State-dependent pricing and cost-push inflation in a production network economy*

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Abstract

This paper analyzes the role of state-dependent pricing in shaping cost-push inflation in a multi-sector new-Keynesian model with input-output linkages and the sector-specific degree of state-dependent price flexibility. Empirically, I estimate sector-specific price flexibility and the degree of its state dependence by fitting the model to sectoral price and quantity series for the US. I find a significant degree of state dependence in most sectors of the US economy. Theoretically, I show that state-dependent pricing can change the size and reverse the sign of cost-push inflation compared to the non-state-dependent pricing model. Based on the empirical estimates of sector-specific state dependence, I evaluate the quantitative importance of state-dependent pricing for the cost-push inflation in the US over time. State dependence substantially affects model-implied cost-push inflation during particular historical episodes - after the Great Recession and the COVID crises.

Keywords: production networks, state-dependent pricing, cost-push inflation

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1 Introduction

Quantifying the role of cost-push factors in the observed inflation is vital for effective monetary policy. The multi-sector New Keynesian literature establishes that cost-push inflation may result from sector-specific shocks. The magnitude of the cost-push effect depends on the input-output structure of the economy and the price rigidity distribution across sectors (Erceg et al., 2000; Aoki, 2001; La'O and Tahbaz-Salehi, 2020; Rubbo, 2020). This literature, however, pays little attention to the importance of the price rigidity framework and largely relies on non-state-dependent pricing approximation (e.g. Calvo). The limitation of non-state-dependent pricing is that the degree of price rigidity in each sector is constant over time. Realistically, however, the degree of price rigidity is likely to depend on the size of the shock[1]. For this reason, state-dependent pricing models may provide a better approximation of pricing behavior. In particular, if state dependence is a quantitatively important feature of price adjustment, a model with constant degree of price rigidity could yield an incorrect assessment of the size and sign of the cost-push effect.

This project analyzes how sector-level state-dependent pricing shapes cost-push inflation in a multi-sector New-Keynesian model. Specifically, it shows that the empirically plausible degree of sector-specific state dependence can change the size and the sign of cost-push inflation compared to the case of non-state-dependent pricing.

The analysis of this paper relies on the New-Keynesian Input-Output framework in the spirit of La'O and Tahbaz-Salehi (2020); Rubbo (2020). The distinctive feature of my model is the presence of sector-specific information friction resulting in state-dependent price adjustment. While the conventional state-dependent pricing frameworks, such as the menu-cost model, do not generally allow an analytical solution, state-dependent pricing based on the information friction allows me to solve the model analytically and make a direct comparison with the non-state-dependent pricing model. I model information friction as a combination of a sticky information model (Mankiw and Reis, 2002) with a heterogeneous inattention framework. This approach yields the degree of price flexibility corresponding to the share of firms updating their information, which in turn depends on the sector-specific state of the economy through a heterogeneous inattention mechanism.

The inattention framework requires establishing a set of variables tracked by inattentive firms as a signal to update their information set. To keep the model tractable, I assume that firms in each sector track only one variable, which I call the sector-relevant state. The sector-relevant state is a sector-specific linear combination of exogenous shocks affecting marginal cost in a given sector directly or through the input-output network. The change in the sector-relevant state triggers a subset of firms to update their information about the economy, and those who update receive the full information.

[1] Empirical evidence of state-dependent pricing Nakamura and Steinsson (2008); Eichenbaum et al. (2011); Campbell and Eden (2014); Cavallo and Rigobon (2016); Carvalho and Kryvtsov (2021).

The analysis of the role of state-dependent pricing in a multi-sector economy requires a realistic parameterization of the state-dependent price rigidity framework in each sector. In the empirical section, I estimate sector-specific price flexibility and its degree of state dependence by fitting the model to a set of sector-specific price and quantity series. I parameterize price flexibility in each sector to depend on two parameters: average price flexibility capturing the time-invariant (non-state-dependent) component of price adjustment, and state-dependence parameter capturing the sensitivity of price flexibility to changes in sector-relevant state. To estimate these two groups of parameters, I construct the model response of sectoral prices to sector-relevant state innovations. This response captures the effect of exogenous shocks on marginal cost in a given sector. Intuitively, the contemporaneous price response to sector-relevant shocks contains information about price flexibility. If prices respond strongly to shocks, then price flexibility is high. Moreover, if the sensitivity of prices to shocks depends on the shock size - price flexibility is state-dependent.

Estimating the price response to sector-relevant shocks requires a time series of sector-relevant state measures for every sector. The model offers a mapping from the observed sector-specific prices, wages, hours worked, and consumption to the corresponding sector-relevant state measures, conditional on the calibration of sector-specific production, consumption, and labor shares. Notably, this mapping does not involve the price-setting block of the model and, hence, is unrelated to the details of the price rigidity framework. I calibrate the sector-specific shares in the model from the US input-output tables. Then, I construct a set of sector-relevant state measures using the observed monthly sector-specific series for 370 sectors of the US economy.

The estimation results yield sector-specific estimates of the average price flexibility and state-dependence parameters, which vary substantially across sectors. Statistically significant evidence of state-dependent pricing is found in about 70% sectors of the US economy (weighted by consumption share). Moreover, the average price flexibility parameter positively correlates with the sector-relevant state volatility, meaning the sectors with volatile marginal costs have more flexible prices on average. In contrast, the degree of state dependence negatively correlates with the sector-relevant state volatility, meaning that sectors with low marginal cost volatility exhibit a higher degree of state dependence.

In the theoretical section, I analyze the conceptual role played by state-dependent pricing in shaping cost-push inflation. To this end, I derive the aggregate Phillips curve for which the residual measures the cost-push effect. The Phillips curve residual is a function of sectoral price flexibilities, production network, and sectoral price gaps between the efficient and the observed sector-specific prices. To facilitate the subsequent analysis of the effect of the state-dependent pricing framework compared to non-state-dependent pricing, I decompose this Phillips curve residual into a main component and an input-output component.

The main component captures the cost-push inflation in a counterfactual economy where prices set by those who update their information (reset prices) equal the efficient prices. The input-output component captures the effect of the real rigidity that arises in equilibrium due to the propagation of nominal rigidity through the input-output network. The real rigidity makes reset prices differ from their efficient counterparts. I show that the main component of the Phillips curve residual is affected by the state dependence of price adjustment in a significant way. In particular, state-dependent pricing may reverse the sign of the main component of the cost-push effect compared to non-state-dependent pricing, notably when an unexpectedly large shock happens in a sector with relatively low average price flexibility and a relatively high degree of state dependence.

In the quantitative section, I evaluate the importance of state dependence in shaping the cost-push effect in the US over time. To this end, I compute the monthly cost-push effect using the expression derived in a theoretical section. I calibrate the price sector-specific price flexibility framework using the estimates of price flexibility and state dependence from the empirical section. For sectoral price gaps computation, I employ the previously constructed monthly series for monthly sector-relevant states and the observed sectoral prices. To evaluate the role of state-dependence, I compute the counterfactual effect without a state-dependent pricing component of price flexibility. Overall, the state-dependent pricing model produces a more volatile cost-push effect over time than the non-state-dependent model. State dependence plays a drastically different role during different historical periods. In 2009, just after the Great Recession, the cost-push effect was positive according to both the state-dependent and non-state-dependent pricing models, with state-dependence serving as an amplifying mechanism that strengthened the cost-push effect. In contrast, for the period after the COVID crisis, the state-dependent pricing model generates a cost-push effect, often having a different sign, compared to the non-state-dependent pricing model. I also document that the model-implied cost-push effect has significant explanatory power when added to a standard Phillips curve regression and outperforms the oil prices and the non-state-dependent counterpart in explaining aggregate inflation fluctuations. Finally, I show that state dependence in a subgroup of service-related sectors constituting less than 25% of consumption accounts for the bulk of the difference between state-dependent and non-state-dependent cost-push effects.

2 Related literature

This paper relates to the literature on monetary policy trade-offs in multi-sector economies. Aoki (2001) study a two-sector horizontal economy and show that with one sticky and one flexible sector, cost-push inflation appears in response to sector shocks. Erceg et al. (2000) show that upstream rigidity (sticky wages) results in a monetary policy trade-off in a two-sector vertical economy. More recently, La'O and Tahbaz-Salehi (2020) and Rubbo (2020) showed that monetary policy trade-off arises in a more general production network economy under information-related price rigidity and Calvo-type price rigidity. The common feature of all these studies is the time-constant degree of price rigidity in each sector. However, Ball and Mankiw (1995) argue that what contributes to cost inflation is a combination of state-dependent price rigidity with asymmetric distribution of desired relative price changes. Building on Ball and Mankiw (1995) conceptual insight, I aim to understand the importance of state dependence for cost-push inflation in a production network economy.

The paper relates the macroeconomic literature on production networks. Seminal contributions include Long Jr and Plosser (1983) and Acemoglu et al. (2012) who develop the framework for efficient production network economy and Baqaee and Farhi (2020), Bigio and La'o (2020) who contribute to the analysis of inefficient network economy with exogenous markups. Similarly to monetary models of La'O and Tahbaz-Salehi (2020) and Rubbo (2020), I endogenize markups by introducing a price rigidity framework. However, in contrast to these papers, I use a price rigidity mechanism based on ad hoc heterogeneous inattention, which allows modeling state-dependent price rigidity at a sectoral level.

The empirical evidence of state-dependent pricing is extensive. Nakamura and Steinsson (2008) show that the frequency of price increases positively depends on inflation in the micro-data underlying the U.S. CPI index. Eichenbaum et al. (2011) and Campbell and Eden (2014) report evidence of the state-dependent frequency of price changes in the U.S. scanner data. Cavallo and Rigobon (2016) report a bi-modal distribution of price changes in online price data, consistent with state-dependent models. Carvalho and Kryvtsov (2021) find evidence of strong selection effect into price adjustment in the micro-data underlying CPI of the U.K., Canada, and the U.S. I contribute to the current stock of evidence of state-dependent price adjustment by providing sector-specific (at the BEA code level) measures of state-dependence. While existing evidence largely relies on micro-level data, my estimation method relies on a production network model combined with sectoral price and wage data.

In terms of approach towards modeling state-dependent price rigidity, my paper belongs to sticky information literature (Mankiw and Reis (2002)) and behavioral inattention literature (Gabaix (2019)) as my state-dependent price rigidity combines these two features. Compared to the two conventional rationality-based frameworks, that is menu-cost approach (Dotsey et al. (1999), Caballero and Engel (2007)) and rational inattention approach (Sims (2003), Reis (2006)) my model remains analytically tractable.

Finally, this paper relates to the literature on money non-neutrality. Nakamura and Steinsson (2010) show that intermediate inputs can fix the weak money non-neutrality feature of menu-cost models brought up by Caplin and Spulber (1987), Golosov and Lucas Jr (2007)). The ability of intermediate inputs to increase money non-neutrality has also been documented for production network models with a heterogeneous but time-invariant degree of price rigidity by Shamloo (2010), Bouakez et al. (2014) and Pasten et al. (2020). The money non-neutrality literature deals with the real effects of monetary policy. In contrast, I focus on the effect of state-dependent pricing on cost-push inflation.

3 Model description

The model is a multi-sector general equilibrium model with prodution network and state-dependent sectoral price rigidity. Two features are specific to the present model 1) sector-sepcific labor, allowing sector-specific wages, 2) custom price rigidity framework based on behavioral inattention and sticky information, allowing for a relatively simple treatment of state-dependent sectoral price rigidity. Next, I describe the model setup.

3.1 Firms

There are N production sectors. In each sector, there is a continuous number of monopolistically competitive firms indexed by $k \in [0,\ 1]$. Sectoral output and price indices are the CES sums across all firms within a sector. Sectoral output index is $Y_{t,i} = \left(\int_0^1 Y_{t,i,k}^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}$ and sectoral price index is $P_{t,i} = \left(\int_0^1 P_{t,i,k}^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}$. The firm-specific demand is

$$Y_{t,i,k} = \left(\frac{P_{t,i,k}}{P_{t,i}} \right)^{-\epsilon} Y_{t,i} \tag{1}$$

Production technology is constant returns to scale and is given by

$$Y_{t,i,k} = A_{t,i} L_{t,i,k}^{\alpha_i} \prod_j X_{t,ij,k}^{\omega_{ij}(1-\alpha_i)}$$

where $A_{t,i}$ is sector-specific productivity, $L_{t,i,k}$ is labor used by firm k of sector i, $X_{t,ij,k}$ is input of sector j used by firm k in sector i; α_i corresponds to the labor share in production costs and ω_{ij} corresponds to the share of input j in the intermediate input costs.

The combination of inputs is chosen to minimize the unit cost of production, given input prices. Let $MC_{t,i}$ be the marginal cost in sector i, which is the same for all firms within sector i. Cost-minimizing resource allocation yields sectoral labor demand and intermediate input demand

$$W_{t,i} L_{t,i} = \alpha_i MC_{t,i} Y_{t,i} \tag{2}$$

$$P_{t,j} X_{t,ij} = (1-\alpha_i) \omega_{ij} MC_{t,i} Y_{t,i} \tag{3}$$

Then, marginal cost of production in sector i is

$$MC_{t,i} = \frac{1}{\alpha_i^{\alpha_i} \prod_j (\omega_{ij}(1-\alpha_i))^{\omega_{ij}(1-\alpha_i)}} \cdot \frac{1}{A_{t,i}} \cdot W_{t,i}^{\alpha_i} \prod_j P_{t,j}^{\omega_{ij}(1-\alpha_i)} \tag{4}$$

Input-output matrix Ω is such that Ω_{ij} is a share of input j in total cost of product j, $\Omega_{ij} = (1-\alpha_i)\omega_{ij}$. $L = (I-\Omega)^{-1}$ is the corresponding *Leontief inverse* matrix capturing the total effect of shocks (see Baqaee and Farhi (2020)). The total effect consists of the direct effect and the effect arising through the production network.

Firms have imperfect information (to be precised below) such that firm k in sector i has sectoral marginal cost belief $\widetilde{MC}_{t,i,k}$. Firm k sets the price $P_{t,i,k}$ to maximize its perceived profits

$$P_{t,i,k}Y_{t,i,k} - (1-\bar{\tau})\widetilde{MC}_{t,i,k}$$

subject to demand constraint (1); $\bar{\tau} = \frac{1}{\epsilon}$ is a subsidy correcting the inefficiency stemming from monopoly power. The price set by firm k is

$$P_{t,i,k} = \widetilde{MC}_{t,i,k}$$

Firm price can be expressed as $P_{t,i,k} = \frac{\widetilde{MC}_{t,i,k}}{MC_{t,i}} MC_{t,i}$. Undesired firm-specific markup resulting from information rigidity is $\frac{\widetilde{MC}_{t,i,k}}{MC_{t,i}}$. I define $\mathcal{M}_{t,i}$ to be the average markup in sector i as

$$P_{t,i} = \mathcal{M}_{t,i} \cdot MC_{t,i} \tag{5}$$

3.2 Information structure

Information updating by firms relies on a sticky information framework (Mankiw and Reis (2002)) extended by an ad-hoc heterogeneous inattention across firms to allow for state-dependence in the intensity of information updating.

3.2.1 Sticky information

Let $F_{t,i}$ be the share of firms in sector i updating their information in the period t. Those firms who update observe the true sectoral marginal costs $MC_{t,i}$ and set their prices to $P_{t,i|t} = MC_{t,i}$. The share of firms who last updated their information 1 period ago is $F_{t-1,i} \cdot (1-F_{t,i})$. The share who has updated h periods ago is $F_{t-h,i} \cdot \prod_{s=0}^{h-1}(1-F_{t-s,i})$. Those who updated their information h periods ago set their price to the perceived marginal costs according to the h-periods outdated information $P_{t,i|t-h} = E_{t-h}MC_{t,i}$. The average price in sector i consists of individual prices of firms with different information sets

$$P_{t,i}^{1-\epsilon} = F_{t,i} \cdot (MC_{t,i})^{1-\epsilon} + \sum_{h=1}^{\infty} \left\{ \left[\prod_{s=0}^{h-1} (1 - F_{t-s,i}) \right] \cdot F_{t-h,i} \cdot (E_{t-h} MC_{t,i})^{1-\epsilon} \right\} \tag{6}$$

3.2.2 Inattention

In a conventional sticky information model the share of firms updating their information at any given period is constant over time. In contrast, I assume that this share is affected by the fluctuations in the underlying *sector-relevant state* $s_{i,t}$. Fluctuations in sector-relevant state lead to the time-varying the intensity of information acquisition. I choose a suitable state variable for each sector based on log-linear characterization of the model equilibrium. Hence, I postpone the precise definition of $s_{t,i}$ to the next section. Next, I describe the inattention framework.

