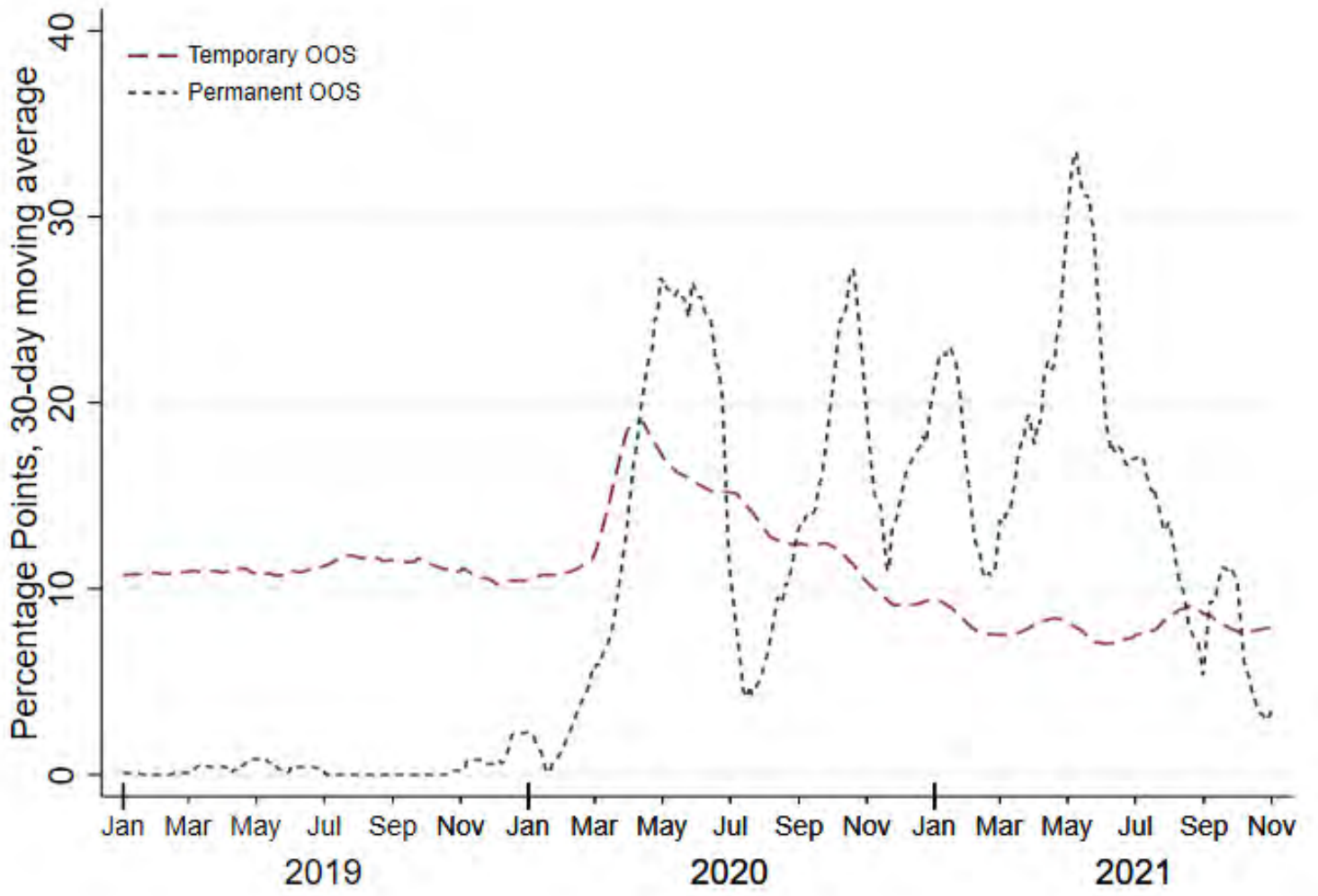



- Accounting for endogeneity of stockouts: inflation response faster, stronger, more transitory
- Static effect: rise in stockouts dampens contemporaneous response of prices
- Dynamic effect: higher stockouts imply higher future costs

