Service Inflation and Missing Pass-Through

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HKU Brownbag Macro Lunch
November 16, 2021

Motivating Facts

- Service inflation normally co-moves with core but recently disconnect.

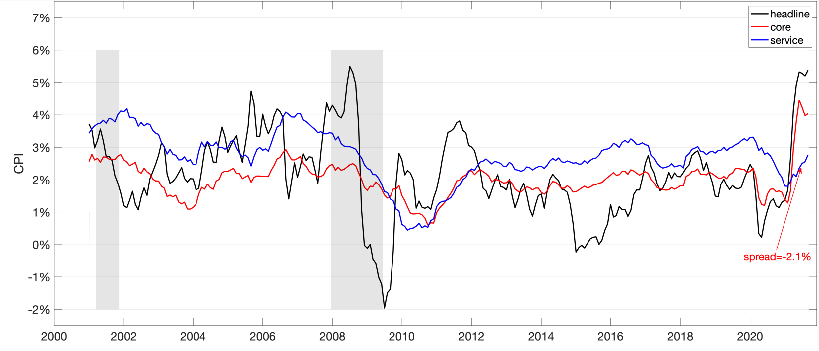


Figure 1: Year-on-Year Service CPI vs Core Inflation in the U.S.

Note: Service excludes energy services and transportation services.
(inflation) spread = service inflation − core inflation, with sample mean 0.7%.

A Brief View

- **Conventional View**: Service $\approx$ 68% core inflation basket. Natural to expect co-movement and no need to keep track of both.
- **Question**: Why disconnected recently?
- **Answer**:
  - Missing pass-through from costs to prices across service industries pre-2020.
  - Large cost shocks in 2021 $\implies$ aggregate disconnection.
- **Implication**: Service inflation deserves special attention.
- **Recent Literature**:
  - Incomplete pass-through in manufacturing: Amiti et al. (2019).
  - Pipeline pressures in production networks: Smet et al. (2019).
  - Theory of oligopoly under Calvo pricing: Wang and Werning (2020).

Outline

- **Framework**: A parsimonious model
  - multi-industry pass-through, price rigidities, production networks
- **Evidence**: Panel data regressions
  - all US industries, quarterly data, oil IV, rich heterogeneities controlled
  - model-based regressions, to estimate sector level pass-through
- **Results**: Quantitative studies of 2021Q2 service inflation gap
  - 0.3% with missing pass-through in service. (0.4% in data)
  - 1.3% with counter-factual complete pass-through.
  - Missing pass-through explains more than 1/3 of the recent disconnection.

Model in a Nutshell

- **Model**: hetero pass-thru + price rigidities + production networks.
- **Assumptions**: no capital + **CRS** + fully sticky nominal wages.
- **Free from Two Mechanisms**:

$$\text{output}\uparrow \implies \text{returns to scale}\downarrow \implies \text{price}\uparrow$$
$$\text{output}\uparrow \implies \text{labor}\uparrow \implies \text{wage}\uparrow \implies \text{price}\uparrow$$

$\implies$ **Irrelevance of output** in modeling.

Pass-Through

- Monopolistic competition within each industry.
- Desired price p^* under marginal cost Φ and aggregate price P solves

$$\max_p \, (p - \Phi) D(p, P).$$

- The solution of p^* satisfies

$$d \ln p^* = \gamma^\Phi d \ln \Phi + \gamma^P d \ln P \quad \xrightarrow{\text{short notations}} \quad \widehat{p}^* = \gamma^\Phi \widehat{\Phi} + \gamma^P \widehat{P}.$$

- (γ^Φ, γ^P) depends on the demand function $D(p, P)$.
- **Missing Pass-through**: $\gamma^\Phi \to 0$.