Let firms in sector i have heterogeneous degree of inattention. That is, every period the degree of inattention of firm k in sector i is drawn from a sector-specific distribution $x \sim F_i$. Firms in sector i track absolute size of fluctuations in the sector-relevant state $|\Delta s_{t,i}|$ where $\Delta s_{t,i} = s_{t,i} - s_{t-1,i}$. Only firms with low enough degree of inattention $x < |\Delta s_{t,i}|$ update their information set. As a result, the share of firms updating their information set in sector i is

$$F_{t,i} = Pr\{x < |\Delta s_{t,i}|\} = F_i(|\Delta s_{t,i}|) \tag{7}$$

The large changes in the sector-relevant state push more firms to update their information set[2]. The time-varying share of firms updating their information in each sector corresponds to the state-dependent price flexibility, allowing to address the role of state-dependent pricing without losing the tractability of the model.

3.3 Households

Representative household chooses final consumption good Y_t and hours worked $L_{t,i}$ in each sector to maximize utility subject to budget constraint. Household utility is

$$u(Y_t) - \sum_i e^{\chi_{t,i}} \cdot v(L_{t,i})$$

where final consumption Y_t good is a combination of sectoral consumption goods $C_{t,i}$

$$Y_t = \prod_i C_{t,i}^{\beta_{t,i}} \tag{8}$$

[2]Similar technique for modeling partial adjustment within a group has been applied in generalized menu-cost models. In these models, the cost of price adjustment is heterogeneous across firms, which results in partial price adjustment (Caballero and Engel (2007)).

with $\sum_i \beta_{t,i} = 1$. The sectoral labor and consumption preference parameters $\chi_{t,i}$ and $\beta_{t,i}$ can be potentially time-varying as indicated by the subscript t. This variation introduces additional sources of fluctuations into the model otherwise driven solely by sectoral productivity shocks. Additional sources of fluctuations allow me to employ more data in the model-based empirical analysis laid out in the next section and check the robustness of my baseline results

The household's budget constraint is $P_t Y_t = \sum_i P_{t,i} C_{t,i} = \sum_i W_{t,i} L_{t,i} + T_t$, where P_t is the consumer price index, $W_{t,i}$ are sectoral wage rates, T_t are net transfers (including lump sum taxes and subsidies as well as profits from firm ownership). Optimal allocation of consumption across sectors yields sectoral consumption demand

$$P_{t,i} C_{t,i} = \beta_{t,i} \cdot P_t Y_t \tag{9}$$

The corresponding consumer price index is $P_t = \prod_i \left(\frac{P_{t,i}}{\beta_{t,i}}\right)^{\beta_{t,i}}$.

Let the functional form of utility is $u(Y) = log(Y)$ and $v(L_i) = \frac{L_i^{1+\gamma}}{1+\gamma}$. Then, optimal consumption-leisure trade-off yields sectoral labor supply

$$W_{t,i} = \chi_{t,i} \cdot L_{t,i}^{\gamma} P_t Y_t \tag{10}$$

3.4 Monetary policy

Monetary policy controls money supply which equals nominal spending, that is

$$P_t \cdot Y_t = M_t \tag{11}$$

3.5 Equilibrium

In a competitive equilibrium, all markets clear given the described behavior of firms and households. Product market clearing in sector i implies that product of sector i is either consumed or used as intermediate input.

$$Y_{t,i} = C_{t,i} + \sum_j X_{t,ji} \tag{12}$$

4 Log-linear model

The model is given by equations (1)-(12). I log-linearize the model around the efficient steady state. Efficient steady state is a time-invariant equilibrium in which markups are $\mathcal{M}_i = 1$ for every sector i.

Throughout the paper, I denote column vectors $[X_1, ..., X_N]'$ with corresponding bold letters $\boldsymbol{X}$. Log-deviation of X is denoted by small x, so that $x = log(X) - log(\bar{X})$. Next, I list the key log-linear equations which are used in the further analysis. All derivations are available in Appendix A.

The model has two conceptual blocks: the demand block and the supply block. The demand block does not depend on the price setting framework and on price flexibility while the supply block is shaped by the price-setting framework.

4.1 Sectoral demand system

Log-lienar sectoral consumption demand and sectoral labor supply from (9) and (10) are

$$\boldsymbol{p_t} + \boldsymbol{c_t} = \boldsymbol{b_t} + (p_t + y_t) \cdot \mathbf{1} \tag{13}$$

$$\boldsymbol{w_t} = \boldsymbol{\chi_t} + \gamma \cdot \boldsymbol{l_t} + (p_t + y_t) \cdot \mathbf{1} \tag{14}$$

where the aggregate nominal spending is $m_t = p_t + y_t$ is controlled by monetary policy; $\boldsymbol{b_t} = log(\boldsymbol{\beta_t}) - \log(\boldsymbol{\bar{\beta}_t})$ captures sectoral consumption demand shifts and $\boldsymbol{\chi_t}$ - sectoral labor supply shifts; $\mathbf{1}$ is the vector of ones.

Sectoral wages. Log-linear equilibrium link between wages and markups is obtained by combining the product market clearing condition (12) with the conditions for optimal input allocation (2)-(3), the link between sectoral prices and marginal costs (5), and the log-linear equations (13)-(14). The resulting system of wage equations is

$$\boldsymbol{w_t} = (p_t + y_t) \cdot \mathbf{1} + \frac{1}{1+\gamma} \cdot \boldsymbol{\chi_t} + \frac{\gamma}{1+\gamma} I_\xi^{-1} L' I_\beta \cdot \boldsymbol{b_t} - \frac{\gamma}{1+\gamma} I_\xi^{-1} L' I_\xi \cdot \boldsymbol{\mu_t} \tag{15}$$

where $\boldsymbol{\mu_t}$ is vector of log-deviations of markups; $L = (I - \Omega)^{-1}$ is Leontief inverse, Ω is input output matrix; $I_\xi = diag\{\boldsymbol{\xi}\}$ is diagonal matrix with sectoral *Domar weights* $\xi_i = \frac{P_i Y_i}{PC}$ (computed at the steady-state) on the diagonal.

Sectoral prices. Sectoral prices expressed through sectoral markups are obtained by combining sectoral marginal cost equations (4), log-linear wage equations (15) and the the definition of sectoral markups (5). The resulting system of price equations is

$$\boldsymbol{p_t} = (p_t + y_t) \cdot \mathbf{1} + \tilde{L} \boldsymbol{\mu_t} + \left[-L \boldsymbol{a_t} + \frac{1}{1+\gamma} L I_\alpha \cdot \boldsymbol{\chi_t} + \frac{\gamma}{1+\gamma} L I_\alpha I_\xi^{-1} L' I_\beta \cdot \boldsymbol{b_t} \right] \tag{16}$$

where $\tilde{L} = L(I - \frac{\gamma}{1+\gamma} I_\alpha I_\xi^{-1} L' I_\xi)$, $I_\alpha = diag\{\boldsymbol{\alpha}\}$ is diagonal matrix with labor shares in sectoral costs α_i on the diagonal. Aggregating the above system using the steady state consumption weights $\boldsymbol{\beta}$, I obtain aggregate final output

$$y_t = \boldsymbol{\xi'} \cdot \boldsymbol{a_t} + \frac{1}{1+\gamma}\boldsymbol{\xi'} I_\alpha \cdot \boldsymbol{\chi_t} - \frac{1}{1+\gamma}\boldsymbol{\xi'} \cdot \boldsymbol{\mu_t} \tag{17}$$

where the first two terms $y_t^e = \boldsymbol{\xi'} \cdot \boldsymbol{a_t} + \frac{1}{1+\gamma}\boldsymbol{\xi'} I_\alpha \cdot \boldsymbol{\chi_t}$ constitute the efficient output and the last term $\tilde{y}_t = -\frac{1}{1+\gamma}\boldsymbol{\xi'} \cdot \boldsymbol{\mu_t}$ is the output gap arising due to non-zero markups and capturing aggregate demand.

4.2 Sector-relevant state definition

From sectoral price system (16), the sectoral marginal cost obtains as $mc = p - \mu$, that is

$$\boldsymbol{mc_t} = (p_t + y_t) \cdot \boldsymbol{1} + (\tilde{L} - I) \cdot \boldsymbol{\mu} + \left[-L\boldsymbol{a_t} + \frac{1}{1+\gamma} L I_\alpha \cdot \boldsymbol{\chi_t} + \frac{\gamma}{1+\gamma} L I_\alpha I_\xi^{-1} L' I_\beta \cdot \boldsymbol{b_t} \right] \tag{18}$$

the first two terms are endogenous, while the term in square brackets is exogenous. I use the term in square brackets to define the sector-relevant state $s_{t,i}$ for every sector. The corresponding sector-relevant state vector is

$$\boldsymbol{s_t} = -L\boldsymbol{a_t} + \frac{1}{1+\gamma} L I_\alpha \cdot \boldsymbol{\chi_t} + \frac{\gamma}{1+\gamma} L I_\alpha I_\xi^{-1} L' I_\beta \cdot \boldsymbol{b_t} \tag{19}$$

Definition 1 (Sector-relevant state)**.** Sector-relevant state for sector i, denoted as $s_{t,i}$, is a linear combination of sectoral productivities, as well as consumption demand and labor supply sifters such that each sector enters this combination with the weight corresponding to the strength of its effect on the marginal costs in sector i.

Note that for productivities the corresponding weights L_{ij} are the elements of the Leontief inverse matrix. For consumption demand and labor supply sifters the corresponding weights are also related to the Leontief inverse. Intuitively, if sector i is strongly connected to sector j by either upward or downward links of the input-output network, then the changes in sector j affect marginal cost in sector i, making sector j shocks relevant for sector i marginal cost.

Finally, the change in relevant state over time is

$$\boldsymbol{\Delta s_t} = \boldsymbol{s_t} - \boldsymbol{s_{t-1}} \tag{20}$$

and the sectoral price flexibility depends on this sector-specific change, that is $F_{t,i} = F_i(|\Delta s_{t,i}|)$, as described in the previous section.

I assume that exogenous forces in the model follow random walks, that is, $\boldsymbol{a_t} = \boldsymbol{a_{t-1}} + \boldsymbol{\epsilon_t^a}$, $\boldsymbol{b_t} = \boldsymbol{b_{t-1}} + \boldsymbol{\epsilon_t^b}$, and $\boldsymbol{\chi_t} = \boldsymbol{\chi_{t-1}} + \boldsymbol{\epsilon_t^\chi}$. Then, the change in the sector-relevant state constitutes an innovation, that is $Cov(\Delta s_{t,i},\ s_{t-1,i}) = 0$.

4.3 Sectoral supply system

The price-setting behavior subject to information friction yields the log-linear supply-side link between prices and markups from Equations (6)-(5). I use the partial log-linearization, that is, I treat all $F_{t-s,i}$ as time-varying coefficients, since they depend only on exogenous sector-relevant states

$$(I - F_t) \cdot (\boldsymbol{p_t} - \boldsymbol{p_{t-1}}) = -F_t \cdot \boldsymbol{\mu_t} + (I - F_t) \cdot \boldsymbol{e_{t-1}} \tag{21}$$

where F_t is a diagonal matrix with sectoral flexibililities $F_{t,i}$ on diagonal (the parameters governing $F_{t,i}$ are estimated in the next section); $\boldsymbol{e_{t-1}}$ is vector collecting past expectations about the present marginal cost growth, such that $e_{t-1,i} = F_{t-1,i}E_{t-1}\Delta mc_{t,i} + \sum\limits_{h=1}^{\infty} \left\{ F_{t-1-h,i} \cdot \left[\prod\limits_{s=0}^{h-1} (1 - F_{t-1-s,i}) \right] \cdot E_{t-1-h}\Delta mc_{t,i} \right\}$ is predetermined in period t; $\Delta mc_{t,i} = mc_{t,i} - mc_{t-1,i}$. Note, that log-linearization is partial for this equation. That is, the sequence $\{F_{h,i}\}_{h=-\infty}^{t}$ of past and present shares of information updating firms is treated as given. Note that in the sticky information framework, prices depend not on current expectations about the future, but on the past expectations about the present. This means that the sequence of past price flexibility, rather than the expected sequence of future price flexibility, influences the equilibrium prices.

The system of equations (21) has time-varying coefficients $F_{t,i}$. The time-average of each $F_{t,i}$ determines the average degree of price flexibility in a given sector over time, encountered in non-state-dependent pricing models. The variability of $F_{t,i}$ over time determines the strength of the state-dependent pricing mechanism in sector i. In the next section, I parameterize $F_{t,i}$ to capture these characteristics and estimate the corresponding sectoral price flexibility and state dependence by fitting the model to the disaggregated sectoral data of the US economy.

5 Empirical evidence of state-dependent pricing

In this section, I estimate sector-specific price flexibility $F_i(|\Delta s_{t,i}|)$ for the disaggregated sectors of the US economy. To this end, I construct the model response of sectoral prices to the contemporaneous sector-relevant state changes. This response is informative about price flexibility - the more sensitive are prices to shocks, the higher the degree of price flexibility is. Moreover, the dependence of price sensitivity to shocks on the size of these shocks captures the state dependence in price adjustment. I construct a monthly time series of sector-relevant state changes $\Delta s_{t,i}$ for each sector from the observed monthly sectoral data using equations from the demand block of the model. Then fit the model response yielding state-dependent price price flexibility estimates for every sector. Next, I lay out the details of the methodology, data construction, and estimation.

5.1 Methodology

Imagine for a moment that we observe a vector of sector-relevant states $\boldsymbol{s_t}$. From (16), the sectoral prices are related to $\boldsymbol{s_t}$ as

$$\boldsymbol{p_t} = m_t \cdot \mathbf{1} + \tilde{L} \cdot \boldsymbol{\mu_t} + \boldsymbol{s_t}$$

The above equation implies that the contemporaneous price response to change in s_t consists of a direct effect as well as the effect that the sector-relevant state change has on markups and monetary policy.

From (15), (16), and (20), sectoral markups $\boldsymbol{\mu_t}$ and sector-relevant state changes $\boldsymbol{\Delta s_t}$ are linked as

$$(\tilde{L} + (I - F_t)^{-1} \cdot F_t) \cdot \boldsymbol{\mu_t} = -\boldsymbol{\Delta s_t} + \boldsymbol{\tilde{v}_t} \tag{22}$$

where $\boldsymbol{\tilde{v}_t} = \boldsymbol{p_{t-1}} + \boldsymbol{e_{t-1}} - m_t \cdot \mathbf{1} - \boldsymbol{s_{t-1}}$. Note, that the term $\boldsymbol{\tilde{v}_t}$ contains only predetermined variables $\boldsymbol{p_{t-1}}$, $\boldsymbol{s_{t-1}}$, $\boldsymbol{e_{t-1}}$ and monetary policy variable m_t, and, hence, is independent from $\boldsymbol{\Delta s_t}$ as long as monetary policy does not react to $\boldsymbol{\Delta s_t}$ within one month period (I use monthly data for estimation).

The matrix $F_t = diag\{F_{t,i}\}$ is diagonal with sectoral price flexibilities $F_{t,i} = F_i(|\Delta s_{t,i}|)$ on the main diagonal. I impose a linear functional form on on F_i such that

$$F_i(|\Delta s_{t,i}|) = \bar{F}_i + f_i \cdot log \frac{|\Delta s_{t,i}|}{E|\Delta s_{t,i}|} \tag{23}$$

where $E|\Delta s_{t,i}|$ is the average absolute size of the relevant productivity state fluctuations (relevant state volatility). With this functional form, the parameter $\bar{F}_i$ corresponds to the average price flexibility over time in sector i, that is, the degree of price flexibility under the average size of sector-relevant state fluctuations in sector i. The parameter f_i measures the degree of state dependence in price adjustment. This parameter shows how much price flexibility varies with the size of the absolute changes in the sector-relevant state.

