Optimal Monetary Policy in Production Networks with Distortions*

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ABSTRACT

This paper studies optimal monetary policy in a multisector economy with input-output linkages and distortions. Our model incorporates both the supply side and the demand side effects of monetary policy. We derive a tractable sufficient statistic for the supply-side effect, which comprises two reallocation channels resulting from substitution between sectoral products for households and firms, and substitution between labor and intermediate inputs in production. The optimal monetary policy induces an inflation bias that stems from both an aggregate wedge and the supply-side effect, and targets an inflation index by assigning higher weights to (i) larger sectors, (ii) sectors with stickier prices, and (iii) sectors with less distortions. Our quantitative results indicate that production networks play a crucial role in generating both the supply and demand effects of monetary policy.

KEYWORDS: production networks, optimal monetary policy, supply-side effects, Phillips curves, stabilization policy

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1 Introduction

The disruptions in supply chains during the COVID-19 pandemic have highlighted the importance of understanding how shocks propagate through production networks and impact the overall economy. It is crucial to recognize that shocks in different industries can have varying effects on aggregate output and inflation. In response to these challenges, the monetary authorities in both advanced and emerging economies have implemented aggressive measures to combat inflation. The canonical New Keynesian frameworks primarily focus on the demand side effects of monetary policy. By tightening monetary policy, aggregate nominal demand is reduced, leading to stabilization of inflation. However, empirical studies have shown that monetary policy can also influence resource allocation and account for a significant portion of aggregate productivity movements (see for instance, Evans, 1992, Barth and Ramey, 2002, Ravenna and Walsh, 2006, Meier and Reinelt, 2022).

How do demand side shocks, such as monetary policy shocks, affect an economy's output and productivity in a distorted economy with input-output linkages? What is the optimal conduct of monetary policy under such circumstances? Based on the frameworks of Long and Plosser (1983) and Baqaee and Farhi (2020), this paper investigates both the supply side and demand side effects of monetary policy in a multisector model with nominal rigidities, initial markups, and input-output linkages. We find that the supply-side effect of monetary policy arises from resource reallocation across sectors, and is characterized by a tractable sufficient statistic, which can be further broken down into two reallocation channels: one channel due to substitution between sectoral products for households and downstream firms, and the other channel due to substitution between labor and intermediate inputs in production.

The reallocation channel resulting from the substitution between sectoral products for households and downstream firms depends on several factors, including the average markup, the covariance between wage pass-throughs to sectoral prices and sectors' upstream markups, elasticities of substitution, and sectoral sales shares. As noted in Baqaee et al. (2024), an initial misallocation of resources is a *necessary* condition for the supply-side effect of monetary policy. When the average markup in an economy is higher, there is greater potential for policy interventions to improve resource allocation. Wage pass-throughs and upstream markups reflect the compound impact of frictions throughout the production chain on sectoral prices and markups, respectively. When sectors with high upstream markups tend to exhibit low wage pass-throughs to prices, and vice versa, sectors with high upstream markups will raise their prices to a less extent than sectors with low upstream markups in response to expansionary monetary policy. Consequently, a reduction in relative prices leads to increased demand and output in sectors with high upstream markups. As a result, both labor and intermediate inputs will be reallocated from sectors with low upstream markups to sectors with high upstream markups. In a distorted economy, the marginal product of input in sectors with high upstream markups is greater than that in sectors with low upstream markups. This reallocation of resources across sectors ultimately contributes to an improvement in total factor productivity.

The reallocation channel resulting from the substitution between labor and intermediate inputs shows how shifts in relative wage compared to the prices of intermediate inputs influence firms' decisions to utilize more intermediate inputs or more labor. In response to expansionary monetary policy, firms tend to substitute labor for intermediate inputs, as sticky sectoral prices increase less than flexible nominal wage due to incomplete pass-throughs. This reallocation towards intermediate inputs enhances economy-wide allocative efficiency, as these inputs are initially underutilized due to double marginalization. These two reallocation channels contribute to the supply-side effects of monetary policy in specific environments, critically depending on the production networks within an economy. For instance, in a horizontal economy where multiple sectors rely solely on labor as a productive input, the only prevailing channel is reallocation due to substitution between sectoral products for households. In contrast, in a one-sector roundabout economy, the reallocation resulting from the substitution between labor and intermediate input in production becomes the sole channel.

The elasticity of substitution among inputs also plays a crucial role in the supply-side effect. A higher elasticity of substitution among inputs leads to a more significant reallocation channel. This is because downstream sectors' demand responds more strongly to changes in relative sectoral prices when the elasticity of substitution is greater. As a result, monetary policy exerts a stronger influence on resource reallocation. Additionally, sector size also affects the reallocation channel, and a change in resource allocation in larger sectors contributes more to the whole economy.

In our model economy, labor supply adjusts endogenously to shocks. Consequently, there is a traditional New Keynesian demand side effect of monetary policy, in addition to the supply-side effect. We provide tractable expressions for both the supply and demand side effects of monetary policy. The manner in which wage and labor respond to shocks determines these two effects. We show that the supply-side effect increases with the inverse Frisch elasticity of labor supply, while the demand side effect decreases with this elasticity. When the labor supply is less elastic, a change in the nominal wage due to shocks becomes more pronounced, whereas the labor supply itself is less responsive to these shocks. In a model with price rigidities and initial markups, a larger response in the nominal wage results in a greater change in ex-post markups, leading to a more significant supply side effect.

The following section constructs sectoral Phillips curves. The slopes of these curves are determined by input-output linkages, sectoral price rigidities, initial markups, and cross-sector elasticities. Our findings indicate that a positive supply side effect of monetary policy flattens the slopes of all sectoral Phillips curves. The rationale is that an increase in the output gap drives up the wage to attract additional labor needed to sustain higher production; however, the beneficial supply-side effects of monetary policy reduce the required labor for a given output gap, which leads to smaller wage hikes. As a result, this decreases input expenses and sector-specific inflation.

Should the central bank optimally induce an inflation bias to enhance allocative efficiency and increase final output? We further examine optimal monetary policy in response to sectoral productivity shocks. Up to a second-order approximation of the social welfare function around a flexible-price but distorted steady state, the approximated welfare gains comprise several additive components: a first-order bias resulting from an aggregate wedge and allocative efficiency, and second-order welfare losses stemming from variation in output gap, within-sector and cross-sector price distortions, and variation in allocative efficiency.

In a model economy with multiple sectors and distortionary markups, the central bank's ability to influence the economy is limited by its dependence on a single policy instrument. This instrument must strike a balance between first-order biases and second-order welfare losses. Under optimal monetary policy, the central bank may introduce an inflation bias, which arises from both the supply-side effect of monetary policy and an aggregate wedge, both of which are affected by initial markups.[1] We find that, all else being equal, the optimal monetary policy targets a constant value for an inflation index by assigning greater weights to larger, stickier, and less distorted sectors. When the supply-side effect is positive, the central bank has an incentive to enhance allocative efficiency by increasing sectoral inflation. Furthermore, because of the presence of an aggregate wedge, the central bank may also increase inflation to bring output closer to its efficient level.

We then apply our theoretical framework to data and quantitatively explore the optimal monetary policy. To achieve this, we utilize the input-output tables provided by the Bureau

[1]The initial state of the economy is inefficient due to lacking of enough tax instruments that can fix sectoral monopolistic markups (see for instance, Adão et al. (2003)). The monetary authority faces a trade-off between stabilizing inflation (second-order welfare losses) and substituting for these missing tax instruments (first-order biases). Note also that initial markups are necessary to generate both the supply-side effect and the aggregate wedge in our model economy.

of Economic Analysis in the USA and map them into our model to obtain a cost-based input-output matrix, labor input shares, and consumption shares from 1997 to 2015. The initial markups at the industry level are taken from Baqaee and Farhi (2020), while the sectoral price rigidities are derived from Pasten et al. (2020). Additionally, industry-level productivities are obtained from the Integrated Industry-Level Production Account of the U.S. Bureau of Economic Analysis and Bureau of Labor Statistics.

Our quantitative analysis demonstrates that monetary policy and production networks play crucial roles in shaping the supply side of the economy. A one percent point increase in the nominal wage resulting from expansionary monetary policy leads to an average increase of 0.018% in total productivity. The inflation bias originating from the supply-side effect moves closely with that arising from the aggregate wedge, varying over time from 0.08% during years of economic downturns to 0.54% during years of economic booms, with an average inflation bias of 0.30%. The welfare analysis illustrates that the supply-side effect generates a welfare gain similar to that induced by the aggregate wedge. When we completely eliminate input-output linkages, the supply-side effect is determined solely by the reallocation resulting from substitution between sectoral products for households. The quantitative results show that the supply-side effect and its associated inflation bias decrease substantially in an economy without input-output linkages. Inflation bias due to the aggregate wedge declines, but it significantly dominates the inflation induced by the supply-side effect.

Can optimal monetary policy be implemented by a simple monetary policy rule? We examine two simple alternative rules: an output gap targeting rule, as in La'O and Tahbaz-Salehi (2022) and Rubbo (2023), and a CPI inflation targeting rule. Our quantitative analysis reveals that while both output gap stabilization and CPI inflation targeting policies incur less second-order welfare losses, they still underperform compared to optimal monetary policy due to their inability to fully leverage reductions in the aggregate wedge and the benefits of allocative efficiency. Furthermore, the output gap stabilization rule yields higher welfare than the CPI inflation targeting rule. This is because the output gap targeting rule partially accounts for changes in output resulting from allocative efficiency, and stabilizing this output gap leads to lower welfare losses compared to the CPI inflation targeting rule.

Related Literature. Our paper is part of the growing literature that investigates production networks in macroeconomics (Long and Plosser, 1983; Basu, 1995; Acemoglu et al., 2012).[2] The framework of this paper builds on Baqaee and Farhi (2020), who studied the

[2]The pioneering work includes Jones (2011), Gabaix (2011) and Acemoglu et al. (2015). More recent studies include Acemoglu et al. (2017), Atalay (2017), Baqaee (2018), Bouakez et al. (2018), Baqaee and Farhi (2019,

implications of exogenous markups in economies with input-output linkages. Compared with Baqaee and Farhi (2020), this paper examines both the supply side and demand side effects of monetary policy and characterizes optimal monetary policy in a multisector general equilibrium economy with nominal rigidities and distortionary markups.

In previous work on monetary policy and production networks, researchers have focused on the demand side of monetary policy in multisector New Keynesian economies (see, for instance, Galí, 2015; Nakamura and Steinsson, 2010; Carvalho and Nechio, 2011; Pastén et al., 2024; Pasten et al., 2020; Ghassibe, 2021a).[3] Several recent articles have explored optimal monetary policy in economies with production networks. La'O and Tahbaz-Salehi (2022) characterized the optimal policy in terms of an economy's production network and the extent and nature of nominal rigidities. In a parallel study, Rubbo (2023) emphasized that introducing intermediate inputs reduces the slope of all sectoral and aggregate Phillips curves in a dynamic multisector model and derived a novel divine coincidence index that the central bank should target.[4] Along this line of research, Afrouzi and Bhattarai (2023) explored how production linkages amplify the persistence of inflation and GDP responses in multisector dynamic models. Our model builds on similar multisector New Keynesian economies, but takes into account sectoral initial markups. These initial markups and production networks help generate the supply-side effect of monetary policy.

This paper also contributes to the literature on the supply-side effect of monetary policy. The literature has documented evidence of monetary policy on the supply side of economies. Evans (1992) found that monetary and fiscal policies Granger-cause measured Solow residuals, and aggregate demand contributes between one-quarter and one-half to the variance of these residuals. Barth and Ramey (2002) presented evidence that monetary policy affects the cost of production and consequently aggregate productivity. Meier and Reinelt (2022) documented that monetary policy shocks increase markup dispersion across firms, and firms with stickier prices have higher markups. On the theoretical side, Ravenna and Walsh (2006) presented a model with a cost channel for monetary policy. David and Zeke (2021) studied business cycle dynamics in a heterogeneous firm economy, and found that resource

2022, 2024), Levchenko et al. (2019), Liu (2019), Acemoglu and Azar (2020), Bigio and La'O (2020), Flynn et al. (2022), Luo (2020), Carvalho et al. (2021), Miranda-Pinto and Young (2022), Devereux et al. (2023), Osotimehin and Popov (2023), Pellet and Tahbaz-Salehi (2023) and Acemoglu and Tahbaz-Salehi (2024). Also see the recent surveys by Carvalho and Tahbaz-Salehi (2019) and Baqaee and Rubbo (2023).

[3] See more recent studies by Altinoglu (2021), Ghassibe (2021b), Giovanni and Hale (2022), and Luo and Villar (2023).

[4] These studies found that monetary policy cannot achieve an efficient allocation of flexible prices if sector-specific tax instruments are non-state-contingent, even when they eliminate distortionary markups at the flexible price and wage equilibrium. This result starkly contrasts with the canonical one-sector New Keynesian model (see, for instance, Correia et al. (2008), Angeletos and La'O (2020)).

allocation can strengthen countercyclical monetary policy. Meier and Reinelt (2022) showed that monetary policy shocks can generate substantial fluctuations in aggregate productivity. Our study complements the existing literature by providing a theoretical exploration of the supply-side effect in a multisector New Keynesian economy. A recent paper related to our study is Baqaee, Farhi and Sangani (2024), who studied an economy with heterogeneous firms and endogenous markups and found that monetary policy has a first-order effect on aggregate productivity using the Kimball (1995) preference. Our work differs from theirs in two main aspects. First, this paper focuses on the role of production networks in generating the supply-side effect of monetary policy. Even if all firms have identical initial markups, there may still be heterogeneity in upstream distortions due to double marginalization along the supply chain. Second, our paper explores the optimal monetary policy in an economy with production networks.

Structure of the paper. Section 2 introduces a baseline multisector model with input-output linkages, and explores cost pass-throughs through production networks. Section 3 provides a tractable sufficient statistic to capture the supply-side effect of monetary policy. Section 4 shows that the supply-side effect of monetary policy flattens the slope of sectoral Phillips curves. Section 5 derives the optimal conduct of monetary policy. Quantitative results are reported in section 6. Section 7 concludes. All proofs are delegated to the Online Appendix.

2 Model

We start with a static model with N industries, and a primary factor, labor. In each industry $i \in \mathcal{N} \equiv \{1, 2, ..., N\}$, there is a unit mass of monopolistically competitive firms. These firms hire labor and use N intermediate inputs to produce goods, which can be used as intermediate inputs or consumed by households. A representative household supplies labor to firms and consumes a basket of sectoral goods produced by different industries. Nominal price rigidity restricts firms' ability to fully adjust their prices in response to shocks. The monetary authority controls the supply of money. This model allows us to analyze both the supply-side effect and the traditional demand side of monetary policy in a New Keynesian economy. Armed with this model, we further explore how production networks facilitate the transmission of monetary policy and shape the optimal conduct of monetary policy.

2.1 Households

The utility function that a representative household maximizes is as follows,

$$U(Y,L) = \frac{Y^{1-\gamma}}{1-\gamma} - \frac{L^{1+\varphi}}{1+\varphi},$$

where γ and φ denote the relative risk aversion and the inverse Frisch elasticity of labor supply, respectively. L is the labor supply and Y is the aggregate final output, which is determined by a constant-returns-to-scale aggregator of final goods produced by N industries,

$$\frac{Y}{\bar{Y}} = \left(\sum_{i=1}^{N} \omega_{0i}^{\frac{1}{\sigma_C}} \left(\frac{c_i}{\bar{c}_i} \right)^{\frac{\sigma_C - 1}{\sigma_C}} \right)^{\frac{\sigma_C}{\sigma_C - 1}}, \tag{1}$$

where c_i represents the quantity of sectoral product i consumed by households, ω_{0i} captures the corresponding expenditure weight in consumption, and σ_C denotes a constant elasticity of substitution among consumption varieties. A variable with an upper bar denotes a constant.

The representative household's budget constraint is given by,

$$\sum_{i=1}^{N} p_i c_i \leq wL + \sum_{i=1}^{N} \Pi_i - T, \tag{2}$$

where p_i and c_i are the price and quantity of good i, w denotes the nominal wage, Π_i is the profit from sector i, and T is a lump-sum tax collected by the government. The left-hand side of the inequality above is equal to the household's nominal expenditure, and the right-hand side shows various sources of the household's nominal income, including labor income, profits from owning firms, and a lump-sum transfer.

2.2 Firms

There exists a unit mass of firms indexed by $\nu \in [0,1]$ in each sector. A competitive sectoral bundler aggregates varieties produced by all the firms within sector i into a sectoral output using a constant elasticity of substitution (CES) aggregator,

$$y_i = \left(\int_0^1 y_{i,\nu}^{\frac{\varepsilon_i - 1}{\varepsilon_i}} d\nu \right)^{\frac{\varepsilon_i}{\varepsilon_i - 1}}, \tag{3}$$

where the within-sector elasticity of substitution is $\varepsilon_i > 1$. The optimal demand for each variety is $y_{i,\nu} = (p_{i,\nu}/p_i)^{-\varepsilon_i} y_i$, and sectoral price reads,

$$p_i = \left(\int_0^1 p_{i,\nu}^{1-\varepsilon_i} d\nu \right)^{\frac{1}{1-\varepsilon_i}}.$$

For simplicity, we assume that all firms within each sector have the same constant returns to scale (CRS) production technology, which uses labor $L_{i,\nu}$ and intermediate inputs $\{x_{ij,\nu}\}_{j=1}^N$ to produce output $y_{i,\nu}$,

$$\frac{y_{i,\nu}}{\bar{y}_{i,\nu}} = A_i \left(\omega_{iL}^{\frac{1}{\sigma_i}} \left(\frac{L_{i,\nu}}{\bar{L}_{i,\nu}} \right)^{\frac{\sigma_i - 1}{\sigma_i}} + \sum_{j=1}^N \omega_{ij}^{\frac{1}{\sigma_i}} \left(\frac{x_{ij,\nu}}{\bar{x}_{ij,\nu}} \right)^{\frac{\sigma_i - 1}{\sigma_i}} \right)^{\frac{\sigma_i}{\sigma_i - 1}}, \tag{4}$$

where A_i is an industry-specific productivity, ω_{ij} denotes the weight of input j in production, and σ_i stands for the elasticity of substitution in production in sector i.

Given the output level and production technology, all firms choose labor and intermediate inputs to minimize marginal costs. Since all firms within an industry share the same CRS production technology, their cost-minimization problems are identical, resulting in sectoral marginal costs defined as:

$$mc_i \equiv \min_{\{x_{ij,\nu}\}_{j=1}^N,\ L_{i,\nu}} wL_{i,\nu} + \sum_{j=1}^N p_j x_{ij,\nu}, \tag{5}$$

subject to a unit production constraint.

Firms maximize their nominal profit, $p_{i,\nu} y_{i,\nu} - (1 - \tau_i) mc_i y_{i,\nu}$, when they have an opportunity to reset their prices, where τ_i is an industry-specific input subsidy (or tax) that the government pays to firms. As a result, the optimal price and corresponding effective markup are given by,

$$p_i = \bar{\mu}_i mc_i \quad \text{and} \quad \bar{\mu}_i = (1 - \tau_i) \frac{\varepsilon_i}{\varepsilon_i - 1}. \tag{6}$$

Markup distortions may exist if policymakers lack a complete set of industry-specific tax instruments to fully offset monopolistic markups.

2.3 Nominal Rigidities

The literature, for example Bils and Klenow (2004), Nakamura and Steinsson (2008, 2010) and Pasten et al. (2020), shows that there exists a notable variation in the frequency of price change between different industries or goods. To capture industry-specific heterogeneity in nominal price resetting, we allow firms in different sectors to adjust their prices with different frequencies. For simplicity but without loss of generality, we assume that firms in sector i are randomly and mutually independently drawn with probability $\theta_i \in [0, 1]$ to freely reset their product prices, while the remaining $1 - \theta_i$ fraction of firms will keep their prices unchanged. Firms who can adjust their nominal prices will optimally set a markup $\bar{\mu}_i$ above the marginal cost. Within each sector, the sectoral nominal price is an aggregate of the reset and unchanged prices, which only partially responds to a change in sectoral marginal cost up to a first-order log-linearization,

$$\mathrm{d}\log p_i = \int \mathrm{d}\log p_{i,v} dv = \theta_i \mathrm{d}\log mc_i. \tag{7}$$

In sectors with high price rigidity (low θ_i), sectoral prices are less responsive to changes in their marginal cost.[5] The realized markup in sector i then becomes,

$$\mathrm{d}\log \mu_i \equiv \mathrm{d}\log(p_i/mc_i) = -(1/\theta_i - 1)\mathrm{d}\log p_i = -(1 - \theta_i)\mathrm{d}\log mc_i. \tag{8}$$

Due to nominal rigidities ($\theta_i < 1$), an increase in marginal cost leads to a decrease in the realized markup.

2.4 Policy Instruments

The policy maker may have access to a set of fiscal policy instruments, for instance, industry-specific subsidies (or taxes), to offset monopolistic markups. We assume that the government funds its subsidies to production by levying a lump-sum tax T on households to maintain a balanced budget,

$$T = \sum_{i=1}^{N} \tau_i mc_i y_i.$$

Nevertheless, when there are not enough policy instruments to fully offset monopolistic markups, the allocation in the economy is inefficient even in the absence of nominal price

[5] Our price resetting mechanism mirrors the sticky price model as outlined in Rubbo (2023) for static scenarios, and aligns with the sticky information approach described in La'O and Tahbaz-Salehi (2022).

rigidities. In the following analysis, we take a more practical view and focus on the scenario in which the policy maker isn't able to fully offset sectoral monopolistic markups. Therefore, the initial allocation of the economy is distorted.

The monetary authority chooses money supply M, which in turn affects nominal prices and wage via a cash-in-advance constraint as in Pasten et al. (2020), La'O and Tahbaz-Salehi (2022) and Devereux et al. (2023),

$$\sum_{i=1}^{N} p_i c_i = P^Y Y = M, \tag{9}$$

where P^Y is the consumer price index defined as $\min_{\{c_i\}_{i=1}^N} \{\sum_{i=1}^N p_i c_i : Y = 1\}$. Note that $P^Y Y$ represents the total consumption expenditure and also the nominal final output (GDP).

2.5 Equilibrium

In our baseline model, labor can move across sectors without any restrictions. Therefore, the market clearing condition for labor is given by,

$$L = \sum_{i=1}^{N} L_i = \sum_{i=1}^{N} \int_0^1 L_{i,v} dv.$$

The output in sector i is either used by firms as inputs for production or consumed by households,

$$y_i = c_i + \sum_{j=1}^{N} x_{ji} = c_i + \sum_{j=1}^{N} \int_0^1 x_{ji,v} dv,$$

for all $i \in \mathcal{N}$.

The equilibrium is defined as a set of variables, including total output (Y), labor supply (L), sectoral outputs ($\{y_i\}_{i=1}^N$), intermediate inputs ($\{x_{ij}\}_{i,j=1}^N$), labor demands ($\{L_i\}_{i=1}^N$), final consumption ($\{c_i\}_{i=1}^N$), consumer price (P^Y), sectoral prices ($\{p_i\}_{i=1}^N$) and nominal wage (w), given productivities ($\{A_i\}_{i=1}^N$), exogenous price adjustment probabilities ($\{\theta_i\}_{i=1}^N$), and initial markups ($\{\bar{\mu}_i\}_{i=1}^N$) determined by industry-specific taxes/subsidies ($\{\tau_i\}_{i=1}^N$) and within-sector substitution elasticities ($\{\epsilon_i\}_{i=1}^N$), such that: (i) in each sector, firms optimally choose intermediate inputs and labor demand to minimize their costs, and optimally reset their prices when they have a chance to adjust; (ii) consumers optimally choose consumption and supply labor given sectoral prices and the nominal wage; (iii) the government chooses fiscal instruments $\{\tau_i\}_{i=1}^N$, and the monetary authority sets monetary supply M; (iv) all markets clear.

An increase in monetary supply M drives up the nominal wage and consequently increases the nominal marginal cost of all firms. From the perspective of firms, their marginal cost critically depends on labor cost since labor is the only primary input in the model economy. Following Baqaee et al. (2024), we treat the nominal wage w as the monetary policy instrument instead to simplify expressions.[6] An increase in the nominal wage corresponds to an expansionary monetary policy and vice versa.

2.6 Production Network and Cost Pass-through

In this section, we examine how production networks and nominal price rigidities alter the transmission of labor and intermediate input costs. We approximate the model around a steady state with initial markups $\{\bar{\mu}_i\}_{i=1}^N$, and obtain a set of log-linearized equations. We then define three types of input-output matrices that will be used throughout our analysis. The first two types are cost-based and revenue-based input-output matrices, which are the same as those in Baqaee and Farhi (2020). The third type, called rigidity-adjusted input-output matrix, closely follows La'O and Tahbaz-Salehi (2022) and Rubbo (2023). Table 1 presents these input-output matrices, their associated Leontief inverse matrices, and Domar weights.