Price Rigidity

- Given Calvo pricing parameter θ, discount factor β, and desired price $\widehat{p}_t^*$, the optimal reset price $\widehat{p}_t^{opt}$ of each individual producer is a weighted average of desired price $\{\widehat{p}_{t+s}^*\}$ subject to markup wedges $\{\xi_{t+s}\}$.

$$\widehat{p}_t^{opt} = (1-\beta\theta)\sum_{s=0}^{+\infty}(\beta\theta)^s \cdot \mathbb{E}_t\left[\widehat{p}_{t+s}^* + \xi_{t+s}\right].$$

- The industry level price $\widehat{P}_t$ satisfies

$$\widehat{P}_t = \theta \cdot \widehat{P}_{t-1} + (1-\theta)\cdot \widehat{p}_t^{opt}.$$

- **Pass-Through + Price Rigidity**:

$$\widehat{P}_t = \theta\widehat{P}_{t-1} + (1-\theta)(1-\beta\theta)\sum_{s=0}^{+\infty}(\beta\theta)^s\mathbb{E}_t\left[\gamma^\Phi\widehat{\Phi}_{t+s} + \gamma^P\widehat{P}_{t+s} + \xi_{t+s}\right].$$

Production Network

- N industries with input-output linkages.
- No capital + **CRS** + fully sticky nominal wages $\implies$

$$\widehat{\Phi}_{it} = \alpha_i \sum_{j=0}^{N} \omega_{ij} \widehat{P}_{jt}.$$

  in which $\{\alpha_i, \omega_{ij}\}$ are steady-state cost shares.
- Note that under log-linearization, the equation above does not depend on the exact functional forms of production technologies.

All in One Equation

- **Log-linearized Solution**:

$$\mathbf{P}_t = \mathbf{\Theta}\mathbf{P}_{t-1} + (\mathbb{I}-\mathbf{\Theta})(\mathbb{I}-\beta\mathbf{\Theta})\sum_{s=0}^{+\infty}(\beta\mathbf{\Theta})^s\mathbb{E}_t[\mathbf{\Gamma}^{\mathbf{\Phi}}\underbrace{\boldsymbol{\alpha}\mathbf{\Omega}\mathbf{P}_{t+s}}_{\mathbf{\Phi}_{t+s}} + \mathbf{\Gamma}^{\mathbf{P}}\mathbf{P}_{t+s} + \boldsymbol{\xi}_{t+s}].$$

  - $\mathbf{P}_t$: vector of endogenous industry level prices,
  - $\boldsymbol{\xi}_t$: vector of exogenous industry level markup wedge,
  - $\mathbf{\Gamma}^{\mathbf{\Phi}}$: diagonal matrix of industry level pass-through,
  - $\mathbf{\Gamma}^{\mathbf{P}}$: diagonal matrix of industry level strategic complementarities,
  - $\mathbf{\Theta}$: diagonal matrix of industry level Calvo pricing parameters,
  - $\boldsymbol{\alpha}$: diagonal matrix of industry level intermediate input cost shares,
  - $\mathbf{\Omega}$: matrix of input-output table,
  - β: common discount factor,
  - $(\mathbf{\Theta}, \boldsymbol{\alpha}, \mathbf{\Omega}, \beta)$: parameters to calibrate.

- **e.g. Kimball Aggregator**: $\mathbf{\Gamma}^{\mathbf{\Phi}} + \mathbf{\Gamma}^{\mathbf{P}} = \mathbb{I} \implies$ NKPC.
- **e.g. Complete Pass-through**: $\mathbf{\Gamma}^{\mathbf{\Phi}} = \mathbb{I}$ and $\mathbf{\Gamma}^{\mathbf{P}} = \mathbf{0}$.

Calibration and Observables

- $\mathbf{\Theta}$: Frequencies of quarterly price changes using confidential microdata underlying PPI from **BLS**, borrowed from Micheal Weber.
- $(\alpha, \mathbf{\Omega})$: The average of BEA annual I-O Tables during 2005Q1-2019Q4.
- $\beta = 0.9968$ (Christiano et al., 2016).
- $\mathbf{P}_t$ and $\mathbf{\Omega P}_t$ observed from **BEA** 2005Q1-2019Q4 directly.