The goal of the empirical exercise is to estimate the average price flexibility $\bar{F}_i$ and the degree of state dependence f_i for each sector of the US economy. For an economy with N sectors there are $2 \times N$ parameters to be estimated. As long as we observe sector-relevant states $\boldsymbol{s_t}$ and sectoral markups $\boldsymbol{\mu_t}$, we can evaluate the price flexibility parameters from the system (22) of N interlinked equations. However, this task is computationally non-trivial. To make the estimation possible, I rearrange the terms in (22) to make individual equations independent from each other with respect to the estimated parameters across sectors. The rearranged system is

$$\boldsymbol{\Delta s_t} + \tilde{L}\boldsymbol{\mu_t} = F_t \cdot \Big[\boldsymbol{\Delta s_t} + (\tilde{L} - I)\boldsymbol{\mu_t}\Big] + (I - F_t) \cdot \boldsymbol{\tilde{v}_t}$$

Since matrix of sectoral price flexibilities F_t is diagonal, i-th equation in the above system contains only sector i price flexibility parameters, meaning that this system can be estimated equation-by-equation, with one equation per sector. Denoting $\boldsymbol{y_t} = \boldsymbol{\Delta s_t} + \tilde{L}\boldsymbol{\mu_t}$, $\boldsymbol{x_t} = \boldsymbol{\Delta s_t} + (\tilde{L} - I)\boldsymbol{\mu_t}$ and $\boldsymbol{v_t} = (I - F_t) \cdot \boldsymbol{\tilde{v}_t}$ and using the parameterized function F_i, I get N equations of the form

$$y_{t,i} = \bar{F}_i \cdot x_{t,i} + f_i \cdot log \frac{|\Delta s_{t,i}|}{E|\Delta s_{t,i}|} x_{t,i} + v_{t,i} \tag{24}$$

These equations can be estimated independently from each other. The only complication is that $x_{t,i}$ is endogenous as it contains (endogenous) markups. At the same time, the sector-relevant state changes $\Delta s_{t,i}$ are exogenous and can serve as an instrument for $x_{t,i}$. In Appendix C, I formally show that $\Delta s_{t,i}$ is not correlated with the residual $v_{t,i}$ and hence is a valid instrument for $x_{t,i}$.

Estimating equations (24) using IV approach yields a set of average sectoral flexibilities $\{\bar{F}_i\}_{i=1}^N$ measuring non-state-dependent price flexibility, and a set of sensitivities to sector-relevant state changes $\{f_i\}_{i=1}^N$ measuring the degree of state-dependence of price flexibility in each sector. Since $v_{t,i}$ is heteroskedastic and autocorrelated I use consistent standard errors to determine estimate statistical significance.

5.2 Constructing sector-relevant states

The empirical method described above requires observing sector-relevant state changes $\boldsymbol{\Delta s_t}$ and markups $\boldsymbol{\mu_t}$. I construct these objects from the demand block of the model using the observed data.

First, let us assume that sectoral productivity changes are the only driving force in the economy, that is $b_{t,i} = 0$ and $\chi_{t,i} = 0$ for all sectors. In what follows I refer to such specification of the model as "baseline". In the "baseline" model, we can compute sectoral markups $\boldsymbol{\mu_t}$ and sector-relevant states $\boldsymbol{s_t}$ from (15) and (16), as long as we observe sectoral wages $\boldsymbol{w_t}$, sectoral prices $\boldsymbol{p_t}$, as well as aggregate consumer price p_t and final consumption y_t. This is a minimal possible set of shocks and data needed for estimation.

Accounting for the possible additional presence of sectoral consumption demand shocks and sectoral labor supply shocks ($b_{t,i}$ and $\chi_{t,i}$) requires more data, notably, on sectoral quantities. Sectoral demand shifts $\boldsymbol{b_t}$ can be computed from sectoral consumption demand equations 13, as long as we additionally observe sectoral consumption $\boldsymbol{c_t}$. Sectoral labor supply shifts $\boldsymbol{\chi_t}$ can be computed from sectoral labor supply equations 14, as long as we additionally observe sectoral hours worked $\boldsymbol{l_t}$. I employ this extended specification to test the robustness of the "baseline" results.

The caveat is that some sectors are missing in the data and the number of missing sectors changes over time. Hence for any t, I compute sectoral markups $\boldsymbol{\mu_t}$ and sector-relevant states $\boldsymbol{s_t}$ only for those sectors for which wages and prices are observed. The details of these computations are provided in Appendix C.

5.3 Data

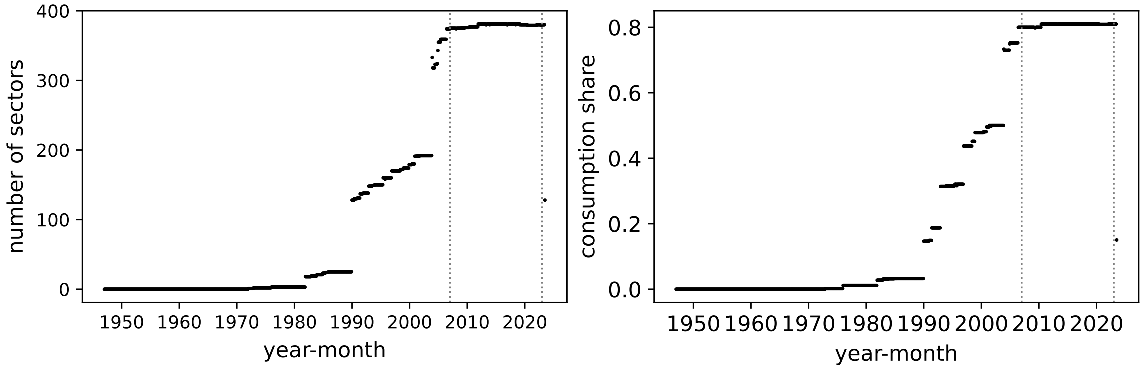
There are two categories of data used in the present analysis: the data used for calibration of the model, and the sectoral/aggregate time-series data.

Model calibration. To compute the intermediate goods, labor, and consumption shares in each sector, I employ the 2007 "Use table" from the BEA (US Bureau of Economic Analysis) inputs-outputs account data . In this table, sectors are classified using BEA codes. I assume that each sector produces only one commodity and remove commodities that do not have a sector correspondence and vice-versa. Further, I remove sectors related to government spending, non-comparable imports, and the rest of the world adjustment. I also remove sectors for which the sum of intermediate and labor costs is zero. I compute labor shares in each sector as a ratio of labor costs to total costs. I compute intermediate input share as a ratio of a given intermediate input cost to the total cost. Finally, I compute consumption shares as the ratio of consumption expenditure on a given sector to the total consumption expenditure. I set the Frisch labor supply elasticity to 1.

Sectoral/aggregate time series. To compute model-implied sector-relevant state and markup series in the "baseline" model, I employ monthly time series for sectoral wages and prices, and the aggregate prices and consumption indices. Monthly wages by sector are available from the "Current Employment Statistics" (CES) from the US BLS and classified with a specific CES classification. Monthly sectoral producer price indices are from the US BLS and classified according to the NAICS classification. Since the BEA input-output matrix uses BEA sector classification codes, I convert the wage and price data to the BEA classification to match the sectors of the input-output matrix. The details are provided in Appendix C. The aggregate consumer spending and price index are from BEA. The extended specification of the model also requires sectoral consumption and hours worked data. I obtain the former from the BEA database and the latter from the CES database.

Figure 1 plots the number of sectors for which both prices and wages are available in a given year and month (left Panel) and the consumption share coverage (right Panel) for each year and month. The data availability improves over time and starts covering the majority of sectors by 2007.

Figure 1: Availablility of sectoral price and wage data



Left Panel: number of sectors for which price and wage observations are available in a given month. **Right Panel**: share of consumption covered by the available sectors in a given month. Vertical dotted lines mark the period for which the large and stable number of sectors is available (2007-2023).

5.4 Estimation results

The estimation procedure yields two sets of sectoral parameters: sectoral average price flexibility measures $\bar{F}_i$ and sectoral state dependence of price flexibility f_i. These parameters determine sectoral price flexibility $F_{t,i}$ at time t according to Equation (23). Table 1 shows the share of sectors with statistically significant parameter estimates. Around 85% of sectors have a statistically significant degree of price flexibility, suggesting that even within a short one-month period most sectoral prices react to shocks to a certain extent. Around 70% sectors have a statistically significant degree of state dependence, meaning that many sectors in the US economy feature state dependence in price adjustment.

Table 1: Share of statistically significant estimates

	signif. at 90% level	signif. at 95% level
Average flex. ($\bar{F}_i$)	0.85	0.84
State-dep. param. (f_i)	0.70	0.64

Note: Sectors are weighted by their corresponding consumption shares β_i

Table 2 plots a summary of the cross-sectoral distribution of estimated parameters. The estimates of average price flexibility vary between 0 and 1 with a median of around 0.27, which means that in the median sector around 27% of firms reset their information within one month period; in other words, in the median sector, prices remain unchanged at least for four months, which corresponds to the evidence of Bils and Klenow (2004) who report median price duration of 4.3 months. However, the range of the average price flexibility estimates across sectors is quite broad. Figure 2 Panel (a) plots the histogram of the average price flexibility estimates in each sector. The pattern of average price flexibility suggests that commodity-related and upstream sectors such as oil and metals have more flexible prices, while various manufacturing sectors have less flexible prices.

The distribution of state dependence parameters in Table 2 suggests the median degree of state dependence of 0.17, which means that the sector-relevant state change of 1 percentage point above its average leads to an increase in sectoral price flexibility by 0.0017 price flexibility units. Figure 2 Panel (b) plots the histogram of the cross-sectoral distribution of state dependence estimates. Sectors with both low and high degree of state dependence include manufacturing and services, hence this histogram does not reveal any obvious pattern for the link between state dependence and the broad type of sector.

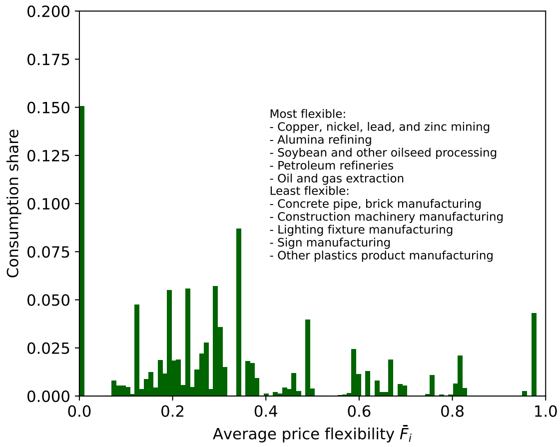
Table 2: Distribution of statistically significant estimates

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Average flex. ($\bar{F}_i$)	0.052	0.177	0.277	0.349	0.473	0.989
State-dep. param. (f_i)	0.013	0.092	0.189	0.203	0.293	0.663

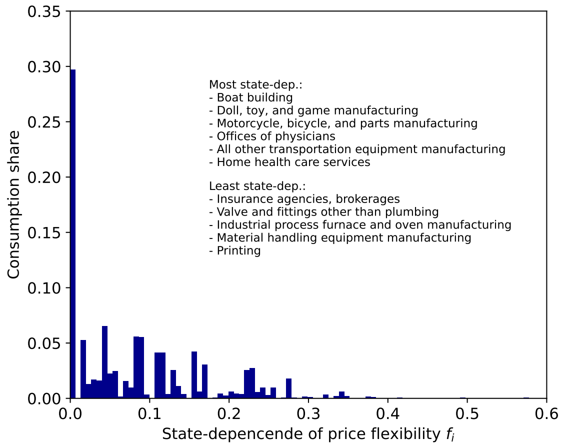
Note: Only sectors with statistically significant estimates at 90% level

Figure 2: Price flexibility estimates

(a) Average price flexibility



(b) State-dependence of price flexibility



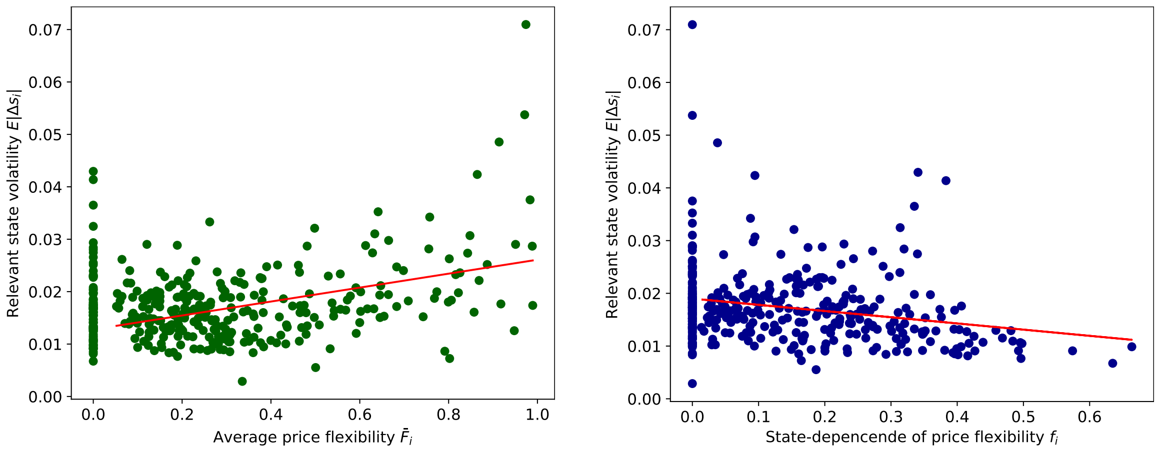
Histogram of average price flexibility estimates $\bar{F}_i$ (a) and state-dependence parameter estimates f_i (b) across 364 sectors; sectors are weighted by consumption shares β_i; variation is plotted only for 90%-level significant estimates; **estimates insignificant at 90% level are forced to zero**; interpretation of state-dependence parameter f_i: 1.p.p. increase in $|\Delta s_{t,i}|$ above its time average leads to price flexibility increase of $0.01 \cdot f_i$.

Next, I analyze how the average price flexibility and the state dependence parameters relate to the volatility of the sector-relevant state. Figure 3 plots the parameter estimates and the corresponding relevant state volatilities. Figure 3 Panel (a) plots the sector-relevant state volatilities against average price flexibility estimates. The higher average volatility in a sector is associated with higher average price flexibility. This suggests that sectors with more volatile conditions have higher price flexibility on average. Panel (b) plots sector-relevant state volatilities against the corresponding state dependence parameters. The higher volatility in a sector is associated with a lower degree of state dependence, suggesting that more volatile sectors have less state dependence in their pricing. This result implies that the less volatile (and hence less flexible) sectors on average tend to adjust their price flexibility more to shocks, meaning that sectors with overall rigid prices may temporarily have larger price flexibility in the face of exceptionally large shocks.

Figure 3: Relevant state volatility and price flexibility

(a) Average price flexibility

(b) State-dependence of price flexibility



Average price flexibility estimates $\bar{F}_i$ and state-dependence parameter estimates f_i are plotted against the time average volatility of sector-relevant productivity state $E|\Delta s_i|$; sectors are weighted by consumption shares β_i; estimates insignificant at 90% level are forced to zero; red lines correspond to linear regressions within the group of significant estimates; **correlation coefficient for Panel (a) is 0.43 and correlation coefficient for Panel (b) is -0.24**.

I also estimate the the parameters of price flexibility using the model with more shocks (and employiing sectoral consumption and labor data). In Appendix C I plot the corresponding price flexibility estimates as well as sector-relevant state volatility. The baseline estimates are considerably correlated with the alternative estimates obtained in the model with more shocks. In the subsequent numerical analysis, I check the robustness of the baseline results against the results obtained using these alternative sector-relevant state measures and price flexibility estimates.

The estimates of sector-specific average price flexibility have a conceptual counterpart of Calvo parameters in the literature. In Appendix C I compare my estimates to the model-free estimates by Pasten et al. (2020) and obtain a reasonable degree of correlation[3].

[3] I am thankful to the authors for providing me their estimates for comparison.

6 Phillips curve and cost-push inflation

In this section, I establish the theoretical role of state-dependent pricing in shaping the cost-push inflation. To this end, I derive the consumer price inflation in terms of aggregate demand and cost-push factors, the relationship known as the Phillips curve. The Phillips curve residual captures the aggregate cost-push effect in the model. Then I provide a Phillips curve residual decomposition which is particularly useful for analyzing the role of state-dependent pricing.

6.1 Phillips curve

The Phillips curve residual captures the cost-push effect in consumer price inflation. I derive this residual in terms of production network parameters, sectoral price flexibilities, and relative price gaps. Next I define sectoral price gaps in the spirit of menu-cost literature

Definition 2 (Sectoral price gaps)**.** Vector of sectoral price gaps $\boldsymbol{\pi_t^\star}$ is the difference of the current efficient prices $\boldsymbol{p_t^\star}$ and the previous period true prices $\boldsymbol{p_{t-1}}$, that is $\boldsymbol{\pi_t^\star} = \boldsymbol{p_t^\star} - \boldsymbol{p_{t-1}}$.

The efficient price in sector i, $\hat{p}_{t,i}^\star$ is a counterfactual price that is obtained under zero markups (all $\mu_{t,i} = 0$). From (16), the efficient prices are related to the sector-relevant states as $\boldsymbol{p_t^\star} = m_t \cdot \mathbf{1} + \boldsymbol{s_t}$.

Sectoral price gaps indicate the difference between the true prices and the efficient prices and reflect the desirable price adjustment towards efficiency. Note, that sectoral price gaps do not depend on the true prices in period t but only on the lagged true prices.

The relative price gaps are denoted as $\boldsymbol{\hat{\pi}_t^\star}$ and represent price gaps measured relatively to the aggregate consumer price index price gap $\hat{\pi}_t^\star = \sum_i \beta_i \hat{\pi}_{t,i}^\star$. The next proposition establishes the Phillips curve in terms of price gaps.

