When are Technology Improvements Inflationary?*

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Abstract

Technology improvements are commonly believed to be disinflationary. This paper argues that this view may not be warranted, showing that the response of aggregate inflation to a technology shock may change sign depending on the sectoral origin of the shock. We start by establishing this result analytically in a tractable production-network economy where sectors differ in their degree of price rigidity and position in the network. We show that the response of aggregate inflation to a favorable technology shock is increasing in the price rigidity of the shocked sector. More importantly, this response may actually turn positive if the shock originates in a sector with a sufficiently higher-than-average degree of price rigidity. This condition holds to the extent that monetary policy reacts to the output gap, and is weaker when the shocked sector is located downstream in the supply chain. We validate these predictions in the context of highly disaggregated multi-sector model, which we calibrate to the U.S. economy. The model implies that aggregate inflation rises when the underlying technology shock originates in 18 (out of 60) industries. Finally, we provide empirical evidence supporting the predicted relationship between sectoral price rigidity and the response of aggregate inflation to sector-specific technology shocks using a panel of U.S. manufacturing industries.

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*The views expressed in this paper are those of the authors and they do not necessarily coincide with the views of European Central Bank.

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1 Introduction

Under what circumstances, if any, can a technology improvement be inflationary? Conventional wisdom and standard textbook models suggest that the answer to this question is: *never*. Changes in technology are universally regarded as supply shocks, which in turn are commonly perceived as those giving rise to negative comovement between inflation and output. Demand shocks, on the other hand, are usually viewed as those moving prices and quantities in the same direction. The sign of comovement implied by supply and demand shocks has long been thought of as the fundamental difference between them and the argument underlying their empirical identification (e.g., Canova and de Nicolo (2003), Peersman (2005)). In this paper, we argue that positive comovement between aggregate inflation and output need not be due to demand shocks, and may arise conditional on supply shocks.

We formalize our idea in the context of a tractable production-network economy composed of two sectors that differ in their degree of price rigidity and position in the network, one being upstream and the other downstream, and across which labor is perfectly mobile. We show analytically that a necessary condition for a positive technology shock to raise aggregate inflation is that the shock originates in a sector with a sufficiently higher-than-average degree of price rigidity. Importantly, this condition does not hinge either on labor-market segmentation or on complementarities in consumption and/or in production. Moreover, we show that the condition never holds when monetary policy does not respond to the output gap, and is weaker when the shock originates in the downstream sector.

The intuition underlying the necessary condition stated above can be understood by inspecting how technology shocks affect aggregate supply and demand. We develop the intuition in two steps. In the first step, we explain why a favorable technology shock leads to a smaller rightward shift in aggregate supply — and thus a smaller disinflation — when it originates in the stickier-price sector. To understand this prediction, it is easiest to abstract from inter-sectoral linkages and to assume that aggregate demand is fixed (for a given price level). Since there is lower cost pass-through in the sector with a stickier price, the decline in nominal marginal cost resulting from a favorable productivity shock translates into a milder price decline. At the same time, there is no change in the nominal marginal cost (and thus the price) of the sector that does not experience an increase in productivity. As a result, the larger the degree of price rigidity of the shocked sector, the smaller the decline in the aggregate price level. In the second step, we explain why this response may actually turn positive. As positive technology shocks raise natural output, they give rise to a negative output gap in the short run. When monetary policy is accommodative, it prompts a rightward shifts in aggregate demand. Aggregate inflation will therefore rise if aggregate demand shifts more than aggregate supply.

Why is this outcome more likely to occur when the technology shock originates in the downstream sector, everything else equal? The answer to this question lies in the way technology shocks propagate through the production network. Consider again the case where aggregate demand is fixed. When a positive shock originates in the upstream sector, it lowers not only its price but also that of the downstream sector, as the cost of intermediate inputs falls. This leads to a large decline in aggregate inflation. Instead, when the shock originates in the downstream sector, it lowers its price but that of the upstream sector remains unchanged, thus mitigating the fall in aggregate inflation.

To validate our theoretical predictions in a richer setting and measure their quantitative implications, we consider a multi-sector economy that embeds multiple sources of sectoral heterogeneity, a realistic input-output structure, and empirically plausible parameters of the monetary-policy rule. The model is calibrated using aggregate and sectoral U.S. data on 60 industries.

Consistent with the analytical results, a counterfactual economy that only allows for differences in the degree of price rigidity across sectors while abstracting from other dimensions of heterogeneity implies that the response of aggregate inflation to a favorable sectoral technology shock is increasing in the price rigidity of the shocked sector. The response is positive only when the shock originates in sectors with sufficiently sticky prices, provided that monetary policy responds to the output gap. Importantly, what matters for sectoral technology shocks to be inflationary is not the absolute level of price rigidity in the shocked sector but instead whether this level is sufficiently higher than average. Indeed, for any given average degree of price rigidity, increasing its dispersion across sectors raises the number of sectors where a technology shock is inflationary in the aggregate.

When we add heterogeneity in the position in the production network, we find that favorable shocks to sectors with a similar degree of price rigidity tend to produce a larger response of inflation when they originate in more downstream (less central) sectors. This result confirms the role of downstreamness in weakening the condition for a sectoral technology shock to raise aggregate inflation. Robustness checks show that our findings hold under alternative assumptions about factor mobility and the degree of substitutability in consumption and in production. In the fully heterogeneous model, positive technology shocks raise aggregate inflation when they originate in 18 out of the 60 sectors.

Finally, we provide empirical evidence in support of the predicted relationship between price rigidity and the response of aggregate inflation to sectoral technology shocks using a panel of U.S. manufacturing industries. In a panel regression where technology shocks are identified as log changes in sectoral Total Factor Productivity, we find that the response of aggregate inflation tends to be relatively less negative in response to positive productivity shocks occurring in industries with a relatively high degree of nominal price rigidity. Moreover, the response turns positive when the shocks originate in sectors in the highest quartile of the price-rigidity distribution. The results stand for a battery of robustness checks.

Literature review This paper contributes to the fast growing literature on the aggregate implications of sectoral shocks in multi-sector economies with nominal frictions.[1] Guerrieri et al. (2022) show that negative supply shocks in one sector can lead to demand shortages, causing aggregate output to fall below potential and giving rise to Keynesian unemployment. They dub shocks that lead to such an outcome *Keynesian supply shocks*, and show that are more likely to occur when the elasticity of substitution between consumption goods is low (relative to the intertemporal elasticity of substitution) and when markets are incomplete. Baqaee and Farhi (2022), however, point out that, in a setting similar to that considered by Guerrieri et al. (2022), negative supply shocks can never be disinflationary unless they are accompanied by exogenous adverse demand shocks. In our model, negative sectoral supply shocks can be disinflationary because monetary policy reacts endogenously to the resulting output gap, causing aggregate demand to fall. This result however, hinges on price rigidity being heterogeneous across sectors, a feature absent from the economies studied by Baqaee and Farhi (2022) and Guerrieri et al. (2022).

Other studies allow for sectoral heterogeneity in price rigidity but focus on different questions than the one considered in this paper. Smets et al. (2019) study pipeline pressure to inflation stemming from the propagation of sectoral shocks through the production network in the context of a multi-sector economy estimated using Bayesian techniques. Relatedly, Minton and Wheaton (2023) assess, both theoretically and empirically, how quickly and fully commodity-price movements propagate through supply chains, and ultimately affect aggregate inflation. Ruge-Murcia and Wolman (2024) rely on an estimated New Keynesian model to disentangle the relative importance of sectoral and aggregate shocks in accounting for the behavior of U.S. inflation. Their paper, however, abstracts from intersectoral linkages. Ferrante et al. (2023) study a similar question in a more general environment that incorporates a production network and shocks to demand reallocation across sectors.[2] Pasten et al. (2024) show that heterogeneity in nominal rigidity amplifies the volatility of aggregate output resulting from sectoral productivity shocks, and changes the identity of the sectors that are responsible for aggregate fluctuations. Afrouzi and Bhattarai (2023) develop sufficient statistics that characterize the dynamics of aggregate output and inflation in response to sectoral and aggregate shocks in a New-Keynesian economy with an arbitrary production network. La'O and Tahbaz-Salehi (2022) derive optimal monetary policy in a production-network economy with sectoral productivity shocks and heterogeneous price-setting frictions. None of these contributions explores the circumstances under which favorable supply shocks can raise aggregate inflation.

[1] An earlier literature has examined the contribution of sector-specific shocks to aggregate fluctuations in production-network economies with flexible prices. Notable examples include Horvath (2000), Foerster et al. (2011), Gabaix (2011), Acemoglu et al. (2012), Carvalho and Gabaix (2013), and Atalay (2017).

[2] De Graeve and Schneider (2023) also evaluate the contribution of sectoral shocks to aggregate fluctuations, but their approach is based on a structural econometric framework rather than a theoretical model.

Closer to our paper is the one by Cesa-Bianchi and Ferrero (2021). Their main contribution is to empirically identify sectoral supply shocks that give rise to positive comovement of aggregate output and inflation, just like aggregate demand shocks. They find that roughly 40% of the identified demand-like shocks are in fact sectoral supply shocks. Interestingly, they reach a similar result when they apply their empirical methodology to artificial data simulated from a production-network model that features multiple sources of sectoral heterogeneity, sector-specific labor markets, and complementarities in production. The authors conclude that the interaction of price rigidity and complementarities in production is the key ingredient to obtain a decline inflation following a contractionary supply shock. While our paper and that of Cesa-Bianchi and Ferrero (2021) share the same focus, our analysis differs from theirs in several important aspects. First, we analytically map the response of aggregate inflation to the price rigidity of the shocked sector and its position in the network, and establish the condition under which a favorable supply shock is inflationary. Second, in our model, the latter outcome does not hinge on complementarities in production. Third, we provide alternative empirical evidence supporting the model predictions.

Structure of the paper The rest of the paper is organized as follows. Section (2) presents a New Keynesian multi-sector model with sectoral technology shocks. Section (3) considers a restricted two-sector version of the model with heterogeneity in price rigidity and position in the supply chain, and derives analytical results about the effects of sectoral shocks on aggregate inflation. Section (4) performs a quantitative analysis based on a realistic multi-sector model, calibrated to the U.S. economy. Section (5) provides empirical evidence supporting the theoretical predictions. Section (6) concludes.

2 A Multi-Sector Model with Sectoral Technology Shocks

We consider a cashless Neo Keynesian model with physical capital and S inter-connected industries that differ in their (i) contribution to consumption, (ii) contribution to investment, (iii) input use, (iv) factor intensities, and (v) degree of nominal price rigidity. Prices are set in a staggered fashion following a Calvo protocol. The economy features a representative household, firms within each sector, and a monetary authority. Finally, the only source of exogenous variation is sectoral technology shocks.

2.1 Households

The economy is populated by a representative household with preferences over consumption, C_t, and labor, N_t. Its expected life-time utility as of time 0 is given by

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{C_t^{1-\sigma}}{1-\sigma} - \theta \frac{N_t^{1+\eta}}{1+\eta} \right\}, \tag{1}$$

where β is the discount factor, σ is the degree of risk aversion, η is the inverse of the Frisch elasticity of labor supply, and θ is a labor-disutility shifter.