Regression Equations

- **Benchmark Regression** ($\gamma_i^P = 0$):

$$\underbrace{\text{Price difference}_{it}}_{\widehat{P}_{it}-\theta_i\widehat{P}_{it-1}} = \gamma_i^{\Phi} \cdot \underbrace{\text{Dynamic costm}_{it}}_{(1-\theta_i)(1-\beta\theta_i)\sum_{s=0}^{4}(\beta\theta_i)^s\widehat{\Phi}_{is}} + \lambda_t + \mu_i + e_{it}.$$

  - λ_t: quarter dummies, exogenous aggregate wedges or GE effects.
  - μ_i: industry dummies, nearly useless under detrended data.
  - e_{it}: exogenous wedges, i.i.d. measurement erorrs, i.i.d. forecast errors.

- **Myopic Calvo Pricing** ($\gamma^P = 0_i,\ \beta = 0$):

$$\underbrace{\text{Price difference}_{it}}_{\widehat{P}_{it}-\theta_i\widehat{P}_{it-1}} = \gamma_i^{\Phi} \cdot \underbrace{\text{Myopic costm}_{it}}_{(1-\theta_i)\widehat{\Phi}_{it}} + \lambda_t + \mu_i + e_{it}.$$

- **Flexible Price Case** ($\gamma_i^P = 0,\ \theta_i = 0$):

$$\underbrace{\text{Price}_{it}}_{\widehat{P}_{it}} = \gamma_i^{\Phi} \cdot \underbrace{\text{Input price}_{it}}_{\widehat{\Phi}_{it}} + \lambda_t + \mu_i + e_{it}.$$

Industry Groups

Table 1: Three Industry Groups in Regressions

#	NAICS	Industry names
		Manufacturing
8	321	Wood products
9	327	Nonmetallic mineral products
10	331	Primary metals
11	332	Fabricated metal products
12	333	Machinery
13	334	Computer and electronic products
14	335	Electrical equipment, appliances, and components
15	3361MV	Motor vehicles, bodies and trailers, and parts
16	3364OT	Other transportation equipment
17	337	Furniture and related products
18	339	Miscellaneous manufacturing
19	311FT	Food and beverage and tobacco products
20	313TT	Textile mills and textile product mills
21	315AL	Apparel and leather and allied products
22	322	Paper products
23	323	Printing and related support activities
24	324	Petroleum and coal products
25	325	Chemical products
26	326	Plastics and rubber products
		Wholesale
27	42	Wholesale trade
28	441	Motor vehicle and parts dealers
29	445	Food and beverage stores
30	452	General merchandise stores
31	4A0	Other retail
32	481	Air transportation
33	482	Rail transportation
34	483	Water transportation
35	484	Truck transportation
36	485	Transit and ground passenger transportation
37	486	Pipeline transportation
38	487OS	Other transportation and support activities
39	493	Warehousing and storage

#	NAICS	Industry names
		Service
40	511	Publishing industries, except internet (includes software)
41	512	Motion picture and sound recording industries
42	513	Broadcasting and telecommunications
43	514	Data processing, internet publishing, and other information services
48	HS	Housing
49	ORE	Other real estate
50	532RL	Rental and leasing services and lessors of intangible assets
51	5411	Legal services
52	5415	Computer systems design and related services
53	5412OP	Miscellaneous professional, scientific, and technical services
54	55	Management of companies and enterprises
55	561	Administrative and support services
56	562	Waste management and remediation services
57	61	Educational services
58	621	Ambulatory health care services
59	622	Hospitals
60	623	Nursing and residential care facilities
61	624	Social assistance
62	711AS	Performing arts, spectator sports, museums, and related activities
63	713	Amusements, gambling, and recreation industries
64	721	Accommodation
65	722	Food services and drinking places
66	81	Other services, except government
		Others (# 1-7,44-47,67-71)

Oil IV

- **Method**: Identify macro equations with old shocks as IV (Barnichon and Mesters, 2020), similar idea as impulse response matching.
- **Exogeneity**: Oil prices exceeding the last 4 quarters (Hamilton, 1996), sudden surge as shocks.
- **Panel-IV**: Oil Shocks interacted with industry dummies (Nakamura and Steinsson, 2014).
- **Other Use of Oil IV**: Bonadio et al. (2021).