Proposition 1. (Consumer price inflation Phillips curve). The Phillips curve for consumer price inflation is

$$\pi_t = \underbrace{\kappa_t \cdot \tilde{y}_t}_{\text{demand inflaton}} + \underbrace{(1-\kappa_t) \cdot \boldsymbol{\beta'} M_t F_t \cdot \boldsymbol{\hat{\pi}_t^\star}}_{\text{cost inflation}} + \underbrace{(1-\kappa_t) \cdot \boldsymbol{\beta'} M_t F_t \cdot \boldsymbol{\tilde{e}_{t-1}}}_{\text{predetermined in period } t \text{ factors}} \tag{25}$$

where $\boldsymbol{\hat{\pi}_t^\star} = \boldsymbol{\hat{p}_t^\star} - \boldsymbol{\hat{p}_{t-1}}$ is a vector of relative sectoral price gaps, the slope of Phillips curve is $\kappa_t = \frac{\boldsymbol{\beta'} M_t F_t \mathbf{1}}{1-\boldsymbol{\beta'} M_t F_t \mathbf{1}}$ with $M_t = (I + \tilde{L} F_t^{-1}(I - F_t))^{-1} F_t^{-1}$ and expectation-related terms are $\boldsymbol{\tilde{e}_{t-1}} = \tilde{L} F_t^{-1}(I - F_t)\boldsymbol{e_{t-1}}$.

See proof in Appendix B.

The first term in the Phillips curve (25) relates inflation to the output gap and corresponds to a demand component of inflation. The second term is the Phillips curve residual

$u_t = \boldsymbol{\beta'} M_t F_t \hat{\boldsymbol{\pi}}_{\boldsymbol{t}}^{\star}$ and measures the cost-push component of inflation. The third term contains predetermined past expectations about the marginal cost growth rate. Next, I focus the properties of the Phillips curve residual term u_t, which depends on the network, price flexibilities, and sectoral price gaps.

6.2 Cost-push effect: main and input-output components

Presence of price rigidity prevents prices from adjustment to their efficient level for two reasons. First reason is that price rigidity does not allow prices to adjust to match the marginal cost. Second reason is that marginal cost itself differs from the efficient level due to input-output links. This means that even those firms who adjust their prices do not set them to the efficient level. To separate these two effects I decompose the cost-push inflation u_t into two components, which I label "main" and "input-output" components. The main component captures the effect of heterogeneous price rigidity across final goods sectors given that marginal cost are at their efficient level. The input-output component captures the effect of price rigidity propagation through input-output links which leads to the deviation of marginal cost (and hence reset price) from its efficient level.

Proposition 2. (Phillips curve residual decomposition). Cost-push effect $u_t = \boldsymbol{\beta'} M_t F_t \hat{\boldsymbol{\pi}}_{\boldsymbol{t}}^{\star}$ can be decomposed to the sum of the man component and the input-output component

$$u_t = \underbrace{\boldsymbol{\beta'} F_t \cdot \hat{\boldsymbol{\pi}}_{\boldsymbol{t}}^{\star}}_{\text{main component} = u_t^m} - \underbrace{\boldsymbol{\beta'}(I - M_t) F_t \cdot \hat{\boldsymbol{\pi}}_{\boldsymbol{t}}^{\star}}_{\text{i-o component} = u_t^i} \tag{26}$$

See proof in Appendix B.

To understand the nature of the above decomposition consider a vector of sectoral reset prices (prices set by those who reset their price)

$$\begin{aligned} \boldsymbol{p_t^{reset}} &= \boldsymbol{mc_t} = (p_t + y_t) \cdot \mathbf{1} + \boldsymbol{s_t} + (\tilde{L} - I)\boldsymbol{\mu_t} = \\ &= \underbrace{m_t \cdot \mathbf{1} + \boldsymbol{s_t}}_{\text{efficient price}} + \underbrace{(L - I)\boldsymbol{\mu_t}}_{\text{interm. cost effect}} \underbrace{- \frac{\gamma}{1+\gamma} L I_\alpha I_\xi^{-1} L' I_\xi \boldsymbol{\mu_t}}_{\text{labor. cost effect}} \end{aligned} \tag{27}$$

The reset price equals marginal cost and consists of the efficient price and the effect of markups. In multi-sectoral model reset prices differ from efficient prices because inefficiency caused by price stickiness propagates through production links leading to real rigidities, that is a situation when marginal costs of production deviate from efficient (flexible price) level. The main component of the decomposition given in Proposition 2 describes the residual arising when all reset prices are at their efficient levels. The input-output component gives the effect of propagation of inefficiency through input-output links.

Further, from Equation 27 we see that the effect of markups on reset price consists of the effect markups have on the intermediate input cost and on sector-specific labor costs. While higher markups lead to higher intermediate good cost, they lead to lower labor costs.

6.3 Main component

Now I focus on the properties of the main component. In the quantitative section, I show that main component is quantitatively more important in shaping cost-push effect than the input-output component. Next I discuss the role of state-dependent pricing in shaping the size and sign on the main component.

The main component of the cost-push effect can be interpreted as a covariance between sectoral price flexibilites and price gaps, taken over the consumption weights

$$u_t^m = \boldsymbol{\beta'} F_t \cdot \boldsymbol{\hat{\pi}_t^\star} = cov_\beta(F_{t,i},\ \pi_{t,i}^\star)$$

which follows form the covariance definition and the fact that $\boldsymbol{\beta'\hat{\pi}_t^\star}$.

Let price flexibility in each sector consist of the non-state-dependent and state-dependent parts: $F_{t,i} = \bar{F}_i + \Delta F_{t,i}$ the non-state-dependent part is different across sectors but does not change over time. The state-dependent part fluctuates depending on the shocks that hit the economy. Then, the main component can be written as a sum of two covariances

$$u_t^m = \underbrace{cov_\beta(\bar{F}_i,\ \pi_{t,i}^\star)}_{\text{Non-st.-dep. pricing}} + \underbrace{cov_\beta(\Delta F_{t,i},\ \pi_{t,i}^\star)}_{\text{St.-dep. pricing}}$$

The first term captures the cost-push effect created by non-state-dependent price rigidity through the heterogeneous degree of price rigidity across sectors. The second term captures the cost-push effect created by the state-dependent pricing.

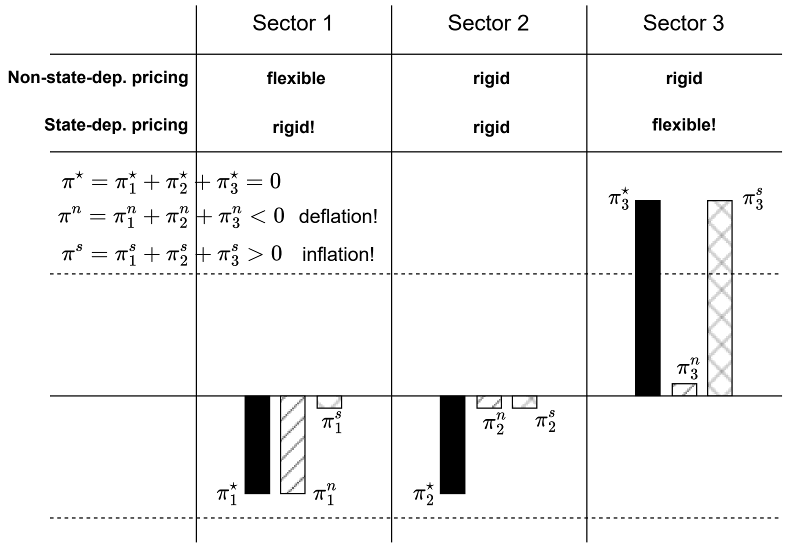
Under state-dependent pricing, price flexibility depends on the absolute size of the desired price adjustment. To build intuition, let this dependence take te simplest possible form $\Delta F_{t,i} = k \cdot |\pi_t^\star|$, $k > 0$. Then, the main component of cost-push effect is

$$u_t^m = \underbrace{cov_\beta(\bar{F}_i,\ \pi_{t,i}^\star)}_{\text{Non-st.-dep. pricing}} + \underbrace{k \cdot cov_\beta(|\pi_{t,i}^\star|,\ \pi_{t,i}^\star)}_{\text{St.-dep. pricing}}$$

The non-state-dependent and state-dependent components of the above expression may have opposite signs. The sign of the non-state-dependent component depends on whether the largest desired price change occurs in the unconditionally flexible price sector or not. The sign on the sate-dependent component depends on whether the largest desired price change is positive or negative. When the largest positive desired price change occurs in an unconditionally sticky price sector, the non-state-dependent pricing might produce a negative cost-push effect due to a negative correlation of non-state-dependent price flexibility with price gaps. At the same time, if this sector becomes more flexible through the state-dependent pricing mechanism, the state-dependent pricing produces a positive cost-push effect. As a result, the presence of state-dependent pricing may change the sign of the cost-push effect.

Figure 4 provides an example illustrating the possible implications of state-dependent pricing for inflation in a three-sector economy. Solid bars represent the desirable price adjustment in each sector such that the aggregate desired inflation is zero. If pricing is non-state-dependent, the degree of price flexibility in each sector is fixed in advance: Sector 1 has fully flexible prices, while Sectors 2 and 3 have fully rigid prices. In this case, Sector 1 is the only sector adjusting its price, and the aggregate inflation is negative. In contrast, if pricing is state-dependent, the degree of price flexibility depends on the size of the desired price change. In this case, only Sector 3 adjusts since its desired price change is sufficiently large, and the resulting aggregate inflation is positive. In this example, non-state-dependent pricing yields cost-push *deflation* driven by Sector 1 while state-dependent pricing yields cost-push *inflation* driven by Sector 3.

Figure 4: Three-sector economy: price adjustment with non-state-dependent and state-dependent pricing



Hashed bars and π^n cross-hashed bars and π^s show price adjustment under state-dependent pricing; aggregate inflation is a sum of price changes in each sector.

6.4 I-O structures with a single effect

Next, I provide the properties of production structures featuring only one of the two component of the cost-push effect decomposition. These results follow from the decomposition provided in Proposition **??**. First, I describe an economy featuring only input-output component.

Corollary 1. (Single final good economy (only I-O component)). Consider an economy with only one final good such that consumption shares are $\beta_1 = 1$ and $\beta_i = 0$ for all $i \neq 1$. 1) In such economy only input-output component is present, that is $u_t^h = 0$. 2) If the only rigid price sector is the final good sector the cost-push effect is zero, $u_t = 0$.

See proof in Appendix B.

In an economy with a single final good the only possible source of cost-push effect is distortion in marginal cost of this good caused by upstream price rigidity. For this reason productivity hocks in one-sector textbook NK model with flexible wages do not create any cost push effect while in a one-sector sticky wage economy (rigidity in marginal costs) cost-push effect emerges (see (Galí, 2015)).

The presence of multiple consumption goods is necessary for having the main component. The main component captures the fact that for a given marginal cost distribution the "cost" of the final consumption basket may be inefficiently high or low due to the fact that prices of different consumption goods have different degree of price flexibility. Indeed, if price rigidities are the same $F_{i,t} = F$ in all sectors, main component disappears since te sum of the relative price gaps weighted by consumption shares is zero by construction.

Next, I describe an economy featuring only main component. From Equation 27 we see that in order to exclude the effect of markups on reset prices we need to have an economy in which the effect of markups on intermediate goods exactly offsets the effect of markups on labor costs. Next, I describe properties of such economy.

Corollary 2. (Quasi-horizontal economy (only main component)). Consider an economy with multiple final sectors and no vertical links except the roundabout production in each sector (meaning that each sector uses part of its own output as its intermediate input) such that $\Omega = I - I_\alpha$ and $\alpha_i = \frac{1}{1+\gamma}$ for all i. Such economy features only the main component of cost push effect, that is $u^v = 0$.

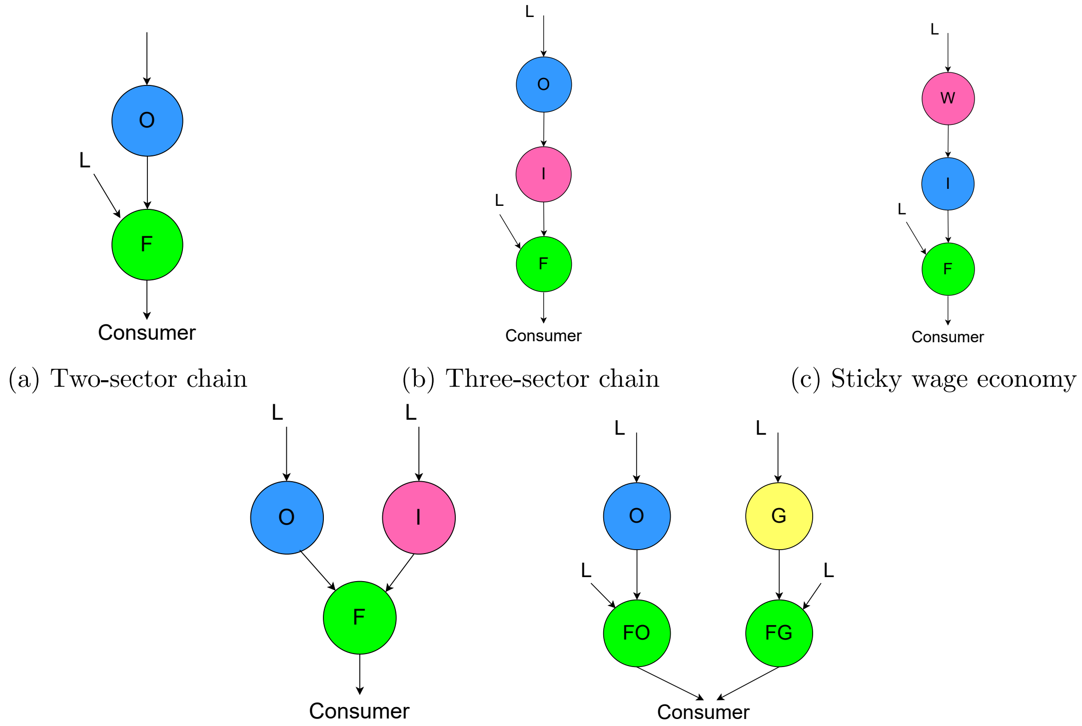
See proof in Appendix B.

The particular degree of roundabout production is needed so that the change in marginal cost due to change in intermediate good price is exactly offset by the change in labor cost. Note that in purely horizontal economy with no roundabout production such that Leontief inverse is $L = I$ input-output component still exists because labor input gets distorted by the presence of price rigidity.

6.5 Commodity shock examples

The cost-push effect is often attributed to commodity shocks such as oil or grain industry shocks. Next, I discuss the consequences of a commodity shock in various I-O structures and the role of state-dependent pricing in shaping the cost-push effect of such shocks[4]. I show that in vertical chain economies, state-dependent may lead to amplification of the cost-push effect but does not lead to any sign reversal. At the same time, in an economy with multiple final goods, the sign reversal of the cost-push effect by the presence of state-dependent pricing is possible.

Figure 5: Example economies with commodity sectors



(a) Two-sector chain (b) Three-sector chain (c) Sticky wage economy

(d) Multiple inputs (e) Two-commodity economy

Example 1. Two-sector vertical chain Consider a two-sector vertical chain economy. Let the upstream sector be the Oil sector and the downstream sector be Final good sector (Figure 5a). Oil sector has fully flexible prices $F^O = 1$ (in line with empirical evidence) while final good sector has partially rigid prices $F^F \leq 1$. The economy is initially at the steady state and that the productivity shock in oil sector ϵ^{Oil} occurs. In this case cost-push effect is

$$u_t = \frac{1+\gamma}{D} \cdot \frac{1-F^O}{F^O} \cdot (1-\alpha^F)\alpha^F \cdot \epsilon^{Oil} = 0$$

where $D = (1+\gamma+f^O)\cdot(1+\gamma+f^F) - (1-\alpha^F)\gamma f^O \cdot f^F > 0$ and $f^F = \frac{1-F^F}{F^F}$, $f^O = \frac{1-F^O}{F^O}$; for derivation see Appendix B.3. Cost-push inflation $u_t = 0$ as long as Oil sector has fully flexible prices $F^O = 1$. The Oil shock does not cause cost-push effect since there is no

[4] In the examples of this section I make a technical assumption that $(1-\alpha^F)\gamma < 1$ where α^F is labor share in final production. This assumption ensures that intermediate input is an important factor of production.

distortion in the marginal cost of production. This result is a consequence of Corollary **??**.