The household enters period t with a stock of physical capital, K_t, and B_t units of one-period nominal bonds. During the period, the household receives interest payments $R_t B_t$, where R_t is the gross nominal interest. It also earns labor income, $W_t N_t$, where W_t denotes the nominal wage rate, capital income, $R_{K,t} K_t$, where $R_{K,t}$ is the nominal rental rate of capital, and profits, D_t. With this income, the household purchases consumption goods at the price $P_{C,t}$, investment goods, I_t, at the price $P_{I,t}$, and a new stock of bonds, B_{t+1}. Its budget constraint is therefore given by

$$P_{C,t} C_t + P_{I,t} I_t + B_{t+1} = W_t N_t + R_{K,t} K_t + R_t B_t + D_t. \tag{2}$$

The accumulation of physical capital is subject to investment adjustment costs as in Christiano et al. (2005). Specifically, the law of motion of capital is

$$K_{t+1} = (1-\delta) K_t + I_t \left[1 - \Omega \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right], \tag{3}$$

where δ denotes the depreciation rate and $\Omega > 0$ captures the magnitude of adjustment costs.

To allow for the possibility of imperfect labor mobility across sectors, we follow Horvath (2000) and posit that aggregate labor is a CES aggregator of sectoral labor flows, that is

$$N_t = \left(\sum_{s=1}^{S} \omega_{N,s}^{-\frac{1}{\nu_N}} N_{s,t}^{\frac{1+\nu_N}{\nu_N}} \right)^{\frac{\nu_N}{1+\nu_N}}, \tag{4}$$

where $N_{s,t}$ denotes labor supplied to sector s, $\omega_{N,s}$ are sectoral labor weights, and $\nu_N \geq 0$ is (the absolute value of) the elasticity of substitution of labor across sectors. The aggregator (4) implies that the household's supply of labor to sector s equals $N_{s,t} = \omega_{N,s} \left(\frac{W_{s,t}}{W_t} \right)^{\nu_N} N_t$, where $W_{s,t}$ is the nominal sectoral wage rate. The aggregate wage rate is then given by $W_t = \left(\sum_{s=1}^{S} \omega_{N,s} W_{s,t}^{1+\nu_N} \right)^{\frac{1}{1+\nu_N}}$. When $\nu_N \to \infty$, labor is perfectly mobile and wages are equalized across sectors (i.e., $W_{s,t} = W_t$ for $s = 1, \ldots, S$). Instead, smaller values of ν_N imply less sectoral mobility and higher wage differentials across industries.

Analogously, we assume that aggregate stock of capital is a CES aggregator of sectoral capital stocks:

$$K_t = \left(\sum_{s=1}^{S} \omega_{K,s}^{-\frac{1}{\nu_K}} K_{s,t}^{\frac{1+\nu_K}{\nu_K}} \right)^{\frac{\nu_K}{1+\nu_K}}, \tag{5}$$

where $K_{s,t}$ denotes capital supplied to firms in sector s, $\omega_{K,s}$ are sectoral capital weights, and $\nu_K \geq 0$ is (the absolute value of) the elasticity of substitution of capital across sectors. The household's supply of capital services to sector s equals $K_{s,t} = \omega_{K,s} \left(\frac{R_{K,s,t}}{R_{K,t}} \right)^{\nu_K} K_t$, where $R_{K,s,t}$ is the nominal sectoral rental rate of capital. The aggregate rental rate of capital is then given by $R_{K,t} = \left(\sum_{s=1}^{S} \omega_{K,s} R_{K,s,t}^{1+\nu_K} \right)^{\frac{1}{1+\nu_K}}$.

2.2 Firms

In each sector, there is a continuum of monopolistically competitive producers and a representative perfectly competitive wholesaler. The former produce different varieties of the sectoral good using labor, capital, and intermediate-inputs, and set prices subject to a Calvo-type pricing protocol. The different varieties are then sold to the wholesaler, who combines them into a final sectoral-good bundle.

The production apparatus also consists of a representative consumption-good retailer, a representative investment-good retailer, and — for each sector — a representative intermediate-input retailer. These retailers combine the different sectoral goods into consumption, investment, and intermediate-input bundles.

2.2.1 Producers

In each sector, there is a unit measure of monopolistically competitive firms, indexed by i, that produce different varieties of goods using labor, capital, and intermediate inputs. Producer i in sector s has the following Cobb-Douglas production function:[3]

$$X_{s,t}^{i} = Z_{s,t} \left({N_{s,t}^{i}}^{\alpha_{N,s}} {K_{s,t}^{i}}^{1-\alpha_{N,s}} \right)^{1-\alpha_{H,s}} {H_{s,t}^{i}}^{\alpha_{H,s}}, \tag{6}$$

where X_s^i denotes its gross output, $N_{s,t}^i$, $K_{s,t}^i$, and $H_{s,t}^i$ denote, respectively, the labor, physical capital, and bundle of intermediate inputs it uses. The parameters $\alpha_{N,s} \in [0,1]$ and $\alpha_{H,s} \in [0,1]$ denote, respectively, the value-added-based labor intensity and the gross-output-based intensity of intermediate inputs in sector s. Importantly, these factor intensities do not vary across firms within the same sector. Finally, $Z_{s,t}$ is the level of sector-specific technology, which is assumed to follow a first-order autoregressive process given by

$$\log Z_{s,t} = \rho \log Z_{s,t-1} + u_{s,t}, \tag{7}$$

[3] The unit elasticity of substitution between value added and intermediate inputs implied by the Cobb-Douglas technology (6) is consistent with the empirical evidence reported by Atalay (2017).

where ρ measures the persistence of the process, and the sectoral technology shock, $u_{s,t}$, is a zero-mean normally distributed innovation.

Producers set their prices à la Calvo, with $1-\varphi_s$ being the constant (and sector-specific) probability of a choosing a new price in a given period. The optimal reset price, $P^{\star}_{s,t}$, maximizes sector s producers' expected discounted stream of real profits, that is

$$P^{\star}_{s,t} = \arg \max_{P^i_{s,t}} \mathbb{E}_t \sum_{\tau=t}^{\infty} (\beta\varphi_s)^{\tau-t} \left(\frac{C_\tau}{C_t}\right)^{-\sigma} \frac{P_{C,t}}{P_{C,\tau}} \frac{D^i_{s,j}\left(P^i_{s,t}\right)}{P_\tau}, \tag{8}$$

where $D^i_{s,\tau}\left(P^i_{s,t}\right)$ denotes producers' nominal profit in period τ — conditional on having set their price to $P^i_{s,t}$ — which equals

$$D^i_{s,t}\left(P^i_{s,t}\right) = P^i_{s,t}X^i_{s,t} - W_{s,t}N^i_{s,t} - R_{K,s,t}K^i_{s,t} - P_{H,s,t}H^i_{s,t}, \tag{9}$$

where $P_{H,s,t}$ denotes the price of the intermediate-input bundle used by the producers of sector s. To express nominal profits in real terms, they are divided by P_t, the GDP deflator index. We define this index in Section 2.4.

2.2.2 Wholesalers

In each sector, there is a representative wholesaler that purchases the different varieties of goods and bundles them into a final sectoral good using the following technology:

$$X_{s,t} = \left(\int_0^1 {X^i_{s,t}}^{\frac{\epsilon-1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}}, \tag{10}$$

where ϵ denotes the elasticity of substitution between varieties within any given sector. As a result, the optimal demand for variety i is $X^i_{s,t} = \left(\frac{P^i_{s,t}}{P_{s,t}}\right)^{-\epsilon} X_{s,t}$, which implies that the price of good s is $P_{s,t} = \left(\int_0^1 {P^i_{s,t}}^{1-\epsilon} di\right)^{\frac{1}{1-\epsilon}}$.

The wholesaler then sells its gross output to the consumption-good, investment-good, and intermediate-input retailers, such that the resource constraint at the sectoral level reads

$$X_{s,t} = C_{s,t} + I_{s,t} + \sum_{x=1}^{S} H_{x,s,t}, \tag{11}$$

where $C_{s,t}$ is the demand of the consumption-good retailers, $I_{s,t}$ is the demand of the investment-good retailers, and $H_{x,s,t}$ is the demand of the intermediate-input retailers of sector x.

2.2.3 Consumption-good retailers

A representative consumption-good retailer bundles the goods purchased from the wholesalers into an aggregate consumption basket using the CES aggregator

$$C_t = \left(\sum_{s=1}^{S} \omega_{C,s}^{\frac{1}{\nu_C}} C_{s,t}^{\frac{\nu_C - 1}{\nu_C}} \right)^{\frac{\nu_C}{\nu_C - 1}} , \tag{12}$$

where $\omega_{C,s}$ is the sectoral consumption weight and ν_C denotes the elasticity of substitution between sectoral consumption goods. The retailer's optimal demand for goods produced by sector s then equals $C_{s,t} = \omega_{C,s} \left(\frac{P_{s,t}}{P_{C,t}} \right)^{-\nu_C} C_t$ and the resulting consumption price index is $P_{C,t} = \left(\sum_{s=1}^{S} \omega_{C,s} P_{s,t}^{1-\nu_C} \right)^{\frac{1}{1-\nu_C}}$.

2.2.4 Investment-good retailers

Analogously, there is a representative investment-good retailer that assembles the goods bought from the wholesalers into an aggregate investment basket using the CES aggregator

$$I_t = \left(\sum_{s=1}^{S} \omega_{I,s}^{\frac{1}{\nu_I}} I_{s,t}^{\frac{\nu_I - 1}{\nu_I}} \right)^{\frac{\nu_I}{\nu_I - 1}} , \tag{13}$$

where $\omega_{I,s}$ is the sectoral investment weight and ν_I denotes the elasticity of substitution between sectoral investment goods. The retailer's optimal demand for goods produced by sector s then equals $I_{s,t} = \omega_{I,s} \left(\frac{P_{s,t}}{P_{I,t}} \right)^{-\nu_I} I_t$ and the resulting investment price index is $P_{I,t} = \left(\sum_{s=1}^{S} \omega_{I,s} P_{s,t}^{1-\nu_I} \right)^{\frac{1}{1-\nu_I}}$.

2.2.5 Intermediate-input retailers

Finally, in each sector, there is a representative intermediate-input retailer that repackages the intermediate inputs used by producers in that sector. Specifically, the retailer of sector s produces the intermediate-input bundle $H_{s,t}$ using the CES aggregator

$$H_{s,t} = \left(\sum_{x=1}^{S} \omega_{H,s,x}^{\frac{1}{\nu_H}} H_{s,x,t}^{\frac{\nu_H - 1}{\nu_H}} \right)^{\frac{\nu_H}{\nu_H - 1}} , \tag{14}$$

where $H_{s,x,t}$ denotes the intermediate input supplied by the wholesalers of sector x and used by producers in sector s, $\omega_{H,s,x}$ is the associated weight, and ν_H denotes the elasticity of substitution between sectoral intermediate inputs. The optimal demand for the intermediate input supplied by the wholesaler of sector x equals $H_{s,x,t} = \omega_{H,s,x} \left(\frac{P_{x,t}}{P_{H,s,t}} \right)^{-\nu_H} H_{s,t}$ and the the price of the intermediate-input bundle used by sector s producers is $P_{H,s,t} = \left(\sum_{x=1}^{S} \omega_{H,s,x} P_{x,t}^{1-\nu_H} \right)^{\frac{1}{1-\nu_H}}$. Given prices $P_{x,t}$ and $P_{H,s,t}$, and the elasticity of substitution ν_H, the parameters $\omega_{H,s,x}$ $(s, x = 1, \ldots, S)$ define the entries of the Input-Output matrix of the economy.

2.3 Monetary Authority

The economy features a monetary authority that sets the gross interest rate in excess of its steady-state level as a function of aggregate inflation in excess of its steady-state level, and the aggregate output gap. The latter is defined as the ratio between real aggregate output, Y_t, and its flexible-price counterpart, Y_t^n. Specifically

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\phi_R} \left[\left(\frac{\Pi_t}{\Pi}\right)^{\phi_\Pi} \left(\frac{Y_t}{Y_t^n}\right)^{\phi_Y}\right]^{1-\phi_R}, \tag{15}$$

where $\Pi_t = \frac{P_t}{P_{t-1}}$ is the gross inflation rate, variables without a time subscript denote steady-state values, $\phi_R \in [0, 1)$, and ϕ_Π and ϕ_Y are positive (finite) parameters.