Correlation in Time Series

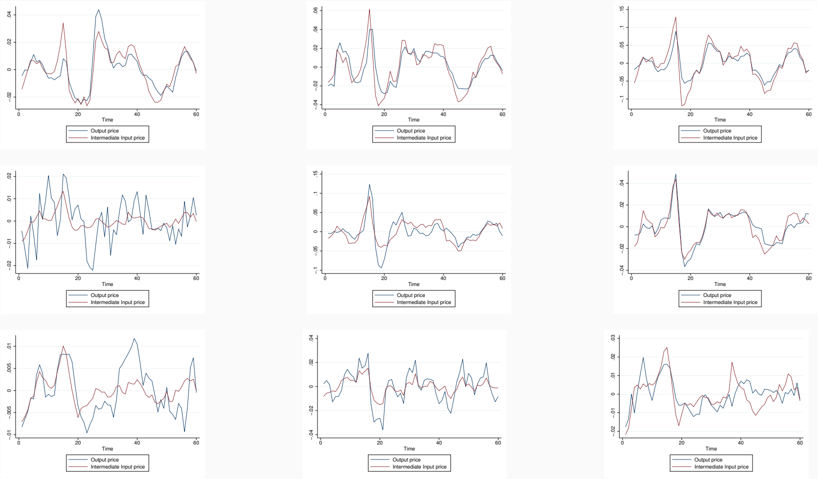
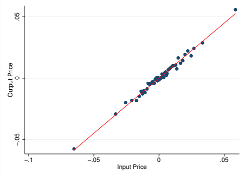


Figure 2: Correlation of Output and Input Prices in Time Series

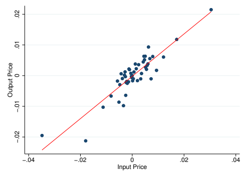
Note: 3 industries within each sector (Manufacturing, Wholesale, Service) to illustrate. Those 3 industries have gross output shares roughly at the 10 percentile, 50 percentile and 90 percentile within each sector. Clear co-movement between output and input prices.

Correlation in Cross Sections

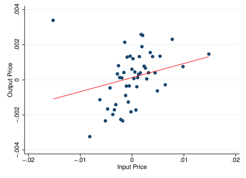
(a) Manufacturing



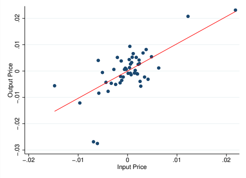
(b) Wholesale



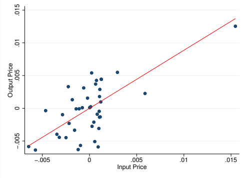
(c) Service



(d) Manufacturing; IV



(e) Wholesale; IV



(f) Service; IV

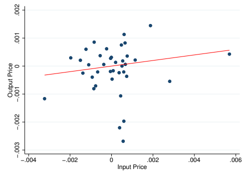


Figure 3: Correlation of Output and Input Prices in Cross Sections

Note: Binscatter plots; Net of quarter and industry fixed effects. The second row uses intermediate input prices projected on oil IV.

Missing Pass-through

Table 2: Benchmark and Special Case Regressions Given $\gamma^P = 0$

	(1) Manu	(2) Whole	(3) Serv	(4) Manu	(5) Whole	(6) Serv	(7) Manu	(8) Whole	(9) Serv
	Price	Price	Price	Price Diff	Price Diff	Price Diff	Price Diff	Price Diff	Price Diff
Input Price	1.035***	0.886***	0.100						
	(0.186)	(0.200)	(0.137)						
Myopic Costm				1.198***	1.000***	0.081			
				(0.192)	(0.256)	(0.183)			
Dynamic Costm							1.294***	1.380***	**0.078**
							(0.205)	(0.248)	(0.209)
Observations	994	714	1,354	994	714	1,354	924	663	1,262
1st-stage F test (p-val)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Testing $\gamma^\Phi = 1$									
p-value (for χ^2)	0.849	0.570	0.000	0.302	0.999	0.000	0.151	0.125	**0.000**

Note: Standard errors are in parentheses and are clustered by industries.