Example 2. Intermediate good
Consider a vertical chain with intermediate good sector (Figure 5b). Oil sector has fully flexible prices $F^{Oil} = 1$ but the intermediate sector has partially rigid prices $F^I \leq 1$. Price distortion in intermediate good sector creates cost distortion in final good sector. The cost-push effect of Oil productivity shock is

$$u_t = \frac{1+\gamma}{D} \cdot \frac{1-F^I}{F^I} \cdot (1-\alpha^F)\alpha^F \cdot \epsilon^{Oil}$$

where $D = (1+\gamma+f^I) \cdot (1+\gamma+f^F) - (1-\alpha^F)\gamma f^I \cdot f^F > 0$ and $f^F = \frac{1-F^F}{F^F}$, $f^I = \frac{1-F^I}{F^I}$; for derivation see Appendix B.3.

When productivity in Oil sector goes down we have cost-push *deflation* and state-dependent pricing (the fact that F^I and F^F change with shock size) changes the size of the cost-push effect of the shock. The negative cost push effect of a negative oil productivity shock goes against the basic intuition that negative shocks in oil industry lead to a positive cost push inflation. Nevertheless, this example illustrates the mechanism of why cost-push effect emerges. After a negative productivity shock prices of Oil go up. Intermediate sector uses Oil as input meaning that optimal price of intermediate good should also go up. But since prices in the intermediate good sector are sticky, they increase by less then they should. As a result, marginal cost in final good sector are smaller than they should be resulting in a negative cost-push effect.

Example 3. "Sticky wages" economy Consider a vertical chain economy in which the most upstream sector has partially rigid prices while intermediate sector has fully flexible prices. The upstream sector may be viewed as the sticky wages sector, intermediate sector be the Oil sector and the final sector be the consumption good sector. This is the case of a so-called "sticky wage" economy (Figure 5c). The corresponding price flexibilities are $F^O = 1$, $F^W \leq 1$ and $F^F \leq 1$. The cost-push effect of Oil productivity shock is

$$u_t = -\frac{1+\gamma}{D} \cdot \frac{1-F^W}{F^W} \cdot (1-\alpha^F) \cdot \epsilon^{Oil}$$

where $D = (1+\gamma+f^W) \cdot (1+\gamma+f^F) - (1-\alpha^F)\gamma f^W \cdot f^F > 0$ and $f^F = \frac{1-F^F}{F^F}$, $f^W = \frac{1-F^W}{F^W}$; for derivation see Appendix B.3.

When oil productivity goes down we have cost-push *inflation* in line with the intuition that the negative productivity shock in the oil industry should create cost-push effect. Upon negative Oil productivity shock, the level of production decreases and less labor is demanded. As a result, wages should optimally go down. But since wages are sticky they remain too high and the marginal cost of producing Oil and ultimately final goods remains higher than it should be. The inefficiently high marginal cost leads to a positive cost-push inflation. Again, the fact that the price flexibility changes with the shock size may influence the size of the cost-push effect.

Example 4. Multiple inputs
Consider an economy in which a single final good is produces using two material inputs: Oil and Intermediate good (Figure 5d). Oil sector has fully flexible prices $F^{Oil} = 1$ while price flexibility in intermediate good sector is partial $F^I \leq 1$. Also, for the exposition purposes, I assume that final good sector also has fully flexible prices $F^F = 1$. After the oil shock ϵ^{Oil}, the cost-push inflation is

$$u_t = -\alpha^I(1-\alpha^I) \cdot (1-F^I) \cdot \epsilon^{Oil}$$

where α^I share of input I in F; for derivation see Appendix B.3.

Negative oil productivity shock leads to a *positive* cost-push inflation and the state-dependence of price flexibility may affect the size of cost-push effect by changing F^I.

The mechanism behind the cost-push effect of oil shock in this example somewhat differs from the previous examples. In this economy when a negative oil productivity shock occurs the marginal cost of producing the final good goes up and the demand for intermediate input goes down as long as substitutability between oil and intermediate good is not too high. Hence prices in the intermediate goods sector should optimally go down which they do not do because of price rigidity in this sector. As a result, the price of intermediate goods is inefficiently high and the resulting marginal cost of producing the final good is also inefficiently high, which creates cost-push inflation.

In the four above examples, changes in price flexibility under state-dependent pricing may lead to a different size of a cost-push effect but never change its sign. Next, let me consider an example, in which the same shock can lead to the opposite sign of the cost-push effect if pricing is state-dependent.

Example 5. Two-commodity economy Consider an economy consisting of two upstream goods (Oil and Grain) and two final goods (Oil-intensive and Grain-intensive) with equal shares in consumption. Oil-intensive final good uses oil as input while grain-intensive final good uses grain as input (Figure 5e). Upstream commodity sectors have fully flexible prices $F^{Oil} = F^{Grain} = 1$ and final good sectors have partially rigid prices $F^{FO} \leq 1$ and $F^{FG} \leq 1$. As before, the economy is initially at the steady state and is perturbed by one of the two commodity shocks - oil and grain shocks $\epsilon^{Oil}, \epsilon^{Grain}$. The corresponding cost-push effect is

$$u_t = -\frac{1}{4} \cdot (F^{FO} - F^{FG}) \cdot (\epsilon^{Oil} - \epsilon^{Grain})$$

Assume first that price rigidity is non-state-dependent such that $F^{FO} > F^{FG}$, that is oil intensive final good has always more flexible prices. Then negative oil shock leads to a positive cost push effect. However, a negative grain shock leads to a *negative* cost-push effect. This behavior is not plausible as there are no obvious reasons why shock in one commodity sector should lead to cost-push inflation while similar shock in another commodity sector should lead to cost-push deflation.

But what happens if price flexibility is state-dependent? In this case, we have larger price flexibility in oil-intensive sector $F^{FO} > F^{FG}$ under oil shock and larger price flexibility in grain-intensive sector $F^{FG} > F^{FO}$ under grain shock. Hence, under state-dependent pricing, a negative shock in any of these two commodity sectors leads to a positive cost-push effect. The presence of state dependence reverses the sign of the cost-push effect of grain shock compared to the non-state-dependent pricing case.

The mechanism of the cost-push effect in this economy is as follows. When a negative oil shock hits, oil price goes up, and the production of oil and oil-intensive goods drops which leads to a lower level of household income. With the lower level of income, households decrease their demand for grain-intensive goods as well (as long as this good is not an "inferior" good) which should cause prices of grain-intensive goods to optimally drop. However, price rigidity in the grain-intensive industry prevents the grain-intensive good price from dropping meaning that the *relative* price of grain-intensive good is higher than it should optimally be, leading to cost-push inflation.

7 Quantitative analysis

In this section, I compute the monthly cost-push effect in the US implied by the model and analyze the role of the state-dependent component of price flexibility in shaping the cost-push effect. The calibration of the model is described in the empirical section above.

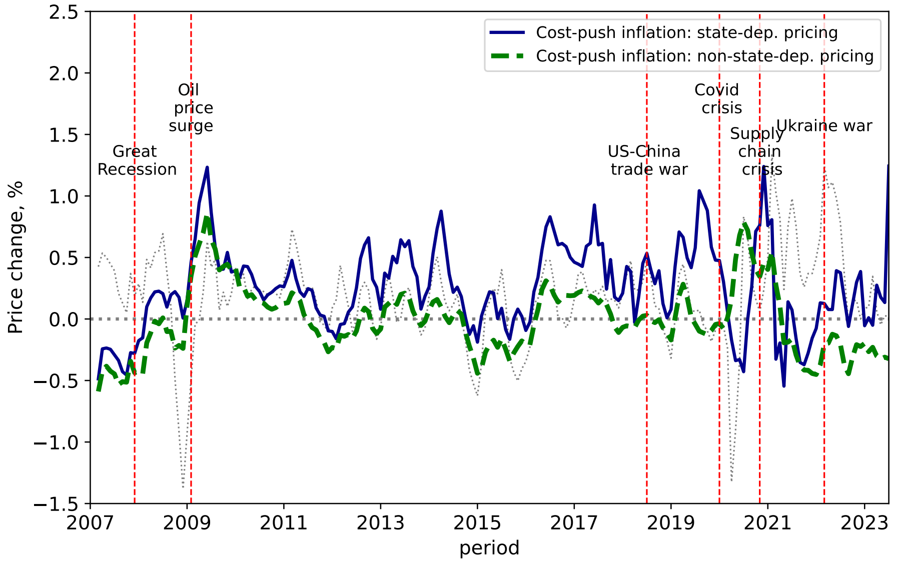
7.1 Cost-push effect and state-dependence

In this section, I compute the monthly cost-push effect using the expression (25) derived in a theoretical section. I calibrate the price sector-specific price flexibility framework using the estimates of price flexibility and state dependence from the empirical section. For sectoral price gaps computation, I employ the previously constructed monthly series for monthly sector-relevant states and the observed sectoral prices. To evaluate the quantitative role of state dependence over time, I also compute counterfactual residual without the state-dependent component of price flexibility. Figure 6 shows the result.

Overall, an empirically plausible degree of state dependence in each sector yields a more volatile cost-push effect than the non-state-dependent pricing model. Two episodes are worth investigating to analyze the role of state dependence: after the Great Recession, and after the Covid crisis. For 2009, both state-dependent and non-state-dependent pricing models produced a positive spike in the cost-push effect, and state dependence plays an amplification role. For 2019, starting from the COVID crisis, the state-dependent model yields a negative cost-push effect at the start of the COVID crisis, followed by a positive cost-push effect just after the crisis when the supply chain disruption issue emerged. For 2022, when the full-scale Russia-Ukraine war broke out, the state-dependent pricing model yields a positive and growing cost-push effect. In contrast, the non-state-dependent pricing model gives quite different predictions: positive cost-push effect during the COVID crisis, and negative cost-push inflation in 2022. Hence, state-dependent pricing often leads to a sign reversal of the cost-push effect compared to non-state-dependent pricing in the post-Covid period.

Note that none of the models predict a long-lasting positive cost-push effect during the post-Covid period, suggesting that the persistent post-Covid inflation cannot be entirely characterized as cost-push but instead has demand or expectation-driven features, which justifies a strong monetary response undertaken by the FED.

Figure 6: Cost-push inflation and state-dependent pricing



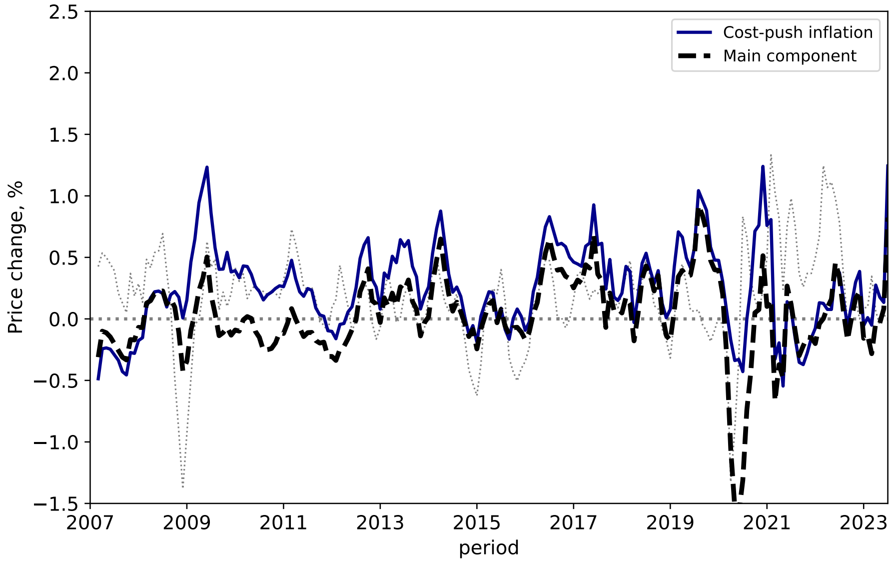
Grey line plots observed CPI inflation; **blue line** plots the Phillips curve residual implied by the model under estimated degree of price flexibility; **dashed green line** plots the Phillips curve residual when the effect of state-dependent pricing is absent (all $f_i = 0$).

In Appendix D, I compute the same state-dependent and non-state dependent residual based on the model specification with more shocks and using the corresponding price flexibility and state estimates. The specification with more shock produces qualitatively reasonably similar results to the baseline specification.

7.2 Cost-push effect decomposition

Now, I look into the quantitative importance of the main and input-output components in the US cost-push inflation by applying the decomposition form Proposition 2. Figure (7) shows that the main component largely shapes the fluctuations of the cost-push effect and that the I-O component merely plays an amplifying/dampening role during different episodes. Hence, the theoretical results importance of the state-dependence in shaping the main component of the cost-push effect appy to the large share of the cost-push inflation.

Figure 7: Cost-push inflation and main component

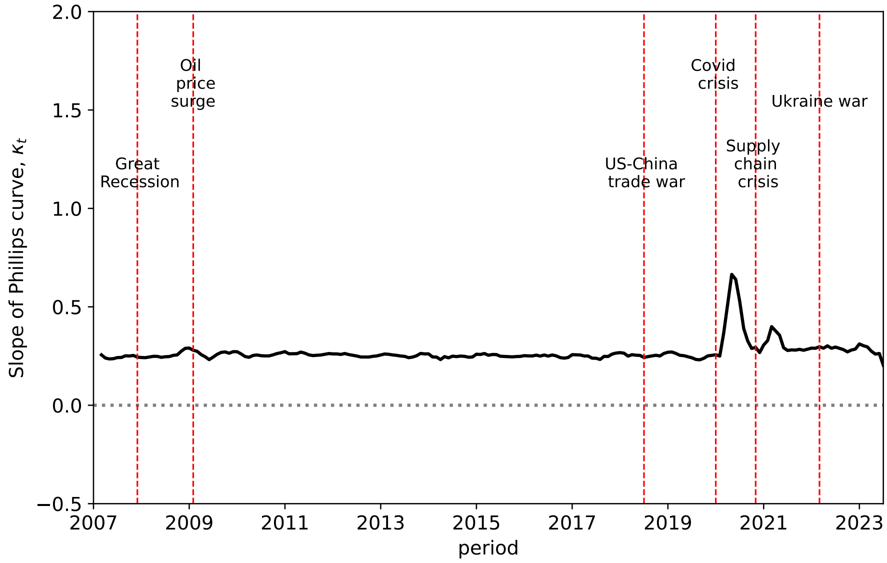


Grey line plots CPI inflation; **blue line** plots the Phillips curve residual implied by the model under estimated degree of price flexibility; **dashed black line** plots the main component of Phillips curve residual. CPI inflation and residual series are smoothed with a 3-month moving average.

7.3 Slope of the Phillips curve

State-dependent pricing implies potentially time-varying slope of the Phillips curve. Hence, I compute the the slope implied by my state-dependent pricing estimates over time. On Figure 8, the slope of the Phillips curve is for the most part is constant except for the COVID period, where it has two subsequent peaks in 2020 and 2021 respectively. The spike in slope is driven mostly by the 2-digit sectoral group representing Finance and Insurance sectors (see sectoral analysis below). The model-free evidence of an increase and a subsequent decrease of the Phillips curve slope around the COVID period were also found by Cerrato and Gitti (2022) for the period corresponding to the second peak on Figure 8.

Figure 8: Slope of the Phillips curve



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7.4 Phillips curve fit

Now, I investigate if the Phillips curve residual implied by the state-dependent model outperforms its non-state-dependent counterpart in explaining inflation in a conventional Phillips curve regression. For this, I regress CPI inflation on the standard Phillips curve variables: unemployment, expected and lagged inflation, and oil prices. Then, I sequentially add the non-state-dependent and state-dependent residual computed from the model. Table 3 shows the regression results. The regression with a non-state-dependent residual outperforms the regression with only oil price inflation, but adding a state-dependent residual improves the fit. Moreover, a state-dependent residual effect is statistically significant even when a non-state-dependent residual is already accounted for.

Table 3: Phillips curve estimation with model implied residual

	Dependent variable:			
	CPI inflation			
	(1)	(2)	(3)	(4)
Unempl.	0.0001	-0.0003^{*}	-0.0002	-0.0005^{***}
	(0.0001)	(0.0002)	(0.0002)	(0.0002)
Lagged infl.	0.172^{**}	0.169^{**}	0.158^{**}	0.159^{***}
	(0.068)	(0.065)	(0.063)	(0.059)
Expected infl.	0.001	0.001	0.001^{**}	0.001^{**}
	(0.001)	(0.001)	(0.001)	(0.001)
Oil infl.	0.028^{***}	0.023^{***}	0.023^{***}	0.030^{***}
	(0.003)	(0.003)	(0.003)	(0.003)
u(non-st.-dep.)		0.282^{***}	0.124	0.190^{***}
		(0.073)	(0.087)	(0.063)
u(st.-dep.)			0.162^{***}	0.076^{**}
			(0.052)	(0.034)
Constant	-0.001	0.004^{*}	0.001	0.003^{*}
	(0.001)	(0.002)	(0.002)	(0.002)
Observations	156	156	156	187
R^2	0.440	0.491	0.522	0.508
Adjusted R^2	0.425	0.474	0.503	0.492
Note:				*p<0.1; **p<0.05; ***p<0.01

The period used in the estimation (1)-(3) is 2007M1-2019M12 to exclude period of non-stable slope of the Phillips curve; The period of estimation in (4) is 2007M1-2022M12.