2.4 Aggregation

The nominal value added of producer i in sector s, $\mathcal{Y}_{s,t}^i$, equals the difference between the nominal value of its gross output and the nominal value of its bundle of intermediate inputs used in production, that is $\mathcal{Y}_{s,t}^i = P_{s,t}^i X_{s,t}^i - P_{H,s,t} H_{s,t}^i$. Aggregating across producers within each sector yields nominal value added at the sectoral level, $\mathcal{Y}_{s,t} = \int_0^1 \mathcal{Y}_{s,t}^i di = P_{s,t} X_{s,t} - P_{H,s,t} H_{s,t}$. We can then determine nominal aggregate value added, $\mathcal{Y}_t$, by aggregating nominal profits across producers and sectors, and substituting them out in the households' budget constraint, which gives

$$\mathcal{Y}_t = \sum_{s=1}^{S} \mathcal{Y}_{s,t} = P_{C,t} C_t + P_{I,t} I_t. \tag{16}$$

Real aggregate value added, Y_t, equals the ratio between the nominal aggregate value added and the GDP deflator, P_t,

$$Y_t = \frac{\mathcal{Y}_t}{P_t}. \tag{17}$$

The GDP deflator is computed as follows:

$$P_t = \frac{P_{C,t} C_t + P_{I,t} I_t}{C_t + I_t}. \tag{18}$$

Finally, the labor and capital markets clear, such that $N_t = \sum_{s=1}^S N_{s,t} = \sum_{s=1}^S \int_0^1 N_{s,t}^i di$ and $K_t = \sum_{s=1}^S K_{s,t} = \sum_{s=1}^S \int_0^1 K_{s,t}^i di$.

To solve the model, we take a first-order approximation of the equilibrium conditions around a deterministic zero-inflation steady state.

3 Analytical Results

In this section, we characterize analytically the response of aggregate inflation to sectoral technology shocks in the context of the stylized economy described below.

3.1 A stylized economy

The economy is a simplified version of the model presented in Section 2, obtained under the following assumptions:

Assumption 1 *The subjective discount factor is nil* ($\beta = 0$) *and the Frisch elasticity of labor supply is infinite* ($\eta = 0$).

Assumption 2 *Production does not depend on capital, that is,* $\alpha_{N,s} = 1\ \forall s \in S$.

Assumption 3 *The economy features only sectors that differ in their degree of price stickiness and position in the production network. To capture the latter feature in a tractable and parsimonious way, we consider an upstream sector, denoted by u, which supplies all the intermediate inputs used by both sectors, and a downstream sector, denoted by d, which demands intermediate inputs, but provides none* ($S = \{u, d\}$). This amounts to setting $\omega_{H,u,u} = \omega_{H,d,u} = 1$ and $\omega_{H,u,d} = \omega_{H,d,d} = 0$.

Assumption 4 *The two sectors are symmetric in every other dimension, that is,* $\alpha_{H,u} = \alpha_{H,d} = \alpha$, $\omega_{N,u} = \omega_{N,d} = \frac{1}{2}$, *and* $\omega_{C,u} = \omega_{C,d} = \frac{1}{2}$.

Assumption 5 *Labor is perfectly mobile across the two sectors, that is,* $\nu_N \to \infty$.

Assumption 6 *The monetary authority sets the level of money supply in excess of its steady-state level as a function of aggregate inflation in excess of its steady-state level, and the aggregate output gap. Specifically,*

$$\frac{M_t}{M} = \left(\frac{\Pi_t}{\Pi}\right)^{-\phi_\Pi} \left(\frac{Y_t}{Y_t^n}\right)^{-\phi_Y}.$$

Assumption 7 *To generate demand for money, we posit that aggregate demand is equal to real money balances. That is,*

$$Y_t = \frac{M_t}{P_t}.$$

Assumption 1 is made for analytical tractability: the restriction $\beta = 0$ implies that aggregate supply does not depend on expected inflation, whereas the restriction $\eta = 0$ implies that consumption is proportional to the aggregate real wage. Assumption 2 means that the parameters affecting capital accumulation, investment adjustment costs, and the aggregation of investment goods are irrelevant.

It also implies that the GDP deflator coincides with the consumption-based price index. Assumption 3 implies that the elasticity of substitution ν_H becomes irrelevant. Assumption 5 implies that $N_t = N_{u,t} + N_{d,t}$ and $W_t = W_{u,t} = W_{d,t}$. Finally, the money-demand equation introduced in Assumption 7 can be easily motivated by a cash-in-advance constraint or a utility function featuring real money balances as one of its arguments. In the remainder of this section, variables are expressed as percentage deviations from their steady-state values.

3.2 Technology shocks and aggregate inflation

Solving the model up to a first-order approximation under Assumptions 1–7 yields the following policy function for aggregate inflation:

$$\pi_t = \Theta_u z_{u,t} + \Theta_d z_{d,t} + \mathcal{H}(\mathbf{p}_{t-1}) \tag{19}$$

where $\mathcal{H}$ is a linear function, $\mathbf{p}_{t-1}$ is a vector of predetermined prices and

$$\begin{aligned}
\Theta_u &= -\frac{1}{2}\left\{\frac{(1+\phi_Y)(1-\varphi_u)[1+\alpha(1-\varphi_d)] - (1-\bar{\varphi})(1-\alpha)\phi_Y}{(1+\phi_Y)[\alpha\varphi_u + (1-\alpha)\bar{\varphi}] + (1+\phi_\Pi)(1-\bar{\varphi})(1-\alpha)}\right\}, \\
\Theta_d &= -\frac{1}{2}\left\{\frac{(1+\phi_Y)(1-\varphi_d) - (1-\bar{\varphi})(1-\alpha)\phi_Y}{(1+\phi_Y)[\alpha\varphi_u + (1-\alpha)\bar{\varphi}] + (1+\phi_\Pi)(1-\bar{\varphi})(1-\alpha)}\right\},
\end{aligned}$$

whith $\bar{\varphi} \equiv \frac{\varphi_u + \varphi_d}{2}$ being the average Calvo probability.

While expression (19) characterizes the response of aggregate inflation to sector-specific technology shocks, it can be used to infer the inflation response to an aggregate shock, that is, a shock that affects the two sectors simultaneously (i.e., $z_{u,t} = z_{d,t} = z_t$). This response is given by $\Theta_u + \Theta_d$. Proposition 1 below characterizes the sign of this expression.

Proposition 1 *The response of aggregate inflation to a favorable aggregate technology shock is unambiguously negative. That is,*

$$\frac{d\pi_t}{dz_t} = \Theta_u + \Theta_d \leq 0.$$

Proof: See Appendix A.

Proposition 1 states that a positive aggregate technology shock is always disinflationary irrespective of sectoral heterogeneity in price rigidity or the intensity of intermediate inputs.[4] This result extends the prediction of the one-sector model (which can be obtained as a special case where the two sectors are perfectly symmetric and no intermediate inputs are used in production), in which monetary policy never closes the output gap, so that real marginal cost declines in equilibrium following a favorable

[4] More generally, the response of aggregate inflation to a favorable aggregate technology shock is negative regardless of the topology of the production network.

technology shock.

Having established this result, we now turn to our main object of inquiry, namely the response of aggregate inflation to sector-specific technology shocks and the way in which it depends on sectoral price rigidity and position in the network.

3.2.1 Role of sectoral (heterogeneity in) price rigidity

In order to isolate the role of sectoral price rigidity, it is easier to first abstract from input-output linkages (by assuming that $\alpha = 0$), so that the production network consists independent sectors. The response of aggregate inflation to a technology shock originating in sector s is therefore given by:

$$\frac{d\pi_t}{dz_{s,t}} = \Theta_s = -\frac{1}{2}\left\{\frac{(1+\phi_Y)(1-\varphi_s) - (1-\bar{\varphi})\,\phi_Y}{(1+\phi_Y)\bar{\varphi} + (1+\phi_\Pi)(1-\bar{\varphi})}\right\}.$$

Before mapping this response into the price rigidity of the shocked sector, we first determine its sign under the assumption of symmetric price rigidity.

Proposition 2 *Assume $\alpha = 0$. Under symmetric price rigidity, the response of aggregate inflation to a favorable technology shock originating in sector s, is unambiguously negative. That is,*

$$\left.\frac{d\pi_t}{dz_{s,t}}\right|_{\varphi_s=\varphi_x=\bar{\varphi}} \leq 0 \qquad \textit{for } x \in S.$$

Proof: See Appendix A.

Thus, under symmetric rigidity, the aggregate effects of sectoral technology shocks are similar (in terms of sign) to those of aggregate ones: they both lead to negative comovement between inflation and output. Proposition 3 below shows that his is no longer the case once one allows for sectoral heterogeneity in price rigidity.

Proposition 3 *Assume $\alpha = 0$. The response of aggregate inflation to a technology shock originating in sector s, $\frac{d\pi_t}{dz_{s,t}}$, is*

(1) increasing in that sector's degree of price rigidity, φ_s, and

(2) strictly positive if and only if

$$\varphi_s > \tilde{\varphi} \equiv \bar{\varphi} + \frac{1-\bar{\varphi}}{1+\phi_Y}.$$

Proof: See Appendix A.

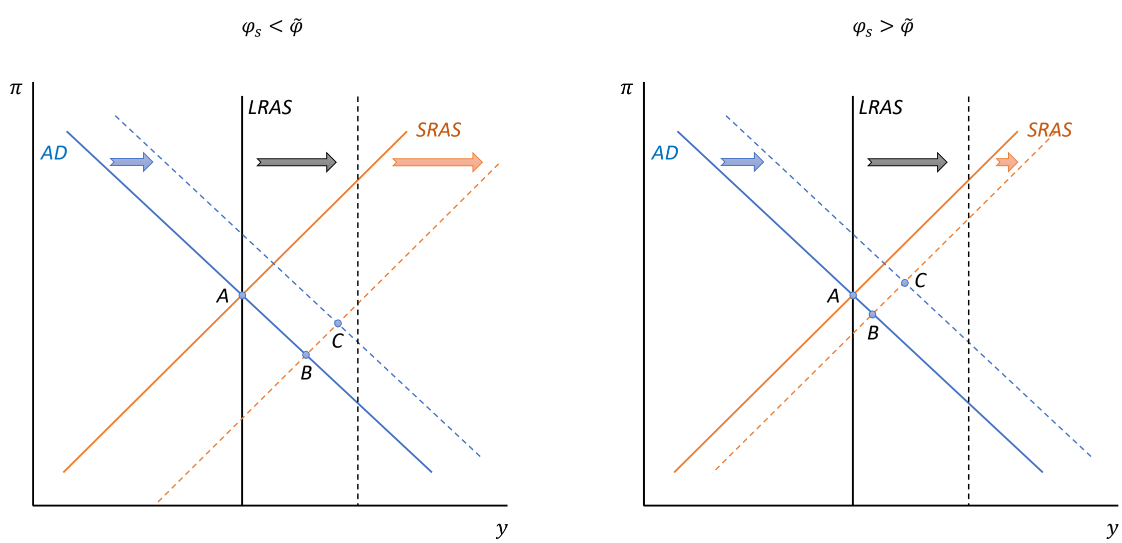
To gain intuition for the results stated in Proposition 3, it is instructive to inspect the short-run aggregate supply (SRAS) and aggregate demand (AD) schedules representing this economy. These are given by (abstracting from predetermined terms)[5]

$$y_t = \frac{\bar{\varphi}}{1-\bar{\varphi}}\pi_t + \frac{1}{2}\left(\frac{1}{1-\bar{\varphi}}\right)\sum_s (1-\varphi_s)\, z_{s,t}, \tag{20}$$

$$y_t = -\frac{1+\phi_\Pi}{1+\phi_Y}\pi_t + \frac{1}{2}\left(\frac{\phi_Y}{1+\phi_Y}\right)\sum_s z_{s,t}. \tag{21}$$

To understand part (1) of Proposition 3, it is easier to assume that the nominal wage is constant, which amounts to assuming that money supply is exogenous (i.e., $\phi_\Pi = \phi_Y = 0$).[6] Under this assumption, AD (equation 21) is fixed, and the aggregate effects of technology shocks are entirely due to shifts in the SRAS (equation 20). As long as $\varphi_s < 1$, a positive technology shock to sector s causes this curve to shift rightward, with the magnitude of the shift being decreasing in φ_s. This in turn implies a smaller decline in aggregate inflation and larger negative output gap.[7] This outcome is illustrated in Figure 1, where the distance between the new equilibrium (point B) and the initial one (point A) is smaller when the shock occurs in the sector with higher price rigidity.