Table 1: Input-Output Matrices

	Cost-based	Revenue-based	Rigidity-adjusted
Consumption share	$b_i = \frac{p_i c_i}{\sum_j p_j c_j}$	-	-
Input-output matrix	$\tilde{\Omega}_{ij} = \frac{p_j x_{ij}}{mc_i y_i}$	$\Omega_{ij} = \bar{\mu}_i^{-1}\tilde{\Omega}_{ij}$	$\hat{\Omega}_{ij} = \theta_i \tilde{\Omega}_{ij}$
Leontief inverse	$\tilde{\Psi} = (I - \tilde{\Omega})^{-1}$	$\Psi = (I - \Omega)^{-1}$	$\hat{\Psi} = (I - \hat{\Omega})^{-1}$
Domar weight	$\tilde{\lambda}' = b'\tilde{\Psi}$	$\lambda' = b'\Psi$	$\hat{\lambda}' = b'\hat{\Psi}$

Notes: Definitions of various input-output matrices and their associated Leontief inverse matrices. To make the notation compact, we treat labor as an additional producer, who sells aggregate labor to producers of products. The associated parameters for the labor sector are $b_L = 0$ and $\bar{\mu}_L = \theta_L = 1$. We then construct $(N+1) \times (N+1)$ input-output matrices where the first N rows and columns correspond to goods, while the last row and column correspond to labor. Accordingly, p_{N+1} and w are used interchangeably to denote the wage, and $x_{i(N+1)}$ or L_i to represent labor used by sector i. In addition, $\tilde{\Lambda}_L$, Λ_L, and $\hat{\Lambda}_L$ stand for the Domar weight of labor associated with three input-output matrices respectively.

Cost-based input-output matrix. The entry in the cost-based input-output matrix $\tilde{\Omega}_{ij}$, encodes the cost share of input produced by sector j (or labor input when $j = N+1$) in

[6] The monetary authority can equivalently choose either nominal wage or money supply as its instrument. Lemma 7 in the Appendix shows that there is an isomorphism between setting the nominal wage and the money supply.

total cost of sector i. This share also measures the elasticity of marginal cost of producers in sector i with respect to output price of sector j by the Shephard's lemma. Its associated Leontief inverse $\tilde{\Psi} = (I - \tilde{\Omega})^{-1} = I + \tilde{\Omega} + \tilde{\Omega}^2 + \tilde{\Omega}^3 + \cdots$ captures the aggregate elasticity of marginal cost in sector i with respect to output price in sector j through direct and indirect use of intermediate inputs in the production network. The last column of $\tilde{\Omega}$, denoted by $\tilde{\Omega}_{(L)}$, measures the elasticity of sector i's marginal cost with respect to the wage. Similarly, the aggregate elasticity of marginal cost in sector i with respect to the wage is captured by the i-th row of the last column of $\tilde{\Psi}$, denoted as $\tilde{\Psi}_{iL}$.

The elasticity of consumer price P^Y with respect to output price in sector i is captured by consumption share b_i. Then the cost-based Domar weight $\tilde{\lambda}_i$ can be interpreted as a consumption-share weighted aggregate elasticity of marginal cost with respect to sectoral price p_i (or wage w when $i = N + 1$). When resource allocation in the economy is efficient (without markups and nominal rigidities) and there exists only one primary input, labor, the value added in each sector is then solely contributed by labor income, and the elasticity of the consumer price P^Y with respect to the wage can be written as $\mathrm{d}\log P^Y / \mathrm{d}\log w = b'\tilde{\Psi}_{(L)} \equiv \tilde{\Lambda}_L = 1$ since $\tilde{\Psi}_{iL} = 1$ for all sectors.

Revenue-based input-output matrix. The element of the revenue-based input-output matrix Ω_{ij} represents the share of sector i's expenditure on input produced by sector j to sector i's total revenue. Let $\bar{\mu}^{-1}$ be a diagonal matrix whose ii-th diagonal element is $1/\bar{\mu}_i$. Similarly to the cost-based Leontief matrix, the revenue-based Leontief matrix $\Psi = I + \bar{\mu}^{-1}\tilde{\Omega} + (\bar{\mu}^{-1}\tilde{\Omega})^2 + (\bar{\mu}^{-1}\tilde{\Omega})^3 + \cdots$ captures the direct and indirect use of intermediate inputs through the production network. In particular, the last column of the Leontief inverse, denoted by $\Psi_{(L)}$, records the total payments to labor as a share of sales in each sector taking into account the fact that intermediate inputs are also produced by labor. Similarly, the revenue-based Domar weight λ_j reflects the total exposure of households to sector j by taking into account consumption expenditure shares and input-output linkages. This Domar weight also coincides with the sales share for each sector. The revenue-based Domar weight of labor Λ_L precisely gives the share of labor income in nominal output, $\Lambda_L = (wL)/(\sum_i p_i c_i)$.

When evaluated at an inefficient equilibrium (that is, $\bar{\mu} \geq 1$), both Ψ_{iL} and Λ_L are bounded between 0 and 1. Moreover, they weakly decrease the initial sector markups $\{\bar{\mu}_i\}_{i=1}^N$: a higher degree of distortion in the supply chain of sector i leads to a lower value of Ψ_{iL} and Λ_L. Specifically, Ψ_{iL} captures the fraction of accumulated direct and indirect labor cost along the production chain in sectoral sales, and therefore Ψ_{iL} can serve as a measure of the inverse upstream markup faced by sector i (a lower Ψ_{iL} implies a higher upstream markup). Note also that for each sector, the inverse upstream markup Ψ_{iL} is not greater than its counterpart in an economy without input-output linkages $\bar{\mu}_i^{-1}$, implying that production networks amplify upstream markups through double marginalization.[7] Aggregating inverse upstream markups using final expenditure shares, the labor income share $\Lambda_L = \mathbb{E}_b(\Psi_{iL})$ reflects economy-wide distortions: greater distortions reduce the share of labor income.

Rigidity-adjusted input-output matrix. Nominal price rigidities limit nominal price responses to cost changes. To better understand how input costs are transmitted through a production chain in a network economy with these rigidities, we adopt the methodologies proposed by La'O and Tahbaz-Salehi (2022) and Rubbo (2023) by introducing a new input-output matrix, the 'rigidity-adjusted input-output matrix' $\hat{\Omega}$. Each element $\hat{\Omega}_{ij}$ of this matrix quantifies the direct pass-through of sector j's price change to sector i's price change,

$$\hat{\Omega}_{ij} \equiv \frac{\partial \log p_i}{\partial \log p_j} = \frac{\partial \log p_i}{\partial \log mc_i} \frac{\partial \log mc_i}{\partial \log p_j} = \theta_i \tilde{\Omega}_{ij}.$$

The associated Leontief inverse matrix $\hat{\Psi} = I + \Theta\tilde{\Omega} + (\Theta\tilde{\Omega})^2 + (\Theta\tilde{\Omega})^3 + \cdots$ measures the overall pass-through of one sector's price to another sector's price, directly and indirectly, through the production network. Analogously, the direct pass-throughs of nominal wage to prices are captured by the last column of the rigidity-adjusted input-output matrix, denoted by $\hat{\Omega}_{(L)}$, and the overall wage pass-throughs are given by the corresponding Leontief inverse $\hat{\Psi}_{(L)}$, which accounts for the total exposure of sectors to labor cost. Finally, using consumption shares as weights, the rigidity-adjusted Domar weight of labor $\hat{\Lambda}_L = \mathbb{E}_b(\hat{\Psi}_{iL})$ aggregates the overall wage pass-through $\hat{\Psi}_{(L)}$ across sectors, and also reflects the overall wage pass-through into the consumer price index since $\mathrm{d}\log P^Y/\mathrm{d}\log w = \hat{\Lambda}_L$.

Similarly to the revenue-based input-output matrix, the sectoral wage pass-through $\hat{\Psi}_{iL}$ is not larger than its own probability of price adjustment θ_i, for all i. The use of intermediate inputs from sticky upstream sectors results in more sluggish nominal price adjustments (Basu, 1995). The pass-through of nominal wage into the sectoral price $\hat{\Psi}_{iL}$ and the consumer price $\hat{\Lambda}_L$ weakly increases the probability of price adjustment $\{\theta_i\}_{i=1}^N$, with both measures bounded between 0 and 1.

Additional notations. We introduce additional notation to simplify our analysis. The superscript n denotes a specific segment within a matrix or a vector. For instance, Ψ^n denotes an $N \times N$ submatrix consisting of the first N rows and columns of matrix Ψ. Similarly, $\Psi^n_{(L)}$ refers to an $N \times 1$ vector containing the first N elements of $\Psi_{(L)}$. $\mathrm{d}\log p$ is an $(N+1) \times 1$ vector, with the last component $\mathrm{d}\log p_{N+1} = \mathrm{d}\log w$. π denotes sectoral price inflation (the

[7] See Lemma 5 in the Online Appendix.

first N components of the vector $\mathrm{d}\log p$). We introduce the following weighted covariance operator similarly to Baqaee and Farhi (2020),

$$\mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\hat{\Psi}_{iL}, \Psi_{iL}\right) = \sum_i \tilde{\Omega}_{ji}\hat{\Psi}_{iL}\Psi_{iL} - \left(\sum_i \tilde{\Omega}_{ji}\hat{\Psi}_{iL}\right)\left(\sum_i \tilde{\Omega}_{ji}\Psi_{iL}\right),$$

where $\tilde{\Omega}(j,:)$ represents the j-th row of matrix $\tilde{\Omega}$, and note that $\sum_i \tilde{\Omega}_{ji} = 1$. The covariance will be zero if either the inverse upstream markup (Ψ_{iL}) or the wage pass-through ($\hat{\Psi}_{iL}$) is uniform across sectors. For example, when firms can freely reset their prices, the wage pass-through is complete, with $\hat{\Psi}_{iL} = 1$ for all i. Alternatively, in the absence of initial markup, the inverse upstream markup is unit, with $\Psi_{iL} = 1$ for all i. The structure of the production network also determines this covariance. For example, in a vertical economy where sector j exclusively relies on a single input from sector i, this leads to $\tilde{\Omega}_{ji} = 1$ for sector i and $\tilde{\Omega}_{jk} = 0$ for all other sectors $k \neq i$, resulting in zero covariance. In general, the covariance $\mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\hat{\Psi}_{iL}, \Psi_{iL}\right)$ could be positive or negative, depending on initial markups, nominal rigidities, and production networks.

3 Supply Side Effect of Monetary Policy

Monetary policy changes the unit of account in the model economy, and hence affects nominal wage and sectoral prices. When prices are fully flexible, monetary policy cannot affect resource reallocation and is thus neutral. However, when sectoral prices are sticky, wage pass-through to sectoral prices can vary across sectors in response to monetary policy shocks, leading to changes in relative sectoral prices. In an economy with initial distortions, relative price changes shift households' and downstream sectors' demand for goods produced by upstream sectors and result in reallocation of labor and intermediate inputs across sectors, which in turn may lead to improvement in resource allocation. This section will investigate the conditions under which monetary policy improves total factor productivity (TFP) and the supply-side effect of monetary policy.

3.1 Total Factor Productivity

Our baseline model is a nested CES economy, as explored by Baqaee and Farhi (2020). Since labor is the only primary input in our model, the total factor productivity is equivalent to the labor productivity, $\mathrm{d}\log\mathrm{TFP} = \mathrm{d}\log Y - \mathrm{d}\log L$. Up to a first-order approximation, a change in TFP can be broken down into two channels (equation (10)): a direct technology channel and a misallocation channel. The direct technology channel reflects the contribution of sectoral productivity changes to TFP, which is governed by the sum of distortion-adjusted (Ψ_{jL}/Λ_L) Domar-weighted (λ_i) sectoral productivity changes ($\mathrm{d}\log A_j$). The misallocation channel captures the impact of allocative efficiency through the reallocation of resources between sectors in response to exogenous shocks, which critically depends on the aggregate wedge (captured by the average markup $1/\Lambda_L$), the elasticity of substitution between inputs in both consumption and production (σ_j), the ratio of sectoral cost to GDP ($\lambda_j/\bar{\mu}_j$), and the covariance between the sectoral price change ($\mathrm{d}\log p_i$) and the inverse upstream markup (Ψ_{iL}),

$$\mathrm{d}\log \mathrm{TFP} = \underbrace{\sum_{j=1}^{N} \lambda_j \frac{\Psi_{jL}}{\Lambda_L} \mathrm{d}\log A_j}_{\text{Direct technology channel}} + \underbrace{\frac{1}{\Lambda_L} \sum_{j=0}^{N} \frac{\sigma_j \lambda_j}{\bar{\mu}_j} \mathrm{Cov}_{\tilde{\Omega}(j,:)} \left(\mathrm{d}\log p_i, \Psi_{iL}\right)}_{\text{Misallocation channel}}, \tag{10}$$

where $\sigma_0 = \sigma_C$, $\lambda_0 = 1$, $\bar{\mu}_0 = 1$ and $\tilde{\Omega}(0,:) = b'$. The decomposition in equation (10) illustrates that sector-specific productivity shocks affect total factor productivity not only through direct technological effects but also via the misallocation channel, as these shocks also alter sectoral prices. In contrast, monetary policy impacts TFP only through the misallocation channel. Changes in the allocation of labor and intermediate goods across sectors are driven by shifts in relative sectoral demands, which result from changes in relative prices due to monetary policy shocks. If the elasticities of substitution among sectoral products in both consumption and production are zero ($\sigma_j = 0, \forall j$), then changes in relative prices do not influence the relative demand from households and firms, leading to no reallocation of resources and, as a result, no change in TFP in response to monetary policy shocks.

If the government can fully counteract all monopolistic markups by implementing a set of industry-specific taxes and subsidies $\{\tau_i\}_{i=1}^N$, resulting in no markups in the initial equilibrium ($\bar{\mu} = \mathbf{1}$), then this initial equilibrium is efficient ($\Psi_{iL} = \Lambda_L = 1, \forall i$), meaning there is no misallocation in this case.[8] However, when the initial resource allocation is inefficient due to monopolistic markups, sectors with these markups supply fewer products than what would be socially optimal. In an economy characterized by production networks, this undersupply is exacerbated by double marginalization along production chains. In the subsequent analysis, we will examine how monetary policy influences resource allocation across different sectors and identify the conditions under which it can enhance total factor

[8]Our model in this scenario degenerate to the frameworks of La'O and Tahbaz-Salehi (2022) and Rubbo (2023), and the expression for TFP reverts to that in Hulten's Theorem (Hulten, 1978).

productivity.

3.2 Supply Side Effect

As stated in Section 2.5, the fact that the monetary authority controls the money supply is equivalent to its direct influence on the nominal wage. So in this section, we consider only a change in monetary policy and treat a change in the nominal wage $\mathrm{d}\log w$ instead as a monetary policy instrument, while assuming that sectoral productivities are unchanged. the supply-side effect of monetary policy is defined as the response of TFP to a change in monetary policy (see Definition 1).

Definition 1. *the supply-side effect of monetary policy is defined as the response of total factor productivity to a change in monetary policy, given the constant primary input and other exogenous shocks.*

Substituting wage path-through to sectoral price $\mathrm{d}\log p_i/\mathrm{d}\log w = \hat{\Psi}_{iL}$ into equation (10), and combining expressions for labor income share and wage pass-through to consumer price, we obtain one of the key results of this study in Proposition 1. This proposition shows that the supply-side effect of monetary policy is driven by the misallocation channel, which can be further characterized by model primitives in terms of production networks, nominal rigidities, initial markups, and cross-sector elasticities of substitution.

the supply-side effect in equation (11) depends on the average distortion, elasticities of substitution, and the weighted covariance between the wage pass-throughs ($\hat{\Psi}_{iL}$) and the inverse upstream markups (Ψ_{iL}) for both consumers and producers. When sectors with higher upstream markups tend to exhibit lower wage pass-throughs, resulting in stickier prices, and vice versa, sectors with higher upstream markups will raise their prices to a less extent than sectors with lower upstream markups in response to an expansionary monetary policy shock. This means that prices in sectors with higher upstream markups become relatively cheaper compared to those in sectors with lower upstream markups. As a result, households and downstream firms increase their demand for goods from these cheaper sectors. Consequently, labor and intermediate inputs are shifted from sectors with lower upstream markups to those with higher upstream markups. It's important to note that the marginal product of inputs in sectors with higher upstream markups is greater than in those with lower markups. This reallocation of resources ultimately enhances total factor productivity.

Proposition 1. *the supply-side effect of monetary policy is given by the following sufficient statistic,*

$$\frac{\mathrm{d}\log\mathrm{TFP}}{\mathrm{d}\log w} = \frac{1}{\Lambda_L}\sum_{j=0}^{N}\frac{\sigma_j\lambda_j}{\bar{\mu}_j}\mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\hat{\Psi}_{iL},\Psi_{iL}\right), \tag{11}$$

where $\sigma_0 = \sigma_C$, $\lambda_0 = 1$, $\bar{\mu}_0 = 1$ and $\tilde{\Omega}(0,:) = b'$. When no sector has fully rigid prices ($\theta_i > 0, \forall i$), the sufficient statistic above (11) can be further decomposed into two components,

$$\frac{\mathrm{d}\log\mathrm{TFP}}{\mathrm{d}\log w} = \underbrace{\frac{1}{\Lambda_L}\sum_{j=0}^{N}\frac{\sigma_j\lambda_j(1-\tilde{\Omega}_{jL})}{\bar{\mu}_j}\mathrm{Cov}_{\tilde{\Omega}^n(j,:)}\left(\hat{\Psi}_{iL},\Psi_{iL}\right)}_{\textit{Substitution between sectoral products}} \\ + \underbrace{\frac{1}{\Lambda_L}\sum_{j=1}^{N}\frac{\sigma_j\lambda_j\tilde{\Omega}_{jL}}{\theta_j(1-\tilde{\Omega}_{jL})}(\theta_j-\hat{\Psi}_{jL})(\bar{\mu}_j^{-1}-\Psi_{jL})}_{\textit{Substitution between labor and intermediate inputs}}, \tag{12}$$

where $(\theta_j-\hat{\Psi}_{jL})(\bar{\mu}_j^{-1}-\Psi_{jL})$ is $o(1-\tilde{\Omega}_{jL})$ as $\tilde{\Omega}_{jL} \to 1$.

It is important to recognize that the ways in which substitution occurs in consumption and production differ due to the distinct roles of labor in each context. In consumption, substitution is restricted between products from different sectors ($\tilde{\Omega}_{0L} = b_L = 0$), while in production, labor is an essential input ($\tilde{\Omega}_{iL} > 0, \forall i \in \mathcal{N}$), and there are substitutions between intermediate inputs and between those inputs and labor. To clarify this distinction, the second part of Proposition 1 breaks down the covariance between wage pass-throughs and inverse upstream markups for each sector into two parts: one that represents the reallocation resulting from substitution among goods produced by different sectors, and the other that illustrates the reallocation due to the substitution between labor and intermediate inputs in production. The substitution among sectoral products indicates how households adjust their demand for different consumption varieties and how downstream firms modify their use of various intermediate inputs in response to changes in relative product prices. Meanwhile, the reallocation from the substitution between labor and intermediate inputs shows how shifts in the relative wage compared to the prices of intermediate inputs influence firms' decisions to utilize more intermediate inputs or more labor.

Since price rigidities are compounded at each step of the production chain, the wage pass-through to the price of sector j is generally bounded above by the sector's probability of price adjustment ($\hat{\Psi}_{jL} \leq \theta_j$). Similarly, with nonnegative initial markups across sectors,

$\Psi_{iL} \leq \bar{\mu}_j^{-1}$ holds as a result of double marginalization. Consequently, the reallocation resulting from the substitution between labor and intermediate inputs is nonnegative as shown in equation (12). This occurs because expansionary monetary policy tends to increase the nominal wage more than sectoral prices ($\hat{\Psi}_{jL} \leq \hat{\Psi}_{LL} = 1$), causing firms to use cheaper intermediate inputs more intensely. This shift towards intermediate goods improves overall allocative efficiency in the economy, as sectoral outputs are under-supplied due to double marginalization ($\Psi_{jL} \leq \Psi_{LL} = 1$), and increased use of intermediate inputs contributes to greater value added in the economy. Furthermore, the roundaboutness in production (represented by $\tilde{\Omega}_{jL}$) is crucial to influencing the supply-side effects of monetary policy. If firms rely solely on labor for production, resulting in $\tilde{\Omega}_{jL} = 1$ for $j = 1, \cdots, N$, the model economy simplifies to a horizontal economy where supply side effects are determined solely by substitution between sectoral products for households.

Reallocation due to substitution between sectoral products operates similarly to the mechanism described in Baqaee et al. (2024), where expansionary policy improves allocative efficiency by reallocating resources from low-markup firms to high-markup firms. However, unlike their findings, where a uniform initial markup among all firms eliminates the supply-side effect, our study shows that input-output linkages add a new dimension of heterogeneity in the distribution of upstream distortions (Ψ_{iL}). Due to double marginalization within a supply chain and the generally asymmetric nature of production processes across different sectors, even if all firms in our economy start with the same initial markups ($\bar{\mu}_i = \bar{\mu}^*, \forall i \in \mathcal{N}$), there remains heterogeneity in the upstream distortions, resulting in an inefficient allocation of resources among sectors.

Equation (12) also emphasizes the important impact of the elasticity of substitution on the supply-side effect. When other factors are kept constant, an increased elasticity of substitution among goods consumed by households or inputs used in downstream production enhances the supply-side effect. This occurs because households' demand for final goods from various sectors and firms' demand for inputs from different sectors react more significantly to changes in relative sectoral prices when substitution is more elastic. Consequently, monetary policy exerts a stronger effect on the reallocation of resources across sectors.

3.3 Illustrative Examples

To better understand how our model works, we explore three simple network economies to illustrate the decomposition in Proposition 1.

Example 1. A Vertical Economy

Consider first a vertical supply chain where the most upstream sector N produces good N using labor, while each of the other sectors $i \neq N$ uses the output produced by its immediate upstream sector $i+1$ as an intermediate input, with households consuming only the output produced by sector 1. In this economy, there is only one feasible allocation of resources for a given level of labor supply, which implies that the misallocation channel through monetary policy is absent.

One can verify that the sufficient statistic $\mathrm{d}\log \mathrm{TFP}/\mathrm{d}\log w$ becomes zero, since there is only one final good and one input involved in both consumption and sectoral production. Therefore, the support of $\tilde{\Omega}(j,:)$ and b degenerates to a single point, which yields,

$$\mathrm{Cov}_b\left(\hat{\Psi}_{iL}, \Psi_{iL}\right) = 0 \quad \text{and} \quad \mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\hat{\Psi}_{iL}, \Psi_{iL}\right) = 0, \forall j \in \mathcal{N}.$$

Example 2. A Horizontal Economy

In a horizontal economy, each sector $i \in \mathcal{N}$ only uses labor to produce goods, which are sold directly to households. Given the absence of input-output linkages, the horizontal economy can be regarded as an economy with heterogeneous firms. When there is heterogeneity in markups, the cross-sector resource allocation is inefficient, providing an avenue for monetary policy to affect TFP. From Proposition 1, the sufficient statistic of the supply-side effect of monetary policy can be simplified as,

$$\frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log w} = \underbrace{\sigma_C \frac{\mathrm{Cov}_b(\theta, \bar{\mu}^{-1})}{\mathbb{E}_b(\bar{\mu}^{-1})}}_{\substack{\text{Substitution between} \\ \text{sectoral products}}} + \underbrace{\qquad 0 \qquad}_{\substack{\text{Substitution between} \\ \text{labor and intermediate inputs}}}.$$

Note that there is no substitution between labor and intermediate inputs since labor is the only input in each sector in this horizontal economy. The channel of misallocation is entirely driven by substitution between sectoral products, characterized by the covariance between price rigidities (θ) and the inverse of markups ($\bar{\mu}^{-1}$), using expenditure shares as weights. This result echoes the insight of Baqaee et al. (2024), which emphasizes that the response of TFP to monetary policy critically depends on the correlation between firms' markups and price rigidities in an economy with heterogeneous firms. In response to an expansionary monetary shock in our model, sectors with rigid prices (lower θ_i) increase their prices to a less extent than those with more flexible prices, leading to a reallocation of resources toward sectors with high price rigidities. If sectors with less flexible prices tend to have high initial markups, $\mathrm{Cov}_b(\theta, \bar{\mu}^{-1}) > 0$, monetary easing shifts resources from sectors with low markups to sectors with high markups, resulting in an improvement in allocative efficiency and therefore an increase in TFP. In addition, a higher average distortion (larger $1/\mathbb{E}_b(\bar{\mu}^{-1})$), given $Cov_b(\theta, \bar{\mu}^{-1})$ remains unchanged, further amplifies the supply-side effect.