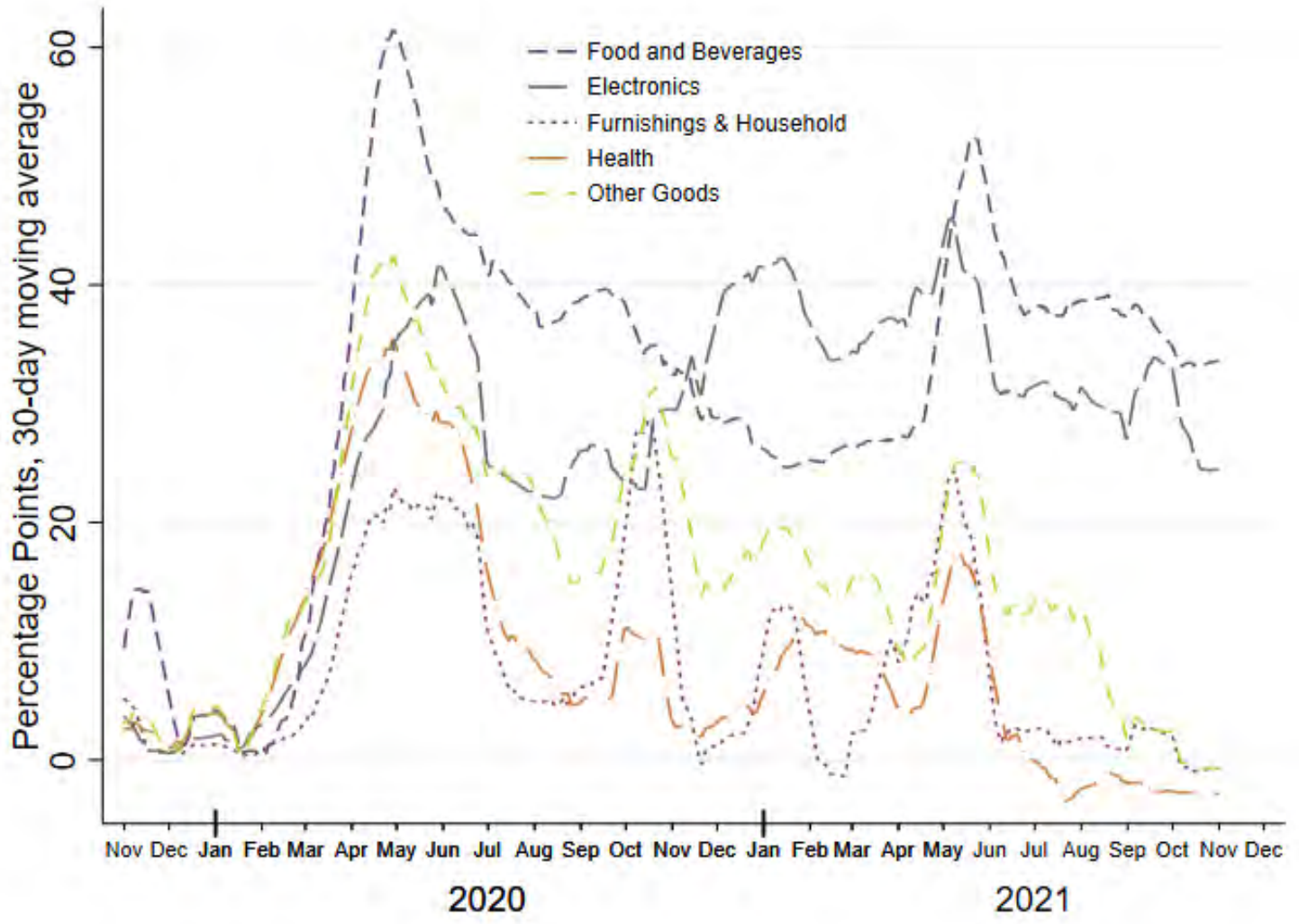
# Key results and takeaways

- 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
    - U.S. Sectors: Consumer Durables, Electronics, and Food
    - Countries: US, Canada, Germany
  - transitory and disappears after 2-3 months
- Inflation outlook depends on how quickly shortages dissipate