7.5 Analysis by sector

Now, I turn to the analysis of the contribution of particular sectors to the difference between the state-dependent and non-state-dependent pricing cost-push effects. To this end, I group the disaggregated sectors into the 2-digit BEA-coded groups. Table 4 gives the list of these groups.

First, I compute the marginal importance of each group in explaining the cost-push effect. For each 2-digit sector group, I recompute the residual, excluding the contribution of sectors in this group, and compare this new residual with the full residual by regressing the

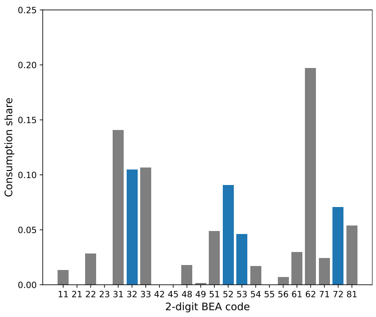
Table 4: 2-digit BEA sector names

2-digit BEA	Sector description
11	Agriculture, Forestry, Fishing and Hunting
21	Mining, Quarrying, and Oil and Gas Extraction
22	Utilities
23	Construction
31	Manufacturing (non-durable goods)
32-33	Manufacturing (durable goods)
42	Wholesale Trade
44 - 45	Retail Trade
48 - 49	Transportation
51	Information
52	Finance and Insurance
53	Real Estate and Rental and Leasing
54	Professional, Scientific, and Technical Services
55	Management of Companies and Enterprises
56	Administrative and Support and Waste Management and Remediation Services
61	Educational Services
62	Health Care and Social Assistance
71	Arts, Entertainment, and Recreation
72	Accommodation and Food Services
81	Other Services (except Public Administration)
92	Public Administration

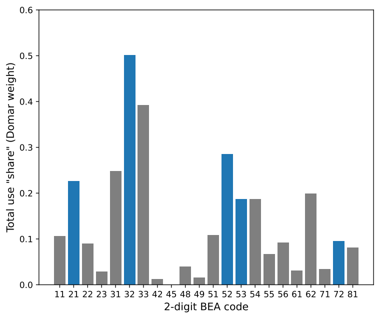
latter on the former; I compute the importance of each sector group as (1 less R-squared) of this regression, which is the loss of fit compared to the full residual. Figure 9 plots the importance of each sector group in consumption (panel A), production (panel B), and in explaining Phillips curve residual (panel C). The five most important sector groups emerge on panel c.

Figure 9: Most important sector groups

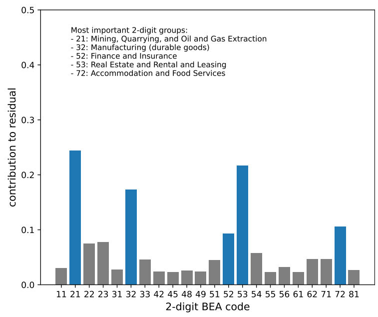
(a) Share in consumption



(b) Share in total use



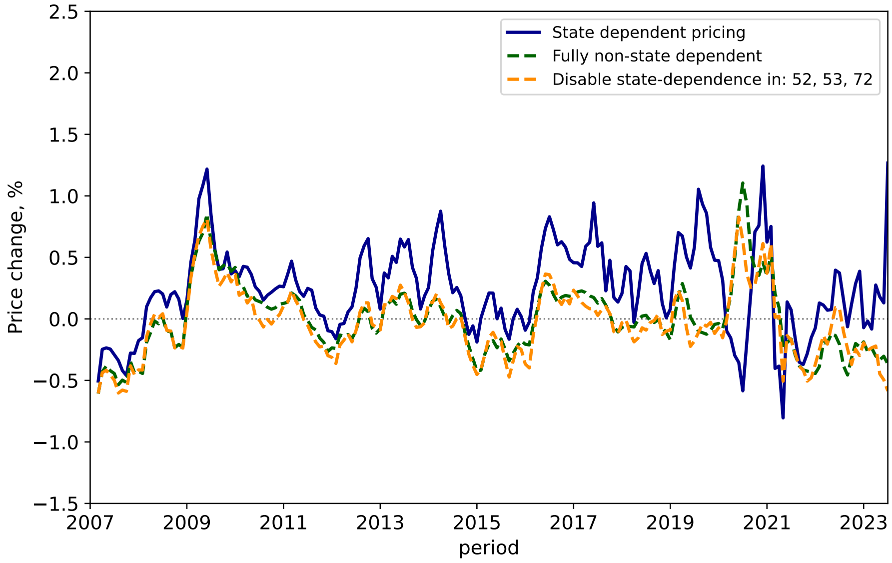
(c) Cost-push effect explained



Panel (a): sum of sectoral consumption shares within each group; Panel (b): sum of sectoral Domar weights (shares in total use) within each group; Panel (c): the share of Phillips curve residual explained by a given 2-digit BEA sector group; computed by forcing the shocks in a given sector of interest to zero and calculating the (1- r-squared) from a total Phillips curve residual regression on the resulting counterfactual Phillips curve residual; **blue** highlights the group of sectors most important in explaining the dynamics of cost-push inflation.

Next, I disable state-dependent pricing in these selected sectoral groups to evaluate the contribution of each group to the difference between non-state-dependent and state-dependent Philips curve residual. In Figure 10 I plot the residual with disabled state-dependence for three out of the five most important sectoral groups. We see that state dependence in these three selected service-related groups of sectors accounts for most of the effect of state-dependent pricing. These three groups together account for around one-quarter of the overall consumption basket.

Figure 10: Contribution of state-dependence in selected sector groups



In Appendix D, I compute the cost-push effect attributed exclusively to the most important sectoral groups over time. The five most important sectoral groups combined account for the bulk of cost-push effect fluctuations over the observed period. I also compute the cost-push effect attributed to the sectors most important during three historical periods: The Great Recession, the COVID crisis, and the Ukraine war. Each of the periods is characterized by its own most important sectors in terms of the contribution to cost cost-push effect.

8 Conclusions

This paper investigates the implications of state-dependent pricing for cost-push inflation in a multi-sectoral New Keynesian economy with a production network. To this end, I estimate the sector-specific degree of state dependence and evaluate its importance for cost-push inflation in the US.

My empirical approach allows the use of the model to estimate sector-specific price flexibility and its degree of state dependence using sector-specific data. The estimates reveal that the majority of sectors in the US economy have a statistically significant degree of state dependence.

Theoretically, I show that state-dependent pricing may lead to cost-push inflation having a different size and even an opposite sign compared to a non-state-dependent pricing framework. This important implication of state-dependent pricing obtains even if one excludes the effect of inefficiency propagation through the production network.

In the model with an empirically plausible degree of state dependence, the importance of state dependence for the cots-push effect is different for different historical periods. After the Great Recession, state dependence amplified the positive cost-push effect, while after the COVID crisis, it often led to a sign reversal of cost-push inflation. Finally, state dependence in a selected subgroup of services accounts for the bulk of the difference between the cost-push effect in state-dependent and non-state-dependent models.

References

Daron Acemoglu, Vasco M Carvalho, Asuman Ozdaglar, and Alireza Tahbaz-Salehi. The network origins of aggregate fluctuations. *Econometrica*, 80(5):1977–2016, 2012.

Kosuke Aoki. Optimal monetary policy responses to relative-price changes. *Journal of monetary economics*, 48(1):55–80, 2001.

Laurence Ball and N Gregory Mankiw. Relative-price changes as aggregate supply shocks. *The Quarterly Journal of Economics*, 110(1):161–193, 1995.

David Rezza Baqaee and Emmanuel Farhi. Productivity and misallocation in general equilibrium. *The Quarterly Journal of Economics*, 135(1):105–163, 2020.

Saki Bigio and Jennifer La'o. Distortions in production networks. *The Quarterly Journal of Economics*, 135(4):2187–2253, 2020.

Mark Bils and Peter J Klenow. Some evidence on the importance of sticky prices. *Journal of political economy*, 112(5):947–985, 2004.

Hafedh Bouakez, Emanuela Cardia, and Francisco Ruge-Murcia. Sectoral price rigidity and aggregate dynamics. *European Economic Review*, 65:1–22, 2014.

Ricardo J Caballero and Eduardo MRA Engel. Price stickiness in ss models: New interpretations of old results. *Journal of monetary economics*, 54:100–121, 2007.

Jeffrey Campbell and Benjamin Eden. Rigid prices: Evidence from us scanner data. *International Economic Review*, 55(2):423–442, 2014.

Andrew S Caplin and Daniel F Spulber. Menu costs and the neutrality of money. *The Quarterly Journal of Economics*, 102(4):703–725, 1987.

Carlos Carvalho and Oleksiy Kryvtsov. Price selection. *Journal of Monetary Economics*, 122:56–75, 2021.

Alberto Cavallo and Roberto Rigobon. The billion prices project: Using online prices for measurement and research. *Journal of Economic Perspectives*, 30(2):151–78, 2016.

Andrea Cerrato and Giulia Gitti. Inflation since covid: Demand or supply. *Available at SSRN 4193594*, 2022.

Michael Dotsey, Robert G King, and Alexander L Wolman. State-dependent pricing and the general equilibrium dynamics of money and output. *The Quarterly Journal of Economics*, 114(2):655–690, 1999.

Martin Eichenbaum, Nir Jaimovich, and Sergio Rebelo. Reference prices, costs, and nominal rigidities. *American Economic Review*, 101(1):234–62, 2011.

Christopher J Erceg, Dale W Henderson, and Andrew T Levin. Optimal monetary policy with staggered wage and price contracts. *Journal of monetary Economics*, 46(2):281–313, 2000.

Xavier Gabaix. Behavioral inattention. In *Handbook of Behavioral Economics: Applications and Foundations 1*, volume 2, pages 261–343. Elsevier, 2019.

Jordi Galí. *Monetary policy, inflation, and the business cycle: an introduction to the new Keynesian framework and its applications.* Princeton University Press, 2015.

Mikhail Golosov and Robert E Lucas Jr. Menu costs and phillips curves. *Journal of Political Economy*, 115(2):171–199, 2007.

Jennifer La'O and Alireza Tahbaz-Salehi. Optimal monetary policy in production networks. Technical report, National Bureau of Economic Research, 2020.

John B Long Jr and Charles I Plosser. Real business cycles. *Journal of political Economy*, 91(1):39–69, 1983.

N Gregory Mankiw and Ricardo Reis. Sticky information versus sticky prices: a proposal to replace the new keynesian phillips curve. *The Quarterly Journal of Economics*, 117 (4):1295–1328, 2002.

Emi Nakamura and Jón Steinsson. Five facts about prices: A reevaluation of menu cost models. *The Quarterly Journal of Economics*, 123(4):1415–1464, 2008.

Emi Nakamura and Jon Steinsson. Monetary non-neutrality in a multisector menu cost model. *The Quarterly journal of economics*, 125(3):961–1013, 2010.

Ernesto Pasten, Raphael Schoenle, and Michael Weber. The propagation of monetary policy shocks in a heterogeneous production economy. *Journal of Monetary Economics*, 116:1–22, 2020.

Ricardo Reis. Inattentive producers. *The Review of Economic Studies*, 73(3):793–821, 2006.

Elisa Rubbo. Networks, phillips curves and monetary policy. *Unpublished manuscript*, 2020.

Maral Shamloo. *Price setting in a model with production chains: Evidence from sectoral data.* International Monetary Fund, 2010.

Christopher A Sims. Implications of rational inattention. *Journal of monetary Economics*, 50(3):665–690, 2003.

Appendices

A Model log-linearization appendix

A.1 Sectoral wages

The product market clearing condition in sector i (12) can be written as $P_{t,i}Y_{t,i} = P_{t,i}C_{t,i} + \sum_j P_{t,i}X_{t,ji}$. Using the conditions for optimal input allocation (2), (3), and the link between sector price and sector marginal cost (5), we get $\frac{P_{t,i}X_{t,ij}}{MC_{t,i}\cdot Y_{t,i}} = \frac{\mathcal{M}_{t,i}P_{t,i}X_{t,ij}}{P_{t,i}\cdot Y_{t,i}} = (1-\alpha_i)\omega_{ij}$, we have $P_{t,j}X_{t,ji} = (1-\alpha_j)\omega_{ji}\frac{P_{t,j}Y_{t,j}}{\mathcal{M}_{t,j}}$. Substituting this result into the market clearing condition

$$P_{t,i}Y_{t,i} = P_{t,i}C_{t,i} + \sum_j (1-\alpha_j)\omega_{ji}\frac{P_{t,j}Y_{t,j}}{\mathcal{M}_{t,j}} \tag{A.1}$$

Consumption shares and Domar weights are connected through a well-known link (see Baqaee and Farhi (2020)).

Proposition (Consumption shares to Domar weights link)**.** $\boldsymbol{\xi} = L'\boldsymbol{\beta}$.

Proof. First, let us compute (A.1) at the efficient steady state and divide by $\bar{P}\bar{Y}$. We have the $\frac{\bar{P}_i\bar{Y}_i}{\bar{P}\bar{C}} = \frac{\bar{P}_i\bar{C}_i}{\bar{P}\bar{C}} + \sum_j (1-\alpha_j)\omega_{ji}\frac{\bar{P}_j\bar{Y}_j}{\bar{P}\bar{C}}$. Then, the steady state product market clearing condition can be expressed as $\xi_i = \beta_i + \sum_j (1-\alpha_j)\omega_{ji}\xi_j$, or in matrix form $\boldsymbol{\xi} = \boldsymbol{\beta} + W'\boldsymbol{\xi}$. This gives us the link between consumption shares and Domar weights: $\boldsymbol{\xi} = L'\boldsymbol{\beta}$. □

Log-linearizing (A.1) and dividing by $\bar{P}\bar{Y}$ yields

$$\xi_i(p_{t,i} + y_{t,i} - \mu_{t,i}) = \beta_i(p_{t,i} + c_{t,i}) - \xi_i\mu_{t,i} + \sum_j (1-\alpha_j)\omega_{ji}\xi_j(p_{t,j} + y_{t,j} - \mu_{t,j})$$

The demand for i-th sector consumption is $p_{t,i} + c_{t,i} = p_t + y_t$. Hence, we have

$$(p_i + y_i - \mu_i) = \frac{1}{\xi_i}\sum_j l_{ji}(\beta_j(p_t + y_t) - \xi_j\mu_j) = p_t + y_t - \frac{1}{\xi_i}\sum_j l_{ji}\xi_j\mu_j \tag{A.2}$$

where l_{ij} is $(i,\ j)$-th element of matrix L.

Labor demand in log-deviations is $w_{t,i} + l_{t,i} = p_{t,i} + y_{t,i} - \mu_{t,i}$ and labor supply is $w_{t,i} = p_t + y_t + \gamma l_{t,i}$. Combining labor demand and labor supply, we get the following expression for equilibrium wage

$$w_{t,i} = \frac{1}{1+\gamma}(p_t + y_t) + \frac{\gamma}{1+\gamma}(p_{t,i} + y_{t,i} - \mu_{t,i}) \tag{A.3}$$

Combining (A.2) and (A.3) yields

$$w_{t,i} = p_t + y_t - \frac{\gamma}{1+\gamma}\frac{1}{\xi_i}\sum_j l_{ji}\xi_j\mu_{t,j} \tag{A.4}$$

which in vector form gives equation 15.

A.2 Sectoral prices

From (4) log-linear marginal cost deviation is sector i is

$$mc_{t,i} = -a_{t,i} + \alpha_i w_{t,i} + (1-\alpha_i)\sum_j \omega_{ij} p_{t,j} \tag{A.5}$$

The link between sector price and sector marginal cost is $p_{t,i} = \mu_{t,i} + mc_{t,i}$. Combining these two results yields the following system of equations for sector prices

$$p_{t,i} = \mu_{t,i} - a_i + \alpha_i w_{t,i} + (1-\alpha_i)\sum_j \omega_{ij} p_{t,j} \tag{A.6}$$

This system of price equations can be written in matrix form as

$$\boldsymbol{p_t} = \boldsymbol{\mu_t} - \boldsymbol{a_t} + I_\alpha \boldsymbol{w_t} + W\boldsymbol{p_t} \tag{A.7}$$

Substituting wage (15) into (A.7), moving parts containing $\boldsymbol{p_t}$ to the left side and multiplying by matrix $L = (I-W)^{-1}$ gives

$$\boldsymbol{p_t} = L\boldsymbol{\mu_t} - L\boldsymbol{a_t} + (p_t + y_t)\cdot L\boldsymbol{\alpha} - \frac{\gamma}{1+\gamma} L I_\alpha I_\xi^{-1} L' I_\xi \boldsymbol{\mu_t} \tag{A.8}$$

Next, I establish a link between labor shares vector and Leontief inverse matrix.