Figure 1: Graphical illustration of the effects of sectoral technology shocks.



Notes: The SRAS and AD curves correspond to equations (20) and (21), respectively. The LRAS corresponds to equation (20) with $\varphi_s = 0$ for $s \in S$.

Intuitively, a favorable technology shock in a given sector reduces its nominal marginal cost. But since there is smaller cost pass-through in the sector with a stickier price, the resulting price cut is milder. At the same time, there is no change in the nominal marginal cost (and thus the price) of the

[5]See Equations (A.31) and (A.32) in Appendix A.

[6]Recall that $c_t = w_t - p_t$ and $y_t = m_t - p_t$ in this model. Since $y_t = c_t$, it follows that $w_t = m_t$.

[7]Under flexible prices, the (vertical) long-run aggregate supply (LRAS) curve shifts by $\frac{1}{2}z_{s,t}$ in response to a technology shock in sector s.

sector that does not experience an increase in productivity. As a result, the larger the degree of price rigidity of the shocked sector, the smaller the decline in the aggregate price level. In the limiting case where prices are fixed in sector s ($\varphi_s = 1$), technology shocks in that sector leave the aggregate price level and aggregate output unchanged. The productivity gain in the shocked sector is entirely offset by a proportional drop in its employment level.

Part (2) of Proposition 3 states that a sectoral technology can raise aggregate inflation if price stickiness in the shocked sector is sufficiently higher than average, provided that the output-gap feedback parameter, ϕ_Y, is strictly positive. Thus, technology shocks can never be inflationary if (i) prices are equally sticky across sectors (see Proposition 2), or (ii) monetary policy only responds to inflation ($\phi_Y = 0$), regardless of sectoral heterogeneity in price rigidity.

The intuition underlying this result can be easily understood by referring again to system (20)–(21). Technology shocks to the two sectors affect AD identically, shifting it rightward as long as monetary policy responds to the output gap ($\phi_Y > 0$) . In equilibrium, the economy moves to point C in Figure 1. Higher values of ϕ_Y lead to a larger shift of the curve while increasing its slope. Instead, higher values of ϕ_π flatten the curve without affecting its intercept. Inflation rises in equilibrium only to the extent that the AD curve shifts more than the SRAS curve, which is only possible when $\frac{\phi_Y}{1+\phi_Y} > \frac{1-\varphi_s}{1-\bar{\varphi}}$ (thus implying that $\varphi_s > \bar{\varphi} + \frac{1-\bar{\varphi}}{1+\phi_Y}$). This situation is illustrated in the right panel of Figure 1. On the other hand, because the AD curve never shifts when $\phi_Y = 0$, technology shocks are always disinflationary, irrespective of their sectoral origin.

To sum up, the stickier the price of a sector hit by a technology shock, the smaller the shift in aggregate supply and the less likely it is to exceed the shift in aggregate demand (provided that $\phi_Y > 0$). When price stickiness is sufficiently high, aggregate inflation rises in equilibrium. In closing this discussion, three remarks are in order. First, it is the relative degree of price rigidity — rather than its absolute level — that matters for whether favorable technology shocks are inflationary. This outcome may arise if the price stickiness of the shocked sector is only moderately high yet sufficiently larger than average. Conversely, the inflationary effect of the shock may not materialize even if prices are very sticky in the shocked sector but are nearly as sticky in the remaining sector. Second, while the threshold $\tilde{\varphi}$ is independent of ϕ_Π, the response of aggregate inflation to a technology shock originating in sector s is increasing in ϕ_Π when $\varphi_s > \tilde{\varphi}$. In other words, higher values of ϕ_Π amplify the inflationary effect of a sectoral technology shock, but do not make it more likely to happen. Third, the response of aggregate inflation to a sector specific technology shock, and thus the condition under which this response is positive, do not depend on the elasticities of substitution between the different varieties of a given good, ϵ, and between consumption goods, ν_C.

3.2.2 Role of the position in the network

Let us now assume that $\alpha > 0$, so that the economy features a well-defined Input-Output matrix. Does a productivity shock originating in a given sector affect aggregate inflation differently depending on whether that sector is located upstream or downstream in the production network, *ceteris paribus*? Proposition 4 shows that the response of aggregate inflation to a positive technology shock is strictly larger when it originates in the downstream sector than when it originates in the upstream sector.

Proposition 4 *Holding the sectoral degree of price stickiness constant, we have*

$$\left.\frac{d\pi_t}{dz_{u,t}}\right|_{\varphi_u=\varphi} < \left.\frac{d\pi_t}{dz_{d,t}}\right|_{\varphi_d=\varphi}.$$

Proof: See Appendix A.

The intuition behind this result lies in the way technology shocks propagate through the production network.[8] Assume for simplicity that $\phi_Y = 0$. When a positive shock originates in the upstream sector (with $\varphi_u = \varphi$), it lowers not only its price but also that of the downstream sector, as the cost of intermediate inputs falls. This leads to a large decline in aggregate inflation. Instead, when the shock originates in the downstream sector (with $\varphi_d = \varphi$), it lowers its price but that of the upstream sector remains unchanged, thus mitigating the fall in aggregate inflation. Finally, notice that when the two sectors have the same degree of price rigidity (i.e., $\varphi_u = \varphi_d = \bar{\varphi}$), a sectoral technology shock is always disinflationary, even if it originates in the downstream sector, thus generalizing the result in Proposition 2 to the case $\alpha \neq 0$.

Let $\tilde{\varphi}_u$ denote the degree of price rigidity above which a favorable sectoral technology shock in the upstream sector is inflationary, and let $\tilde{\varphi}_d$ have an analogous definition for the downstream sector. These thresholds are given by

$$\begin{aligned}\tilde{\varphi}_u &\equiv \bar{\varphi} + \frac{(1-\bar{\varphi})\left[1+\alpha\phi_Y+\alpha\left(1+\phi_Y\right)\left(1-\varphi_d\right)\right]}{\left(1+\phi_Y\right)\left[1+\alpha\left(1-\varphi_d\right)\right]}, \\ \tilde{\varphi}_d &\equiv \bar{\varphi} + \frac{(1-\bar{\varphi})\left(1+\alpha\phi_Y\right)}{1+\phi_Y}.\end{aligned}$$

An immediate implication of Proposition 3 is stated in Corollary 1.

Corollary 1 *For any average degree of price rigidity* ($\bar{\varphi} < 1$) *and provided that* $\phi_Y > 0$, *we have*

$$\tilde{\varphi}_d < \tilde{\varphi}_u.$$

Proof: See Appendix A.

[8] See see Acemoglu et al. (2016) for further discussion of the propagation of technology shocks through the network.

In other words, as long as monetary policy responds to the output gap, the range of Calvo probabilities for which inflation rises in response to a favorable sectoral technology shock is larger for the downstream sector than for the upstream sector. Since, in the data, downstream sectors tend to have more rigid prices, this implies that the inflationary effect of a positive technology shock is more likely to occur if the shock originates in those sectors.

4 Quantitative Analysis

4.1 Calibration

We calibrate the model to the U.S. economy at a quarterly frequency, and consider a level of disaggregation that corresponds to the 3-digit level of the North American Industry Classification System (NAICS), by setting $S = 60$. We report in Appendix B the list of sectors, as well as further details about the calibration of the model.

We set the time discount factor to $\beta = 0.995$, implying a 2% annual real interest rate. Following standard values in the literature, we calibrate the risk-aversion parameter to $\sigma = 2$, and set $\eta = 1$, so as to have a unitary Frisch elasticity of labor supply. The labor-disutility shifter is set to $\theta = 32.80$, which, conditional on the remaining parameters, implies a steady-state value of aggregate labor of $N = 0.33$. We consider a quarterly capital depreciation rate of $\delta = 0.025$, and calibrate the adjustment-cost parameter to $\Omega = 1.5$ to match the ratio of the standard deviations of investment to that of output.

We use information from the Input-Output Tables of the U.S. Bureau of Economic Analysis to calibrate the sectoral factor intensities, the parameters that govern the sectoral contributions to consumption and investment, as well as the entries of the Input-Output matrix. As far as the factor intensities are concerned, we set the elasticity of substitution across varieties between sectors to $\epsilon = 4$, consistently with the 33% average markup that de Loecker et al. (2020) estimate for U.S. firms during the last decade. Given this markup, we back out the intermediate-input factor intensities, $\alpha_{H,s}$, by matching the shares of sectoral expenditures on intermediate inputs in gross output, defined as the sum of the sectoral expenditures in intermediate inputs, the compensation of employees, and the gross operating surplus. The labor intensities, $\alpha_{H,s}$, are set to match the shares of the sectoral compensation of employees in value added, defined as the sum of the sectoral compensation of employees and the gross operating surplus.

We set the elasticity of substitution between consumption goods to $\nu_C = 0.8$, in line with the estimate of Herrendorf et al. (2013) on the elasticity of substitution of consumption between services, manufacturing, and agriculture. Analogously, we set the elasticity of substitution between investment goods to $\nu_I = 0.8$. The elasticity of substitution between intermediate inputs is set to $\nu_H = 0.1$, which is motivated by the empirical evidence of Barrot and Sauvagnat (2016), Atalay (2017), and Boehm et al. (2019) on the very high degree of complementarity across intermediate inputs at business-cycle frequencies. Given the elasticities of substitution, we calibrate the sectoral consumption weights, $\omega_{C,s}$, to match the sectoral contributions to personal consumption expenditures, the sectoral investment weights, $\omega_{I,s}$, to match the sectoral contributions to the sum of nonresidential private fixed investment in equipment, intellectual property products, and structures, and the sectoral intermediate-input weights, $\omega_{H,s,x}$, to match the entries of the Input-Output matrix.

Following the estimate in Horvath (2000), we set the elasticity of substitution between sectoral labor services to $\nu_N = 1$. We then calibrate the sectoral labor weights to the steady-state ratios of sectoral to aggregate labor, that is, $\omega_{N,s} = \frac{N_s}{N}$. This choice implies that sectoral wages are identical at the steady state. We choose the parameters of the aggregator of aggregate capital in an analogous manner: the elasticity of substitution between sectoral capital stocks equals $\nu_K = 1$, and the sectoral capital weights are set to $\omega_{K,s} = \frac{K_s}{K}$.