Example 3. A Roundabout Economy

Now consider a one-sector roundabout economy in which a representative firm combines labor and its own goods by using a CES production function with elasticity of substitution σ_1,

$$\frac{y_1}{\bar{y}_1} = A_1 \left[\omega_L \left(\frac{L_1}{\bar{L}_1} \right)^{\frac{\sigma_1 - 1}{\sigma_1}} + (1 - \omega_L) \left(\frac{x_{11}}{\bar{x}_{11}} \right)^{\frac{\sigma_1 - 1}{\sigma_1}} \right]^{\frac{\sigma_1}{\sigma_1 - 1}},$$

where $\omega_L \in (0, 1)$ represents the intensity of labor in production. According to Proposition 1, it follows that:

$$\frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log w} = \underbrace{0}_{\substack{\text{Substitution between} \\ \text{sectoral products}}} + \underbrace{\sigma_1(1-\alpha)(1-\Lambda_L)(1-\hat{\Lambda}_L)}_{\substack{\text{Substitution between} \\ \text{labor and intermediate inputs}}}.$$

where $\hat{\Lambda}_L = \alpha\theta_1/(1-(1-\alpha)\theta_1)$ and $\Lambda_L = \alpha\bar{\mu}_1^{-1}/(1-(1-\alpha)\bar{\mu}_1^{-1})$ with $\alpha = \tilde{\Omega}_{1L} = \tilde{\lambda}_1^{-1}$.

In contrast to the horizontal economy in Example 2, this roundabout economy has a single final good in the consumption basket, and therefore no reallocation occurs due to substitution between sectoral products. Nevertheless, a positive supply side effect still arises from the substitution between labor and intermediate inputs when the sectoral price is rigid ($\theta_1 < 1$), the substitution elasticity is positive ($\sigma_1 > 0$) and there exists an initial distortion ($\bar{\mu}_1 > 1$). In response to an expansionary monetary shock, firms substitute labor with intermediate inputs in production. This substitution occurs because the wage pass-through is incomplete due to nominal rigidity ($\mathrm{d}\log p_1 < \mathrm{d}\log w$, or $\hat{\Psi}_{1L} = \alpha\theta_1/(1-(1-\alpha)\theta_1)) < 1$). This reallocation of resources toward intermediate goods improves allocative efficiency, since intermediate input is under deployed relative to the optimal level ($\Psi_{1L} = \alpha\bar{\mu}_1^{-1}/(1-(1-\alpha)\bar{\mu}_1^{-1}) < 1$).

Note also that the supply-side effect decreases with α. This is because a lower α, indicating a greater roundabout in production, weakens the wage pass-through (smaller $\hat{\Psi}_{1L}$) and increases upstream markups (smaller Ψ_{1L}), thereby amplifying the reallocation effect. Another point worth highlighting is that the supply-side effect is more pronounced when firms suffer more initial distortions (higher $\bar{\mu}_1$) or price rigidity (lower θ_1). The reason is that a stickier price is associated with a larger increase in the real wage in response to expansionary monetary policy, which in turn pushes firms more intensively to take use of intermediate inputs, and therefore, labor productivity rises. Following similar logic, by using more intermediate inputs, an economy with a higher initial markup generates a higher gain from harvesting a larger marginal product of input, and accordingly the supply-side effect of monetary policy becomes stronger.

4 Output Response and Phillips Curve

Monetary policy not only affects households' labor supply through the intratemporal decision between consumption and leisure, but may also change the allocation of labor and intermediate inputs across sectors. In this section, we will explore how monetary policy changes real output through its traditional New Keynesian demand side effect and also the supply-side effect explored in the previous section. In addition, we will show that a positive supply side effect can flatten the slopes of all sectoral Phillips curves.

4.1 Output Response

Given the specification of households' preference, the elasticity of real final output with respect to money supply is given by Proposition 2. It shows that the response of real output to a change in money supply can be decomposed into two components up to a first-order approximation: a supply side effect that arises from a change in allocative efficiency and a demand side effect due to nominal price rigidities that has been studied in the New Keynesian models with production networks such as Pasten et al. (2020), La'O and Tahbaz-Salehi (2022), Afrouzi and Bhattarai (2023), Rubbo (2023) and Baqaee et al. (2024).

The demand side effect arises from the endogenous response of the labor supply to a change in the money supply. When the monetary authority expands the money supply, the nominal wage increases, but sectoral prices, along with consumer prices, might not respond to the same extent due to price rigidities. This incomplete wage pass-through to consumer price ($1 - \hat{\Lambda}_L > 0$) results in a higher real wage, which in turn leads households to supply more labor to firms, particularly when the wealth effect on labor supply is relatively weak (small γ). For the supply-side effect, Proposition 2 explicitly shows how TFP responds to monetary policy. When $1 - \hat{\Lambda}_L - \xi > 0$, an expansionary monetary policy increases total factor productivity, and vice versa.

Another point worth highlighting is that the Frisch elasticity of labor supply $1/\varphi$ also determines the magnitude of the supply-side effect of monetary policy. We find that a less elastic labor supply (higher φ) amplifies the supply-side effect while dampening the demand side effect. This is because, with a less elastic labor supply, the labor supply remains relatively unresponsive to aggregate demand shocks, while a change in the nominal wage becomes more pronounced. The larger wage response leads to more significant changes in ex-post markups, thereby amplifying the supply-side effect. In an extreme case where labor supply becomes completely inelastic ($\varphi \to \infty$), monetary policy has no impact on labor supply. In this scenario, the supply-side effect is given by $\mathrm{d}\log \mathrm{TFP}/\mathrm{d}\log M = (1-\hat{\Lambda}_L-\xi)/(1-\xi)$, which is independent of the preferences of households.

Proposition 2. *Following a monetary shock, the output response can be broken down into supply and demand side effects,*

$$\frac{\mathrm{d}\log Y}{\mathrm{d}\log M} = \underbrace{\frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log M}}_{\textit{Supply side effect}} + \underbrace{\frac{\mathrm{d}\log L}{\mathrm{d}\log M}}_{\textit{Demand side effect}} = \frac{1-\hat{\Lambda}_L+\varphi(1-\hat{\Lambda}_L-\xi)}{1+(\gamma-1)\hat{\Lambda}_L+\varphi(1-\xi)}, \tag{13}$$

specifically,

$$\frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log M} = \frac{(\gamma+\varphi)(1-\hat{\Lambda}_L-\xi)}{1+(\gamma-1)\hat{\Lambda}_L+\varphi(1-\xi)} \quad \textit{and} \quad \frac{\mathrm{d}\log L}{\mathrm{d}\log M} = \frac{1-\hat{\Lambda}_L-\gamma(1-\hat{\Lambda}_L-\xi)}{1+(\gamma-1)\hat{\Lambda}_L+\varphi(1-\xi)},$$

with $\hat{\Lambda}_L = \mathbb{E}_b(\hat{\Psi}_{iL})$, *and* $\xi = \frac{\mathrm{d}\log \Lambda_L}{\mathrm{d}\log w} = 1-\hat{\Lambda}_L-\frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log w}$.[9]

Our findings here are closely related to recent studies on production networks, but differ from the literature in several aspects. In the absence of distortionary markups ($\bar{\mu} = \mathbf{1}$), the supply-side effect of monetary policy in our model disappears ($1-\hat{\Lambda}_L-\xi = 0$) up to a first-order approximation, and monetary policy only has the standard demand side effect, as illustrated in Proposition 5 of La'O and Tahbaz-Salehi (2022) in an efficient economy with input-output linkages. The reason is that although relative price changes in response to shocks alternate relative demand for goods produced by different sectors, the marginal product of inputs in sectors facing higher demand is the same as that in sectors experiencing lower demand in equilibrium, and therefore these marginal products of inputs induced by the opposite shift of demand exactly cancel each other out based on the envelope theorem. Consequently, there is no additional gain from resource reallocation, even with nominal

[9] See Lemma 7 for more details. We assume $\xi \leq 1$, under which expansionary monetary policy increases the nominal wage, implying that all the denominators in Proposition 2 are positive. This assumption is valid for the calibration in our model.

rigidities in place. However, their model does not account for any supply side effect, while our paper investigates both the supply and demand side effects of monetary policy.

Our work is also closely related to Baqaee et al. (2024), which decomposes the output response into supply and demand side effects in a horizontal economy with real rigidities. Our approach differs from theirs in two aspects. First, we examine the supply and demand side effects of monetary policy in an economy with production networks, without relying on any real rigidities to generate significant supply side effects. Second, the demand side effect in our model is defined as the response of labor, which includes an adjustment resulting from the misallocation channel $-\gamma(1-\hat{\Lambda}_L-\xi)$, while they attribute this component of the labor response to the supply-side effect.

4.2 The Divine Coincidence Condition

In an economy with initial distortions, the misallocation channel may have a first-order impact on TFP. Up to a first-order approximation, the misallocation channel in equation (10) can be written as the difference between an output gap $\tilde{y}$ (the logarithmic difference between sticky-price and flexible-price equilibria with the same initial markups) and an employment gap $\tilde{l}$, which can be further expressed as a weighted sum of sectoral price inflation $\pi_k = d\log p_k$,

$$\tilde{y}-\tilde{l}=\sum_{k=1}^{N}\underbrace{\left(\frac{1}{\Lambda_L}\sum_{j=0}^{N}\frac{\sigma_j\lambda_j}{\bar{\mu}_j}\mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\tilde{\Psi}_{ik},\Psi_{iL}\right)\right)(1-\theta_k^{-1})}_{\doteq\,\mathcal{J}_k}\pi_k \doteq \mathcal{J}'\pi, \tag{14}$$

where $\mathcal{J}$ is an $N\times 1$ vector with the k-th component $\mathcal{J}_k$ measuring the impact of sector k's inflation on allocative efficiency. A larger $\mathcal{J}_k$ implies that a given level of sectoral inflation π_k could generate a greater improvement in allocative efficiency. $\mathcal{J}_k$ increases when substitution between inputs in production and substitution between varieties in consumption become more elastic, and the covariances between desired pass-throughs of sectoral inflation π_k to downstream sectors and upstream markups are greater in magnitude, in addition to stickier price and larger size in sector k.[10] Note also that when the initial allocation is efficient, the misallocation channel is absent ($\mathcal{J}=\mathbf{0}$).

Next, we derive a trade-off between the output gap $\tilde{y}$ and sectoral price inflation π without

[10] In a Cobb-Douglass economy, the big bracket in $\mathcal{J}_k$ can be simplified by using Lemma 9 in the Appendix as, $\frac{1}{\Lambda_L}\sum_{j=0}^{N}\frac{\lambda_j}{\bar{\mu}_j}\mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\tilde{\Psi}_{ik},\Psi_{iL}\right)=\lambda_k\frac{\Psi_{kL}}{\Lambda_L}-\tilde{\lambda}_k$. Then, $\mathcal{J}_k=(\lambda_k\frac{\Psi_{kL}}{\Lambda_L}-\tilde{\lambda}_k)(1-\theta_k^{-1})=\tilde{\lambda}_k(1-\frac{\lambda_k}{\tilde{\lambda}_k}\frac{\Psi_{kL}}{\Lambda_L})(\theta_k^{-1}-1)$.

a cost push term as in standard New Keynesian models, and explore how the supply-side effect changes this trade-off. In a one-sector version of our model, closing the output gap $\tilde{y} = 0$ is equivalent to stabilizing the sectoral price inflation $\pi = 0$, which is known as the Divine coincidence. However, in a multisector model with input-output linkages, there are multiple sectoral price inflation rates, but only a single output gap. This suggests that the output gap merely reflects a composite measure of sectoral inflation rates, which means that closing the output gap $\tilde{y} = 0$ does not automatically ensure that price inflation is stabilized in all sectors simultaneously.

From the optimal conditions of the labor supply of households and firms, the output gap $\tilde{y}$ and the sectoral price inflation π can be linked by a divine coincidence condition in Lemma 1. The divine coincidence condition shows that when aggregate output exceeds that in the flexible price equilibrium, price inflation on average has to rise to make firms produce more output.

Lemma 1. *Assume no sector has fully rigid prices ($\theta_i > 0, \forall i$). The divine coincidence condition in a distorted economy is given by,*

$$(\gamma + \varphi)\tilde{y} = [\tilde{\lambda}'(\Theta^{-1} - I) + \varphi \mathcal{J}']\pi. \tag{15}$$

There are two components in the coefficients of sectoral price inflation on the right hand side of equation (15). The first component $\tilde{\lambda}'(\Theta^{-1} - I)$ captures cost-based Domar-weighted sectoral price rigidities, as emphasized by Rubbo (2023), implying that for a given level of sectoral inflation, sectors with stickier prices and larger sizes have a greater impact on real output. The second component demonstrates a scenario in which if sectoral price movements enhance allocative efficiency (i.e., $\mathcal{J}'\pi > 0$), sectoral inflation would further increase output. This effect is amplified by the inverse of Frisch elasticity, as the misallocation channel has more pronounced effects on output with a less elastic labor supply (see Proposition 2). In an extreme case where labor supply is fully elastic (as φ approaches zero), the misallocation channel becomes irrelevant to the divine coincidence condition and the output response is independent of resource reallocation, since any improvement in TFP due to reallocation is precisely offset by its adverse impact on labor supply.

4.3 Phillips Curves

Combining the divine coincidence condition in Lemma 1 with sectoral inflation $\pi = \hat{\Psi}^n_{(L)} \mathrm{d}\log w - \hat{\Psi}^n \Theta \mathrm{d}\log A$, we obtain a wage Phillips curve,

$$[1 - \hat{\Lambda}_L + \varphi(1 - \hat{\Lambda}_L - \xi)]\mathrm{d}\log w = (\gamma + \varphi)\tilde{y} + (\tilde{\lambda}' - \hat{\lambda}'\Theta + \varphi \mathcal{J}' \hat{\Psi}^n \Theta)\mathrm{d}\log A. \tag{16}$$

The coefficient of the change in the nominal wage comprises two components: one reflects an increase in the real wage $(1 - \hat{\Lambda}_L)$ due to nominal rigidities, and the other is driven by the misallocation channel. Rearranging the coefficient of wage inflation to the right-hand side of the equation above, we obtain the wage Phillips curve, which is flatter relative to the benchmark model without initial markups when resource allocation becomes more efficient following shocks and labor supply is not fully elastic. The reason is that a positive output gap $\tilde{y}$ drives up the wage to attract additional labor needed to sustain the higher level of production. However, enhanced allocative efficiency $(1 - \hat{\Lambda}_L - \xi > 0)$ reduces the labor required for a given output gap, thus moderating the required increase in the wage.

Note that sectoral value added is generated by labor through both direct labor input and indirect labor input from its upstream sectors. Therefore, dampened wage inflation in response to the output gap implies that firms adjust their product prices to a lesser extent when there exists a positive supply side effect. Combining the wage Phillips curve with explicit expressions for sectoral inflation rates, Proposition 3 presents sectoral Phillips curves in the economy with initial distortions. It states that all sectoral price inflation Phillips curves become flattened when expansionary monetary policy improves allocative efficiency.

Proposition 3. *Sectoral Phillips curves in a distorted economy are given by,*

$$\underbrace{\pi}_{N\times 1} = \underbrace{\mathcal{K}}_{N\times 1}\tilde{y} + \underbrace{\mathcal{V}}_{N\times N}\underbrace{\mathrm{d}\log A}_{N\times 1} \tag{17}$$

where $\mathcal{K}$ and $\mathcal{V}$ denote the slope and residual coefficient matrix of the Phillips curves, respectively. Specifically, $\mathcal{K}$ is an $N \times 1$ vector given by,

$$\mathcal{K} = \frac{\gamma + \varphi}{1 - \hat{\Lambda}_L + \varphi(1 - \hat{\Lambda}_L - \xi)}\hat{\Psi}^n_{(L)},$$

and $\mathcal{V}$ is an $N \times N$ matrix defined as,

$$\mathcal{V} = \frac{1}{1 - \hat{\Lambda}_L + \varphi(1 - \hat{\Lambda}_L - \xi)}\hat{\Psi}^n_{(L)}(\tilde{\lambda}' - \hat{\lambda}'\Theta + \varphi\mathcal{J}'\hat{\Psi}^n\Theta) - \hat{\Psi}^n\Theta.$$

When the initial equilibrium is efficient, there is no supply side effect of monetary policy ($1 - \hat{\Lambda}_L - \xi = 0$), the sectoral Phillips curves are then in line with Proposition 2 in Rubbo (2023). According to that study, input-output linkages flatten sectoral Phillips curves due to compounded price rigidities along production chains. In our model economy with initial distortions, the sectoral Phillips curves are further flattened as a result of the improvement in allocative efficiency ($1 - \hat{\Lambda}_L - \xi > 0$). The reason is that when the monetary expansion improves allocative efficiency, the supply-side effect brings up higher output but without much increase in inflation. Following similar logic, other aggregate Phillips curves, including consumer price Phillips curve, which uses expenditure shares as weights, also flatten due to the supply-side effect of monetary policy. We summarize these results in Corollary 1.

Corollary 1. *In a distorted economy, the wage, sectoral, and aggregate Phillips curves become flatter if an expansionary monetary policy improves allocative efficiency.*

5 Optimal Monetary Policy

The divine coincidence condition in Lemma 1 reveals that sectoral price inflation and the output gap may not be stabilized simultaneously. Additionally, the presence of a supply side effect of monetary policy allows the monetary authority to stimulate the economy to improve allocative efficiency, which in turn results in inflation bias. This section will explore the optimal monetary policy.

5.1 Welfare Function

Our model economy features two frictions: nominal rigidities and initial markups. On the one hand, higher price dispersions both within and across sectors due to nominal rigidities reduce welfare (see, for instance, La'O and Tahbaz-Salehi, 2022; Rubbo, 2023). On the other hand, an economy with initial markups produces lower output than that without markups, and therefore, the monetary authority may use its policy instruments to boost output as in Galí (2015). The proposition 4 below provides a second-order approximation of the welfare of households around a distorted flexible price equilibrium. The welfare function in equation (18) comprises five terms: first-order bias, variation in the output gap, price dispersions within and between sectors, and variation in allocative efficiency.

The first term in equation (18) represents a first-order bias, characterized by the aggregate wedge weighted sum of output gap $\tilde{y}$ and allocative efficiency $\mathcal{J}'\pi$. The weight in the output gap, $1 - \Lambda_L$, measures the aggregate wedge between natural and efficient levels of output.

When some sectors exhibit positive markups ($\bar{\mu}_j > 1$ for some j and $\bar{\mu}_i \geq 1$ for others), these markups propagate through production networks and lead to a positive aggregate wedge. Monetary policy could obtain first-order welfare gains by driving the economy to its efficient production frontier.

Proposition 4. *Under the assumption of small distortions, up to second-order approximation, the welfare function is given by,*

$$\begin{aligned}\mathbb{W} = \underbrace{(1-\Lambda_L)\tilde{y} + \Lambda_L \mathcal{J}'\pi}_{\text{First-order bias}} \quad \underbrace{-\frac{\gamma+\varphi}{2}(\tilde{y} - \frac{1+\varphi}{\gamma+\varphi}\mathcal{J}'\pi)^2}_{\text{Variation in output gap}} \quad \underbrace{-\frac{1}{2}\pi'\mathcal{H}_1\pi}_{\text{Within-sector price dispersion}} \\ \underbrace{-\frac{1}{2}\pi'\mathcal{H}_2\pi}_{\text{Cross-sector price dispersion}} \quad \underbrace{-\frac{\gamma-1}{2}\frac{1+\varphi}{\gamma+\varphi}\pi'\mathcal{J}\mathcal{J}'\pi}_{\text{Variation in allocative efficiency}}\end{aligned} \tag{18}$$

where $\mathcal{H}_1 = \mathrm{diag}(\epsilon)\mathrm{diag}\left((\theta^{-1}-1)\circ\lambda\circ\frac{\Psi_{(L)}}{\Lambda_L} - \mathcal{J}\right)$ *and* $\mathcal{H}_2 = (I-\Theta^{-1})\mathcal{B}(I-\Theta^{-1})$ *are* $N\times N$ *matrices, with* $\mathcal{B}$ *defined as an* $N\times N$ *matrix where each element* $\mathcal{B}(k,l)$ *equals* $\sum_j \sigma_j\lambda_j \mathrm{Cov}_{\Omega(j,:)}(\Psi_{ik},\Psi_{il})$.

The second term illustrates a welfare loss due to variation of output, captured by an effective output gap, $\tilde{y} - (1+\varphi)/(\gamma+\varphi)\mathcal{J}'\pi$. This effective output gap is a weighted average of output and employment gaps, reflecting a trade-off between closing these two gaps when they diverge. When expansionary monetary policy can improve the allocative efficiency, $\mathcal{J}'\pi > 0$, the output in the economy will increase but without a great loss in welfare caused by inflation. Therefore, output should be stabilized around an efficiency-adjusted target.

The third and fourth terms in the welfare function characterize welfare losses due to within-sector and cross-sector price dispersions, respectively. Within each sector, firms with and without the opportunity to adjust prices in response to shocks may experience different prices. This price dispersion leads to within-sector distortions since resources are inefficiently allocated to firms with lower prices. Similarly, sectoral prices may not adjust uniformly to changes in input costs due to nominal rigidities and input-output linkages, resulting in lower welfare. This cross-sector price dispersion contributes to a second-order misallocation effect (La'O and Tahbaz-Salehi, 2022 and Rubbo, 2023). Specifically, in a distorted horizontal economy, the cross-sector price dispersion can be written as,

$$\frac{1}{2}\pi'\mathcal{H}_2\pi = \frac{1}{2}\sigma_C \mathrm{Var}_\beta(\mathrm{d}\log\mu_i),$$

where β denotes a vector of weights in the variance operator, with element $\beta_k = b_k\bar{\mu}_k^{-1}/\mathbb{E}_b(\bar{\mu}_k^{-1})$.

The right hand side of the expression above is a measure of second-order misallocation effect as in Hsieh and Klenow (2009).[11] Higher price dispersion across sectors results in lower TFP and welfare.

The last term in equation (18) shows welfare cost due to the variation in allocative efficiency. A key parameter determining the sign of this term is γ, which captures the wealth effect on labor supply. When resource allocation improves in response to shocks $\mathcal{J}'\pi > 0$, the TFP increases accordingly, resulting in a higher level of output and household income, given other conditions unchanged. If the wealth effect on labor is strong, $\gamma > 1$, higher income from a better allocation of resources dampens the response of labor supply, resulting in lower welfare, and vice versa. The knife-edge case is when $\gamma = 1$, where this variation in allocative efficiency does not generate any welfare loss.

5.2 Optimal Policy

Optimal monetary policy maximizes the welfare function $\mathbb{W}$ in Proposition 4 by choosing the output gap and sectoral inflation rates, subject to the sectoral Phillips curves in Proposition 3. In a multisector model with input-output linkages and various frictions, a central bank equipped with a single policy instrument generally isn't able to close all of gaps shown in the welfare function. On the one hand, the central bank must balance the output gap, sectoral inflation rates, and allocative efficiency, all of which contribute to second-order welfare losses. On the other hand, in an economy with initial distortions, the central bank encounters an additional trade-off: balancing second-order welfare losses against first-order welfare gains. This additional trade-off results in inflation bias. Proposition 5 presents the condition for sectoral inflation rates under optimal monetary policy.

The right-hand side of equation (19) highlights the source of the inflation bias, which arises from an aggregate wedge $1-\Lambda_L$ and the supply-side effect of monetary policy $1-\hat{\Lambda}_L-\xi$. In a distorted economy, the natural level of output is lower than its efficient level $(1-\Lambda_L > 0)$, as in standard New Keynesian models. This discrepancy due to the aggregate wedge provides room for the monetary authority to boost up output toward its efficient level via higher inflation. The other source of inflation bias comes from the supply-side effect, which is novel in our model. When monetary policy can generate a positive supply side effect $(1 - \hat{\Lambda}_L - \xi > 0)$, the monetary authority utilizes this effect to improve allocative efficiency and welfare.

[11] In Hsieh and Klenow (2009), the negative effect of distortions on TFP is summarized by the variance of log TFPR: $\frac{1}{2}\sigma_C \mathrm{Var}(\mathrm{d}\log \mathrm{TFPR}_i)$. Under constant returns to scale, changes in TFPR coincide with changes in markups: $\mathrm{d}\log \mathrm{TFPR}_i = \mathrm{d}\log \mu_i$.