- Robust to (1) restrictions on extreme values, (2) detrending methods (e,g, HP, polynomial, Hamilton), (3) controlling labor costs.

Size-dependent Pass-through?

Table 3: Summary Statistics of Output and Input Prices

	Obs.	Mean	S.D.	Percentiles						
				5^{th}	10^{th}	25^{th}	50^{th}	75^{th}	90^{th}	95^{th}
Manufacturing Sector										
Output price (HP)	994	0.0006	0.0203	-0.0237	-0.0174	-0.0064	0.0001	0.0060	0.0159	0.0249
Int. Input price (HP)	994	0.0007	0.0217	-0.0303	-0.0198	-0.0083	0.0014	0.0092	0.0195	0.0296
Service Sector										
Output price (HP)	1354	0.0002	0.0067	-0.0102	-0.0071	-0.0036	-0.0001	0.0034	0.0080	0.0114
Int. Input price (HP)	1354	0.0001	0.0053	-0.0069	-0.0049	-0.0024	0.0001	0.0022	0.0054	0.0084

- Concern: size-dependent pass-through (e.g. rational inattention)?

Testing Size-dependence

Table 4: Regressions Grouped By the Weighted Median of Cost Moves

	(1) Manu Price Diff	(2) Whole Price Diff	(3) Serv Price Diff
Small shocks			
Dynamic Costm	-0.479	1.972*	-1.256
	(0.343)	(1.057)	(1.395)
Obs.	222	263	810
Time FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Large shocks			
Dynamic Costm	1.283***	1.282***	0.241
	(0.224)	(0.204)	(0.261)
Obs.	702	400	452
Time FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes

	(1) Manu Price Diff	(2) Whole Price Diff	(3) Serv Price Diff
Small shocks			
Dynamic Costm	1.213***	-0.213	0.222
	(0.0639)	(0.761)	(0.195)
Obs.	97	213	884
Time FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Large shocks			
Dynamic Costm	1.292***	1.465***	0.030
	(0.221)	(0.274)	(0.130)
Obs.	826	450	378
Time FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes

- By size of input price fluctuations (left) or those projected on IV (right).
- No clear evidence of size-dependence.

What If $\gamma^P > 0$?

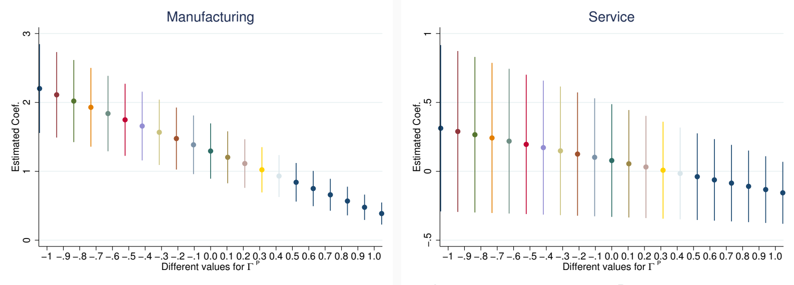


Figure 4: Estimates of γ^Φ under Various γ^P

- When $\gamma^P \in (0, 1)$, the manufacturing sector has γ^Φ around 1 and the service sector has γ^Φ around 0.
- We choose $\gamma^\Phi = 0.1$ for service sector and $\gamma^\Phi = 1$ otherwise.
- We choose $\gamma^P = 1 - \gamma^\Phi$ in benchmark and $\gamma^P = 0$ for robustness.