To discipline the sectoral heterogeneity in nominal price rigidity, we calibrate the sectoral Calvo probabilities, ϕ_s, to match the price durations implied by the microdata of Pasten et al. (2020). This approach leads to an average frequency of price changes of 43%, which implies an average price duration of around 7 months.

We set the auto-regressive coefficient in the law of motion of sectoral technology shocks to $\rho = 0.95$, in line with the estimated average persistence of the sectoral TFP shocks, which is slightly below 0.9 at an annual frequency (Horvath, 2000). Finally, we calibrate the Taylor-rule parameters following the estimates of Clarida et al. (2000). Specifically, we set the interest-rate-smoothing parameter to $\phi_R = 0.8$, and fix the inflation and output-gap feedback parameters to $\phi_\Pi = 1.5$ and $\phi_Y = 0.2$, respectively.

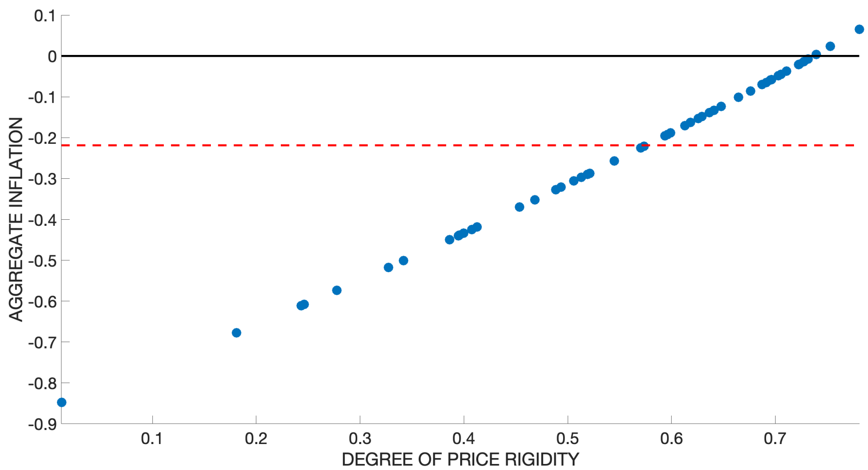
4.2 Validating the analytical results

The purpose of this section is to show that the analytical results derived in Section 3 continue to hold in calibrated quantitative model. In what follows, we compute the response of aggregate inflation to expansionary sectoral technology shocks. Specifically, we set the size of the shock such that the annualized impact response of value added in the shocked industry — in a model specification which fully homogeneous sectors — equals 1%. In all cases, we report the annualized impact response of aggregate inflation to sectoral technology shocks, measured in percentage point deviations from steady state.

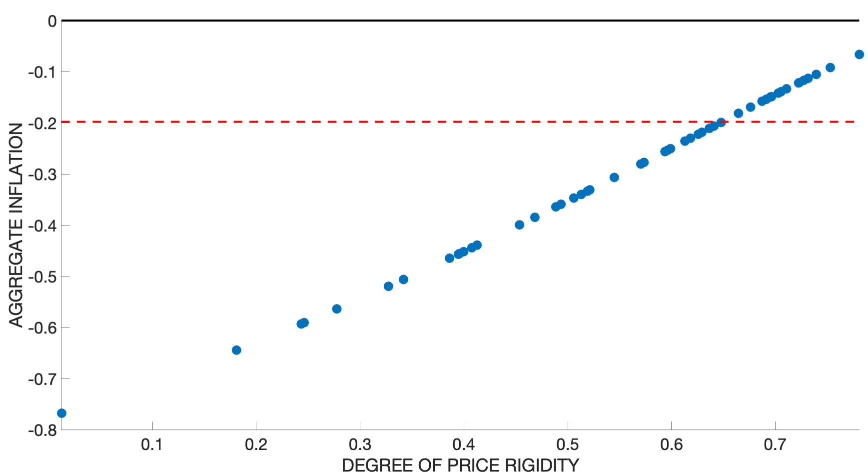
To isolate the role of sectoral heterogeneity in price rigidity, we assume that the 60 sectors only differ in this dimension but are otherwise identical. Figure 2 depicts the response of aggregate inflation to equal-sized sector-specific technology shocks in this baseline economy (upper panel) and in a

Figure 2: Sectoral price rigidity and the response of aggregate inflation.

(a) Baseline



(b) No output gap in the Taylor rule ($\phi_Y = 0$)



Notes: The dots represent the annualized impact response of aggregate inflation (in percentage point deviation from steady state) to each of the 60 sectoral technology shocks in a counterfactual economy where the sectors only differ in their degree of price rigidity. Panel a depicts the results under the baseline calibration, while Panel b depicts the results when the Taylor rule does not respond to the output gap ($\phi_Y = 0$). The dashed red line represents the response of aggregate inflation in the fully symmetric model. The technology shocks are normalized so that the annualized impact response of sectoral output of the shocked sector in the fully symmetric model equals 1%.

counterfactual one in which monetary policy does not react to the output gap (lower panel). As a benchmark, we also consider the case in which the sectors are symmetric in their degree of price rigidity (dashed lines). The figure confirms the following results regarding the response of aggregate inflation to a favorable sectoral productivity shock. First, the response is never positive when sectors have the same degree of price rigidity, consistently with Proposition 1. Second, the response is increasing in the price rigidity of the shocked sector, and is only positive when the shocks originate in sectors with sufficiently sticky prices and monetary policy responds to the output gap, as stated in Proposition 2.

Furthermore, this proposition implies that what matters for sectoral technology shock to be inflationary is not the *absolute* level of price rigidity in the shocked sector but instead whether this level is sufficiently higher than average. This in turn means that, holding the average degree of price rigidity constant, the inflationary effect of a sectoral shock will be more likely to occur when price rigidity is more dispersed across sectors. Table 1 confirms this implication: raising the dispersion of price rigidity by 30% (respectively, 60%) increases the number of sectors where a technology shock is inflationary in the aggregate from 7 to 13 (respectively, 19).

Table 1: Dispersion in Sectoral Price Rigidity and the Response of Aggregate Inflation.

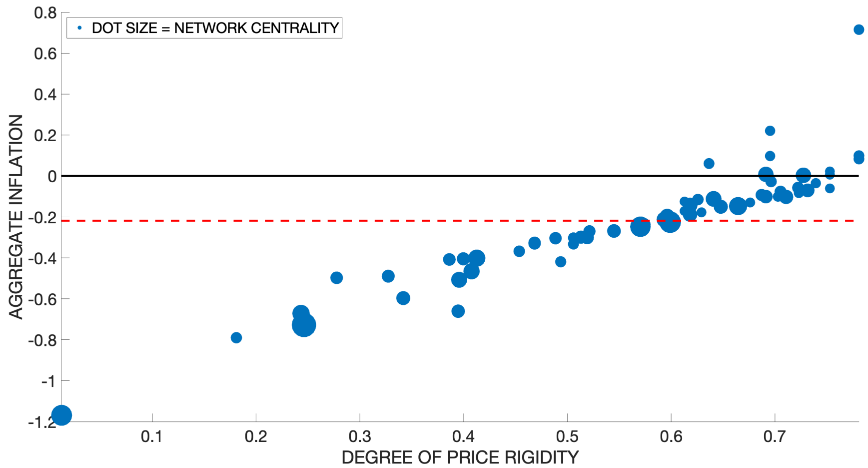
Baseline	30% More Dispersion	60% More Dispersion
7	13	19

Notes: Entries are the number of sectors where a favorable technology shock raises aggregate inflation. Sectors differ only in their price rigidity. The first column (in bold) corresponds to the baseline calibration of sectoral price rigidity. The second (respectively, third) column corresponds to the case where the distribution of the sectoral Calvo probabilities has the same mean but a standard deviation that is 30% (respectively, 60%) larger than that in the baseline.

Next, we study the role of the position in the network in weakening the condition for a favorable technology shock to be inflationary. Since the quantitative model is calibrated based on the actual Input-Output matrix of the U.S. economy, the production network is more complex than the simple vertical economy considered in Section 3. To identify a sector's position in the supply chain, we therefore resort to the Katz-Bonacich centrality measure, which increases in the level of upstreamness. Figure 3 depicts the response of aggregate inflation to sectoral technology shocks as a function of the shocked sectors' price rigidity and centrality, where the latter is indicated by the size of the dots. The figure conveys two important messages. First, in conformity with Proposition 3, favorable shocks to sectors with a similar degree of price rigidity tend to produce a larger response of inflation when they originate in more downstream (less central) sectors. Second, as stickier price sectors tend to be located downstream in the supply chain, shocks to those sectors tend to raise inflation, as can be seen in the upper right corner of Figure 3.

To sum up, the predictions of the quantitative model corroborate our main conclusions from the stylized model, namely that (*i*) aggregate inflation is more likely to rise in response to a positive technology shock when the latter originates in sectors with sufficiently more rigid prices than average, (*ii*) this requirement is never fulfilled if monetary policy does not respond to the output gap, and (*iii*) it becomes weaker when the shocked sector is located downstream in the production network.

Figure 3: Sectoral price rigidity, position in the production network, and the response of aggregate inflation.



Notes: The dots represent the annualized impact response of aggregate inflation (in percentage point deviation from steady state) to each of the 60 sectoral technology shocks in a counterfactual economy where the sectors only differ in their price rigidity and position in the production network, measured by centrality. The latter is indicated by the dot size. The dashed red line represents the response of aggregate inflation in the fully symmetric model. The technology shocks are normalized so that the annualized impact response of sectoral output of the shocked sector in the fully symmetric model equals 1%.

4.3 Sensitivity analysis

We now study the sensitivity of our results to perturbations in the values of some key parameters, namely the elasticities of substitution between labor services, ν_N, capital services, ν_K, intermediate inputs, ν_H, consumption goods, ν_C, and investment goods, ν_I. The choice of these parameters is motivated by the fact that the literature has emphasized the interaction of heterogeneity in price rigidity with labor-market segmentation and complementarities in production/consumption as the key mechanism rationalizing why supply shocks may behave like demand disturbances (see Cesa-Bianchi and Ferrero (2021)). To investigate the role of these features in our economy and the extent to which they are essential for generating inflationary technology shocks, we vary ν_N and ν_K between 0 to ∞, allowing for immobile, partially mobile and perfectly mobile labor and capital. We also consider the cases where ν_H, ν_C, and ν_I are equal to 1, in which case, inputs/goods are aggregated using a Cobb-Douglas technology, and 2, in which case, they are substitutes. In all of these cases, we assume that the sectors only differ in their degree of price rigidity.

Table 2 reports the number of occurrences of inflationary sectoral technology shocks. In each entry, the left number corresponds to the scenario where monetary authorities respond to the output gap ($\phi_Y = 0.125$), while the right number corresponds to the scenario where they do not ($\phi_Y = 0$). The numbers in bold correspond to our benchmark parameter values for $\nu_N, \nu_K, \nu_H, \nu_C$, and ν_I. When $\phi_Y =$

0, labor and capital immobility and complementarities in production/consumption are necessary for some sectoral technology shocks to raise aggregate inflation. If any of the two prerequisites fails, such an outcome will be impossible. This result corroborates Cesa-Bianchi and Ferrero (2021)'s conclusion. This is no longer the case, however, when the Taylor rule reacts to the output gap. In our economy, sectoral technology shocks can be inflationary even when labor and capital are perfectly mobile and goods are substitutes in production and consumption. Put differently, the necessary condition that prices in the shocked sector need to be sufficiently more rigid than average becomes much weaker in the more empirically plausible case where monetary policy reacts to the output gap.

Table 2: Sensitivity Analysis: Number of Inflationary Sectoral Technology Shocks.