In contrast, the left-hand side of equation (19) illustrates how optimal policy balances various sources of second-order welfare losses and stabilizes an index of sectoral inflation rates. The weight on sectoral inflation in the index consists of three components that minimize the output gap, price dispersions within and across sectors, and variation in allocative efficiency, respectively. These weights are shaped by production networks, nominal rigidities, initial markups, elasticities of substitution, and preference parameters. A higher weight implies a lower desired inflation under the optimal policy.

Proposition 5. *The optimal monetary policy generates an inflation bias and targets an inflation index, which are determined by the following condition,*

$$\left[\underbrace{\tilde{\lambda}'(\Theta^{-1} - I) - \mathcal{J}'}_{\textit{Output gap}} + \underbrace{\frac{\gamma+\varphi}{\xi}(\hat{\Psi}^n_{(L)})'\mathcal{H}}_{\textit{Price dispersion}} + \underbrace{\frac{(1+\varphi)(\gamma-1)(1-\hat{\Lambda}_L-\xi)}{\xi}\mathcal{J}'}_{\textit{Variation in allocative efficiency}}\right]\pi$$
$$= \underbrace{1-\Lambda_L}_{\textit{Inflation bias due to aggregate wedge}} + \underbrace{[1+\varphi+(\gamma-1)\Lambda_L](1-\hat{\Lambda}_L-\xi)/\xi}_{\textit{Inflation bias due to supply side effect}}, \tag{19}$$

where $\mathcal{H} = \mathcal{H}_1 + \mathcal{H}_2$.

As emphasized by La'O and Tahbaz-Salehi (2022) and Rubbo (2023), a monetary policy aimed at stabilizing the output gap assigns specific weights to different sectors in the inflation index, which closely resemble those under optimal monetary policy in calibrated models. The weights of sectoral inflation in stabilizing the output gap in equation (19) show that the monetary authority should assign higher weights to the following sectors in the inflation index: (i) sectors with stickier prices (lower θ_i) due to their higher price distortions; (ii) larger sectors, as indicated by higher cost-based Domar weights ($\tilde{\lambda}_i$), which have a greater impact on the economy for a given price dispersion; and (iii) sectors with less distortions (lower $\mathcal{J}_k$), whose price fluctuations in response to shocks have a limited impact on resource allocation.[12] Comparing with La'O and Tahbaz-Salehi (2022) and Rubbo (2023), point (iii) is novel in our study, demonstrating that the monetary authority assigns a lower weight to sectoral inflation in sectors that contribute more to allocative efficiency across the economy (e.g. higher $\mathcal{J}_k$). This highlights a key mechanism where the monetary policy prioritizes stabilizing inflation less in sectors that contribute positively to the efficient allocation of resources, balancing between inflation stabilization and improving allocative efficiency in

[12] Appendix F presents an explicit expression for each component in a Cobb-Douglass economy.

the production network.

5.3 Alternative Stabilization Policies

In practice, the monetary authority may follow alternative stabilization policies to implement its monetary policy. In line with the literature, we consider two simple alternative rules: a consumer price inflation targeting rule, $\sum_{i=1}^{N} b_i \pi_i = 0$ and an output gap targeting rule, $\tilde{y} - (1+\varphi)/(\gamma+\varphi)\mathcal{J}'\pi = 0$, which is taken from the welfare function (18). Combining with the divine coincidence condition (15), this output gap stabilization policy can be rewritten as an inflation stabilization policy, $\sum_i \phi_i^{o.g.} \pi_i = 0$, with $\phi_i^{o.g.} = (1/\theta_i - 1)\tilde{\lambda}_i - \mathcal{J}_i$. Note that $b_i \neq \phi_i^{o.g.}$ generally, since the output-gap stabilization policy partly takes into account input-output linkages and the adjustments in nominal rigidities and allocative efficiency. There are two main differences between the optimal monetary policy and these two simple rules. On the one hand, optimal monetary policy creates inflation bias due to the aggregate wedge and supply side effects, which these simple rules do not address. On the other hand, these rules fail to consider price dispersion both within and across sectors, as well as variation in allocative efficiency.

6 Quantitative Analysis

In the previous sections, we show that monetary policy can influence realized sectoral markups in general, leading to resource reallocation across sectors and improvements in social welfare. Policymakers could take advantage of this supply side effect to boost up TFP by improving allocative efficiency of the economy, beyond merely stabilizing output and inflation as in standard New Keynesian models. A critical question is how important the supply-side effect will be when we take our model to data. In this section, we calibrate our model using data from the United States, quantitatively showing that both the supply side and the demand side effects of monetary policy are essential in the transmission of monetary policy. Moreover, we find that these effects decrease substantially in an economy without input-output linkages.

6.1 Calibration

Our model period is one quarter and includes two sets of parameters. The first set includes preference and production parameters, which are set as standard values in the literature. Specifically, the relative risk aversion coefficient is $\gamma = 1$, and the inverse Frisch elasticity is $\varphi = 2$. In our baseline calibration, we set all within-sector elasticities of substitution at 6 (i.e., $\varepsilon_i = 6, \forall i \in \mathcal{N}$).[13] We also specify the elasticity of substitution in consumption to be one ($\sigma_C = 1$) and cross-sector elasticities of substitution in firms' production to be 0.5 (i.e., $\sigma_i = 0.5, \forall i \in \mathcal{N}$) following the literature Atalay (2017), Levchenko et al. (2019) and Devereux et al. (2023).

The second set of parameters includes input-output linkages, nominal rigidities, initial markups, final consumption shares, and productivity shocks. To estimate these parameters, we utilize four different but consistent data sets. First, we calibrate the cost-based input-output matrix $\tilde{\Omega}$ and consumption shares b using annual input-output data from the Bureau of Economic Analysis (BEA) in the United States. Following standard practice in the literature (see Baqaee and Farhi (2020) and La'O and Tahbaz-Salehi (2022)), we exclude sectors related to federal, state, and local government because our model does not consider the role of government. The data set covers 66 industries. Since sectoral production technology hardly changes within one year, we assume that the quarterly cost-based input-output matrix $\tilde{\Omega}$ and consumption shares b remain constant throughout the year, matching their annual values.

We incorporate annual sectoral markups estimated by Baqaee and Farhi (2020) as one of the key parameters in our model. The data on markups, spanning from 1997 to 2015, include information on 66 industries in our input-output dataset. We use the user-cost (UC) markup series as our benchmark calibration for initial markups. For simplicity, we assume that quarterly markups remain constant for a year. By combining the estimated markups with the cost-based input-output matrices from the BEA, we construct the revenue-based input-output matrix Ω in our model.

Sectoral price rigidities are calibrated using data from Pasten et al. (2020) which utilize confidential microdata from the Bureau of Labor Statistics (BLS) Producer Price Index (PPI) to analyze the frequency of price adjustments in different industries. The data covers the period from 2005 to 2011. This measure calculates the ratio of the number of price changes to the number of months in the sample. By merging the BEA input-output data with price adjustment data, classified according to the 3-digit codes of the North American Industry Classification System (NAICS), we calibrate price rigidity for each industry. Combining constant sectoral price rigidities with a time-varying cost-based input-output matrix allows us to derive a time-varying rigidity-adjusted input-output matrix $\hat{\Omega}$.

Finally, we measure productivity shocks by the sector-level growth rate of the Multifactor

[13] We do not directly calibrate within-sector elasticities to match initial markups in each sector and each period. Instead, we align the values of within-sector elasticities with benchmarks in the New Keynesian literature (e.g., McKay et al., 2016), and vary sectoral tax (subsidy) rates to match the gap between markups in the data and monopolistic markups in the model.

Productivity (MFP) index. The data for this analysis, covering the period from 1987 to 2019, is taken from the BEA/BLS Integrated Industry-Level Production Account (ILPA). The BEA input-output data are more disaggregated compared to the ILPA data. For each of the 66 industries, we calculate productivity shocks by disaggregating larger industries into smaller sub-industries. Annual productivities are linearly interpolated to generate quarterly values for each industry, which are then detrended to construct the covariance matrix of detrended productivity shocks.

6.2 Supply Side Effect and Inflation Bias

Figure 1 provides a breakdown of the supply-side effect of monetary policy, represented by the sufficient statistic $\mathrm{d}\log \mathrm{TFP}/\mathrm{d}\log w$ in equation (12). The solid blue line indicates the supply-side effect from substituting between different sectoral products, while the dashed purple line shows the supply-side effect resulting from substitution between labor and intermediate inputs in production. The red dotted line with circle markers represents the combined effects of the blue and purple lines. Panel (a) presents numerical findings based on our benchmark calibration. The overall supply side effect (dotted red line) varies between 0.005% and 0.031%, averaging 0.018%. This suggests that a 1% increase in the nominal wage due to expansionary monetary policy leads to an approximate 0.018% increase in TFP. The figure indicates that reallocation resulting from the substitution between labor and intermediate inputs in production is the main contributor to the total supply side effect, accounting for about 80% of the total effect on average during the sample period. In contrast, the reallocation from substitution between sectoral products is generally smaller, except in 2009 and 2015, when it surpasses the effect from substitution between labor and intermediate inputs.[14]

Note that sectoral markups in the data substantially vary with business cycles. Firms typically experience lower markups during recessions and higher markups in economic booms. Panel (a) in figure 1 shows that the channel of reallocation from substitution between labor and intermediate inputs in production varies significantly over time, with several troughs occurring in 2001, 2009, and 2015. During these years, some industries experienced severe markdowns, which were attributed to dramatic contraction in aggregate demand in 2001 and 2009, and substantial declines in energy commodity prices in 2015. This reduction in markups leads to a decrease in the total supply side effect during economic downturns.

To better understand the contributions of each sector to the supply-side effect, as shown in

[14] The correlation between wage pass-throughs to prices and inverse upstream markups is generally positive in the data, as illustrated in Figure A.2 in the Appendix.

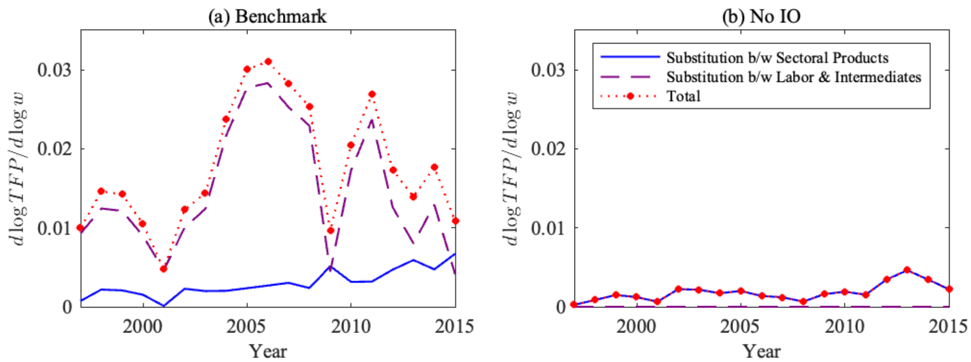

Figure 1: The Decomposition of Supply Side Effect with UC Markups. Notes: This figure reports numerical values for two components in the supply-side effect of monetary policy. The solid blue line corresponds to substitution between sectoral products, the dashed purple line shows the substitution between labor and intermediate inputs in production, and the dotted red line with circle markers indicates the total effect.

equation (11), Figure A.1 in the Appendix illustrates the roles of households and 66 different sectors in 2006. the supply-side effect due to reallocation from consumption (households) accounts for 5.7% of the total effect, while some key sectors including construction, wholesale trade, and professional, scientific, and technical services contribute to about one-fifth of the total supply side effect due to the resource allocation in production.

The above analysis shows that the supply-side effect of monetary policy is quantitatively important when we take our model to data. The next question is whether the monetary authority has an incentive to create inflation to harvest this supply side effect, and, moreover, whether the inflation bias induced by the supply-side effect is quantitatively important. Figure 2 shows the inflation bias under the optimal monetary policy in equation (19). The dashed red line represents the inflation bias caused by the aggregate wedge, while the solid blue line shows the inflation bias arising from the supply-side effect. Panel (a) is for the baseline model. It shows that the inflation bias attributed to the supply-side effect moves quite along with that due to the aggregate wedge, fluctuating from 0.08% during economic downturns to 0.54% in booms, with an average around 0.30%.

What are the welfare implications under the optimal policy? Table 2 presents the overall welfare gains and its decomposition in equation (18). In our model, monetary policy affects the output in two different ways. On one hand, expansionary monetary policy could push up output closer to its efficient level via creating higher inflation when there exists an aggregate wedge in the economy. On the other hand, it may also improve allocative efficiency and expand final output through the reallocation of labor and intermediate inputs when

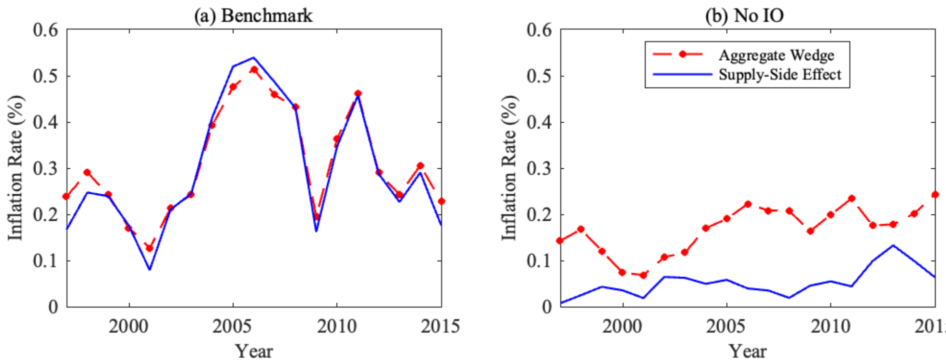

Figure 2: The Decomposition of Inflation Bias with UC Markups. Notes: This figure reports numerical values for two components on the right-hand side of equation (19) when the sum of industry weights on the left-hand side are normalized to 1. The blue line stands for the supply-side effect and the dashed red line with circle markers represents the aggregate wedge.

there exists a supply side effect of monetary policy. However, it is important to note that expansionary monetary policy can also lead to higher inflation, potentially increasing price dispersion within and across sectors, and thus resulting in larger welfare losses.

Table 2: Welfare Gains under Various Policies with UC Markups

	(1) Optimal Policy	(2) Output-Gap Targeting	(3) CPI Targeting
Welfare Gain (% of Real GDP)	-0.562	-0.617	-0.622
First order welfare gain			
Aggregate wedge	0.059	10^{-7}	0.001
Supply side effect	0.048	10^{-6}	10^{-5}
Second order welfare gain			
Variation in output gap	-0.007	0	-0.002
Within-sector price dispersion	-0.567	-0.529	-0.529
Cross-sector price dispersion	-0.094	-0.088	-0.092
Variation in allocative efficiency	0	0	0
Cosine similarity to optimal policy	1	0.987	0.663

Column (1) in Table 2 reports welfare losses (indicated by negative numbers) under the optimal monetary policy. The overall welfare loss is equivalent to 0.562% reduction in consumption relative to that under the flexible price equilibrium. However, both first-order welfare gains due to the aggregate wedge and the supply-side effect are positive and have similar magnitudes. The middle panel of Table 2 displays second-order welfare losses resulting from volatility in the output gap, as well as price dispersions within and between sectors. The within-sector price dispersion generates a welfare loss of 0.567% of consumption, and the cross-sector price dispersion also gives rise to a 0.094% reduction in consumption. In our baseline specification, we set $\gamma = 1$ and therefore the welfare cost associated with variation in allocative efficiency becomes zero.[15]

6.3 Production Networks and Supply Side Effect

Our theory suggests that the share of intermediate inputs in production plays a critical role in determining the supply-side effect of monetary policy. How do changes in input-output linkages quantitatively affect the two reallocation channels of the supply-side effect, as well as the demand side effect of monetary policy? Panel (b) of Figure 1 presents the same decomposition as in panel (a), but firms do not employ any intermediate input in production. The model economy now essentially degenerates to a horizontal economy. As shown in Section 3.3, the supply-side effect is completely driven by the reallocation from substitution between sectoral products in consumption as in Baqaee et al. (2024). The figure shows that the supply-side effect is positive, but it becomes much smaller than in panel (a). This comparison indicates that an economy with production networks as in the data is able to generate a sizable supply side effect of monetary policy even without resorting to real rigidities as in Baqaee et al. (2024). Panel (b) in Figure 2 shows the inflation bias due to the aggregate wedge and the supply-side effect of monetary policy without input-output linkages in production. Both the aggregate wedge and the supply-side effect lead to a smaller inflation bias in the horizontal economy than the baseline model. More importantly, the inflation bias due to the aggregate wedge significantly dominates that caused by the supply-side effect under the optimal monetary policy, accounting for 57% to 95% of the total inflation bias in the data sample. Furthermore, Figure A.3 in the Appendix demonstrates that the demand side effect of monetary policy also significantly decreases in the absence of input-output linkages, aligning with findings by Nakamura and Steinsson (2010) and Pasten et al. (2020).

6.4 Simple Rules of Monetary Policy

Can the monetary authority take use of alternative simple rules to approximate the optimal monetary policy? In this section, we examine two alternative simple rules of monetary policy. One is an output gap stabilization rule $\sum_i \phi_i^{o.g.} \pi_i = 0$ similar to Rubbo (2023), and

[15]Even when γ significantly deviates from 1, for example $\gamma = 2$, the welfare loss from variation in allocative efficiency remains negligible (smaller than 10^{-4}).

the other is a CPI inflation targeting rule $\sum_{i=1}^{N} b_i \pi_i = 0$. Note that these two simple rules do not have the first-order inflation bias as optimal monetary policy (equation (19)). Consequently, unlike the optimal monetary policy which trades off first-order welfare gains against second-order welfare losses, these two simple rules mainly balance second-order welfare losses induced by output gap, within and cross-sector price distortions, and variation in allocative efficiency.

Column (2) in Table 2 presents welfare gains and their decomposition under the stabilization rule of the output gap. Results show that the first-order welfare gains are essentially zero, but welfare losses from within-sector and cross-sector price dispersions are smaller than those under the optimal monetary policy, although the cosine similarity (see La'O and Tahbaz-Salehi (2022)) of weights on sectoral inflation rates between optimal monetary policy and output stabilization is quite large, 0.987, implying that the distributions of weights on sectoral inflation are quite similar under these two monetary policies.

Column (3) in Table 2 presents welfare gains and their decomposition under the CPI inflation targeting rule. Welfare gains from first-order aggregate wedge and the supply-side effect are quite small, while welfare losses due to price dispersion across sectors are larger than those under output gap stabilization, and variation in the output gap also brings welfare losses. Compared with output gap stabilization, CPI inflation targeting results in an even larger welfare loss. The reason is that output gap stabilization already partially accounts for output change due to allocative efficiency, and stabilizing such an output gap reduces welfare losses. The bottom line in Table 2 shows that sectoral weights under CPI inflation targeting are less aligned with those under the optimal policy compared to those under output gap stabilization.

6.5 Robustness Analysis

Figure 3 illustrates the inflation bias arising from the aggregate wedge and the supply-side effect of monetary policy under different preference parameterization. Panel (a) shows that an increase in the wealth effect ($\gamma = 2$) amplifies the supply-side effect, leading to a higher inflation bias compared to the aggregate wedge, while a decrease in the wealth effect ($\gamma = 0.5$) leads to a lower inflation bias induced by the supply-side effect. In addition, Proposition 5 suggests that inflation bias due to the supply-side effect is also amplified with lower elasticity of the labor supply. Panels (c) and (d) confirm this point: a more elastic labor supply ($\varphi = 0.5$) leads to a lower inflation bias generated by the supply-side effect, while a less elastic supply ($\varphi = 5$) increases the impact of the supply-side effect on inflation bias.

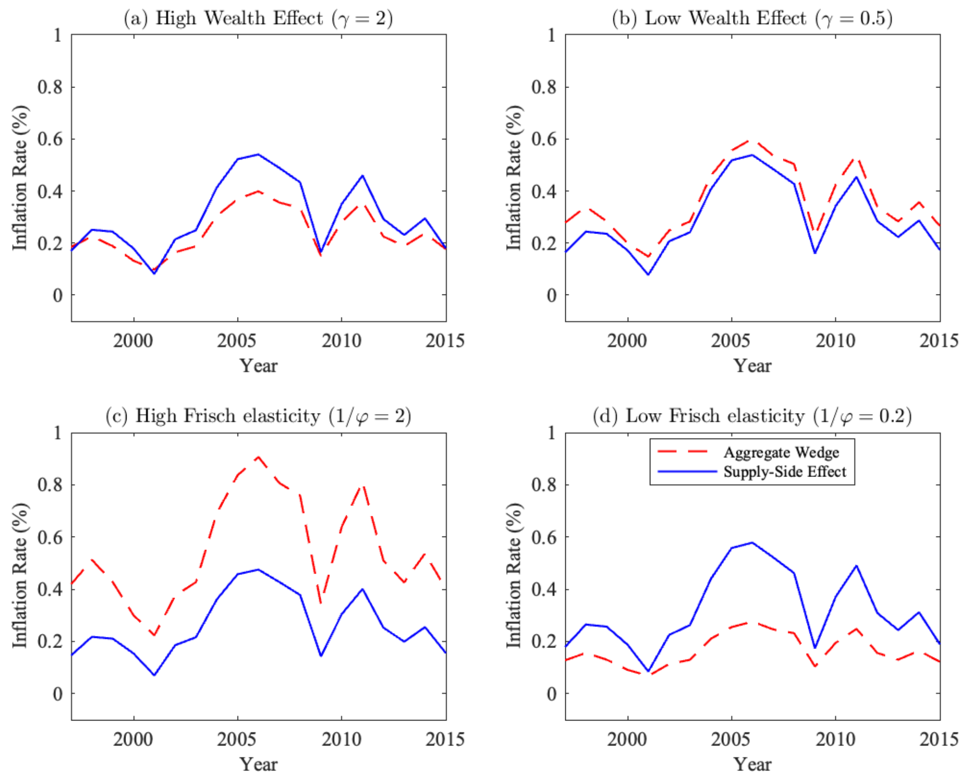

Figure 3: Decomposition of Inflation Bias with UC Markups under Different Preference Parameter Values. Notes: This figure reports numerical values for two components on the right-hand side of equation (19) when the sum of industry weights on the left-hand side are normalized to 1. The blue line stands for the supply-side effect and the dashed red line represents the aggregate wedge.

Heterogeneity in sectoral markups and input-output linkages might also affect the supply-side effect. We then conduct two counterfactual experiments. First, we eliminate heterogeneity in sectoral markups by setting all sectors to have the same average markup within a year, while still allowing these markups to vary over time. The results in panel (a) of Figure A.4 are similar to the baseline calibration. In the second experiment, the input-output linkages for all years are adjusted to align with those from the first year of the data sample, while sectoral markups remain consistent with the baseline calibration. Note that the input-output linkages depend largely on the production technology, which evolves slowly over time in the data. Results in panel (b) of Figure A.4 indicate that the supply-side effect is very similar to the baseline model.

7 Conclusion

This paper studies the supply and demand side effects of monetary policy in a multisector economy with input-output linkages. We show that the supply-side effect of monetary policy is driven by two reallocation channels: reallocation due to substitution between sectoral products for both households and firms, and reallocation due to substitution between labor and intermediate inputs in production. These two channels become more pronounced when the elasticities of substitution are higher, sectors with larger upstream markups tend to exhibit lower wage pass-throughs, and the aggregate wedge is larger.

The wage, sectoral, and aggregate Phillips curves become flatter when expansionary monetary policy improves allocative efficiency. Under optimal monetary policy, the monetary authority has an incentive to inflate the economy due to both an aggregate wedge and the supply-side effect, and it assigns greater weights of inflation to larger, stickier, and less distorted sectors.

When calibrating our model to data from the United States, we find that the supply-side effect of monetary policy is quantitatively important, and production networks play a crucial role in determining this effect. Under optimal monetary policy, the welfare gains from supply side effects are comparable to those resulting from the aggregate wedge. Our sensitivity analysis indicates that our findings remain robust to variation in model parameterization. When we eliminate production networks, both the supply side and the demand side effects of monetary policy decrease substantially.