Proposition (Labor shares and Leontief inverse.)**.** $L\boldsymbol{\alpha} = \boldsymbol{1}$.

Proof. Indeed, $L\boldsymbol{\alpha} = \boldsymbol{1} \Leftrightarrow (I-W)^{-1}\boldsymbol{\alpha} = \boldsymbol{1} \Leftrightarrow \boldsymbol{\alpha} = (I-W)\cdot\boldsymbol{1} = \boldsymbol{1} - (\boldsymbol{1} - \boldsymbol{\alpha}) = \boldsymbol{\alpha}$. □

Then, the system of price equations can be expressed as

$$\boldsymbol{p_t} = (p_t + y_t)\cdot\boldsymbol{1} - L\boldsymbol{a_t} + \tilde{L}\boldsymbol{\mu_t} \tag{A.9}$$

where $\tilde{L} = L(I - \frac{\gamma}{1+\gamma} I_\alpha I_\xi^{-1} L' I_\xi)$.

A.3 Final output

Log-linearization of consumer price index yields $p_t = \sum_i \beta_i p_{t,i} = \boldsymbol{\beta'} \cdot \boldsymbol{p_t}$. Multiplying both sides of price equations (16) by vector $\boldsymbol{\beta'}$ and noticing that $\boldsymbol{\beta'} \cdot \mathbf{1} = \sum_i \beta_i = 1$, we get

$$0 = y_t - \boldsymbol{\beta'} \cdot L \cdot a_t + \boldsymbol{\beta'} \tilde{L} \cdot \boldsymbol{\mu_t} \tag{A.10}$$

Next, as shown shown before $\boldsymbol{\beta}' L = \boldsymbol{\xi}'$. Then, $\boldsymbol{\beta}' \tilde{L} = \boldsymbol{\xi}' - \frac{\gamma}{1+\gamma} \boldsymbol{\xi}' I_\alpha I_\xi^{-1} L' I_\xi = \boldsymbol{\xi}' - \frac{\gamma}{1+\gamma} \boldsymbol{\alpha}' L' I_\xi = \boldsymbol{\xi}' - \frac{\gamma}{1+\gamma} \mathbf{1}' \cdot I_\xi = \frac{1}{1+\gamma} \boldsymbol{\xi}'$, where in the third step I use the previous result that $L\boldsymbol{\alpha} = \mathbf{1}$. Hence, we have the expression for output as a function of productivities and markups.

$$y_t = \boldsymbol{\xi'} \cdot \boldsymbol{a_t} - \frac{1}{1+\gamma} \boldsymbol{\xi'} \cdot \boldsymbol{\mu_t} \tag{A.11}$$

A.4 Price-markup link

Log-linearizing Equation (21), while treating all $F_{t-s,i}$ as time-varying coefficients

$$p_{t,i} = F_{t,i} \cdot mc_{t,i} + \sum_{h=1}^{\infty} \left\{ \left[\prod_{s=0}^{h-1} (1 - F_{t-s,i}) \right] \cdot F_{t-h,i} \cdot E_{t-h} mc_{t,i} \right\} \tag{A.12}$$

Let $mc_{t,i} = mc_{t-1,i} + \Delta mc_{t,i}$. Then, we can write

$$p_{t,i} = F_{t,i} mc_{t,i} + (1 - F_{t,i}) \left[F_{t-1,i} E_{t-1} mc_{t,i} + \sum_{h=1}^{\infty} \left\{ \left[\prod_{s=0}^{h-1} (1 - F_{t-1-s,i}) \right] \cdot F_{t-1-h,i} mc_{t,i} \right\} \right] =$$
$$= F_{t,i} mc_{t,i} + (1 - F_{t,i}) p_{t-1,i} + (1 - F_{t,i}) e_{t-1,i}$$

where $e_{t-1,i} = F_{t-1,i} E_{t-1} \Delta mc_{t,i} + \sum_{h=1}^{\infty} \left\{ \left[\prod_{s=0}^{h-1} (1 - F_{t-1-s,i}) \right] \cdot F_{t-1-h,i} \Delta mc_{t,i} \right\}$ is predetermined at period t. Markup is $\mu_{t,i} = p_{t,i} - mc_{t,i}$. Hence, the price-markup link is

$$(1 - F_{t,i}) \cdot (p_{t,i} - p_{t-1,i}) = -F_{t,i} \mu_{t,i} + (1 - F_{t,i}) e_{t-1,i} \tag{A.13}$$

B Cost-push inflation theoretical appendix

This appendix contains proofs for Section 6.

B.1 Phillips curve

Proof of Proposition 1 (Consumer price inflation Phillips Curve). Rewriting price equations (16) in terms of sectoral inflations gives

$$\boldsymbol{\pi_t} = -\boldsymbol{p_{t-1}} + p_{t-1} \mathbf{1} + (\pi_t + y_t) \mathbf{1} - L a_t + \tilde{L} \mu_t$$

where $\tilde{L} = L(I - \frac{\gamma}{1+\gamma} I_\alpha I_\xi^{-1} L' I_\xi)$.
On the other hand, the markup-inflation link through price prigdity (21) can be written as

$$(I - F_t)\boldsymbol{\pi_t} = -F_t \boldsymbol{\mu_t} + (I - F_t)\boldsymbol{e_{t-1}}$$

where $F_t = diag\{F_{t,i}\}$, $\boldsymbol{e_{t-1}}$ is such that
$e_{t-1,i} = F_{t-1,i} E_{t-1} \Delta mc_{t,i} + \sum_{h=1}^{\infty} \left\{ \left[\prod_{s=0}^{h-1} (1 - F_{t-1-s,i}) \right] \cdot F_{t-1-h,i} \Delta mc_{t,i} \right\}$ is predetermined at period t.

Efficient relative prices are

$$\boldsymbol{\hat{p}_t^\star} = \boldsymbol{p_t^\star} - p_t^\star \cdot \mathbf{1} = y_t^e \cdot \mathbf{1} - L \cdot \boldsymbol{a_t}$$

In terms of price gaps $\boldsymbol{\hat{\pi}_t^\star} = \boldsymbol{\hat{p}_t^\star} - \boldsymbol{\hat{p}_{t-1}}$, price equation can be rewritten as

$$\boldsymbol{\pi_t} - \pi_t \cdot \mathbf{1} = \tilde{y}_t \cdot \mathbf{1} + \boldsymbol{\hat{\pi}_t^\star} + \tilde{L} \cdot \mu_t$$

Substituting markup-rigidity link into the previous equation and rearranging, we get

$$F_t(I + \tilde{L} F_t^{-1}(I - F_t))\boldsymbol{\pi_t} - F_t \mathbf{1} \pi_t = F_t \mathbf{1} \tilde{y}_t + F_t \boldsymbol{\hat{\pi}_t^\star} + \tilde{L} F_t^{-1}(I - F_t)\boldsymbol{e_{t-1}}$$

Let $M_t^{-1} = F_t(I + \tilde{L} F_t^{-1}(I - F_t))$. Multipling previous equation by M_t and then by $\boldsymbol{\beta'}$, we get Phillips curve

$$\pi_t(1 - \boldsymbol{\beta'} M_t F_t \mathbf{1}) = \boldsymbol{\beta'} M_t F_t \mathbf{1} \tilde{y}_t + \boldsymbol{\beta'} M_t F_t \boldsymbol{\hat{\pi}_t^\star} + \boldsymbol{\beta'} M_t F_t \tilde{L} F_t^{-1}(I - F_t)\boldsymbol{e_{t-1}}$$

Let $\kappa_t = \frac{\boldsymbol{\beta'} M_t F_t \mathbf{1}}{1 - \boldsymbol{\beta'} M_t F_t \mathbf{1}}$. Then, Phillips curve takes the form stated in proposition. □

B.2 Cost-push effect decomposition

Proof of Proposition 2 (Phillips curve residual decomposition). Absence of input-output effect in price setting means that firms set their prices ignoring the inefficient component of their marginal costs. Instead they consider marginal costs being equal to the efficient prices $\boldsymbol{p_t^\star}$. Hence, the resulting sector prices are $\boldsymbol{p_t} = F_t \cdot \boldsymbol{p_t^\star} + (I - F_t)(\boldsymbol{p_{t-1}} + \boldsymbol{e_{t-1}})$, which yields $(I - F_t) \cdot (\boldsymbol{p_t} - \boldsymbol{p_{t-1}}) = F_t \cdot (\boldsymbol{p_t^\star} - \boldsymbol{p_t}) + (I - F_t) \cdot \boldsymbol{e_{t-1}}$.

Since $\boldsymbol{p_t^\star} - \boldsymbol{p_t} = -\tilde{L} \cdot \boldsymbol{\mu_t}$, we have $(I - F_t) \cdot (\boldsymbol{p_t} - \boldsymbol{p_{t-1}}) = -F_t \tilde{L} \cdot \boldsymbol{\mu_t} + (I - F_t) \cdot \boldsymbol{e_{t-1}}$. Under this link between inflation and markups, the Phillips curve is

$$\pi_t(1 - \boldsymbol{\beta'} F_t \mathbf{1}) = \boldsymbol{\beta'} F_t \mathbf{1} \tilde{y}_t + \boldsymbol{\beta'} F_t \boldsymbol{\hat{\pi}_t^\star} + \boldsymbol{\beta'} F_t \tilde{L} F_t^{-1}(I - F_t)\boldsymbol{e_{t-1}}$$

and the Phillips curve residual not-related to inefficiency in marginal cost is $u_t^h = \boldsymbol{\beta'} F_t \boldsymbol{\hat{\pi}_t^\star}$
□

Proof of Corollary 1 (Single final good economy(only I-O component)). Let $\boldsymbol{\pi}_t^\star$ be desired price changes. $\boldsymbol{\beta}'\boldsymbol{\pi}_t^\star = \pi_{1,t}^\star$ is the desired consumer price change. Then, price gaps (relative desired price changes) are $\hat{\boldsymbol{\pi}}_t^\star = \left[0, \hat{\pi}_{2,t}^\star,\ ..., \hat{\pi}_{N,t}^\star\right]$. As a result $u_t^h = \boldsymbol{\beta}' F_t \hat{\boldsymbol{\pi}}_t^\star = 0$

If $F_{1,t} < 1$ and $F_{i,t} = 1$ for all $i \neq 1$ then we have $[F_t^{-1}(I - F_t)]_{1,1} \neq 0$ and $[F_t^{-1}(I - F_t)]_{i,j} = 0$ otherwise. Then $M_t F_t = [I + \tilde{L}F_t^{-1}(I - F_t)]^{-1}$ is such that it has non-zero first column, ones on the diagonal and zeros otherwise. Then $\boldsymbol{\beta}' M_t F_t$ is a row vector with the first element being the only non-zero element. Hence, we have $\boldsymbol{\beta}' M_t F_t \hat{\boldsymbol{\pi}}_t^\star = 0$ since $\hat{\pi}_{1,t}^\star = 0$. □

Proof of Corollary 2 (Quasi-horizontal economy (only horizontal component)). If $\tilde{L} = I$ the net effect of markups on marginal cost is zero as intermediate cost effect exactly compensates the labor cost effect. In this case, $M_t = (I + \tilde{L}F_t^{-1}(I - F_t))^{-1}F_t^{-1} = I$ and the vertical component disappears.

In the case described by corollary, Leontief inverse is $L = I_\alpha^{-1}$, which gives $\tilde{L} = \frac{1}{1+\gamma} I_\alpha^{-1}$. To eliminate vertical component we need to have $\alpha_i = \frac{1}{1+\gamma}$ for all sectors i. □

B.3 Illustrative examples derivations

B.3.1 Vertical chain economies

Consider a general case of a two-sector vertical chain. U - upstream sector, D - downstream sector. F^U - upstream price flexibility, F^D - downstream price flexibility. The share of upstream input in downstream production is w. Let productivity vector be $a' = [\epsilon^U,\ \epsilon^D]$. Price flexibility matrix is $F_t = \begin{pmatrix} F^U & 0 \\ 0 & F^D \end{pmatrix}$. I-O matrix is $W = \begin{pmatrix} 0 & 0 \\ w & 0 \end{pmatrix}$. Leontief inverse is $L = \begin{pmatrix} 1 & 0 \\ w & 1 \end{pmatrix}$. Consumption shares are $\boldsymbol{\beta}' = [0,\ 1]$ and Domar weigths are $\boldsymbol{\xi}' = \boldsymbol{\beta}' L = [w,\ 1]$. Labor shares $\alpha' = [1,\ (1-w)]$. Phillips curve residual is $u_t = \boldsymbol{\beta}' M_t F_t \hat{\boldsymbol{\pi}}_t^\star$ where $M_t F_t = (I + \tilde{L}F_t^{-1}(I - F_t))^{-1}$ and $\tilde{L} = \frac{1}{1+\gamma} \cdot \begin{pmatrix} 1 & -\gamma \\ w & 1 \end{pmatrix}$.

$M_t F_t = \frac{1+\gamma}{Det} \cdot \begin{pmatrix} 1+\gamma+f^D & \gamma f^D \\ -wf^U & 1+\gamma+f^U \end{pmatrix}$ where $f^U = \frac{1-F^U}{F^U}$, $f^D = \frac{1-F^D}{F^D}$ and $Det = (1+\gamma+f^U)\cdot(1+\gamma+f^D) - w\gamma f^U \cdot f^D > 0$. $\boldsymbol{\beta}' M_t F_t = \frac{1+\gamma}{Det} \cdot [-wf^U,\ 1+\gamma+f^U]$. Desired price changes are $\hat{\boldsymbol{\pi}}_t^\star = -[(1-w)\epsilon^U - \epsilon^D,\ 0]'$. Then, Phillips curve residual

$$u_t = \frac{1+\gamma}{Det} \cdot w((1-w)\epsilon^U - \epsilon^D) \cdot \frac{1-F^U}{F^U} \tag{A.14}$$

Example 1: two-sector vertical chain. In this example Oil sector is Upstream and Final good sector is Downstream. We have $F^U = F^O = 1$, $\epsilon^U = \epsilon^O$ and $\epsilon^D = 0$. As a result we have $u = \frac{1+\gamma}{Det} \cdot w((1-w)\epsilon^O) \cdot \frac{1-F^O}{F^O} = 0$.

Example 2: Intermediate good. Consider a three-sector vertical chain Oil $\rightarrow$ Intermediate good $\rightarrow$ Final good. Assume that intermediate good uses only oil and no labor. Let price flexibilities be $F^O = 1$, $F^I < 1$ and $F^F < 1$. Then, Oil and Intermediate good can be combined in one Upstream sector such that $F^U = F^I$ and $F^D = F^F$. Under the oil shock ϵ^O, we have $\epsilon^U = \epsilon^O$ and $\epsilon^D = 0$. Then, the residual is is $u = \frac{1+\gamma}{Det} \cdot w(1-w) \cdot \epsilon^O \cdot \frac{1-F^I}{F^I}$. When oil productivity goes down (oil price goes up), Phillips curve residual also goes down (consumer prices go down).

Example 3: "Sticky wage" economy. Consider a three-sector vertical chain Labor sector$\rightarrow$ Oil$\rightarrow$ Final good. Assume that final good uses only oil and no labor. Let price flexibilities be $F^L < 1$, $F^O = 1$ and $F^F < 1$. Then, Oil and Final good can be combined in one Downstream sector such that $F^U = F^L$ and $F^D = F^F$. Under the oil shock ϵ^O, we have $\epsilon^U = 0$ and $\epsilon^D = \epsilon^O$. Then, the residual is is $u = \frac{1+\gamma}{Det} \cdot -w\epsilon^O \cdot \frac{1-F^L}{F^L}$. When oil productivity goes down (oil price go up), Phillips curve residual goes up (consumer prices go up).

B.3.2 Multiple input/goods economies

Next, consider a two-sector horizontal economy with good 1 (G1) and (G2) such that only labor and own output is used for production of each good. Then production network is $W = I - I_\alpha$, $L = I_\alpha^{-1}$, $\tilde{L} = I$ and $M_t = I$ which eliminates vertical component of cost-push inflation. The shares of each good in consumption are s_1 and s_2 such that $s_1 + s_2 = 1$. Let each of these sectors be hit by a respective shock ϵ_1 and ϵ_2 and the respective price flexibilities be F_1 and F_2. Then $\boldsymbol{La_t} = [(1-\alpha_1)^{-1} \cdot \epsilon_1,\ (1-\alpha_2)^{-1} \cdot \epsilon_2]'$. Then, $\hat{\boldsymbol{\pi}}_{\boldsymbol{t}}^{\star} = -[s_2((1-\alpha_1)^{-1} \cdot \epsilon_1 - (1-\alpha_2)^{-1} \cdot \epsilon_2),\ -s_1((1-\alpha_1)^{-1} \cdot \epsilon_1 - (1-\alpha_2)^{-1} \cdot \epsilon_2)]'$. Then cost-push inflation is $u = -s_1 \cdot s_2 \cdot (F_1 - F_2) \cdot ((1-\alpha_1)^{-1} \cdot \epsilon_1 - (1-\alpha_2)^{-1} \cdot \epsilon_2)$.