	$\nu_N = \nu_K = 0$	$\nu_N = \nu_K = 0.5$	$\nu_N = \nu_K = 1$	$\nu_N = \nu_K = \infty$
$\nu_H = 0.1$; $\nu_C = \nu_I = 0.8$	14/3	9/0	**7/0**	3/0
$\nu_H = \nu_C = \nu_I = 1$	12/3	7/0	6/0	3/0
$\nu_H = \nu_C = \nu_I = 2$	7/0	6/0	3/0	3/0

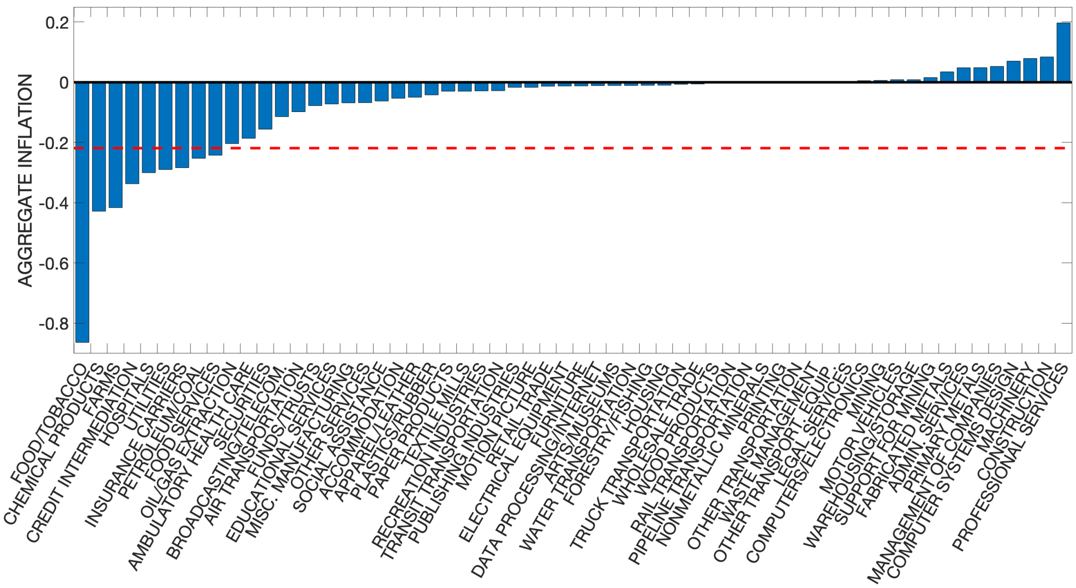
Notes: Entries are the number of sectors where a favorable technology shock raises aggregate inflation. In each entry, the left number corresponds to the scenario where monetary authorities respond to the output gap ($\phi_Y = 0.125$), while the right number corresponds to the scenario where they do not ($\phi_Y = 0$). The numbers in bold correspond to the benchmark parameter values of ν_N, ν_K, ν_H, ν_C, and ν_I.

4.4 Sectoral (supply-side) origins of aggregate inflation

The counterfactual analysis carried out in sub-section 4.2 shows how the response of aggregate inflation to sectoral technology shocks depends on the price rigidity and position in the network of the shocked sector, everything else constant. These two attributes, however, may interact with each other and with other dimensions of sectoral heterogeneity in a way that either dampens or magnifies the dispersion in the response of aggregate inflation to sectoral shocks.

To shed light on this point — and to identify the sectors where positive technology shocks are more likely to be inflationary — we evaluate the annualized impact response of aggregate inflation in the fully heterogeneous model, and report the results in Figure 4. Whereas this response is roughly equal to -0.2 percentage points in the fully homogeneous model, ranges from -0.86 percentage points when the technology shock originates in the Food and Tobacco sector to 0.15 percentage points when the shock occurs in the Professional Services sector. Importantly, the response is strictly positive in 18 of the 60 sectors.

Figure 4: Response of aggregate inflation to sectoral technology shocks.



Notes: The bars represent the annualized impact response of aggregate inflation (in percentage-point deviation from steady state) to each of the 60 sectoral technology shocks in the fully heterogeneous model. The dashed red line denotes the response of aggregate inflation in the fully symmetric model. The technology shocks are normalized so that the annualized impact response of sectoral output of the shocked sector in the fully symmetric model equals 1%.

5 Empirical Evidence

In this section, we provide empirical evidence supporting the model's predictions. More specifically, we test for (i) a positive relationship between the response of aggregate inflation to a sectoral technology shock and the degree of price rigidity of the shocked sector, and (ii) the possibility that such a response turns positive when the shock originates in the stickiest-price sectors. To do so, we leverage data from the NBER-CES Manufacturing industry database, which provides granular information on output, employment, input costs, investment, capital stocks, five-factor Total Factor Productivity (TFP),[9] and various industry-specific price indexes for a pool of 462 6-digit manufacturing industries, at the yearly frequency from 1958 to 2018. This yields a panel of roughly 27,000 industry-year observations. We define sectoral productivity shocks as the log-changes in the series of sectoral TFP.

Our empirical strategy consists in estimating the following panel regression:

$$\begin{aligned}\pi_t =& \beta_1 \Delta \log TFP_{s,t} + \beta_2 \Delta \log TFP_{s,t} \times \mathbb{I}_{s \in \text{Calvo }_{25-50}} + \dots \\ & \dots + \beta_3 \Delta \log TFP_{s,t} \times \mathbb{I}_{s \in \text{Calvo }_{50-75}} + \beta_4 \Delta \log TFP_{s,t} \times \mathbb{I}_{s \in \text{Calvo }_{75-100}} + \epsilon_{s,t}, \end{aligned} \tag{22}$$

[9] This measure of TFP is computed as the residual of real gross output once accounting for physical capital, the hours of production workers, the number of non-production workers, energy inputs, and non-energy intermediate inputs.

where π_t is aggregate CPI inflation, $\Delta \log TFP_{s,t}$ is the sectoral productivity shock, and $\mathbb{I}_{s \in \text{Calvo}_{25-50}}$, $\mathbb{I}_{s \in \text{Calvo }_{50-75}}$, and $\mathbb{I}_{s \in \text{Calvo }_{75-100}}$ are dummy variables that take the value of 1 if sector s has a Calvo probability that lies between, respectively, the 25th and 50th percentile, the 50th and 75th percentile, and the 75th and 100th percentile of the distribution of Calvo probabilities across industries. Thus, the omitted category includes the sectors with Calvo probabilities that are in the first quartile of the distribution, i.e., sectors with the lowest degree of price rigidity. Since the theoretical model predicts that positive TFP shocks to these sectors should lower inflation, the coefficient β_1 is expected to be negative. On the other hand, the model implies that the coefficients on the interaction terms (β_2 to β_4) should be positive, and that $\beta_2 \leq \beta_3 \leq \beta_4$ so that the response of aggregate inflation increases with the degree of price rigidity of the shocked sector. Furthermore, if the degree of rigidity is sufficiently high in a sector, the inflation response should turn positive.

Column (1) of Table 3 reports estimation results of the baseline regression (22), where the sectors are weighted by their gross output, and standard errors are clustered at the year-sector level. Consistent with theory, the estimate of β_1 is negative, while those of β_2, β_2, and β_4 are positive and are such that $\beta_2 \leq \beta_3 \leq \beta_4$, indicating that the response of aggregate inflation becomes less negative as the degree of price rigidity of the shocked sector increases. Moreover, this response turns positive and significant for productivity shocks originating in sectors with Calvo probabilities in the highest quartile of the distribution, as indicated by the estimate of $\beta_1 + \beta_4$.

As a robustness check, we re-estimate (22) by including sectoral fixed effects (Column (2)), adding changes in real sectoral value added, sectoral wage bill, and sectoral employment as additional controls at the sectoral level (Column (3)), and weighting the sectors by their value added instead of their gross output (Column (4)). In all cases, the estimated coefficients are very similar, both in sign and magnitude, to those of the baseline regression, and the sum of β_1 and β_4 is positive and statistically significant.

Overall, these results provide compelling empirical evidence validating the predicted relationship between sectoral price rigidity and the response of aggregate inflation to sector-specific technology shocks. The response of aggregate inflation to favorable sectoral productivity shocks tends to be relatively less negative when the shock originates in industries with a high degree of nominal price rigidity and even becomes positive for the stickies-price sectors.

6 Conclusion

In this paper, we have shown analytically that favorable technology shocks can raise aggregate inflation when they originate in sectors that have sufficiently rigid prices relative to the average, provided that monetary policy reacts to the output gap. This condition does not hinge on factor-market segmentation

Table 3: Sectoral Heterogeneity in Price Rigidity and the Response of Aggregate Inflation to Productivity Shocks in the Data.

	Dependent Variable: $\Delta \log CPI_t$			
	Baseline (1)	Fixed Effects (2)	Sectoral Controls (3)	Value Added Weighted (4)
$\Delta \log TFP_{s,t}$	-0.025** (0.012)	-0.030** (0.012)	-0.028** (0.013)	-0.026*** (0.008)
$\Delta \log TFP_{s,t} \times \mathbb{I}_{s \in \text{Calvo } 25-50}$	0.030** (0.013)	0.039*** (0.014)	0.039*** (0.014)	0.037*** (0.010)
$\Delta \log TFP_{s,t} \times \mathbb{I}_{s \in \text{Calvo } 50-75}$	0.035*** (0.013)	0.038*** (0.014)	0.042*** (0.014)	0.039*** (0.010)
$\Delta \log TFP_{s,t} \times \mathbb{I}_{s \in \text{Calvo } 75-100}$	0.037*** (0.013)	0.041*** (0.013)	0.043*** (0.014)	0.039*** (0.010)
Industry Fixed Effects	NO	YES	YES	YES
Sectoral Controls	NO	NO	YES	YES
N. Observations	26,757	26,757	26,291	26,291
$\beta_1 + \beta_4$	0.012** (0.006)	0.011** (0.006)	0.014** (0.006)	0.013** (0.006)

Notes: Standard errors (between parentheses) are double-clustered at the sector-year level. ⋆⋆⋆, ⋆⋆, and ⋆ denote statistical significance at the 1%, 5%, and 10% level, respectively. Sectoral controls include lags of the change in real sectoral value added, sectoral wage bill, sectoral employment.

or on complementarity between goods in consumption or in production. In a quantitative multi-sector model calibrated to the U.S. economy, technology shocks are found to be inflationary when they originate in 18 out of 60 sectors. Empirical evidence based on a panel of U.S. industries lends support to the role of sectoral price rigidity in giving rise to inflationary technology shocks.

While this paper shows that technology shocks can behave like demand shocks, Bai et al. (2024) develop a model where search for goods implies that demand shocks affect measured TFP, acting like productivity shocks. Both papers imply that the empirical identification of supply and demand shocks based on the sign of comovement between output and inflation to which they give rise is questionable and is likely to lead to incorrect inference about the relative importance of these shocks in accounting for business-cycle fluctuations. Identifying the sources of aggregate fluctuations should instead be based on structural models where the paths of aggregate variables are derived from first principles.

References

Acemoglu, D., U. Akcigit, and W. Kerr (2016). Networks and the macroeconomy: An empirical exploration. *NBER Macroeconomics Annual 30*(1), 273–335.

Acemoglu, D., V. Carvalho, A. Ozdaglar, and A. Tahbaz-Salehi (2012). The network origins of aggregate fluctuations. *Econometrica 80*(5), 1977–2016.

Afrouzi, H. and S. Bhattarai (2023). Inflation and GDP dynamics in production networks: A sufficient statistics approach. *Mimeo*.

Atalay, E. (2017). How important are sectoral shocks? *American Economic Journal: Macroeconomics 9*(4), 254–280.