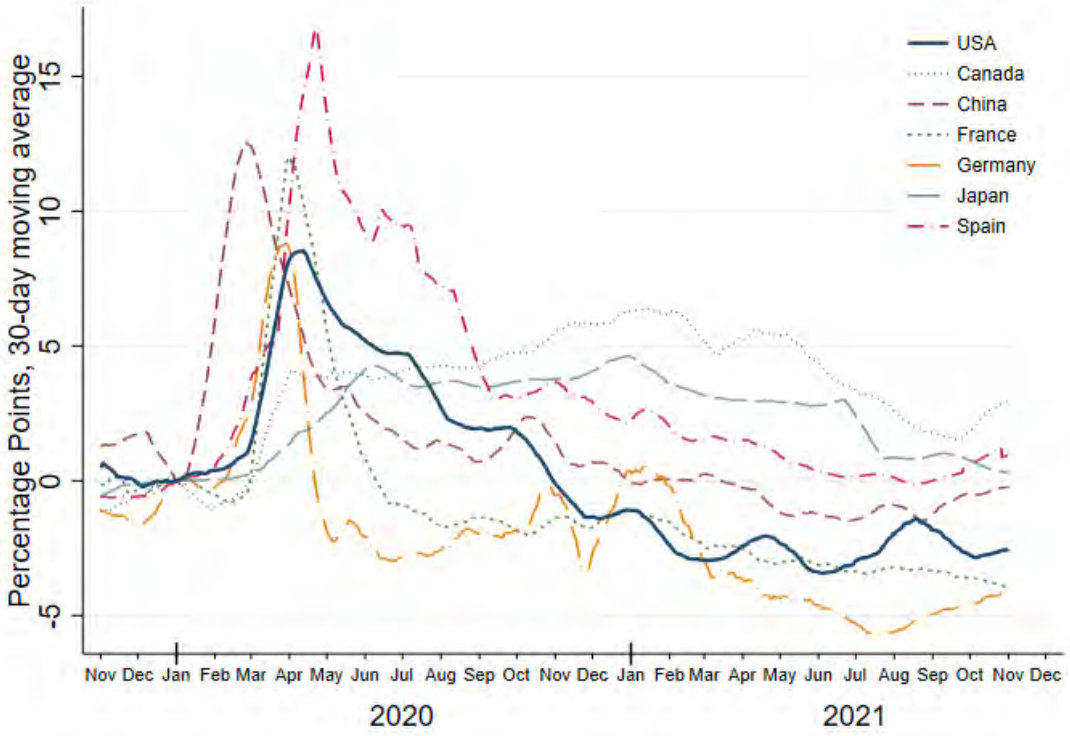
# Update US - Stockouts have fallen since May