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Not-For-Publication Technical Appendix for Optimal Monetary Policy in Production Networks with Distortions

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A Additional Figures and Tables

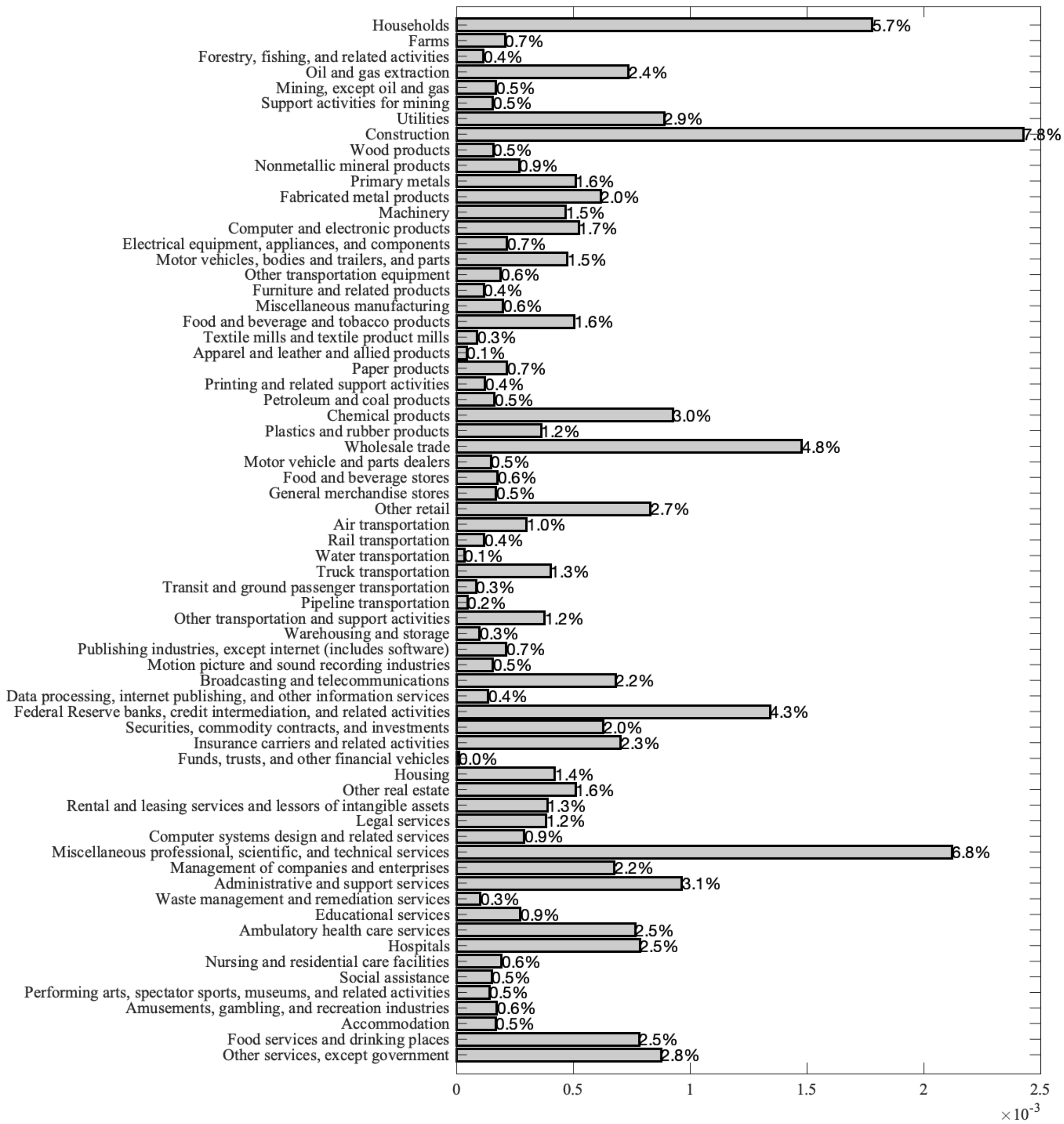

Figure A.1: Industry Contribution to the supply-side effect in 2006. Notes: The horizontal axis represents the magnitude of the supply-side effect. The percentages on each bar indicate the relative contribution of each sector to the total supply side effect.

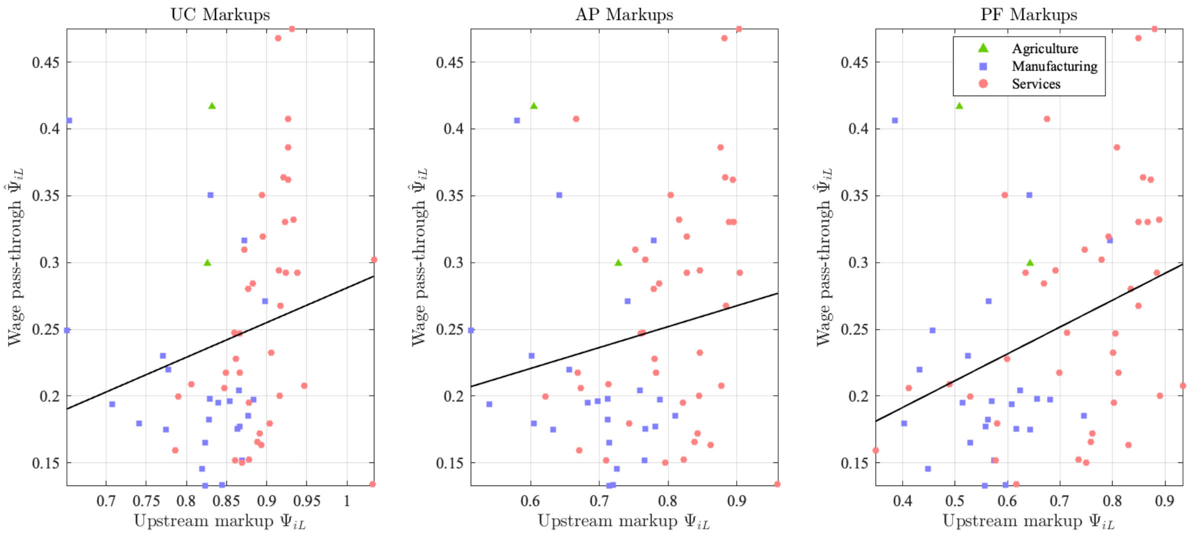

Figure A.2: Scatter Plot of Wage Pass-throughs and Inverse Upstream Markups in 2006. Notes: The sector corresponding to labor is not included in the figure. The wage pass-through and inverse upstream markup corresponding to the labor sector are $\hat{\Psi}_{LL} = 1$ and $\Psi_{LL} = 1$, respectively.

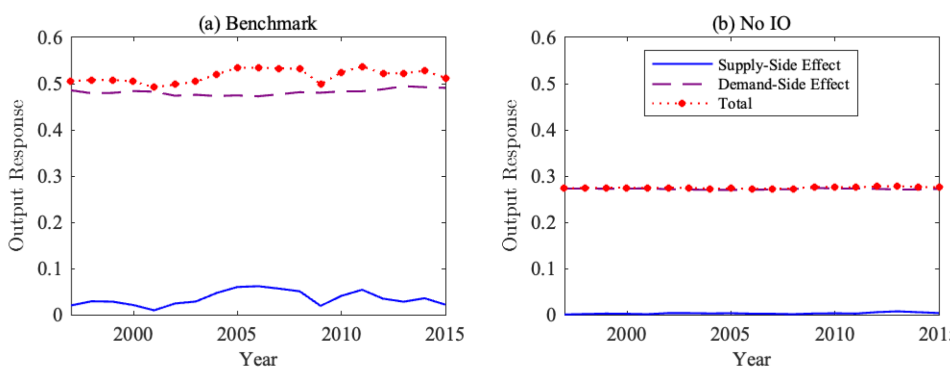

Figure A.3: The Supply Side and Demand Side Effects of Monetary Policy under UC Markups. Notes: This figure reports numerical values for the supply side and demand side effects of monetary policy. The solid blue line corresponds to the supply-side effect, the dashed purple line denotes the demand side effect, and the dotted red line with circle markers indicates the total effect.

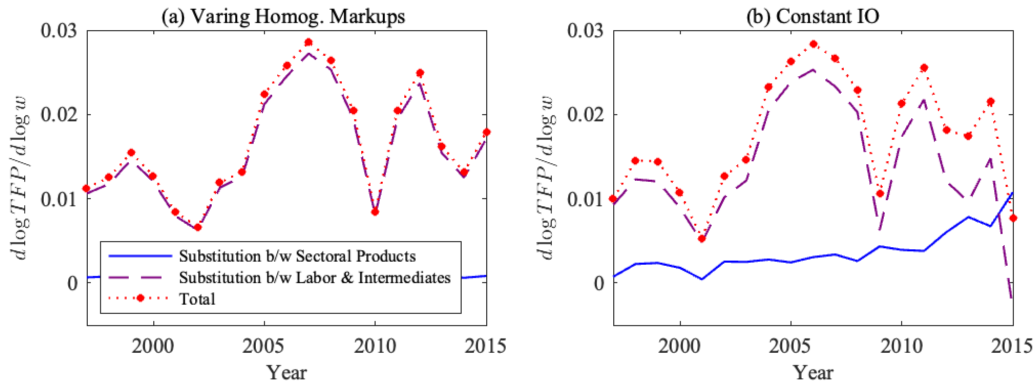

Figure A.4: Decomposition of Supply Side Effect with UC Markups: Homogeneous Markups (Panel a) and Constant Input Output (IO) Table (Panel b).

	Optimal Policy	Output-Gap Targeting	CPI Targeting	DC Targeting
Welfare Gain (Quad. Approx., % of Real GDP)	-0.565	-0.663	-0.671	-0.664
First order welfare gain				
Aggregate wedge	0.079	10^{-5}	0.001	0
Supply side effect	0.119	10^{-4}	0.001	10^{-4}
Second order welfare gain				
Variation in output gap	-0.011	0	-0.002	-10^{-5}
Within-sector price dispersion	-0.609	-0.542	-0.542	-0.543
Cross-sector price dispersion	-0.146	-0.126	-0.134	-0.126
Variation in allocative efficiency	0	0	0	0
$(1-\Lambda_L)\times$ second-order terms	0.004	0.004	0.005	0.004
Welfare Gain (Exact Model, % of Real GDP)	-0.517	-0.568	-0.582	-0.569
Cosine similarity to optimal policy	1	0.989	0.617	0.987

Table A.1: Welfare Gains under Various Monetary Policies in a Cobb-Douglas Economy with UC Markups. Notes: This table reports welfare gains under various monetary policies as a percentage of steady-state consumption, based on 10,000 draws. The row labeled 'Exact Model' calculates welfare gain based on the exact social welfare function. The remaining rows show welfare gains and their decomposition, derived from a second-order quadratic approximation of the welfare function. The last column reports the welfare gain under the divine coincidence (DC) targeting policy which closes the actual output gap using the divine coincidence index as inflation index.

B Related Proofs

Throughout the appendix, we interchangeably use Ω^f and $\Omega^n_{(L)}$ to represent the $N \times 1$ vector of labor income share, while the Ψ^f and $\Psi^n_{(L)}$ are used interchangeably to represent the $N \times 1$ vector of Leontief inverse of labor.

Lemma 2 (Property of the Leontief Inverse Matrix)**.** *In general, for any input-output matrix Ω satisfying $\sum_{j=1}^{N+1} \Omega_{ij} \leq 1$ for all i, and its corresponding Leontief inverse matrix Ψ which is defined as $\Psi = (I - \Omega)^{-1}$, we have (i) $\Psi^n = (I - \Omega^n)^{-1}$, (ii) $\Psi^n \Omega^f = \Psi^f$.*

Proof of Lemma 2. By definition of the Leontief inverse matrix, $\Psi\Omega = \Psi - I$. This can be rewritten in a block matrix form as

$$\Psi\Omega = \begin{bmatrix} \Psi^n & \Psi^f \\ \mathbf{0} & I \end{bmatrix} \begin{bmatrix} \Omega^n & \Omega^f \\ \mathbf{0} & \mathbf{0} \end{bmatrix} = \begin{bmatrix} \Psi^n\Omega^n & \Psi^n\Omega^f \\ \mathbf{0} & \mathbf{0} \end{bmatrix} = \begin{bmatrix} \Psi^n - I & \Psi^f \\ \mathbf{0} & \mathbf{0} \end{bmatrix} = \Psi - I.$$

Thus, $\Psi^n\Omega^n = \Psi^n - I$ and $\Psi^n\Omega^f = \Psi^f$.

□

Lemma 3. *Given the probability of price adjustment $\theta_i \in [0, 1]$ for all i, we observe that: (i) the rigidity adjusted Domar weight $\hat{\lambda}_k$ is less than the corresponding cost-based Domar weight $\tilde{\lambda}_k$; and (ii) the wage pass-through $\hat{\Psi}_{iL}$ is less than its corresponding price adjustment probability θ_i.*

Proof of Lemma 3. By definition of Leontief inverse, we have

$$\hat{\Psi}^n = (I - \Theta\tilde{\Omega}^n)^{-1} = I + \Theta\tilde{\Omega}^n + (\Theta\tilde{\Omega}^n)^2 + \ldots \leq I + \tilde{\Omega}^n + (\tilde{\Omega}^n)^2 + \ldots = (I - \tilde{\Omega}^n)^{-1} = \tilde{\Psi}^n. \tag{B-1}$$

Hence,

$$\hat{\lambda}' = b'\hat{\Psi}^n \leq b'\tilde{\Psi}^n = \tilde{\lambda}'. \tag{B-2}$$

Analogously, we find that $(I - \tilde{\Omega}^n\Theta)^{-1} \leq (I - \tilde{\Omega}^n)^{-1}$, which implies that

$$\hat{\Psi}^f - \theta = \hat{\Psi}^f - \Theta\tilde{\Psi}^f \tag{B-3}$$

$$= (I - \Theta\tilde{\Omega}^n)^{-1}\Theta\tilde{\Omega}^f - \Theta(I - \tilde{\Omega}^n)^{-1}\tilde{\Omega}^f \tag{B-4}$$

$$= \Theta[(I - \tilde{\Omega}^n\Theta)^{-1} - (I - \tilde{\Omega}^n)^{-1}]\tilde{\Omega}^f \leq \mathbf{0} \tag{B-5}$$

where the first equality uses the fact that $\tilde{\Psi}^f = \mathbf{1}$.

□

Lemma 4. *The pass-through of nominal wage into sector prices $\hat{\Psi}_{(L)}$ is weakly increasing in the probability of price adjustment $\{\theta_i\}_{i=1}^N$. Moreover, the pass-through of nominal wage into consumer price $\hat{\Lambda}_L$ is weakly increasing in price adjustment probability $\{\theta_i\}_{i=1}^N$ and it is bounded between 0 and $\mathbb{E}_b(\theta)$.*

Proof of Lemma 4. Since $\hat{\Psi}^f = [I - \Theta\tilde{\Omega}^n]^{-1}\Theta\tilde{\Omega}^f = [\Theta^{-1} - \tilde{\Omega}^n]^{-1}\tilde{\Omega}^f$, we have

$$\begin{aligned}
d\hat{\Psi}^f &= d[\Theta^{-1} - \tilde{\Omega}^n]^{-1}\tilde{\Omega}^f && \text{(B-6)}\\
&= [\Theta^{-1} - \tilde{\Omega}^n]^{-1}\Theta^{-1}(d\Theta)\Theta^{-1}[\Theta^{-1} - \tilde{\Omega}^n]^{-1}\tilde{\Omega}^f && \text{(B-7)}\\
&= \underbrace{[I - \Theta\tilde{\Omega}^n]^{-1}}_{\hat{\Psi}^n}(d\Theta)\Theta^{-1}\underbrace{[I - \Theta\tilde{\Omega}^n]^{-1}\Theta\tilde{\Omega}^f}_{\hat{\Psi}^f} && \text{(B-8)}\\
&= \hat{\Psi}^n(d\Theta)\Theta^{-1}\hat{\Psi}^f && \text{(B-9)}
\end{aligned}$$

and

$$d\hat{\Lambda}_L = b'd\hat{\Psi}^f = b'\hat{\Psi}^n(d\Theta)\Theta^{-1}\hat{\Psi}^f = \hat{\lambda}'(d\Theta)\Theta^{-1}\hat{\Psi}^f. \tag{B-10}$$

Or equivalently,

$$d\hat{\Psi}_{iL} = \sum_k \hat{\Psi}_{ik}\hat{\Psi}_{kL} d\log\theta_k \quad \text{and} \quad d\hat{\Lambda}_L = \sum_k \hat{\lambda}_k\hat{\Psi}_{kL} d\log\theta_k. \tag{B-11}$$

Thus, $\hat{\Psi}_{iL}$ and $\hat{\Lambda}_L$ increase weakly in $\{\theta_i\}_{i=1}^N$.

We then show that $\hat{\Lambda}_L$ is bounded above by $\mathbb{E}_b(\theta)$. Since $\hat{\Psi}_{iL} \leq \theta_i$ (Lemma 3), we have

$$\hat{\Lambda}_L = b'\hat{\Psi}^f \leq b'\theta = \mathbb{E}_b(\theta) \leq 1. \tag{B-12}$$

This result states that as long as a sector takes use of an intermediate input produced by a sector (either its own sector or another sector) with sticky price, the wage pass-through into consumer price is incomplete.

□

Lemma 5. *When evaluated at an inefficient initial equilibrium where all initial markups are non-negative ($\bar{\mu} \geq 1$), both Ψ_{iL} and Λ_L are bounded between 0 and 1. They weakly decrease with initial sectoral markups $\{\bar{\mu}_i\}_{i=1}^N$, indicating that a lower Ψ_{iL} corresponds to a higher degree of markup in the supply chain of sector i. Furthermore, for each sector, the inverse upstream markup Ψ_{iL} is less than or equal to its counterpart in an economy without input-output linkages, $\bar{\mu}_i^{-1}$.*

Proof of Lemma 5. Analogy of Lemma 3 and Lemma 4 by replacing θ_i with $\bar{\mu}_i^{-1}$. □

Lemma 6. *The covariance between wage pass-throughs ($\hat{\Psi}_{iL}$) and inverse upstream markups (Ψ_{iL}) for each producer can be further written as,*

$$\mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\hat{\Psi}_{iL}, \Psi_{iL}\right) = \underbrace{(1-\tilde{\Omega}_{jL})\mathrm{Cov}_{\tilde{\Omega}^n(j,:)}\left(\hat{\Psi}_{iL}, \Psi_{iL}\right)}_{\text{Substitution between intermediate inputs}} + \underbrace{\frac{\tilde{\Omega}_{jL}}{1-\tilde{\Omega}_{jL}}\frac{\theta_j - \hat{\Psi}_{jL}}{\theta_j}\frac{\bar{\mu}_j^{-1} - \Psi_{jL}}{\bar{\mu}_j^{-1}}}_{\text{Substitution between labor and intermediate inputs}} \tag{B-13}$$

Proof of Lemma 6.

$$\begin{aligned}
\mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\hat{\Psi}_{iL}, \Psi_{iL}\right) &= \mathbb{E}_{\tilde{\Omega}_{(j,:)}}(\hat{\Psi}_{iL}\Psi_{iL}) - \mathbb{E}_{\tilde{\Omega}_{(j,:)}}(\hat{\Psi}_{iL})\mathbb{E}_{\tilde{\Omega}_{(j,:)}}(\Psi_{iL}) \\
&= \tilde{\Omega}_{jL} + (1-\tilde{\Omega}_{jL})\mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\hat{\Psi}_{iL}\Psi_{iL}) - \left[\tilde{\Omega}_{jL} + (1-\tilde{\Omega}_{jL})\mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\hat{\Psi}_{iL})\right]\left[\tilde{\Omega}_{jL} + (1-\tilde{\Omega}_{jL})\mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\Psi_{iL})\right] \\
&= (1-\tilde{\Omega}_{jL})\mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\hat{\Psi}_{iL}\Psi_{iL}) - (1-\tilde{\Omega}_{jL})^2\mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\Psi_{iL})\mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\Psi_{iL}) + \tilde{\Omega}_{jL}(1-\tilde{\Omega}_{jL}) \\
&\quad - \tilde{\Omega}_{jL}(1-\tilde{\Omega}_{jL})\left[\mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\Psi_{iL}) + \mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\Psi_{iL})\right] \\
&= (1-\tilde{\Omega}_{jL})\mathrm{Cov}_{\tilde{\Omega}^n_{(j,:)}}(\hat{\Psi}_{iL}, \Psi_{iL}) + \tilde{\Omega}_{jL}(1-\tilde{\Omega}_{jL})\mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\Psi_{iL})\mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\Psi_{iL}) \\
&\quad + \tilde{\Omega}_{jL}(1-\tilde{\Omega}_{jL}) - \tilde{\Omega}_{jL}(1-\tilde{\Omega}_{jL})\left[\mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\Psi_{iL}) + \mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\Psi_{iL})\right] \\
&= (1-\tilde{\Omega}_{jL})\mathrm{Cov}_{\tilde{\Omega}^n_{(j,:)}}(\hat{\Psi}_{iL}, \Psi_{iL}) + \tilde{\Omega}_{jL}(1-\tilde{\Omega}_{jL})\left[1 - \mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\hat{\Psi}_{iL})\right]\left[1 - \mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\Psi_{iL})\right]
\end{aligned}$$

Since

$$(1-\tilde{\Omega}_{jL})\mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\Psi_{iL}) = \sum_{i=1}^{N}\tilde{\Omega}_{ji}\Psi_{iL} = \bar{\mu}_j\sum_{i=1}^{N}\Omega_{ji}\Psi_{iL} = \bar{\mu}_j(\Psi_{jL} - \Omega_{jL}) = \bar{\mu}_j\Psi_{jL} - \tilde{\Omega}_{jL},$$

we have

$$0 \le 1 - \mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\Psi_{iL}) = \frac{1-\bar{\mu}_j\Psi_{jL}}{1-\tilde{\Omega}_{jL}}.$$

By analogy, we get

$$0 \le 1 - \mathbb{E}_{\tilde{\Omega}^n_{(j,:)}}(\hat{\Psi}_{iL}) = \frac{1-\theta_j^{-1}\hat{\Psi}_{jL}}{1-\tilde{\Omega}_{jL}}.$$

□

C Nested CES Economies

C.1 Standard-Form for Nested CES Economies

In this section, we expand our input-output notation to incorporate producer 0 (households). We begin by adjusting the cost-based input-output matrix, setting indices of $\tilde{\Omega}$ to start at 0. Specifically, $\tilde{\Omega}_{i0} = 0$ for all $0 \leq i \leq N+1$ and $\tilde{\Omega}_{0j} = b_j$ for all $1 \leq j \leq N+1$. Correspondingly, $x_{i0} = 0$ for all $0 \leq i \leq N+1$ and $x_{0i} = c_i$ for all $1 \leq j \leq N+1$. We then set the household-related parameters: $\bar{\mu}_C = \theta_C = 1$ and expand all Leontief inverse matrices to dimensions of $(1+N+1) \times (1+N+1)$. Finally, we extend the $(N+1) \times 1$ vector $\mathrm{d}\log p$ to an $(1+N+1) \times 1$ vector by defining $p_0 = P^Y$.

Aggregating the production function (equation (4)) to the sector level yields:

$$\frac{y_k}{\bar{y}_k} = \bar{A}_k \left(\sum_l \omega_{kl}^{\frac{1}{\sigma_k}} \left(\frac{x_{kl}}{\bar{x}_{kl}} \right)^{\frac{\sigma_k - 1}{\sigma_k}} \right)^{\frac{\sigma_k}{\sigma_k - 1}}$$

where $\bar{A}_k = q_k A_k$, with the loss of sector productivity q_k defined by equation (E-29). Note that $\mathrm{d}\log \bar{A}_i = \mathrm{d}\log A_i$ since $\mathrm{d}\log q_i = 0$.[3] Additionally, each sector is associated with a unique elasticity of substitution σ_k.

The optimal condition yields (omitting subscripts for varieties),

$$\mathrm{d}\log x_{ki} - \mathrm{d}\log x_{kj} = -\sigma_k(\mathrm{d}\log p_i - \mathrm{d}\log p_j) \; \forall i, j, \tag{C-1}$$

which indicates how resources are reallocated due to relative price changes.

In addition, the production function of producer 0 (households) is given by equation (1) in the main text.

C.2 Related Proofs in An Arbitrary CES Economy

In this section, we apply the methodology of Baqaee and Farhi (2020) to derive the expression for the share of the labor income. This expression comprises two components: first, the direct effect of changes in ex-post markups, holding constant the distribution of resources (input shares); and second, the equilibrium changes in the distribution of resources. Consequently, our equations from (C-3) to (C-19) adapt their findings to the context of a single-factor case.

[3] See more discussions in Appendix E.3.

Theorem 1. *In response to sectoral productivity and monetary policy shocks, the change in TFP is governed by*

$$\mathrm{d}\log \mathrm{TFP} = \underbrace{\sum_{j=1}^{N} \lambda_j \frac{\Psi_{jL}}{\Lambda_L} \mathrm{d}\log A_j}_{\textit{Direct technology channel}} + \underbrace{\frac{1}{\Lambda_L} \sum_{j=0}^{N} \frac{\sigma_j \lambda_j}{\bar{\mu}_j} \mathrm{Cov}_{\tilde{\Omega}(j,:)} \left(\mathrm{d}\log p_i, \Psi_{iL}\right)}_{\textit{Misallocation channel}} \tag{C-2}$$

with $\sigma_0 = \sigma_C$, $\lambda_0 = 1$, $\bar{\mu}_0 = 1$ *and* $\tilde{\Omega}(0,:) = b'$.