Bai, Y., J.-V. Ríos-Rull, and K. Storesletten (2024). Demand Shocks as Technology Shocks. NBER Working Papers 32169, National Bureau of Economic Research, Inc.

Baqaee, D. and E. Farhi (2022). Supply and demand in disaggregated keynesian economies with an application to the Covid-19 crisis. *American Economic Review 112*(5), 1397–1436.

Barrot, J.-N. and J. Sauvagnat (2016). Input specificity and the propagation of idiosyncratic shocks in production networks. *Quarterly Journal of Economics 131*(3), 1543–1592.

Boehm, C., A. Flaaen, and N. Pandalai-Nayar (2019). Input linkages and the transmission of shocks: Firm-level evidence from the 2011 Tōhoku earthquake. *Review of Economics and Statistics 101*(1), 60–75.

Canova, F. and G. de Nicolo (2003, January). On the sources of business cycles in the G-7. *Journal of International Economics 59*(1), 77–100.

Carvalho, V. and X. Gabaix (2013). The great diversification and its undoing. *American Economic Review 103*(5), 1697–1727.

Cesa-Bianchi, A. and A. Ferrero (2021). The transmission of Keynesian supply shocks. *Mimeo*.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy 113*(1), 1–45.

Clarida, R., J. Gali, and M. Gertler (2000). Monetary policy rules and macroeconomic stability: Evidence and some theory. *Quarterly Journal of Economics 115*(1), 147–180.

De Graeve, F. and J. D. Schneider (2023). Identifying sectoral shocks and their role in business cycles. *Journal of Monetary Economics 140*, 124–141.

de Loecker, J., J. Eeckhout, and G. Unger (2020). The rise of market power and the macroeconomic implications. *Quarterly Journal of Economics 135*(2), 561–644.

Ferrante, F., S. Graves, and M. Iacoviello (2023). The inflationary effects of sectoral reallocation. *Journal of Monetary Economics 140*, S64–S81.

Foerster, A. T., P.-D. G. Sarte, and M. W. Watson (2011). Sectoral versus aggregate shocks: A structural factor analysis of industrial production. *Journal of Political Economy 119*(1), 1–38.

Gabaix, X. (2011). The granular origins of aggregate fluctuations. *Econometrica 79*(3), 733–772.

Guerrieri, V., G. Lorenzoni, L. Straub, and I. Werning (2022). Macroeconomic implications of COVID-19: Can negative supply shocks cause demand shortages? *American Economic Review 112*(5), 1437–1474.

Herrendorf, B., R. Rogerson, and A. Valentinyi (2013). Two perspectives on preferences and structural transformation. *American Economic Review 103*(7), 2752–2789.

Horvath, M. (2000). Sectoral shocks and aggregate fluctuations. *Journal of Monetary Economics 45*(1), 69–106.

La'O, J. and A. Tahbaz-Salehi (2022). Optimal monetary policy in production networks. *Econometrica 90*(3), 1295–1336.

Minton, R. and B. Wheaton (2023). Delayed inflation in supply chains: Theory and evidence. *Mimeo*.

Pasten, E., R. Schoenle, and M. Weber (2020). The propagation of monetary policy shocks in a heterogeneous production economy. *Journal of Monetary Economics 116*, 1–22.

Pasten, E., R. Schoenle, and M. Weber (2024). Sectoral heterogeneity in nominal price rigidity and the origin of aggregate fluctuations. *American Economic Journal: Macroeconomics*, forthcoming.

Peersman, G. (2005). What caused the early millennium slowdown? Evidence based on vector autoregressions. *Journal of Applied Econometrics 20*(2), 185–207.

Ruge-Murcia, F. and A. L. Wolman (2024). Relative price shocks and inflation. *Mimeo*.

Smets, F., J. Tielens, and J. Van Hove (2019). Pipeline pressures and sectoral inflation dynamics. *Mimeo*.

Appendix

A Derivations

This appendix solves the stylized model employed to derive the analytical results discussed in Section 3, and reports the proofs to the propositions contained therein.

A.1 Non-linear economy

This subsection reports the necessary set of equations to solve the stylized model. From households' optimal allocation between consumption and labor hours we obtain

$$\theta C_t = \frac{W_t}{P_t}. \tag{A.1}$$

Given the assumed Input-Output matrix of the stylized economy, the sectoral production technologies are

$$X_{u,t} = Z_{u,t} N_{u,t}^{1-\alpha} H_{u,u,t}^{\alpha}, \tag{A.2}$$

$$X_{d,t} = Z_{d,t} N_{d,t}^{1-\alpha} H_{d,u,t}^{\alpha}. \tag{A.3}$$

Thus, producers' cost-minimization returns the following first-order conditions:

$$W_t = (1-\alpha)\frac{MC_{u,t}X_{u,t}}{N_{u,t}}, \tag{A.4}$$

$$P_{u,t} = \alpha\frac{MC_{u,t}X_{u,t}}{H_{u,u,t}}, \tag{A.5}$$

$$W_t = (1-\alpha) MC_{d,t}\frac{X_{d,t}}{N_{d,t}}, \tag{A.6}$$

$$P_{u,t} = \alpha\frac{MC_{d,t}X_{d,t}}{H_{d,u,t}}, \tag{A.7}$$

where $MC_{s,t}$ is the nominal marginal cost of production in sector s. Let $\tilde{P}_{s,t}$ denotes the optimal price chosen by producers in sector s ($s = u, d$). Under the assumption of zero discount factor ($\beta = 0$), this price is by $\tilde{P}_{s,t} = \vartheta MC_{s,t}$, where $\vartheta \equiv \frac{\epsilon}{\epsilon-1}$. Since the sectoral price level in sector s satisfies $P_{s,t}^{1-\epsilon} = \varphi_s P_{s,t-1}^{1-\epsilon} + (1-\varphi_s)\tilde{P}_{s,t}^{1-\epsilon}$, we have

$$P_{s,t}^{1-\epsilon} = \varphi_s P_{s,t-1}^{1-\epsilon} + (1-\varphi_s)\vartheta^{1-\epsilon} MC_{s,t}^{1-\epsilon}, \qquad \text{for } s = u, d. \tag{A.8}$$

The aggregate price level is related to sectoral relative prices through

$$P_t = \left[\frac{1}{2}P_{u,t}^{1-\nu_C} + \frac{1}{2}P_{d,t}^{1-\nu_C}\right]^{\frac{1}{1-\nu_C}}. \tag{A.9}$$

The aggregate resource constraint is

$$Y_t = C_t. \tag{A.10}$$

The model is closed by postulating that aggregate demand is given by

$$Y_t = \frac{M_t}{P_t}, \tag{A.11}$$

and by assuming the following monetary policy rule:

$$\frac{M_t}{M} = \left(\frac{\Pi_t}{\Pi}\right)^{-\phi_\Pi} \left(\frac{Y_t}{Y_t^n}\right)^{-\phi_Y}, \tag{A.12}$$

where:

$$\Pi_t = \frac{P_t}{P_{t-1}}, \tag{A.13}$$

A.2 Log-linear economy

We solve the model by log-linearizing its equilibrium conditions around a non-stochastic steady state in which nominal prices are constant and normalized to 1. Given the assumptions of constant returns to scale in production and perfect labor mobility, it is easy to verify that $P_u = P_u = P = 1$. Letting lowercase variables denote percentage deviations from steady-state values, the log-linearized counterparts of Equations (A.1)–(A.13) are, respectively:

$$\begin{aligned}
c_t &= w_t - p_t, && \text{(A.14)}\\
x_{u,t} &= z_{u,t} + (1-\alpha)\, n_{u,t} + \alpha h_{u,u,t}, && \text{(A.15)}\\
x_{d,t} &= z_{d,t} + (1-\alpha)\, n_{d,t} + \alpha h_{d,u,t}, && \text{(A.16)}\\
w_t &= mc_{u,t} + x_{u,t} - n_{u,t}, && \text{(A.17)}\\
p_{u,t} &= mc_{u,t} + x_{u,t} - h_{u,u,t}, && \text{(A.18)}\\
w_t &= mc_{d,t} + x_{d,t} - n_{d,t}, && \text{(A.19)}\\
p_{u,t} &= mc_{d,t} + x_{d,t} - h_{d,u,t}, && \text{(A.20)}\\
p_{u,t} &= \varphi_u p_{u,t-1} + (1-\varphi_u)\, mc_{u,t}, && \text{(A.21)}\\
p_{d,t} &= \varphi_d p_{d,t-1} + (1-\varphi_d)\, mc_{d,t}, && \text{(A.22)}\\
p_t &= \frac{1}{2}\left(p_{u,t} + p_{d,t}\right), && \text{(A.23)}\\
y_t &= c_t, && \text{(A.24)}\\
y_t &= m_t - p_t, && \text{(A.25)}\\
m_t &= -\phi_\Pi \left(p_t - p_{t-1}\right) - \phi_Y \left(y_t - \tilde{y}_t\right), && \text{(A.26)}\\
\pi_t &= p_t - p_{t-1} && \text{(A.27)}
\end{aligned}$$

A.3 Derivation of Equation (19)

From (A.14), (A.24), and (A.25), it is straightforward to see that

$$w_t = m_t = c_t + p_t = y_t + p_t. \tag{A.28}$$

Combining (A.15) and (A.18) yields $x_{u,t} - n_{u,t} = \frac{\alpha}{1-\alpha}\left(mc_{u,t} - p_{u,t}\right) + \frac{1}{1-\alpha} z_{u,t}$. Substituting this expression into (A.17) and using (A.28), we obtain $mc_{u,t} = (1-\alpha)(y_t + p_t) + \alpha p_{u,t} - z_{u,t}$. Using this equation to substitute for $mc_{u,t}$ in (A.15) gives

$$p_{u,t} = \frac{(1-\alpha)(1-\varphi_u)}{1-\alpha(1-\varphi_u)}(y_t + p_t) - \frac{1-\varphi_u}{1-\alpha(1-\varphi_u)} z_{u,t} + \frac{\varphi_u}{1-\alpha(1-\varphi_u)} p_{u,t-1}. \tag{A.29}$$

Analogously, combining (A.16) and (A.20) yields $x_{d,t} - n_{d,t} = \frac{1}{1-\alpha} z_{d,t} + \frac{\alpha}{1-\alpha}\left(mc_{d,t} - p_{u,t}\right)$. Substituting this expression into (A.19) and using (A.28), we get $mc_{d,t} = (1-\alpha)(y_t + p_t) + \alpha p_{u,t} - z_{d,t}$. Using this equation to substitute for $mc_{d,t}$ in (A.22) gives

$$p_{d,t} = \frac{(1-\alpha)(1-\varphi_d)}{1-\alpha(1-\varphi_u)}(y_t + p_t) - \frac{\alpha(1-\varphi_u)(1-\varphi_d)}{1-\alpha(1-\varphi_u)} z_{u,t} - (1-\varphi_d) z_{d,t} + \frac{\alpha\varphi_u(1-\varphi_d)}{1-\alpha(1-\varphi_u)} p_{u,t-1} + \varphi_d p_{d,t-1}. \tag{A.30}$$

Inserting (A.29) and (A.30) into (A.23), using (A.27), and rearranging, we obtain

$$y_t = \frac{\alpha\varphi_u + (1-\alpha)\bar{\varphi}}{(1-\alpha)(1-\bar{\varphi})}\pi_t + \frac{1}{2}\left(\frac{(1-\varphi_u)\left[1+\alpha(1-\varphi_d)\right]}{(1-\alpha)(1-\bar{\varphi})}\right) z_{u,t} - \frac{1}{2}\left(\frac{1-\varphi_d}{(1-\alpha)(1-\bar{\varphi})}\right) z_{d,t} + \mathcal{F}(\mathbf{p}_{t-1}), \tag{A.31}$$

where $\mathcal{F}$ is a 1×2 matrix of coefficients and $\mathbf{p}_{t-1} = (p_{u,t-1}, p_{d,t-1})'$.