Example 4: Multiple inputs economy. Consider an economy where single final good is produced using two inputs Oil and Intermediate good. If price flexibility in final good sector is 1 and no labor is used in this sector, then this economy is a special case of a horizontal economy described above. We have $F_1 = F^O = 1$, $F_2 = F^I$, $s_1 = 1 - \alpha^I$, $s_2 = \alpha^I$, $\alpha_1 = \alpha_2 = 1$ and $\epsilon_1 = \epsilon^{Oil}$, $\epsilon_2 = 0$. As a result we have cost-push effect $u = -\alpha^I(1-\alpha^I) \cdot (1-F^I) \cdot \epsilon^{Oil}$.

Example 5: Two-commodity economy. Consider an economy consisting of two commodities: Oil and Grain and two final goods: Oil-intensive final good and Grain-intensive final good. Commodity sectors have fully flexible prices, while final good sectors have partially rigid prices. If final goods sectors do not use any labor and use only respective commodities, then this economy can be represented as a special case of a two-sector horizontal economy described above with Oil commodity and Oil intensive final good representing the first sector and Grain commodity and Grain-intensive final good representing the second sector. Then, we have $F_1 = F^{FO}$, $F_2 = F^{FG}$, $\alpha_1 = \alpha_2 = 1$, $s_1 = s_2 = 0.5$ are consumption shares, $\epsilon_1 = \epsilon^{Oil}$ and $\epsilon_2 = \epsilon^{Grain}$. Then, cost-push effect is $u = -\frac{1}{4} \cdot (F^{FO} - F^{FG}) \cdot (\epsilon^{Oil} - \epsilon^{Grain})$

C Empirical evidence appendix

C.1 Methodology appendix

Computing sector relevant states and markups. Let all industies be indexed by $i \in \{1, ..., N\}$. At any period t the available k sectors have indices $\{i^1, ..., i^k\} \subseteq \{1, ..., N\}$. I construct $N \times k$ selection matrix S, such that $S[i^j, j] = 1$ and zero otherwise. Note, that $S^T S = I$. Then transformation $S\boldsymbol{u}$ transforms k-sized vector $\boldsymbol{u}$ to N-sized vector with zeros for unavailable sectors; $S^T \boldsymbol{v}$ transforms N-sized vector $\boldsymbol{v}$ to k-sized, by choosing only elements for available industires. Hence, we can write a system of k equations for k markups and productivities in terms of k wages and prices

$$\boldsymbol{\mu} = \frac{1+\gamma}{\gamma} \cdot S^T (I_\xi^{-1} L^T I_\xi)^{-1} S \cdot ((p+y) \cdot \mathbf{1} - \boldsymbol{w}) \tag{A.15}$$

$$\boldsymbol{s} = \boldsymbol{p} - S^T (\tilde{L} S \cdot \boldsymbol{\mu} + (p+y) \cdot \mathbf{1}) \tag{A.16}$$

Instrument validity. . Note that $\tilde{v}_{t,i}$ is independent of $z_{t,i}$ as long as monetary policy does not react within a month to a productivity shock. Furthermore, $F_i(|z_{t,i}|) z_{t,i}$ has mean zero, since $z_{i,t}$ is zero mean normally distributed. Hence, we have

$$\begin{aligned} &Cov(F_i(|z_{t,i}|) z_{t,i},\ F_i(|z_{t,i}|) \tilde{v}_{t,i}) = E(F_i(|z_{t,i}|)^2 z_{t,i} \tilde{v}_{t,i}) = \\ &\qquad = \int \int F_i(|z_{t,i}|)^2 z_{t,i} \tilde{v}_{t,i} f_z f_{\tilde{v}} dz d\tilde{v} = \int_{\tilde{v}} \left[\int_z F_i(|z_{t,i}|)^2 z_{t,i} f_z dz \right] \tilde{v}_{t,i} f_{\tilde{v}} d\tilde{v} = 0 \end{aligned}$$

The last equality follows as inner integral equals to zero due to zero mean symmetric distribution of $z_{i,t}$. Hence, instruments constructed in this matter are valid. □

C.2 Dataset construction

This Appendix describes the construction of BEA-coded sectoral prices and wages.

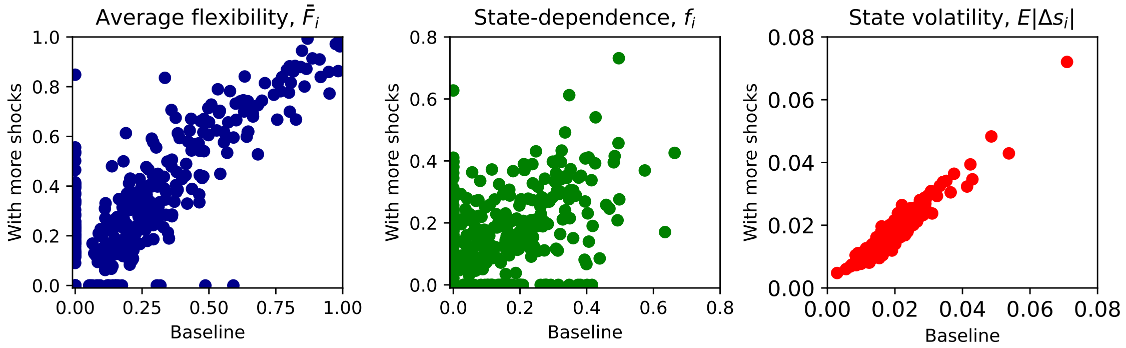
Sectoral wages (from CES to NAICS). Sectoral wages are initially classified with CES codes, with available correspondence from CES to NAICS codes. So first I transform the wages classification to NAICS-based. The main complication is that CES to NAICS mapping is not one-to-one as at least for some NAICS codes more than one CES sector exists.To overcome this complication I compute the weighted average wage for each NAICS sector as $w^{NAICS} = \sum \alpha_i w_i^{CES}$ where w_i^{CES} are CES-sector wages corresponding to a given NAICS sector code. Each weight α_i is computed as a ratio of the number of workers employed in sector i to the total number of workers in all CES sectros corresponding to a given NAICS sector. The number of employed workers is taken form the same CES dateset as the average number for the year 2012, to correspond to the year of the Input-Output table used.

NAICS to BEA concordance. The producer prices data is classified by NAICS codes as well as wages data (after the transformation from CES to NAICS described above). To apply this data to the available input-output tables I convert NAICS based sectoral data to BEA based sectoral data. BEA Bridge tables have a rough BEA-NAICS code correspondence, from which I make use to establish a concordance between NAICS codes and BEA codes. The problem is that the BEA-NAICS codes correspondence is not one-to-one. For those cases when one BEA code corresponds to several NAICS codes I need weights to evaluate the BEA-based price as a weighted average of the NAICS based prices. For this I need to compute the relative sector size of each NAICS sector withing a given BEA sector. The primary data source I use to compute NAICS sector sizes is the Annual survey of manufacturers from the US Census. I use the corresponding "Shipment value" quantities for the survey of 2012. The secondary data source is the Current Employment Survey. I use the number of employed people as an sector size variable, translated from CES into NAICS codes in the same manner as wages. First I try to compute NAICS sector weights in each BEA code using ASM data. If ASM data is unavailable, I use CES data. For those sectors, that are not covered by either dataset I use the uniformal weights.

NAICS to BEA matching procedure. Having constructed the mapping from NAICS to BEA codes with corresponding weights, I convert the NAICS data into the BEA data. I want to find a corresponding NAICS code for as many NAICS sectors from the NAICS-BEA mapping as possible. First, I find the the NAICS codes in the data that have the identical NAICS codes in the NAICS-BEA mapping. For the remaining NAICS codes from the BEA-NAICS mapping I try to find the correspondence at the more aggregated level. I subsequently remove 1,2 and 3 last digits of NAICS codes form the mapping and try to find the corresponding more aggregated sector in the data.

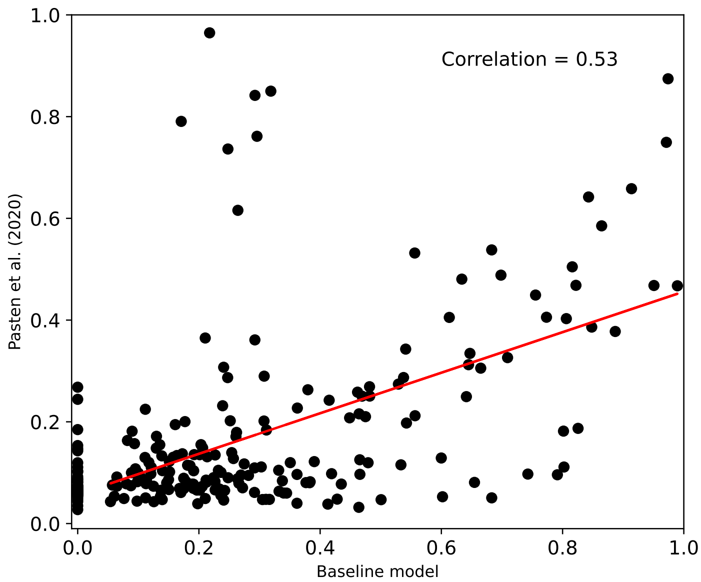
C.3 Additional results

Figure C.1: Baseline estimates vs. model with more shocks



Correlation of average flexibilities is 0.83; state-dependence parameters - 0.45; average state volatilities - 0.96.

Figure C.2: Baseline estimates vs. Pasten et al. (2020) estimates

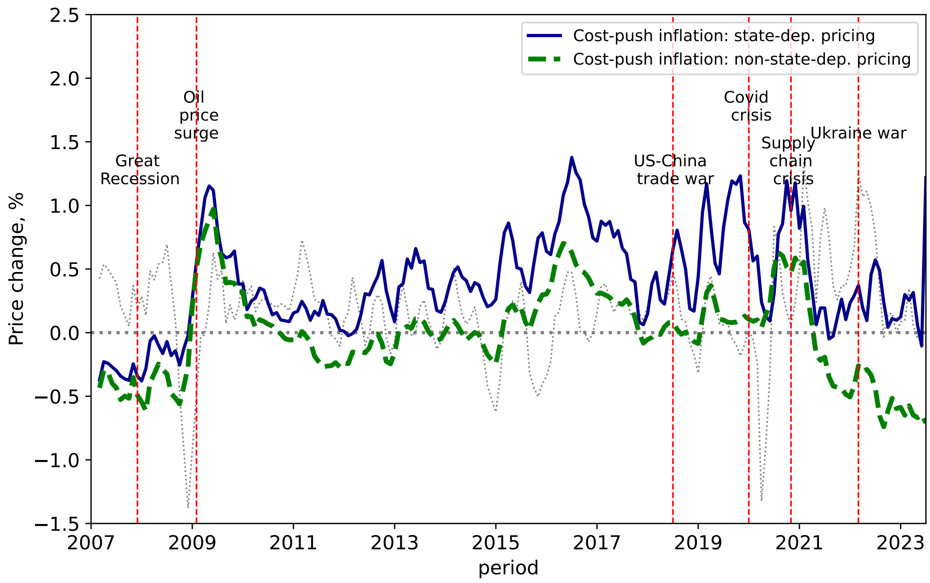


D Quantitative appendix

D.1 Model with more shocks

To check the robustness of baseline cost-push effect computations I now compute the alternative cost-push effect from the model with more shocks. In this computations sector-relevant states are computed using more sectoral data and the parameters of price flexibility and state-dependence estimated based on this alternative sector-relevant state.

Figure D.3: Phillips curve residual in model with more shocks



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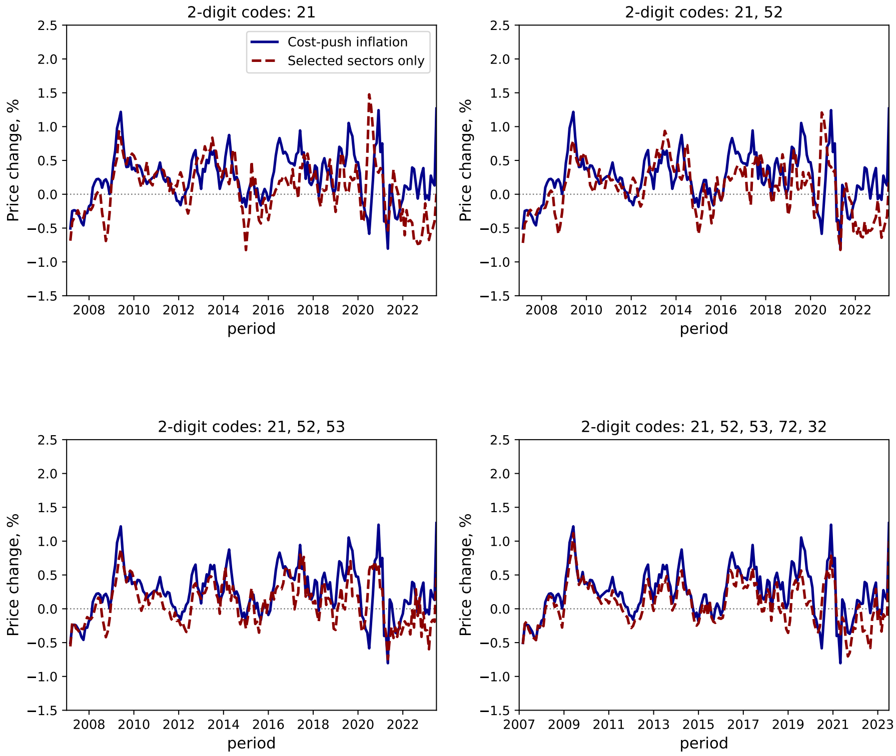
D.2 Most important sectoral groups contribution

For these five most important groups, I compute counterfactual cost-push effects generated exclusively by fluctuations in sectors belonging to these groups. Figure D.4 panel A plots the residual induced by sector group 21 (Mining, Quarrying, and Oil and Gas Extraction) and indicates that this sector group alone can partially explain the cost-push effect of 2009 but does not explain any other episode. Adding other important groups 52, 53 (Finance and Insurance, Real Estate, and Rental and Leasing) on panel B, and 32, 72 (Manufacturing of durable goods, Accommodation and Food Services) on panel C, improves the fit to full residual - many fluctuations can be attributed to these most important sectors.

Figure D.4: Cost-push inflation due to 2-digit sector groups



Red dashed line plots counterfactual residuals computed by shutting down the shocks in all sectors except a given 2-digit sector group.

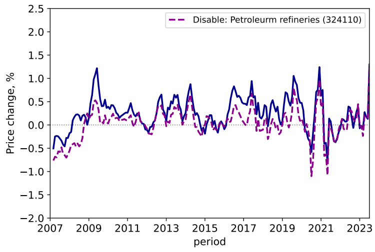
D.3 Sectoral contribution during particular episodes

Now, I investigate which sectors have contributed the most during three important historical episodes: the post-Great Recession, the post-Covid episode, and the Ukraine war. For this, I find the largest-seized elements of the sum constituting the main component of the cost-push effect within each episode of interest. Then, I compute counterfactual residual by switching off these sectors.

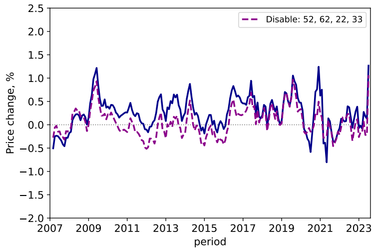
In 2009, a lot of cost-push effect was attributed to the "Petroleum refineries" sector alone. Figure D.5 (panel A) shows that switching off this sector substantially reduces the 2009 cost-push effect. The Covid and post-Covid episode was not attributed to any particular sector but rather to several groups simultaneously 52, 62, 22, 33 (Finance and Insurance, Health Care and Social Assistance, Utilities, Manufacturing (durable goods). Figure D.5 (panel B) shows that these groups explain most of the cost-push effect in 2020-2021. The 2022 surge of the cost-push effect is largely attributed to sector groups 53 and 72 (Real Estate and Rental and Leasing, Accommodation and Food Services) as shown on D.5 (panel C).

Figure D.5: Cost-push inflation due to 2-digit sector groups

(a) disable Great Recession sectors



(b) disable Covid sectors



(c) disable Ukraine war sectors