Theorem 1 here is similar to Theorem 1 in Baqaee and Farhi (2020), but with key differences. In Baqaee and Farhi (2020), 'changes in technology' are derived while holding the resource allocation matrix (i.e., the cost-based input-output matrix) constant, implying their baseline economy is Cobb-Douglas. In contrast, our decomposition assumes a baseline economy of Leontief. Consequently, we derive our 'direct technology channel' while holding the demand matrix constant, making it distinct from their 'changes in technology.'

Proof of Theorem 1. Since $\Omega_{ji} = \frac{p_i x_{ji}}{\mu_j \sum_l p_l x_{jl}}$ for all $0 \le i, j \le N+1$, we have

$$\begin{aligned}
\mathrm{d}\log \Omega_{ji} &= -\mathrm{d}\log \mu_j + \mathrm{d}\log p_i + \mathrm{d}\log x_{ji} - \sum_l \tilde{\Omega}_{jl} \mathrm{d}\log(p_l x_{jl}) && \text{(C-3)}\\
&= -\mathrm{d}\log \mu_j + \sum_l \tilde{\Omega}_{jl} \left(\mathrm{d}\log p_i - \mathrm{d}\log p_l\right) - \sum_l \tilde{\Omega}_{jl} \left(\mathrm{d}\log x_{ji} - \mathrm{d}\log x_{jl}\right) && \text{(C-4)}\\
&= -\mathrm{d}\log \mu_j + (1-\sigma_j) \sum_l \tilde{\Omega}_{jl} \left(\mathrm{d}\log p_i - \mathrm{d}\log p_l\right) && \text{(C-5)}\\
&= -\mathrm{d}\log \mu_j + (1-\sigma_j)(\mathrm{d}\log p_i - \sum_l \tilde{\Omega}_{jl} \mathrm{d}\log p_l). && \text{(C-6)}
\end{aligned}$$

Considering the covariance with $\tilde{\Omega}(j,:)$ as weights, we have

$$\begin{aligned}
\mathrm{Cov}_{\tilde{\Omega}(j,:)}(\mathrm{d}\log p, I_{(i)}) &= \tilde{\Omega}_{ji} \mathrm{d}\log p_i - \sum_l \tilde{\Omega}_{jl} \mathrm{d}\log p_l \cdot \tilde{\Omega}_{ji} && \text{(C-7)}\\
&= \tilde{\Omega}_{ji}(\mathrm{d}\log p_i - \sum_l \tilde{\Omega}_{jl} \mathrm{d}\log p_l), && \text{(C-8)}
\end{aligned}$$

where $\tilde{\Omega}(j,:)$ is the j-th row of $\tilde{\Omega}$ and $I_{(i)}$ is the i-th column of the identity matrix I.

Thus, the total differential of Ω_{ji} is given by

$$d\Omega_{ji} = \Omega_{ji}\left[-\mathrm{d}\log\mu_j + (1-\sigma_j)(\mathrm{d}\log p_i - \sum_l \tilde{\Omega}_{jl}\mathrm{d}\log p_l)\right] \tag{C-9}$$

$$= -\Omega_{ji}\mathrm{d}\log\mu_j + \frac{\Omega_{ji}}{\tilde{\Omega}_{ji}}(1-\sigma_j)\mathrm{Cov}_{\tilde{\Omega}(j,:)}(\mathrm{d}\log p, I_{(i)}) \tag{C-10}$$

$$= -\Omega_{ji}\mathrm{d}\log\mu_j + \frac{1}{\bar{\mu}_j}(1-\sigma_j)\mathrm{Cov}_{\tilde{\Omega}(j,:)}(\mathrm{d}\log p, I_{(i)}). \tag{C-11}$$

Using $\Psi = (I-\Omega)^{-1}$, we obtain

$$\mathrm{d}\Psi = \Psi\mathrm{d}\Omega\Psi. \tag{C-12}$$

Or equivalently,

$$d\Psi_{mn} = \sum_j\sum_i \Psi_{mj}d\Omega_{ji}\Psi_{in} \tag{C-13}$$

$$= -\sum_j\sum_i \Psi_{mj}\Psi_{in}\Omega_{ji}\mathrm{d}\log\mu_j + \sum_j\sum_i \Psi_{mj}\Psi_{in}\bar{\mu}_j^{-1}(1-\sigma_j)\mathrm{Cov}_{\tilde{\Omega}(j,:)}(\mathrm{d}\log p, I_{(i)}) \tag{C-14}$$

$$= -\sum_j \Psi_{mj}\mathrm{d}\log\mu_j\sum_i \Omega_{ji}\Psi_{in} + \sum_j \Psi_{mj}\bar{\mu}_j^{-1}(1-\sigma_j)\mathrm{Cov}_{\tilde{\Omega}(j,:)}(\mathrm{d}\log p, \Psi_{(n)}). \tag{C-15}$$

Using $\Omega\Psi = \Psi - I$, we can rewrite the expression above as

$$d\Psi_{mn} = -\sum_j \Psi_{mj}(\Psi_{jn}-\delta_{jn})\mathrm{d}\log\mu_j + \sum_j \Psi_{mj}\bar{\mu}_j^{-1}(1-\sigma_j)\mathrm{Cov}_{\tilde{\Omega}(j,:)}(\mathrm{d}\log p, \Psi_{(n)}), \tag{C-16}$$

where δ_{jn} is the jn-th element of the identity matrix.

Given $b'\Psi = \lambda$, we get

$$d\lambda_n = \sum_k b_k d\Psi_{kn} = -\sum_j \lambda_j(\Psi_{jn}-\delta_{jn})\mathrm{d}\log\mu_j + \sum_j \lambda_j\bar{\mu}_j^{-1}(1-\sigma_j)\mathrm{Cov}_{\tilde{\Omega}(j,:)}(\mathrm{d}\log p, \Psi_{(n)}). \tag{C-17}$$

Dividing both sides by λ_n, we have

$$\mathrm{d}\log\lambda_n = -\sum_j \frac{\lambda_j}{\lambda_n}(\Psi_{jn}-\delta_{jn})\mathrm{d}\log\mu_j + \sum_j \frac{\lambda_j}{\lambda_n}\bar{\mu}_j^{-1}(1-\sigma_j)\mathrm{Cov}_{\tilde{\Omega}(j,:)}(\mathrm{d}\log p, \Psi_{(n)}). \tag{C-18}$$

Accordingly,

$$\mathrm{d}\log\Lambda_L = -\sum_j \lambda_j \frac{\Psi_{jL}}{\Lambda_L}\mathrm{d}\log\mu_j + \frac{1}{\Lambda_L}\sum_j \frac{\lambda_j}{\bar{\mu}_j}(1-\sigma_j)\mathrm{Cov}_{\tilde{\Omega}(j,:)}(\mathrm{d}\log p, \Psi_{(L)}). \tag{C-19}$$

To further simplify the expression above, note that

$$\frac{1}{\Lambda_L}\sum_{j=1}^{N}\frac{\lambda_j}{\bar{\mu}_j}\mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\mathrm{d}\log p, \Psi_{(L)}\right)$$

$$=\frac{1}{\Lambda_L}\sum_{j=1}^{N}\frac{\lambda_j}{\bar{\mu}_j}\left[\mathbb{E}_{\tilde{\Omega}(j,:)}(\Psi_{iL}\mathrm{d}\log p_i) - \mathbb{E}_{\tilde{\Omega}(j,:)}(\Psi_{iL})\mathbb{E}_{\tilde{\Omega}(j,:)}(\mathrm{d}\log p_i)\right] \tag{C-20}$$

$$=\frac{1}{\Lambda_L}\sum_{j=1}^{N}\frac{\lambda_j}{\bar{\mu}_j}\left[\sum_{k=1}^{N+1}\tilde{\Omega}_{jk}\Psi_{kL}\mathrm{d}\log p_k - \underbrace{\left(\sum_{k=1}^{N+1}\tilde{\Omega}_{jk}\Psi_{kL}\right)}_{\bar{\mu}_j\Psi_{jL}}\underbrace{\left(\sum_{k=1}^{N+1}\tilde{\Omega}_{jk}\mathrm{d}\log p_k\right)}_{\mathrm{d}\log p_j+\mathrm{d}\log A_j-\mathrm{d}\log\mu_j}\right] \tag{C-21}$$

$$=\frac{1}{\Lambda_L}\sum_{j=1}^{N}\frac{\lambda_j}{\bar{\mu}_j}\left[\sum_{k=1}^{N+1}\tilde{\Omega}_{jk}\Psi_{kL}\mathrm{d}\log p_k - \bar{\mu}_j\Psi_{jL}(\mathrm{d}\log p_j + \mathrm{d}\log A_j - \mathrm{d}\log\mu_j)\right] \tag{C-22}$$

$$=\sum_{k=1}^{N+1}\frac{\Psi_{kL}}{\Lambda_L}\underbrace{\sum_{j=1}^{N}\lambda_j\frac{\tilde{\Omega}_{jk}}{\bar{\mu}_j}}_{\lambda_k-b_k}\mathrm{d}\log p_k - \sum_{j=1}^{N}\lambda_j\frac{\Psi_{jL}}{\Lambda_L}(\mathrm{d}\log p_j + \mathrm{d}\log A_j - \mathrm{d}\log\mu_j) \tag{C-23}$$

$$=\mathrm{d}\log w + \sum_{j=1}^{N}(\lambda_j - b_j)\frac{\Psi_{jL}}{\Lambda_L}\mathrm{d}\log p_j - \sum_{j=1}^{N}\lambda_j\frac{\Psi_{jL}}{\Lambda_L}(\mathrm{d}\log p_j + \mathrm{d}\log A_j - \mathrm{d}\log\mu_j) \tag{C-24}$$

$$=\mathrm{d}\log w - \sum_{j=1}^{N}b_j\frac{\Psi_{jL}}{\Lambda_L}\mathrm{d}\log p_j + \sum_{j=1}^{N}\lambda_j\frac{\Psi_{jL}}{\Lambda_L}(\mathrm{d}\log\mu_j - \mathrm{d}\log A_j). \tag{C-25}$$

where the third equality is derived by using Sheppard's Lemma, where $\mathrm{d}\log p_j = -\mathrm{d}\log A_j + \mathrm{d}\log\mu_j + \sum_{k=1}^{N+1}\tilde{\Omega}_{jk}\mathrm{d}\log p_k$, and the fifth equality uses the facts that $\sum_{j=1}^{N}\lambda_j\frac{\tilde{\Omega}_{jk}}{\bar{\mu}_j} = \sum_{j=1}^{N}\lambda_j\Omega_{jk} = \lambda_k - b_k$ and $\frac{\Psi_{LL}}{\Lambda_L}(\Lambda_L - b_L)\mathrm{d}\log p_{N+1} = \mathrm{d}\log w$.

In addition,

$$\frac{1}{\Lambda_L}\frac{\lambda_0}{\bar{\mu}_0}\mathrm{Cov}_{\tilde{\Omega}(0,:)}\left(\mathrm{d}\log p,\Psi_{(L)}\right)=\frac{1}{\Lambda_L}\left[\mathbb{E}_b(\Psi_{iL}\mathrm{d}\log p_i)-\underbrace{\mathbb{E}_b(\Psi_{iL})}_{\Lambda_L}\underbrace{\mathbb{E}_b(\mathrm{d}\log p_i)}_{\mathrm{d}\log P^Y}\right] \tag{C-26}$$

$$=\sum_{j=1}^{N}b_j\frac{\Psi_{jL}}{\Lambda_L}\mathrm{d}\log p_j-\mathrm{d}\log P^Y. \tag{C-27}$$

Combining the expressions above, we get:

$$\sum_{j=0}^{N}\frac{\lambda_j}{\Lambda_L}\frac{1}{\bar{\mu}_j}\mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\mathrm{d}\log p,\Psi_{(L)}\right)=\mathrm{d}\log w-\mathrm{d}\log P^Y+\sum_{j=1}^{N}\lambda_j\frac{\Psi_{jL}}{\Lambda_L}(\mathrm{d}\log\mu_j-\mathrm{d}\log A_j). \tag{C-28}$$

Thus, we can express $\mathrm{d}\log\Lambda_L$ as:

$$\mathrm{d}\log\Lambda_L=\mathrm{d}\log w-\mathrm{d}\log P^Y-\sum_{j=1}^{N}\lambda_j\frac{\Psi_{jL}}{\Lambda_L}\mathrm{d}\log A_j-\sum_j\frac{\sigma_j\lambda_j}{\bar{\mu}_j}\mathrm{Cov}_{\tilde{\Omega}(j,:)}(\mathrm{d}\log p_i,\frac{\Psi_{iL}}{\Lambda_L}) \tag{C-29}$$

By the definition of the labor income share, we have:

$$\mathrm{d}\log\Lambda_L=\mathrm{d}\log w+\mathrm{d}\log L-(\mathrm{d}\log P^Y+\mathrm{d}\log Y). \tag{C-30}$$

Combining equations (C-29) and (C-30) yields:

$$\mathrm{d}\log\mathrm{TFP}=\mathrm{d}\log Y-\mathrm{d}\log L \tag{C-31}$$

$$=\mathrm{d}\log w-\mathrm{d}\log P^Y-\mathrm{d}\log\Lambda_L \tag{C-32}$$

$$=\underbrace{\sum_{j=1}^{N}\lambda_j\frac{\Psi_{jL}}{\Lambda_L}\mathrm{d}\log A_j}_{\text{Direct technology channel}}+\underbrace{\sum_j\frac{\sigma_j\lambda_j}{\bar{\mu}_j}\mathrm{Cov}_{\tilde{\Omega}(j,:)}(\mathrm{d}\log p_i,\frac{\Psi_{iL}}{\Lambda_L})}_{\text{Misallocation channel}} \tag{C-33}$$

□

Proof of Proposition 1. By applying the Sheppard's lemma, we obtain the following relationship:

$$\mathrm{d}\log mc=-\mathrm{d}\log A+\tilde{\Omega}^n\pi+\tilde{\Omega}^f\mathrm{d}\log w. \tag{C-34}$$

Combining this with the equation $\pi = \Theta \mathrm{d}\log mc$, we derive:

$$\pi = -(I - \Theta\tilde{\Omega}^n)^{-1}\Theta(\mathrm{d}\log A - \tilde{\Omega}^f \mathrm{d}\log w) \tag{C-35}$$

$$= -\hat{\Psi}^n \Theta \mathrm{d}\log A + \hat{\Psi}^f \mathrm{d}\log w. \tag{C-36}$$

As for the consumer price, it evolves as follows:

$$\mathrm{d}\log P^Y = (b^n)'\pi \tag{C-37}$$

$$= -\underbrace{(b^n)'\hat{\Psi}^n}_{\hat{\lambda}'} \Theta \mathrm{d}\log A + \underbrace{(b^n)'\hat{\Psi}^f}_{\hat{\Lambda}_L} \mathrm{d}\log w \tag{C-38}$$

$$= -\hat{\lambda}'\Theta \mathrm{d}\log A + \hat{\Lambda}_L \mathrm{d}\log w. \tag{C-39}$$

By Theorem 1, we have

$$\frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log w} = \sum_j \frac{\sigma_j \lambda_j}{\bar{\mu}_j} \mathrm{Cov}_{\tilde{\Omega}(j,:)}(\underbrace{\frac{\mathrm{d}\log p_i}{\mathrm{d}\log w}}_{\hat{\Psi}_{iL}}, \frac{\Psi_{iL}}{\Lambda_L}) = \sum_{j=0}^{N} \frac{\sigma_j \lambda_j}{\bar{\mu}_j} \mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\hat{\Psi}_{iL}, \frac{\Psi_{iL}}{\Lambda_L}\right) \tag{C-40}$$

The proof of decomposition in Proposition 1 follows from combining it with Lemma 6.

□

Analogously, the response of TFP to a productivity shock is

$$\frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log A_k} = \lambda_k \frac{\Psi_{kL}}{\Lambda_L} + \sum_j \frac{\sigma_j \lambda_j}{\bar{\mu}_j} \mathrm{Cov}_{\tilde{\Omega}(j,:)}(\underbrace{\frac{\mathrm{d}\log p_i}{\mathrm{d}\log A_k}}_{-\theta_k \hat{\Psi}_{ik}}, \frac{\Psi_{iL}}{\Lambda_L}) \tag{C-41}$$

$$= \underbrace{\lambda_k \frac{\Psi_{kL}}{\Lambda_L}}_{\text{Direct technology channel}} - \underbrace{\theta_k \sum_{j=0}^{N} \frac{\sigma_j \lambda_j}{\bar{\mu}_j} \mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\hat{\Psi}_{ik}, \frac{\Psi_{iL}}{\Lambda_L}\right)}_{\text{Misallocation channel}} \doteq \varpi_k. \tag{C-42}$$

Note that $\tilde{\Omega}_{i0} = 0$ for all i. The formulas in this section remain valid when all input-output matrices and Leontief inverse matrices are replaced with $(N+1)\times(N+1)$ matrices, as defined in the main text.

C.3 Alternative Decomposition

The use of sectoral output can be divided into two groups, consumption and downstream production. Corollary 2 hence decomposes the supply-side effect into two reallocation channels: reallocation due to substitution in consumption and reallocation due to substitution in production. The reallocation channel from downstream production depends positively on the elasticity of substitution, the ratio of sectoral cost to GDP, and a covariance term. Note that reallocation due to substitution in production only occurs in network economies. In an economy without input-output linkages, such a reallocation mechanism is absent, and the supply-side effect of monetary policy is entirely attributed to substitution in consumption.

Corollary 2. *the supply-side effect of monetary policy can be alternatively broken down into two reallocation channels,*

$$\frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log w} = \underbrace{\frac{1}{\Lambda_L}\sigma_C \mathrm{Cov}_b\left(\hat{\Psi}_{iL}, \Psi_{iL}\right)}_{\substack{\textit{Reallocation due to}\\ \textit{substitution in consumption}}} + \underbrace{\frac{1}{\Lambda_L}\sum_{j=1}^{N}\frac{\sigma_j \lambda_j}{\bar{\mu}_j}\mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\hat{\Psi}_{iL}, \Psi_{iL}\right)}_{\substack{\textit{Reallocation due to}\\ \textit{substitution in production}}}. \tag{C-43}$$

Figure C.1 illustrates the different reallocation channels in this decomposition. Panel (a) reports numerical results based on our benchmark calibration, demonstrating that the reallocation from substitution in production co-moves quite closely with the total supply side effect, accounting for 79% to 95% of the total effect in the sample periods, while the reallocation due to substitution in consumption is quite small and remains stable over time.

D Money Supply and Nominal Wage

In this section, we demonstrate that the monetary authority can equivalently select either the nominal wage or the money supply as its policy instrument. We then leverage this one-to-one mapping between the money supply and the nominal wage to analyze the decomposition of the output response.

D.1 Isomorphic Relationship

Lemma 7. *Suppose that the elasticity of labor income share to the nominal wage is less than one, there exists a one-to-one mapping between money supply M and nominal wage w for all realizations of productivity shocks A.*

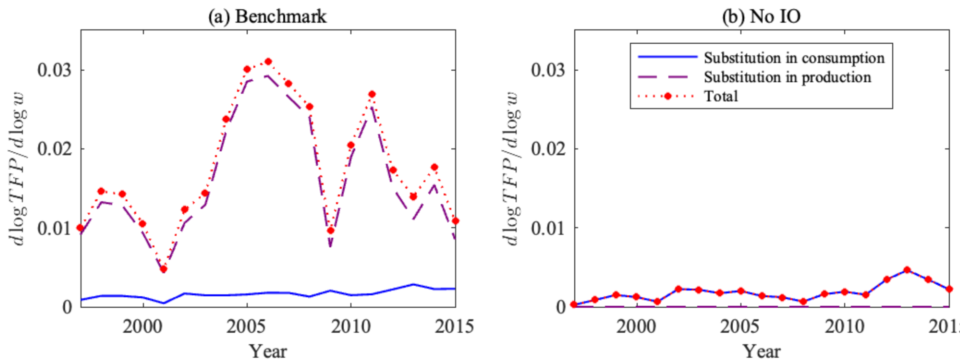

Figure C.1: The Decomposition of Supply Side Effect with UC Markups. Notes: This figure reports numerical values for two components in the supply-side effect of monetary policy. The solid blue line corresponds to the consumption-related reallocation channel, the dashed purple line shows the production-related reallocation channel, and the dotted red line with circle markers indicates the total effect.

Proof of Lemma 7. The consumption-leisure trade-off is expressed as:

$$\begin{aligned} \mathrm{d}\log w - \mathrm{d}\log P^Y &= \gamma \mathrm{d}\log Y + \varphi \mathrm{d}\log L && \text{(D-1)} \\ &= (\gamma + \varphi)\mathrm{d}\log Y - \varphi \mathrm{d}\log \mathrm{TFP}. && \text{(D-2)} \end{aligned}$$

When integrated with the cash-in-advance constraint, this results in:

$$(\gamma + \varphi)\mathrm{d}\log M = \mathrm{d}\log w + (\gamma + \varphi - 1)\mathrm{d}\log P^Y + \varphi \mathrm{d}\log \mathrm{TFP}. \tag{D-3}$$

Referencing the previous section:

$$\mathrm{d}\log \mathrm{TFP} = \varpi' \mathrm{d}\log A + (1 - \hat{\Lambda}_L - \xi)\mathrm{d}\log w. \tag{D-4}$$

Combining the above with equation (C-39) yields:

$$\begin{aligned} [1 + (\gamma - 1)\hat{\Lambda}_L + \varphi(1 - \xi)]\mathrm{d}\log w = (\gamma + \varphi)d\log M& \\ - [\varphi\varpi' - (\gamma + \varphi - 1)\hat{\lambda}'\Theta]\mathrm{d}\log A.& && \text{(D-5)} \end{aligned}$$

This derivation suggests that the nominal wage decreases relative to the money supply only when the supply-side effect is substantially negative. Given that the elasticity of labor income share to nominal wage is less than one, we derive the following inequality:

$$1 + (\gamma - 1)\hat{\Lambda}_L + \varphi(1 - \xi) \geq 1 - \hat{\Lambda}_L + \gamma\hat{\Lambda}_L \geq 1 - \hat{\Lambda}_L \geq 0 \tag{D-6}$$

where the second inequality becomes an equality when $\hat{\Lambda}_L = 0$ (given $\gamma > 0$), and the third inequality becomes an equality when $\hat{\Lambda}_L = 1$. Since these two conditions are mutually exclusive, we have: $1 + (\gamma - 1)\hat{\Lambda}_L + \varphi(1 - \xi) > 0$.

Consequently, equation (D-5) confirms a one-to-one mapping between money supply M and nominal wage w for all realizations of productivity shocks A. □

D.2 Decomposition of Output Response

We then investigate how labor supply responds to monetary shocks. In response to a change in nominal wage, the consumption-leisure tradeoff implies

$$\mathrm{d}\log L = \underbrace{\frac{1-\hat{\Lambda}_L}{\varphi}\mathrm{d}\log w}_{\text{Substitution effect}} - \underbrace{\frac{\gamma}{\varphi}\mathrm{d}\log Y}_{\text{Wealth effect}} \tag{D-7}$$

This equation decomposes the labor response into two components, as in the literature. The first term represents the substitution effect, which arises when the nominal wage increases ($\mathrm{d}\log w > 0$) and consumer prices do not completely offset this increase due to nominal rigidities (i.e. $\hat{\Lambda}_L < 1$), resulting in an increase in the real wage that increases labor supply. The factor $1 - \hat{\Lambda}_L$ measures the increase in the real wage that affects the household's choice between consumption and leisure. If $\hat{\Lambda}_L$ is close to 1, the effect of wage changes on leisure is small, since most increase in the wage directly translates into price increases, reducing the effect of real wage. The second term, the wealth effect, suggests that an increase in output would typically lead to an increase in leisure, reducing labor supply.