Using (A.26), (A.27), and the fact that $\tilde{y}_t = \frac{1}{2}\left(z_{u,t} + z_{d,t}\right)$, (A.25) can be written as

$$y_t = -\frac{1+\phi_\Pi}{1+\phi_Y}\pi_t + \frac{1}{2}\left(\frac{\phi_Y}{1+\phi_Y}\right)(z_{u,t} + z_{d,t}) + \mathcal{G}(\mathbf{p}_{t-1}), \tag{A.32}$$

where $\mathcal{G}$ is a 1×2 matrix of coefficients. Combining (A.31) and (A.32) yields

$$\pi_t = \Theta_u z_{u,t} + \Theta_d z_{d,t} + \mathcal{H}(\mathbf{p}_{t-1}), \tag{A.33}$$

where $\mathcal{H}$ is a 1×2 matrix of coefficients and

$$\begin{aligned}
\Theta_u &= -\frac{1}{2}\left\{\frac{(1+\phi_Y)(1-\varphi_u)\left[1+\alpha(1-\varphi_d)\right] - (1-\alpha)(1-\bar{\varphi})\phi_Y}{(1+\phi_Y)\left[\alpha\varphi_u + (1-\alpha)\bar{\varphi}\right] + (1-\alpha)(1-\bar{\varphi})(1+\phi_\Pi)}\right\}, \\
\Theta_d &= -\frac{1}{2}\left\{\frac{(1+\phi_Y)(1-\varphi_d) - (1-\alpha)(1-\bar{\varphi})\phi_Y}{(1+\phi_Y)\left[\alpha\varphi_u + (1-\alpha)\bar{\varphi}\right] + (1-\alpha)(1-\bar{\varphi})(1+\phi_\Pi)}\right\}.
\end{aligned}$$

A.4 Proofs

Proof of Proposition 1. Proving that $\Theta_u + \Theta_d \leq 0$ amounts to proving that

$$(1+\phi_Y)(1-\varphi_u)[1+\alpha(1-\varphi_d)] - (1-\alpha)(1-\bar{\varphi})\phi_Y + (1+\phi_Y)(1-\varphi_d) - (1-\alpha)(1-\bar{\varphi})\phi_Y \geq 0.$$

Simplifying this expression yields $2(1-\bar{\varphi})(1+\alpha\phi_Y) + \alpha(1+\phi_Y)(1-\varphi_u)(1-\varphi_d)$, which is unambiguously positive. ■

Proof of Proposition 2. Assuming that $\alpha = 0$, $\left.\frac{d\pi_t}{dz_{s,t}}\right|_{\varphi_s=\varphi_x=\bar{\varphi}} = -\frac{1}{2}\left\{\frac{1-\bar{\varphi}}{(1+\phi_Y)\bar{\varphi}+(1-\bar{\varphi})(1+\phi_\Pi)}\right\} \leq 0 \quad for$ $s, x \in S$. ■

Proof of Proposition 3. Assuming that $\alpha = 0$, we have:

(1)

$$\frac{\partial\left(\frac{d\pi_t}{dz_{s,t}}\right)}{\partial\varphi_s} = \frac{1}{2}\left\{\frac{\left(1+\frac{\phi_Y}{2}\right)[(1+\phi_Y)\bar{\varphi}+(1+\phi_\Pi)(1-\bar{\varphi})] + \frac{(\phi_Y-\phi_\Pi)}{2}[(1+\phi_Y)(1-\varphi_s)-(1-\bar{\varphi})\phi_Y]}{[(1+\phi_Y)\bar{\varphi}+(1+\phi_\Pi)(1-\bar{\varphi})]^2}\right\}.$$

The sign of this derivative depends on the sign of the numerator, which we denote by $\mathcal{N}$, and which can be expressed as

$$\mathcal{N} = \phi_\Pi(1+\phi_Y)\left[\frac{1}{2}(1+\varphi_s)-\bar{\varphi}\right] + \bar{\varphi}(1+\phi_Y)\left(1+\frac{\phi_Y}{2}\right) + \frac{\phi_Y}{2}[(1+\phi_Y)(1-\varphi_s)-(1-\bar{\varphi})\phi_Y].$$

The first term on the right-hand side of the equation is strictly positive. It remains therefore to show that

$$\bar{\varphi}(1+\phi_Y)\left(1+\frac{\phi_Y}{2}\right) + \frac{\phi_Y}{2}[(1+\phi_Y)(1-\varphi_s)-(1-\bar{\varphi})\phi_Y] > 0.$$

Rearranging this expression yields $\frac{\phi_Y}{2}[\phi_Y(2\bar{\varphi}-\varphi_s)+1+\bar{\varphi}-\varphi_s]+(1+\phi_Y)\bar{\varphi}$, which is strictly positive. Thus, $\mathcal{N} > 0$ and hence $\frac{\partial\left(\frac{d\pi_t}{dz_{s,t}}\right)}{\partial\varphi_s} > 0$.

(2) $\frac{d\pi_t}{dz_{s,t}} > 0$ if and only if $(1+\phi_Y)(1-\varphi_s)-(1-\bar{\varphi})\phi_Y > 0$, which is equivalent to $\varphi_s > \tilde{\varphi} \equiv \bar{\varphi}+\frac{1-\bar{\varphi}}{1+\phi_Y}$.
■

Proof of Proposition 4. For any $\alpha > 0$, $\Theta_u|_{\varphi_u=\varphi} \leq \Theta_d|_{\varphi_d=\varphi}$, thus implying that $\left.\frac{d\pi_t}{dz_{u,t}}\right|_{\varphi_u=\varphi} \leq \left.\frac{d\pi_t}{dz_{d,t}}\right|_{\varphi_d=\varphi} < 0$. ■

Proof of Corollary 1. Proving that $\tilde{\varphi}_d < \tilde{\varphi}_u$ amounts to proving that $1+\alpha\phi_Y < \frac{1+\alpha\phi_Y+\alpha(1+\phi_Y)(1-\varphi_d)}{1+\alpha(1-\varphi_d)}$. Subtracting the second term from the first yields $-\frac{\alpha(1-\alpha)(1-\varphi_d)\phi_Y}{1+\alpha(1-\varphi_d)}$, which is strictly negative. ■

B More on the Calibration

This section provides additional information on the calibration of the model. First, we report in Tables B.1-B.2 the entire list of 60 sectors of the model. As we mention in Section 4.1, this granularity of the economy corresponds to the three-digit level of the NAICS code classification, once excluded the real estate and the financial industries.

We then report in Table B.3 the list of calibrated values and the description of the aggregate parameters of the model, and Table B.4 shows the values and the calibration targets of the set of sector-specific parameters. The information on the calibrated values for the sector-specific parameters (i.e., $\alpha_{N,s}$, $\alpha_{H,s}$, $\omega_{C,s}$, $\omega_{I,s}$, $\omega_{H,s,x}$, $\omega_{N,s}$, $\omega_{K,s}$, and ϕ_s) is available upon request.

Table B.1: Sectors 1-30.

1	Farms
2	Forestry, fishing, and related activities
3	Oil & Gas Extraction
4	Mining
5	Support Activities for Mining
6	Utilities
7	Construction
8	Wood products
9	Nonmetallic mineral products
10	Primary metals
11	Fabricated metal products
12	Machinery
13	Computer and electronic products
14	Electrical equipment, appliances, and components
15	Motor vehicles, bodies and trailers, and parts
16	Other transportation equipment
17	Furniture and related products
18	Miscellaneous manufacturing
19	Food and beverage and tobacco products
20	Textile mills and textile product mills
21	Apparel and leather and allied products
22	Paper products
23	Printing and related support activities
24	Petroleum and coal products
25	Chemical products
26	Plastics and rubber products
27	Wholesale trade
28	Retail trade
29	Air transportation
30	Rail transportation

Table B.2: Sectors 31-60.

31	Water transportation
32	Truck transportation
33	Transit and ground passenger transportation
34	Pipeline transportation
35	Other transportation and support activities
36	Warehousing and storage
37	Publishing industries, except internet (includes software)
38	Motion picture and sound recording industries
39	Broadcasting and telecommunications
40	Data processing, internet publishing, and other information services
41	Credit intermediation
42	Securities, commodity contracts, and other financial investments
43	Insurance carriers
44	Funds, trusts, and other financial vehicles
45	Housing
46	Legal services
47	Computer systems design and related services
48	Miscellaneous professional, scientific, and technical services
49	Management of companies and enterprises
50	Administrative and support services
51	Waste management and remediation services
52	Educational services
53	Ambulatory health care services
54	Hospitals
55	Social assistance
56	Performing arts, spectator sports, museums, and related activities
57	Amusements, gambling, and recreation industries
58	Accommodation
59	Food services and drinking places
60	Other services, except government

Table B.3: Calibration of the Aggregate Parameters.

Parameter	Description	Target/Source
$\beta = 0.995$	Time discount factor	2% annual real rate
$\sigma = 2$	Risk aversion	Standard value
$\eta = 1$	Inverse of the Frisch elasticity	Standard value
$\theta = 32.80$	Labor disutility shifter	$N^{\star} = 0.33$
$\Delta = 0.025$	Physical capital depreciation rate	10% annual depreciation
$\Omega = 1.5$	Investment adjustment cost	Relative volatility of investment
$\nu_C = 0.8$	Elasticity of substitution b/w sectoral consumption goods	Herrendorf et al. (2013)
$\nu_I = 0.8$	Elasticity of substitution b/w sectoral investment goods	$\nu_I = \nu_C$
$\nu_H = 0.1$	Elasticity of substitution b/w sectoral intermediate inputs	Atalay (2017)
$\nu_N = 1$	Elasticity of substitution b/w sectoral labor flows	Horvath (2000)
$\nu_K = 1$	Elasticity of substitution b/w sectoral capital services	$\nu_K = \nu_N$
$\epsilon = 4$	Elasticity of substitution b/w within-sector varieties	de Loecker et al. (2020)
$\rho = 0.95$	Auto-regressive coefficient for	Horvath (2000)
$\phi_R = 0.8$	Taylor-rule interest rate smoothing	Clarida et al. (2000)
$\phi_\Pi = 1.5$	Taylor-rule responsiveness to inflation	Clarida et al. (2000)
$\phi_Y = 0.2$	Taylor-rule responsiveness to output gap	Clarida et al. (2000)

Table B.4: Calibration of the Sector-Specific Parameters.

Parameter	Description	Target/Source
$\alpha_{N,s}$	Value-added labor intensity	Sectoral value-added labor share
$\alpha_{H,s}$	Gross-output intermediate inputs intensity	Sectoral gross-output intermediate input share
$\omega_{C,s}$	Contribution to consumption	Sectoral share in total personal consumption expenditures
$\omega_{I,s}$	Contribution to Investment	Sectoral share in total private fixed investment expenditures
$\omega_{H,s,x}$	Contribution to sectoral intermediate inputs	Sectoral shares in Input-Output matrix
$\omega_{N,s}$	Sectoral labor weight	$\omega_{N,s} = \frac{N_s^\star}{N^\star}$
$\omega_{K,s}$	Sectoral capital weight	$\omega_{K,s} = \frac{K_s^\star}{K^\star}$
ϕ_s	Sectoral degree of price rigidity	Pasten et al. (2020)