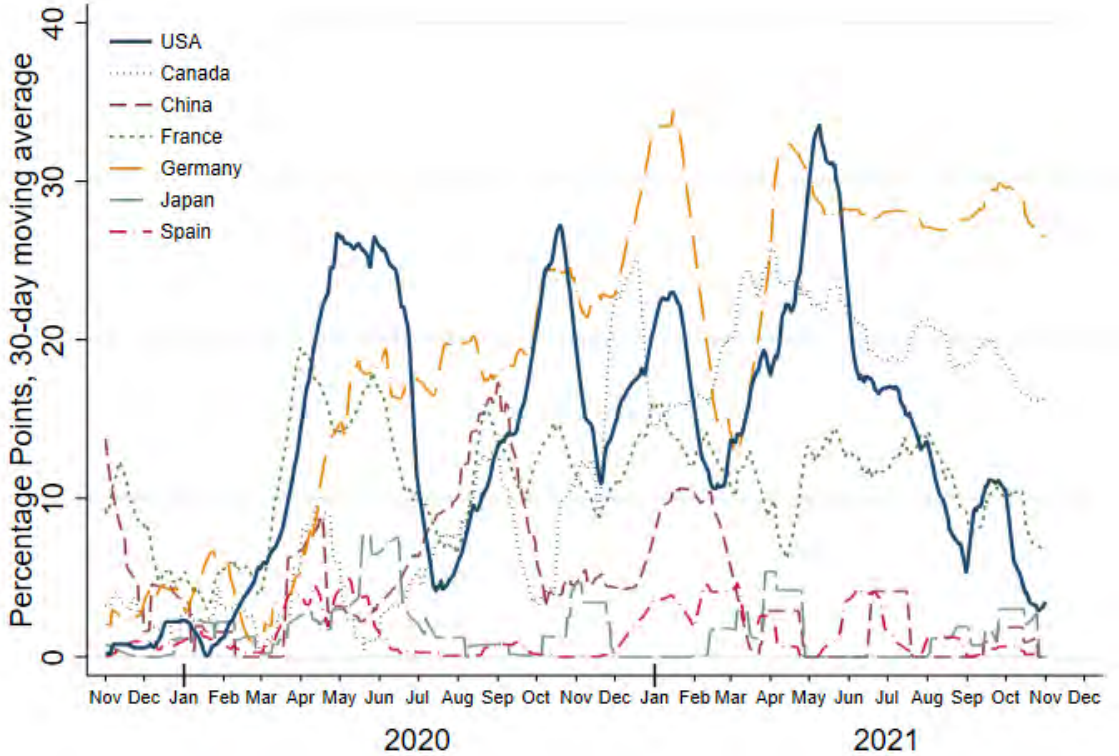


# Update US Stockouts remain high in Food and Electronics



# Update 7 countries



# THANK YOU!

# Estimation of process for cost $\omega_{jt}$

- Emprirical specification:

$$G(p_{jt}, OOS_{jt}, OOS_{jt-1}, COV_{jt}, R_t, \pi_t; \bar{a}_j, b_j, \bar{\delta}_j) = \varepsilon_{jt}$$

- Estimate key paremter $b_j$ and residuals $\varepsilon_{jt}$ using two-step GMM
  - calibrate $\bar{a}_j$ and $\bar{\delta}_j$ 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
- $\pi_t$ is average inflation across sectors, $R_t$ is 3-month T-bill rate
- Calibrate: $\bar{\delta}_j = 0.0046\%$ (2% monthly rate), $\bar{a}_j$ 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*** | 15.56 | 237.52 | 0.68 | 0.04*** | 13.10 | 13.31 | 0.61 |
| | (0.00) | | | | (0.00) | | | |
| Household | 0.43*** | 60.12 | 163.94 | 0.82 | 0.18*** | 50.62 | 7.15 | 0.57 |
| | (0.02) | | | | (0.02) | | | |
| Health | 0.09*** | 10.97 | 96.43 | 0.86 | 0.05*** | 11.93 | 16.50 | 0.73 |
| | (0.00) | | | | (0.00) | | | |
| Electronics | 0.52*** | 34.04 | 11.05 | 0.82 | 0.17*** | 27.34 | 12.97 | 0.78 |
| | (0.02) | | | | (0.00) | | | |
| Other Goods | 0.02*** | 6.53 | 38.92 | 0.65 | 0.04*** | 7.24 | 7.59 | 0.97 |
| | (0.01) | | | | (0.00) | | | |

- Coefficient of 0.43 implies that an increase in stockout rate from 10% to 20% raises the replacement cost by 2.2% on annualized terms.