Proof of Proposition 2. By combining the previous equation with $\mathrm{d}\log Y - \mathrm{d}\log L = (1 - \hat{\Lambda}_L - \xi)\mathrm{d}\log w$ from equation (11), we find that, following a change in nominal wage, the response of output is

$$\frac{\mathrm{d}\log Y}{\mathrm{d}\log w} = \frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log w} + \frac{\mathrm{d}\log L}{\mathrm{d}\log w} = \frac{1-\hat{\Lambda}_L + \varphi(1-\hat{\Lambda}_L-\xi)}{\gamma+\varphi}, \tag{D-8}$$

Specifically,

$$\frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log w} = 1 - \hat{\Lambda}_L - \xi \quad \text{and} \quad \frac{\mathrm{d}\log L}{\mathrm{d}\log w} = \frac{1-\hat{\Lambda}_L - \gamma(1-\hat{\Lambda}_L-\xi)}{\gamma+\varphi}.$$

This analysis, in conjunction with equation (D-5), establishes Proposition 2. □

Equation (D-8) breaks down the output response into the supply side and demand side effects. the supply-side effect is due to changes in TFP, arising through the misallocation channel. The demand side effect characterizes the endogenous response of labor supply, which consists of two distinct channels: nominal rigidity and misallocation. Firstly, the substitution effect, highlighted in equation (D-7), illustrates the nominal rigidity channel, showing that an expansionary monetary shock enhances the real wage and stimulates labor supply. Second, the wealth effect, also from equation (D-7), reveals that any factor that changes output, such as supply side effects, also affects labor. Therefore, the demand side effect in our model accounts for labor adjustments induced by the misallocation channel, quantified as $-\frac{\gamma}{\gamma+\varphi}(1-\hat{\Lambda}_L-\xi)$. Consequently, supply side effects complement demand side effects, leading to an increase in monetary non-neutrality.

E Optimal Monetary Policy

E.1 Discrepancy between Output and Employment Gaps

In this section, we aim to express aggregate macroeconomic variables in terms of changes in productivities and ex-post markups, and define output and employment gaps.

From the supply side, we have

$$\pi = -\mathrm{d}\log A + \mathrm{d}\log\mu + \tilde{\Omega}^n\pi + \tilde{\Omega}^f\mathrm{d}\log w \tag{E-1}$$

$$= -\tilde{\Psi}^n\mathrm{d}\log A + \tilde{\Psi}^n\mathrm{d}\log\mu + \tilde{\Psi}^f\mathrm{d}\log w \tag{E-2}$$

$$= -\tilde{\Psi}^n\mathrm{d}\log A + \tilde{\Psi}^n\mathrm{d}\log\mu + \mathrm{d}\log w \tag{E-3}$$

Furthermore, the change in consumer price is

$$\mathrm{d}\log P^Y = b'\pi = -\tilde{\lambda}'\mathrm{d}\log A + \tilde{\lambda}'\mathrm{d}\log\mu + \mathrm{d}\log w \tag{E-4}$$

Combining with equation (C-30), this implies the change in TFP is determined by

$$\mathrm{d}\log Y - \mathrm{d}\log L = \tilde{\lambda}'\mathrm{d}\log A - \tilde{\lambda}'\mathrm{d}\log\mu - \mathrm{d}\log\Lambda_L. \tag{E-5}$$

This result aligns with proposition 2 of Baqaee and Farhi (2020).

On the other hand, from Theorem 1, the change in TFP relates with changes in productivities and changes in ex-post markups via

$$
\begin{aligned}
&\mathrm{d}\log Y - \mathrm{d}\log L \\
&= \sum_{j=1}^{N} \lambda_j \frac{\Psi_{jL}}{\Lambda_L} \mathrm{d}\log A_j + \sum_{j=0}^{N} \frac{\sigma_j \lambda_j}{\bar{\mu}_j} \mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\mathrm{d}\log p_i, \frac{\Psi_{iL}}{\Lambda_L}\right) && \text{(E-6)} \\
&= \sum_{j=1}^{N} \lambda_j \frac{\Psi_{jL}}{\Lambda_L} \mathrm{d}\log A_j + \sum_{j=0}^{N} \frac{\sigma_j \lambda_j}{\bar{\mu}_j} \mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\sum_{k=1}^{N} \tilde{\Psi}_{ik}(\mathrm{d}\log \mu_k - \mathrm{d}\log A_k) + \mathrm{d}\log w, \frac{\Psi_{iL}}{\Lambda_L}\right) && \text{(E-7)} \\
&= \sum_{j=1}^{N} \lambda_j \frac{\Psi_{jL}}{\Lambda_L} \mathrm{d}\log A_j + \sum_{k=1}^{N} \sum_{j=0}^{N} \frac{\sigma_j \lambda_j}{\bar{\mu}_j} \mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\tilde{\Psi}_{ik}, \frac{\Psi_{iL}}{\Lambda_L}\right)(\mathrm{d}\log \mu_k - \mathrm{d}\log A_k) && \text{(E-8)} \\
&= \left[(\lambda \circ \frac{\Psi_{(L)}}{\Lambda_L})' - \mathcal{M}'\right] \mathrm{d}\log A + \mathcal{M}' \mathrm{d}\log \mu && \text{(E-9)}
\end{aligned}
$$

where $\mathcal{M}$ is an $N \times 1$ vector, whose kth element is given by

$$
\mathcal{M}_k \doteq \frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log \mu_k} = \sum_{j=0}^{N} \frac{\sigma_j \lambda_j}{\bar{\mu}_j} \mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\tilde{\Psi}_{ik}, \frac{\Psi_{iL}}{\Lambda_L}\right) \tag{E-10}
$$

By combining equations (E-5) and (E-9), we obtain

$$
\mathrm{d}\log \Lambda_L = \left[\tilde{\lambda}' - (\lambda \circ \frac{\Psi_{(L)}}{\Lambda_L})' + \mathcal{M}'\right] \mathrm{d}\log A - \left[\tilde{\lambda}' + \mathcal{M}'\right] \mathrm{d}\log \mu \tag{E-11}
$$

Combining the definition of labor income share (equation (C-30)) with the consumption-leisure trade-off (equation (D-1)), yields:

$$
\mathrm{d}\log L = \frac{1-\gamma}{1+\varphi} \mathrm{d}\log Y + \frac{1}{1+\varphi} \mathrm{d}\log \Lambda_L \tag{E-12}
$$

Combined with equations (E-5) and (E-11), we get:

$$
\begin{aligned}
\mathrm{d}\log Y &= \frac{1+\varphi}{\gamma+\varphi} \tilde{\lambda}'(\mathrm{d}\log A - \mathrm{d}\log \mu) - \frac{\varphi}{\gamma+\varphi} \mathrm{d}\log \Lambda_L && \text{(E-13)} \\
&= \left\{\frac{1}{\gamma+\varphi} \tilde{\lambda}' + \frac{\varphi}{\gamma+\varphi}\left[(\lambda \circ \frac{\Psi_{(L)}}{\Lambda_L})' - \mathcal{M}'\right]\right\} \mathrm{d}\log A - \left[\frac{1}{\gamma+\varphi} \tilde{\lambda}' - \frac{\varphi}{\gamma+\varphi} \mathcal{M}'\right] \mathrm{d}\log \mu && \text{(E-14)}
\end{aligned}
$$

and

$$\mathrm{d}\log L = \frac{1-\gamma}{\gamma+\varphi}\tilde{\lambda}'(\mathrm{d}\log A - \mathrm{d}\log\mu) + \frac{\gamma}{\gamma+\varphi}\mathrm{d}\log\Lambda_L \tag{E-15}$$

$$= \left\{\frac{1}{\gamma+\varphi}\tilde{\lambda}' - \frac{\gamma}{\gamma+\varphi}\left[(\lambda\circ\frac{\Psi_{(L)}}{\Lambda_L})' - \mathcal{M}'\right]\right\}\mathrm{d}\log A - \left[\frac{1}{\gamma+\varphi}\tilde{\lambda}' + \frac{\gamma}{\gamma+\varphi}\mathcal{M}'\right]\mathrm{d}\log\mu. \tag{E-16}$$

In the flexible price equilibrium, changes in output and employment are given by

$$y^n \equiv \mathrm{d}\log Y^n = \left\{\frac{1}{\gamma+\varphi}\tilde{\lambda}' + \frac{\varphi}{\gamma+\varphi}\left[(\lambda\circ\frac{\Psi_{(L)}}{\Lambda_L})' - \mathcal{M}'\right]\right\}\mathrm{d}\log A \tag{E-17}$$

and

$$l^n \equiv \mathrm{d}\log L^n = \left\{\frac{1}{\gamma+\varphi}\tilde{\lambda}' - \frac{\gamma}{\gamma+\varphi}\left[(\lambda\circ\frac{\Psi_{(L)}}{\Lambda_L})' - \mathcal{M}'\right]\right\}\mathrm{d}\log A. \tag{E-18}$$

The output and employment gaps, which quantify the deviations between the sticky price and flexible price equilibria, can be expressed as:

$$\tilde{y} \equiv \mathrm{d}\log Y - \mathrm{d}\log Y^n = \left[-\frac{1}{\gamma+\varphi}\tilde{\lambda}' + \frac{\varphi}{\gamma+\varphi}\mathcal{M}'\right]\mathrm{d}\log\mu \tag{E-19}$$

and

$$\tilde{l} \equiv \mathrm{d}\log L - \mathrm{d}\log L^n = \left[-\frac{1}{\gamma+\varphi}\tilde{\lambda}' - \frac{\gamma}{\gamma+\varphi}\mathcal{M}'\right]\mathrm{d}\log\mu \tag{E-20}$$

When the initial equilibrium is inefficient, the discrepancy between output and employment gaps reflects an allocative efficiency:

$$e \equiv \tilde{y} - \tilde{l} = \mathcal{M}'\mathrm{d}\log\mu \tag{E-21}$$

Accounting for endogenous realized markups, the allocative efficiency e is related to sectoral inflation rates through the equation:

$$e = \underbrace{\mathcal{M}'(I-\Theta^{-1})}_{\doteq\mathcal{J}'}\pi \tag{E-22}$$

Specifically, in response to a change in the nominal wage,

$$e = (1-\hat{\Lambda}_L - \xi)\mathrm{d}\log w = \mathcal{J}'\hat{\Psi}^f\mathrm{d}\log w. \tag{E-23}$$

E.2 Flatter Phillips Curves

Proof of Lemma 1. By combining equations (8) and (E-19), we derive the divine coincidence condition:

$$(\gamma+\varphi)\tilde{y} = \left[\tilde{\lambda}'(\Theta^{-1}-I)\underbrace{-\varphi\mathcal{M}'(\Theta^{-1}-I)}_{\varphi\mathcal{J}'}\right]\pi \tag{E-24}$$

$$= \left[\lambda'(\Theta^{-1}-I)+\varphi\mathcal{J}'\right]\pi \tag{E-25}$$

□

Combining with the sectoral inflation from equation (C-36), leads to a wage Phillips curve:

$$[1-\hat{\Lambda}_L+\varphi(1-\hat{\Lambda}_L-\xi)]\mathrm{d}\log w = (\gamma+\varphi)\tilde{y}+(\tilde{\lambda}'-\hat{\lambda}'\Theta+\varphi\mathcal{J}'\hat{\Psi}^n\Theta)\mathrm{d}\log A. \tag{E-26}$$

The derivation of this equation is based on three equations: (i) $\mathcal{J}'\hat{\Psi}^n_{(L)} = 1-\hat{\Lambda}_L-\xi$, (ii) $\tilde{\lambda}(\Theta^{-1}-I)\hat{\Psi}^n_{(L)} = 1-\hat{\Lambda}_L$, and (iii) $\tilde{\lambda}(\Theta^{-1}-I)\hat{\Psi}^n\Theta = \tilde{\lambda}'-\hat{\lambda}'\Theta$.

The wage Phillips curve also suggests that if the output response to a change in the nominal wage is nonzero, $1-\hat{\Lambda}_L+\varphi(1-\hat{\Lambda}_L-\xi)\neq 0$, then a one-to-one mapping exists between nominal wage w and output gap $\tilde{y}$ for all realization of productivity shocks A. Consequently, combined with Lemma 7, this allows the monetary authority to target any desired output level by adjusting the money supply.

Proof of Proposition 3. Substituting the wage Phillips curve into sectoral inflation (equation (C-36)), yields sectoral Phillips curves,

$$\pi = -\hat{\Psi}^n\Theta\mathrm{d}\log A+\hat{\Psi}^f\mathrm{d}\log w \tag{E-27}$$

$$= \underbrace{\frac{\gamma+\varphi}{1-\hat{\Lambda}_L+\varphi(1-\hat{\Lambda}_L-\xi)}\hat{\Psi}^f}_{\doteq\mathcal{K}}\tilde{y} + \underbrace{\left[\frac{1}{1-\hat{\Lambda}_L+\varphi(1-\hat{\Lambda}_L-\xi)}\hat{\Psi}^f(\tilde{\lambda}'-\hat{\lambda}'\Theta+\varphi\mathcal{J}'\hat{\Psi}^n\Theta)-\hat{\Psi}^n\Theta\right]}_{\doteq\mathcal{V}}\mathrm{d}\log A \tag{E-28}$$

Note that $\left[\tilde{\lambda}'(\Theta^{-1} - I) + \varphi\mathcal{J}'\right]\mathcal{V} = \mathbf{0}$ and $\mathcal{V}\tilde{\Omega}^n_{(L)} = \mathbf{0}$. Given that $\tilde{\lambda}_i(\theta_i^{-1} - 1) + \varphi\mathcal{J}_i \geq 0$ and $\tilde{\Omega}_{iL} > 0$ for all $i \in \mathcal{N}$, these conditions guarantee that $\mathcal{V}$ is a non-zero matrix. [4] □

E.3 Optimal Monetary Policy in Distorted Economies

We now move to a second-order approximation around the flexible-price equilibrium with distortions. [5]

First, note that price dispersion within each sector is distortionary. Let q denote an $N \times 1$ vector representing the productivity loss due to within-sector price distortions, with component:

$$q_i \doteq \frac{y_i}{A_i F_i(\{x_{ij}\}_{j=1}^{N+1})} < 1 \tag{E-29}$$

where $x_{ij} = \int_0^1 x_{ij,\nu} \mathrm{d}\nu, \forall i, j$.

We then show that

$$q_i = \frac{p_i^{-\varepsilon_i}}{\int p_{i,\nu}^{-\varepsilon_i} d\nu}. \tag{E-30}$$

Cost minimization by the firm in sector i results in the following demand for input j:

$$x_{ij,\nu} = A_i^{\sigma_i - 1} \omega_{ij} y_{i,\nu} \left(p_j / mc_i\right)^{-\sigma_i}, \quad \forall i, j \tag{E-31}$$

Hence, the aggregate demand for input j by firms in industry i is

$$x_{ij} = \int_0^1 x_{ij,\nu} \mathrm{d}\nu \tag{E-32}$$

$$= A_i^{\sigma_i - 1} \omega_{ij} \int_0^1 y_{i,\nu} \mathrm{d}\nu \left(p_j / mc_i\right)^{-\sigma_i} \tag{E-33}$$

$$= A_i^{\sigma_i - 1} \omega_{ij} y_i \left(p_j / mc_i\right)^{-\sigma_i} p_i^{\varepsilon_i} \int_0^1 p_{i,\nu}^{-\varepsilon_i} \mathrm{d}\nu \tag{E-34}$$

where the last equality uses the fact that $y_{i,\nu} = y_i (p_{i,\nu}/p_i)^{-\varepsilon_i}$.

[4] Within the divine coincidence inflation index, in general the term $\tilde{\lambda}_i(\theta_i^{-1} - 1)$ is dominant and positive.

[5] A second-order approximation of a variable Z around its deterministic steady state Z^* is written as,

$$\frac{Z - Z^*}{Z^*} \approx \hat{z} + \frac{1}{2}\hat{z}^2$$

where $\hat{z} = \Delta \log z = \log z - \log Z^*$.

Then, we have

$$q_i = \frac{y_i}{A_i\left(\sum_j \omega_{ij}^{\frac{1}{\sigma_i}} x_{ij}^{\frac{\sigma_i-1}{\sigma_i}}\right)^{\frac{\sigma_i}{\sigma_i-1}}} = \frac{mc_i^{-\sigma_i}}{\underbrace{\left[\frac{1}{A_i}\left(\sum_j \omega_{ij} p_j^{1-\sigma_i}\right)^{\frac{1}{1-\sigma_i}}\right]^{-\sigma_i}}_{=1}} \frac{p_i^{-\varepsilon_i}}{\int p_{i,v}^{-\varepsilon_i} dv} \tag{E-35}$$

In line with the traditional NK model (Galí, 2015), we observe $\mathrm{d}\log q_i = 0$ and:

$$-d^2 \log q_i = \varepsilon_i \mathrm{Var}_i(p_{i,v}) \tag{E-36}$$

$$= \varepsilon_i\left[\int (\log p_{i,v} - \log p_i)^2 dv - \left(\int (\log p_{i,v} - \log p_i) dv\right)^2\right] \tag{E-37}$$

$$= \varepsilon_i\left(\frac{1}{\theta_i} - 1\right)(\mathrm{d}\log p_i)^2. \tag{E-38}$$

Lemma 8. *Up to a second-order approximation around the flexible price equilibrium, the logarithmic change in output per worker in the sticky price equilibrium is expressed as*

$$\hat{y} - \hat{l} = \underbrace{e}_{\text{first-order}} - \underbrace{f}_{\text{second order}} + \textit{higher order terms} \tag{E-39}$$

where e is allocative efficiency given by equation (E-21).

Proof of Lemma 8. Following the same steps as in the proof of Theorem 1, we can derive

$$\mathrm{d}\log Y - \mathrm{d}\log L = \left[(\lambda \circ \frac{\Psi_{(L)}}{\Lambda_L})' - \mathcal{M}'\right](\mathrm{d}\log A + \mathrm{d}\log q) + \mathcal{M}'\mathrm{d}\log\mu \tag{E-40}$$

and

$$\mathrm{d}\log Y^n - \mathrm{d}\log L^n = \left[(\lambda \circ \frac{\Psi_{(L)}}{\Lambda_L})' - \mathcal{M}'\right]\mathrm{d}\log A \tag{E-41}$$

A first-order approximation of the logarithmic change in output per worker is

$$\mathrm{d}(\hat{y} - \hat{l}) = (\mathrm{d}\log Y - \mathrm{d}\log Y^n) - (\mathrm{d}\log L - \mathrm{d}\log L^n) \tag{E-42}$$

$$= (\mathrm{d}\log Y - \mathrm{d}\log L) - (\mathrm{d}\log Y^n - \mathrm{d}\log L^n) \tag{E-43}$$

$$= \left[(\lambda \circ \frac{\Psi_{(L)}}{\Lambda_L})' - \mathcal{M}'\right]\mathrm{d}\log q + \mathcal{M}'\mathrm{d}\log\mu \tag{E-44}$$

$$= \mathcal{M}'\mathrm{d}\log\mu = e \tag{E-45}$$

Differentiating the equation (E-44) again, we obtain

$$\mathrm{d}^2(\hat{y}-\hat{l}) = \left[(\lambda \circ \frac{\Psi_{(L)}}{\Lambda_L})' - \mathcal{M}'\right]\mathrm{d}^2\log q + \sum_i\sum_j \frac{\mathrm{d}\log\mathcal{M}_i}{\mathrm{d}\log\mu_j}\mathrm{d}\log\mu_i\mathrm{d}\log\mu_j \tag{E-46}$$

Thus, the second-order component f, consists of two critical components: within-sector misallocation ($\mathcal{L}^{\text{within}}$) and cross-sector misallocation ($\mathcal{L}^{\text{across}}$)

$$f = \mathcal{L}^{\text{within}} + \mathcal{L}^{\text{across}}. \tag{E-47}$$

The second-order welfare loss due to within-sector misallocation can be expressed as

$$\mathcal{L}^{\text{within}} = -\frac{1}{2}\sum_i\left(\lambda_i\frac{\Psi_{iL}}{\Lambda_L} - \mathcal{M}_i\right)\mathrm{d}^2\log q_i \doteq \frac{1}{2}\pi'\mathcal{H}_1\pi, \tag{E-48}$$

where $\mathcal{H}_1 = \mathrm{diag}((\lambda \circ \frac{\Psi_{iL}}{\Lambda_L} - \mathcal{M}) \circ \epsilon \circ (\theta^{-1}-1))$.

The cross-sector misallocation is determined by:

$$\mathcal{L}^{\text{across}} = -\frac{1}{2}\sum_i\sum_j\frac{\mathrm{d}\log\mathcal{M}_i}{\mathrm{d}\log\mu_j}\mathrm{d}\log\mu_i\mathrm{d}\log\mu_j \doteq \frac{1}{2}\pi'\mathcal{H}_2\pi. \tag{E-49}$$

Referring to Baqaee and Farhi (2020), a second-order approximation of the cross-sector misallocation is given by:

$$\mathcal{L}^{\text{across}} \approx \frac{1}{2}\sum_j \sigma_j\lambda_j\mathrm{Var}_{\Omega(j,:)}(\sum_k \Psi_{(k)}\mathrm{d}\log\mu_k) \tag{E-50}$$

which implies that

$$\mathcal{L}^{\text{across}} \approx \frac{1}{2}\underbrace{\sum_j \sigma_j\lambda_j\mathrm{Cov}_{\Omega(j,:)}(\Psi_{(k)},\Psi_{(l)})}_{\doteq\mathcal{B}(k,l)}\mathrm{d}\log\mu_k\mathrm{d}\log\mu_l = \frac{1}{2}\pi(I-\Theta^{-1})\mathcal{B}(I-\Theta^{-1})\pi \tag{E-51}$$

Hence, $\mathcal{H}_2$ is given by $(I-\Theta^{-1})\mathcal{B}(I-\Theta^{-1})$.