Inflation in Pandemic

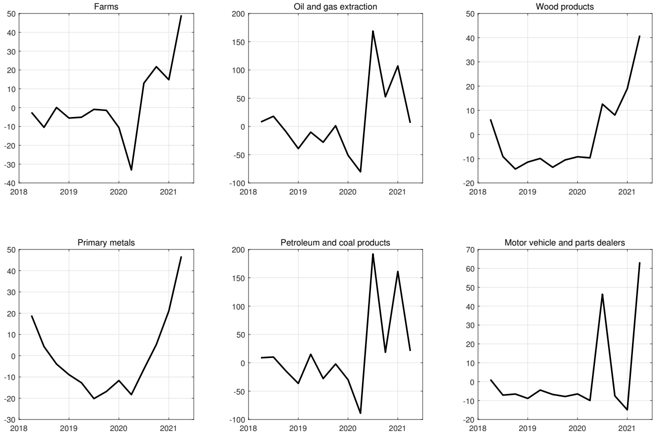


Figure 5: Inflation Gaps (APR) in 6 Leading Industries

Pandemic Study

- Why pandemic?
  - **Quasi-experiment**: not that bad to say cost driven inflation.
  - **Large shocks**: zoom in the role of service pass-through.
  - **Out-of-sample**: external validity check of our model.
  - **Disconnection**: unusual events worth exploring.

- How to study?
  - **Match** industry-level inflation gaps since 2018Q2 using markup shocks.
  - **Simulate** the model with only markups shocks before the service group.
  - **Compare** the benchmark model with data and alternative specifications for 2021Q1 and 2021Q2.

Model Solution

- **Parametric Assumption**: $\xi_t = \rho \cdot \xi_{t-1} + \epsilon_t$.
- **Equilibrium Law of Motion**: $\mathbf{P}_t = \mathbf{A} \cdot \mathbf{P}_{t-1} + \mathbf{B} \cdot \xi_t$ in which

$$\mathbf{A} = \mathbf{\Theta} + (\mathbb{I} - \mathbf{\Theta})(\mathbb{I} - \beta\mathbf{\Theta}) \sum_{s=0}^{+\infty} (\beta\mathbf{\Theta})^s (\mathbf{\Gamma}^{\Phi} \alpha \mathbf{\Omega} + \mathbf{\Gamma}^{\mathbf{P}}) \mathbf{A}^{s+1},$$

$$\mathbf{B} = (\mathbb{I} - \mathbf{\Theta})(\mathbb{I} - \beta\mathbf{\Theta}) \sum_{s=0}^{+\infty} (\beta\mathbf{\Theta})^s \left[(\mathbf{\Gamma}^{\Phi} \alpha \mathbf{\Omega} + \mathbf{\Gamma}^{\mathbf{P}}) \sum_{\tau=0}^{s} \mathbf{A}^{\tau} \mathbf{B} \rho^{s-\tau} + \rho^s \right].$$

- **Equilibrium Price Dynamics**:

$$\mathbf{P}_t = \sum_{s=0}^{+\infty} \left(\sum_{\tau=0}^{s} \mathbf{A}^{\tau} \mathbf{B} \rho^{s-\tau} \right) \epsilon_{t-s} \equiv \sum_{s=0}^{+\infty} \mathbf{IRF}_s \epsilon_{t-s}.$$

in which $\mathbf{IRF}_h$ is the h period ahead impulse response.

Shocks and Simulation

- **Calibration**: $\boldsymbol{\rho} = \rho \cdot \mathbb{I}$ and $\rho = 0.8$ from Smet et al. (2019).

- **Shocks from Observations**: one-to-one mapping as in DSGE models

$$\epsilon_t^{simu} = (\mathbf{IRF}_0^{model})^{-1} \left(\mathbf{P}_t^{data} - \sum_{s=1}^{t} \mathbf{IRF}_s^{model} \cdot \epsilon_{t-s}^{simu} \right).$$

- **Simulated Price Dynamics**: Use diagonal matrix $\mathbf{S}$ to select shocks (39 shocks from non-service industries in the benchmark model)

$$\mathbf{P}_t^{simu} = \sum_{s=0}^{t} \mathbf{IRF}_s^{model} \cdot \mathbf{S} \cdot \epsilon_{t-s}^{simu}.$$

Industry Inflation

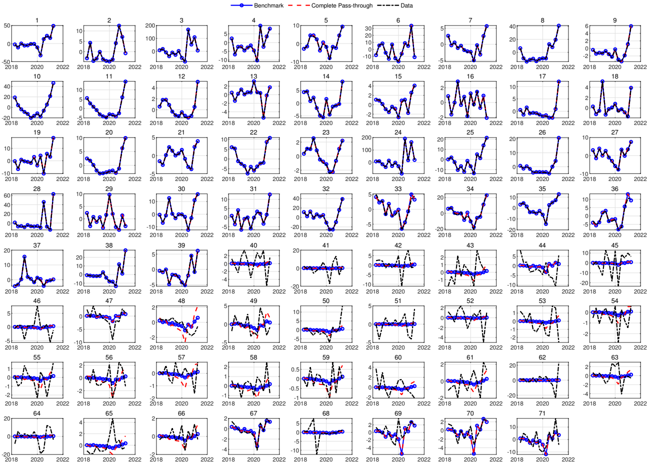


Figure 6: Industry-level Inflation Gaps (APR) with 39 Non-Service Shocks

Aggregate Inflation

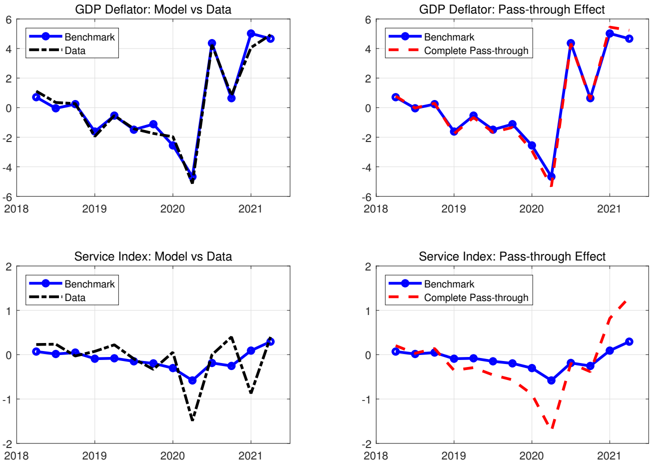


Figure 7: Aggregate-level Inflation Gaps (APR) with 39 Non-Service Shocks

Alternative Models

Table 5: Inflation Gaps (APR) with 39 Non-Service Shocks

	2021Q1		2021Q2	
	GDP deflator	Service index	GDP deflator	Service index
		Benchmark Shocks		
Data	4.07	-0.87	4.93	0.40
Benchmark	5.02	0.09	4.67	0.29
$\gamma^{\Phi}_{service} = 1$	5.45	0.82	5.24	1.29
$\gamma^{P}_{service} = 0$	5.00	0.06	4.56	0.10
$\mathbf{\Omega}^{2005-2019}$	7.41	0.19	5.25	0.34
$\mathbf{\Omega}^{uniform}$	3.34	0.18	4.50	0.70
$\mathbf{\Theta}^{uniform}$	3.10	0.07	4.40	0.40
6 shocks	3.84	0.07	2.30	0.11
		Recomputed Shocks		
$\gamma^{\Phi}_{service} = 1$	5.43	0.81	5.24	1.29
$\gamma^{P}_{service} = 0$	4.98	0.06	4.58	0.10
$\rho = 0.95$	5.15	0.21	4.79	0.49

Takeaways

- With non-service shocks, the benchmark model has a service inflation closer to data than the complete pass-through model ($\gamma^{\Phi} = 1$).
- Missing pass-through in the service sector accounts for about 1% of the missing service inflation.
- Neither hetero price rigidities nor hetero production networks are more important than the missing pass-through in the service sector.
- The simulated inflation is not sensitive to whether the model deviates from the Kimball aggregator, whether shocks are recomputed for each model, or whether markup wedge persistence is higher.

Conclusions

- The missing pass-through in service sector explains more than 1/3 (1.0% out of 2.8%) of the recent missing service inflation.
- Potential future research on
  - the deep reasons for missing pass-through in service;
  - the sources of business cycles inferred from service inflation;
  - the design of monetary policy with a target on service inflation;
  - cross-country studies.

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