□

Proof of Proposition 4. Using Lemma 8, we can approximate the utility function around the flexible price equilibrium as [6]

$$
\begin{aligned}
\frac{U-U^n}{U_yY} &\approx \hat{y}+\frac{1}{2}\hat{y}^2+\frac{1}{2}\frac{U_{yy}Y}{U_y}\hat{y}^2+\frac{U_lL}{U_yY}(\hat{l}+\frac{1}{2}\hat{l}^2+\frac{1}{2}\frac{U_{ll}L}{U_l}\hat{l}^2) && \text{(E-52)}\\
&= \hat{y}+\frac{1-\gamma}{2}\hat{y}^2-\Lambda_L(\hat{l}+\frac{1+\varphi}{2}\hat{l}^2) && \text{(E-53)}\\
&= \hat{y}+\frac{1-\gamma}{2}\hat{y}^2-\Lambda_L\left(\hat{y}-e+f+\frac{1+\varphi}{2}(\hat{y}-e+f)^2\right) && \text{(E-54)}\\
&= (1-\Lambda_L)\hat{y}+\Lambda_L(e-f)+\frac{1-\gamma}{2}\hat{y}^2-\frac{1+\varphi}{2}\Lambda_L(\hat{y}-e)^2-\underbrace{\frac{1+\varphi}{2}\Lambda_L f(2\hat{y}-2e+f)}_{O\left((\mathrm{d}\log\mu)^3\right)} && \text{(E-55)}\\
&\approx (1-\Lambda_L)\hat{y}+\Lambda_L(e-f)+\frac{1-\gamma}{2}\hat{y}^2-\frac{1+\varphi}{2}\Lambda_L(\hat{y}-e)^2 && \text{(E-56)}\\
&= (1-\Lambda_L)\hat{y}+\Lambda_L e-f+\frac{1-\gamma}{2}\hat{y}^2-\frac{1+\varphi}{2}(\hat{y}-e)^2+\underbrace{(1-\Lambda_L)[f+\frac{1+\varphi}{2}(\hat{y}-e)^2]}_{O\left((\mathrm{d}\log\mu)^3\right)} && \text{(E-57)}\\
&\approx (1-\Lambda_L)\hat{y}+\Lambda_L e-f+\frac{1-\gamma}{2}\hat{y}^2-\frac{1+\varphi}{2}(\hat{y}-e)^2 && \text{(E-58)}\\
&= (1-\Lambda_L)\hat{y}+\Lambda_L e-f-\frac{\gamma+\varphi}{2}(\hat{y}-\frac{1+\varphi}{\gamma+\varphi}e)^2-\frac{\gamma-1}{2}\frac{1+\varphi}{\gamma+\varphi}e^2 && \text{(E-59)}\\
&\approx (1-\Lambda_L)\tilde{y}+\Lambda_L e-f-\frac{\gamma+\varphi}{2}(\tilde{y}-\frac{1+\varphi}{\gamma+\varphi}e)^2-\frac{\gamma-1}{2}\frac{1+\varphi}{\gamma+\varphi}e^2 \\
&+\underbrace{(\hat{y}-\tilde{y})}_{O\left((\mathrm{d}\log\mu)^2\right)}\underbrace{\left[(1-\Lambda_L)-\frac{\gamma+\varphi}{2}(\hat{y}+\tilde{y}-2\frac{1+\varphi}{\gamma+\varphi}e)\right]}_{O\left(\mathrm{d}\log\mu\right)} && \text{(E-60)}\\
&\approx (1-\Lambda_L)\tilde{y}+\Lambda_L e-f-\frac{\gamma+\varphi}{2}(\tilde{y}-\frac{1+\varphi}{\gamma+\varphi}e)^2-\frac{\gamma-1}{2}\frac{1+\varphi}{\gamma+\varphi}e^2. && \text{(E-61)}
\end{aligned}
$$

In this derivation, we use the fact that the difference between $\hat{y}$ and $\tilde{y}$ is given by second order terms:

$$
\begin{aligned}
\hat{y}-\tilde{y} \approx \frac{1}{2}\left\{\frac{1}{\gamma+\varphi}\tilde{\lambda}'+\frac{\varphi}{\gamma+\varphi}\left[(\lambda\circ\frac{\Psi_{(L)}}{\Lambda_L})'-\mathcal{M}'\right]\right\}\mathrm{d}^2\log q \\
+\frac{1}{2}\frac{\varphi}{\gamma+\varphi}\sum_i\sum_j\frac{\mathrm{d}\log\mathcal{M}_i}{\mathrm{d}\log\mu_j}\mathrm{d}\log\mu_i\mathrm{d}\log\mu_j \qquad \text{(E-62)}
\end{aligned}
$$

Substituting $e=\mathcal{J}'\pi$ and $f=\frac{1}{2}\pi'\mathcal{H}_1\pi+\frac{1}{2}\pi'\mathcal{H}_2\pi$ into equation (E-61), the welfare function

[6] Under the assumption of small distortions in the equilibrium, the product of $1-\Lambda_L$ with a second-order term is a third-order timer and can be dropped from the approximation.

is then given by

$$\mathbb{W} = \underbrace{(1-\Lambda_L)\tilde{y} + \Lambda_L \mathcal{J}'\pi}_{\textit{first-order bias}} \quad \underbrace{-\frac{\gamma+\varphi}{2}(\tilde{y} - \frac{1+\varphi}{\gamma+\varphi}\mathcal{J}'\pi)^2}_{\textit{Volatility of output gap}} \quad \underbrace{-\frac{1}{2}\pi'\mathcal{H}_1\pi}_{\textit{Within-sector price dispersion}}$$
$$\underbrace{-\frac{1}{2}\pi'\mathcal{H}_2\pi}_{\textit{Cross-sector price dispersion}} \quad \underbrace{-\frac{\gamma-1}{2}\frac{1+\varphi}{\gamma+\varphi}\pi'\mathcal{J}\mathcal{J}'\pi}_{\textit{Variation in allocative efficiency}}. \tag{E-63}$$

□

Proof of Proposition 5. The optimal monetary policy problem can be written as

$$\max_{\tilde{y},\pi} \mathbb{W} = (1-\Lambda_L)\tilde{y} + \Lambda_L\mathcal{J}'\pi - \frac{\gamma+\varphi}{2}\left(\tilde{y} - \frac{1+\varphi}{\gamma+\varphi}\mathcal{J}'\pi\right)^2 - \frac{1}{2}\pi'\mathcal{H}\pi - \frac{\gamma-1}{2}\frac{1+\varphi}{\gamma+\varphi}\pi'\mathcal{J}\mathcal{J}'\pi$$

subject to

$$\pi = \mathcal{K}\tilde{y} + \mathcal{V}\mathrm{d}\log A.$$

The Lagrangian $\mathcal{L}$ is

$$\mathcal{L}(\tilde{y},\pi;\psi) = \mathbb{W}(\tilde{y},\pi) - \psi'(\pi - \mathcal{K}\tilde{y} - \mathcal{V}\mathrm{d}\log A) \tag{E-64}$$

The corresponding first-order conditions are

$$(1-\Lambda_L) - (\gamma+\varphi)\left(\tilde{y} - \frac{1+\varphi}{\gamma+\varphi}\mathcal{J}'\pi\right) + \psi'\mathcal{K} = 0 \tag{E-65}$$

and

$$\Lambda_L\mathcal{J}' + (1+\varphi)\left(\tilde{y} - \frac{1+\varphi}{\gamma+\varphi}\mathcal{J}'\pi\right)\mathcal{J}' - \pi'\mathcal{H} - (\gamma-1)\frac{1+\varphi}{\gamma+\varphi}\pi'\mathcal{J}\mathcal{J}' - \psi' = 0. \tag{E-66}$$

Combine two equations above and obtain

$$\Lambda_L\mathcal{J}' + \frac{1+\varphi}{\gamma+\varphi}(1-\Lambda_L+\psi'\mathcal{K})\mathcal{J}' - \pi'\mathcal{H} - (\gamma-1)\frac{1+\varphi}{\gamma+\varphi}\pi'\mathcal{J}\mathcal{J}' - \psi' = 0, \tag{E-67}$$

or equivalently,

$$\psi' = \left[\Lambda_L \mathcal{J}' + \frac{1+\varphi}{\gamma+\varphi}(1-\Lambda_L)\mathcal{J}' - \pi'\mathcal{H} - (\gamma-1)\frac{1+\varphi}{\gamma+\varphi}\pi'\mathcal{J}\mathcal{J}'\right]\left[I - \frac{1+\varphi}{\gamma+\varphi}\mathcal{K}\mathcal{J}'\right]^{-1}. \tag{E-68}$$

To simplify the equation, we observe that

$$\left[I - \frac{1+\varphi}{\gamma+\varphi}\mathcal{K}\mathcal{J}'\right]^{-1} = I + \frac{(1+\varphi)\hat{\Psi}^f\mathcal{J}'}{(1-\hat{\Lambda}_L) + \varphi(1-\hat{\Lambda}_L-\xi) - (1+\varphi)\mathcal{J}'\hat{\Psi}^f} = I + \frac{1+\varphi}{\xi}\hat{\Psi}^f\mathcal{J}' \tag{E-69}$$

and

$$\left[I - \frac{1+\varphi}{\gamma+\varphi}\mathcal{K}\mathcal{J}'\right]^{-1}\mathcal{K} = \frac{\gamma+\varphi}{(1-\hat{\Lambda}_L) + \varphi(1-\hat{\Lambda}_L-\xi)}\left[\hat{\Psi}^f + \frac{1+\varphi}{\xi}\hat{\Psi}^f\mathcal{J}'\hat{\Psi}^f\right] = \frac{\gamma+\varphi}{\xi}\hat{\Psi}^f. \tag{E-70}$$

Hence, combining equations (E-65) and (E-68) yields

$$\begin{aligned}&(\gamma+\varphi)(\tilde{y} - \frac{1+\varphi}{\gamma+\varphi}\mathcal{J}'\pi) + \frac{\gamma+\varphi}{\xi}(\hat{\Psi}^f)'\mathcal{H}\pi + \frac{(1+\varphi)(\gamma-1)(1-\hat{\Lambda}_L-\xi)}{\xi}\mathcal{J}'\pi\\ =&1-\Lambda_L + \left[1+\varphi+(\gamma-1)\Lambda_L\right](1-\hat{\Lambda}_L-\xi)/\xi,\end{aligned} \tag{E-71}$$

or equivalently,

$$\begin{aligned}&\left[\frac{\gamma+\varphi}{\xi}(\hat{\Psi}^f)'\mathcal{H} - \frac{(1+\varphi)[1-\hat{\Lambda}_L-\gamma(1-\hat{\Lambda}-\xi)]}{\xi}\mathcal{J}'\right]\pi\\ =&1-\Lambda_L + \left[1+\varphi+(\gamma-1)\Lambda_L\right](1-\hat{\Lambda}_L-\xi)/\xi - (\gamma+\varphi)\tilde{y}.\end{aligned} \tag{E-72}$$

Using divine coincidence condition, we get

$$\begin{aligned}&\left[\tilde{\lambda}'(\Theta^{-1}-I) - \mathcal{J}' + \frac{\gamma+\varphi}{\xi}(\hat{\Psi}^f)'\mathcal{H} + \frac{(1+\varphi)(\gamma-1)(1-\hat{\Lambda}_L-\xi)}{\xi}\mathcal{J}'\right]\pi\\ =&1-\Lambda_L + \left[1+\varphi+(\gamma-1)\Lambda_L\right](1-\hat{\Lambda}_L-\xi)/\xi\end{aligned} \tag{E-73}$$

Note that when the flexible price equilibrium is efficient, $\Lambda_L = 1, \mathcal{J} = \mathbf{0}$ and $1-\hat{\Lambda}_L-\xi = 0$. The condition above degenerates to the results of La'O and Tahbaz-Salehi (2022) and Rubbo (2023):

$$\left[\tilde{\lambda}'(\Theta^{-1}-I) + \frac{\gamma+\varphi}{1-\hat{\Lambda}_L}(\hat{\Psi}^f)'\mathcal{H}\right]\pi = 0$$

$\square$

F Cobb-Douglas Economy

In this section, we explore a Cobb-Douglas model economy characterized by unitary elasticities of substitution in both consumption and production ($\sigma_i = 1, \forall i$).

F.1 Supply Side Effect in a Cobb-Douglas Economy

With unitary elasticity of substitution, the supply-side effect of monetary policy in Proposition 1 can be simplified as,

$$\frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log w} = \sum_{j=0}^{N} \frac{\lambda_j}{\bar{\mu}_j} \mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\hat{\Psi}_{iL}, \frac{\Psi_{iL}}{\Lambda_L}\right) \tag{F-1}$$

$$=1 - \hat{\Lambda}_L - \sum_{j=1}^{N} \lambda_j \frac{\Psi_{iL}}{\Lambda_L} \frac{1-\theta_j}{\theta_j} \hat{\Psi}_{jL} \tag{F-2}$$

$$= \sum_{j=1}^{N} \tilde{\lambda}_j \left(1 - \frac{\lambda_j}{\tilde{\lambda}_j} \frac{\Psi_{iL}}{\Lambda_L}\right) \frac{1-\theta_j}{\theta_j} \hat{\Psi}_{jL} \tag{F-3}$$

where the second equality is obtained by taking directive of both sides of equation (C-28) with respect to $\mathrm{d}\log w$, and the last equality uses the fact that

$$1 - \hat{\Lambda}_L = \sum_{j=1}^{N} \tilde{\lambda}_j \frac{1-\theta_j}{\theta_j} \hat{\Psi}_{jL}. \tag{F-4}$$

Alternatively, the sufficient statistic for the supply-side effect can be derived through the following lemma.

Lemma 9. *In a Cobb-Douglas economy, the change in TFP, in terms of productivities and ex-post markups, is determined by the following expression:*

$$\mathrm{d}\log \mathrm{TFP} = \tilde{\lambda}' \mathrm{d}\log A + \left[\left(\lambda \circ \frac{\Psi_{(L)}}{\Lambda_L}\right)' - \tilde{\lambda}' \right] \mathrm{d}\log \mu \tag{F-5}$$

Proof of Lemma 9. When all cross-sector elasticities are set to one, we have

$$\mathcal{M}_k = \sum_{j=0}^{N} \frac{\lambda_j}{\bar{\mu}_j} \mathrm{Cov}_{\tilde{\Omega}(j,:)}\left(\tilde{\Psi}_{ik}, \frac{\Psi_{iL}}{\Lambda_L}\right) \tag{F-6}$$

$$= \sum_{j=0}^{N} \frac{\lambda_j}{\bar{\mu}_j} \left[\sum_i \tilde{\Omega}_{ji} \tilde{\Psi}_{ik} \frac{\Psi_{iL}}{\Lambda_L} - \underbrace{\left(\sum_i \tilde{\Omega}_{ji} \tilde{\Psi}_{ik}\right)}_{\tilde{\Psi}_{jk} - \delta_{jk}} \underbrace{\left(\sum_i \tilde{\Omega}_{ji} \frac{\Psi_{iL}}{\Lambda_L})\right)}_{\bar{\mu}_j \Psi_{jL}/\Lambda_L} \right] \tag{F-7}$$

$$= \sum_{j=0}^{N} \lambda_j \sum_{i=1}^{N+1} \Omega_{ji} \tilde{\Psi}_{ik} \frac{\Psi_{iL}}{\Lambda_L} - \sum_{j=0}^{N} \lambda_j (\tilde{\Psi}_{jk} - \delta_{jk}) \frac{\Psi_{jL}}{\Lambda_L} \tag{F-8}$$

$$= \sum_{i=1}^{N+1} \tilde{\Psi}_{ik} \frac{\Psi_{iL}}{\Lambda_L} \underbrace{\sum_{j=0}^{N} \lambda_j \Omega_{ji}}_{\lambda_i} - \sum_{j=0}^{N} \lambda_j \tilde{\Psi}_{jk} \frac{\Psi_{jL}}{\Lambda_L} + \lambda_k \frac{\Psi_{kL}}{\Lambda_L} \tag{F-9}$$

$$= \sum_{i=1}^{N} \lambda_i \tilde{\Psi}_{ik} \frac{\Psi_{iL}}{\Lambda_L} - \sum_{j=0}^{N} \lambda_j \tilde{\Psi}_{jk} \frac{\Psi_{jL}}{\Lambda_L} + \lambda_k \frac{\Psi_{kL}}{\Lambda_L} \tag{F-10}$$

$$= \underbrace{- \lambda_0 \tilde{\Psi}_{0k} \frac{\Psi_{0L}}{\Lambda_L}}_{\tilde{\lambda}_k} + \lambda_k \frac{\Psi_{kL}}{\Lambda_L} \tag{F-11}$$

$$= \lambda_k \frac{\Psi_{kL}}{\Lambda_L} - \tilde{\lambda}_k \tag{F-12}$$

This, combined with equation (E-9), completes the proof. □

By Lemma 9, we obtain

$$\frac{\mathrm{d} \log \mathrm{TFP}}{\mathrm{d} \log w} = \left[(\lambda \circ \frac{\Psi_{(L)}}{\Lambda_L})' - \tilde{\lambda}' \right] (I - \Theta^{-1}) \hat{\Psi}^f \tag{F-13}$$

$$= \sum_{j=1}^{N} \tilde{\lambda}_j (1 - \frac{\lambda_j}{\tilde{\lambda}_j} \frac{\Psi_{jL}}{\Lambda_L}) \frac{1 - \theta_j}{\theta_j} \hat{\Psi}_{jL} \tag{F-14}$$

F.2 Network-Adjusted Markups

Inspired by equation (F-14), we define χ_i as a network-adjusted markup. Specifically, for all $i \in \mathcal{N}$, it is given by:

$$\chi_i = \left(\frac{\lambda_i}{\tilde{\lambda}_i}\frac{\Psi_{iL}}{\Lambda_L}\right)^{-1}, \tag{F-15}$$

where $\frac{\lambda_i}{\tilde{\lambda}_i}$ captures sector i's inverse downstream markup, while $\frac{\Psi_{iL}}{\Lambda_L}$ represents sector i's inverse upstream markup relative to the aggregate wedge. Therefore, their product $\frac{\lambda_i}{\tilde{\lambda}_i}\frac{\Psi_{iL}}{\Lambda_L}$ captures the network-adjusted markup of sector i. [7]

With this definition, equation (F-14) simplifies to

$$\frac{\mathrm{d}\log \mathrm{TFP}}{\mathrm{d}\log w} = \sum_{j=1}^{N}(1-\chi_j^{-1})\tilde{\lambda}_j\frac{1-\theta_j}{\theta_j}\hat{\Psi}_{jL}. \tag{F-16}$$

This equation illustrates that, in a Cobb-Douglas economy, the supply-side effect depends on the interaction between network-adjusted markups measured by $1-\chi_i^{-1}$ and network-adjusted nominal rigidities represented by $(\theta_i^{-1}-1)\hat{\Psi}_{iL}$. Without either initial distortions ($\chi_i = 1, \forall i \in \mathcal{N}$), or nominal rigidities ($\theta = \mathbf{1}$), there is no supply side effect.

Note that if a sector has a higher markup, and its upstream and downstream sectors also have higher markups, it is generally associated with higher network-adjusted markups (higher χ_i). Specifically, when two sectors i and j are symmetric both upstream and downstream, that is, they share identical production technologies and have the same roles as input suppliers to firms and in household preferences (La'O and Tahbaz-Salehi, 2022), their network-adjusted markups, χ_i and χ_j, directly reflect their respective markups, $\bar{\mu}_i$ and $\bar{\mu}_j$, as demonstrated in Lemma 10.

Lemma 10. *If sector i and j are upstream and downstream symmetric, then $\chi_i > \chi_j$ if and only if $\bar{\mu}_i > \bar{\mu}_j$.*

Proof of Lemma 10. Given sector i and j are upstream and downstream symmetric, we have $\tilde{\lambda}_i = \tilde{\lambda}_j$. Hence, $\left(\frac{\lambda_i}{\tilde{\lambda}_i}\frac{\Psi_{iL}}{\Lambda_L}\right)^{-1} > \left(\frac{\lambda_j}{\tilde{\lambda}_j}\frac{\Psi_{jL}}{\Lambda_L}\right)^{-1}$ is equivalent to $\lambda_i\Psi_{iL} < \lambda_j\Psi_{jL}$.

[7] For example, in a vertical economy, the inverse downstream and upstream markups are given by,

$$\frac{\lambda_i}{\tilde{\lambda}_i} = \prod_{k=1}^{i-1}\bar{\mu}_k^{-1} \quad \text{and} \quad \frac{\Psi_{iL}}{\Lambda_L} = \frac{\prod_{k=i}^{N}\bar{\mu}_k^{-1}}{\prod_{k=1}^{N}\bar{\mu}_k^{-1}} = \prod_{k=1}^{i-1}\bar{\mu}_k.$$

Here, downstream and upstream markups exactly cancel each other out, resulting in network-adjusted markups uniformly being equal to one.

Similar to Lemma 4, we find:

$$\frac{\partial \log \lambda_k}{\partial \log \bar{\mu}_k} = -(\Psi_{kk} - 1) \leq 0 \tag{F-17}$$

and

$$\frac{\partial \log \Psi_{kL}}{\partial \log \bar{\mu}_k} = -\Psi_{kk} < 0. \tag{F-18}$$

Therefore, $\lambda_i \Psi_{iL} < \lambda_j \Psi_{jL}$ is also equivalent to $\bar{\mu}_i > \bar{\mu}_j$.

□

F.3 Optimal Monetary Policy in a Cobb-Douglas Economy

Following La'O and Tahbaz-Salehi (2022), we rewrite the optimal policy weight for industry i, ϕ_i^*, as a sum of components related to the output gap (*o.g.*), within-sector price dispersion (*within*), cross-sector price dispersion (*across*), and variation in allocative efficiency (*adjust*):

$$\phi_i^* \equiv \phi_i^{o.g.} + \phi_i^{within} + \phi_i^{across} + \phi_i^{adjust}. \tag{F-19}$$

To investigate the optimal monetary policy in a Cobb-Douglas economy, we begin by analyzing matrices $\mathcal{H}_1$ and $\mathcal{H}_2$, which are associated with within-sector and cross-sector misallocations, respectively.

Within-Sector Misallocation

The matrix $\mathcal{H}_1$ associated with within-sector misallocation is

$$\mathcal{H}_1 = \text{diag}(\tilde{\lambda} \circ \epsilon \circ (\theta^{-1} - 1)) \tag{F-20}$$

The derivation of this equation is based on Lemma 9, which states $\mathcal{M}_k = \lambda_k \frac{\Psi_{kL}}{\Lambda_L} - \tilde{\lambda}_k$.

Cross-Sector Misallocation

In terms of cross-sector misallocations, we deduce from Lemma 11 that for Cobb-Douglas elasticities across all sectors.

Lemma 11. *When elasticities of substitution are Cobb-Douglas across all sectors, $\sigma_j = 1, \forall j$, then*

$$\mathcal{B}(k,l) = \sum_j \lambda_j \text{Cov}_{\Omega(j,:)}(\Psi_{(k)}, \Psi_{(l)}) = \lambda_k \lambda_l \left[\frac{\Psi_{lk}}{\lambda_k} + \frac{\Psi_{kl}}{\lambda_l} - \frac{\delta_{kl}}{\lambda_k} - 1 \right] \tag{F-21}$$

Proof of Lemma 11.

$$\sum_j \lambda_j \mathrm{Cov}_{\Omega(j,:)}(\Psi_{ik},\Psi_{il}) = \sum_j \lambda_j \left[\sum_i \Omega_{ji}\Psi_{ik}\Psi_{il} - \underbrace{\left(\sum_i \Omega_{ji}\Psi_{ik}\right)}_{\Psi_{jk}-\delta_{jk}} \underbrace{\left(\sum_i \Omega_{ji}\Psi_{il}\right)}_{\Psi_{jl}-\delta_{jl}} \right] \tag{F-22}$$

$$= \sum_{i=1}^{N+1} \Psi_{ik}\Psi_{il} \underbrace{\sum_{j=0}^{N} \lambda_j \Omega_{ji}}_{\lambda_i} - \sum_{j=0}^{N} \lambda_j (\Psi_{jk} - \delta_{jk})(\Psi_{jl} - \delta_{jl}) \tag{F-23}$$

$$= \sum_{i=1}^{N} \lambda_i \Psi_{ik}\Psi_{il} - \sum_{j=1}^{N} \lambda_j (\Psi_{jk} - \delta_{jk})(\Psi_{jl} - \delta_{jl}) - \underbrace{\lambda_0 \Psi_{0k}\Psi_{0l}}_{\lambda_k\lambda_l} \tag{F-24}$$

$$= \lambda_k\lambda_l \left[\frac{\Psi_{lk}}{\lambda_k} + \frac{\Psi_{kl}}{\lambda_l} - \frac{\delta_{kl}}{\lambda_k} - 1 \right] \tag{F-25}$$

□

In this paper, we refine our understanding of cross-sector misallocation in a Cobb-Douglas economy. We derive the following expression for $\mathcal{L}^{\text{across}}$:

$$\mathcal{L}^{\text{across}} = \sum_{i=1}^{N}\sum_{j=1}^{N} \lambda_j \Psi_{ji} \frac{\Psi_{iL}}{\Lambda_L} \mathrm{d}\log\mu_i \mathrm{d}\log\mu_j - \frac{1}{2}\sum_{i=1}^{N} \lambda_i \frac{\Psi_{iL}}{\Lambda_L} \mathrm{d}\log^2\mu_i - \frac{1}{2}\left(\sum_{i=1}^{N} \lambda_i \frac{\Psi_{iL}}{\Lambda_L} \mathrm{d}\log\mu_i\right)^2 \tag{F-26}$$

$$= \sum_{i=1}^{N}\sum_{j=1}^{N} \lambda_k\lambda_l \left[\frac{\Psi_{lk}}{\lambda_k}\frac{\Psi_{kL}}{\Lambda_L} + \frac{\Psi_{kl}}{\lambda_l}\frac{\Psi_{lL}}{\Lambda_L} - \frac{\delta_{kl}}{\lambda_k}\frac{\Psi_{kL}}{\Lambda_L} - \frac{\Psi_{kL}}{\Lambda_L}\frac{\Psi_{lL}}{\Lambda_L} \right] \mathrm{d}\log\mu_k \mathrm{d}\log\mu_l \tag{F-27}$$

This leads to the expression for the matrix $\mathcal{H}_2$ associated with cross-sector misallocation:

$$\mathcal{H}_2 = (I - \Theta^{-1})\mathcal{B}(I - \Theta^{-1}), \tag{F-28}$$

where $\mathcal{B} = \mathcal{D} + \mathcal{D}' - \mathrm{diag}(\lambda \circ \frac{\Psi^f}{\Lambda_L}) - (\lambda \circ \frac{\Psi^f}{\Lambda_L})(\lambda \circ \frac{\Psi^f}{\Lambda_L})'$ and $\mathcal{D} = \mathrm{diag}(\lambda)\Psi^n\mathrm{diag}(\frac{\Psi^f}{\Lambda_L})$.

Finally, we derive the components of the inflation index under optimal monetary policy, which can be simplified as follows:

$$\phi_i^{o.g.} = (\theta_i^{-1} - 1)\lambda_i \frac{\Psi_{iL}}{\Lambda_L} = (\theta_i^{-1} - 1)\tilde{\lambda}_i \chi_i^{-1}, \tag{F-29}$$

$$\phi_i^{within} = \frac{\gamma + \varphi}{\xi}(\theta_i^{-1} - 1)\tilde{\lambda}_i \varepsilon_i \hat{\Psi}_{iL}, \tag{F-30}$$

$$\phi_i^{across} = \frac{\gamma + \varphi}{\xi}(\theta_i^{-1} - 1)\left[\sum_{k=1}^{N}(\theta_k^{-1} - 1)\hat{\Psi}_{kL}(\lambda_k \Psi_{ki}\frac{\Psi_{iL}}{\Lambda_L} + \lambda_i \Psi_{ik}\frac{\Psi_{kL}}{\Lambda_L}) - \lambda_i \frac{\Psi_{iL}}{\Lambda_L}[\hat{\Psi}_{iL}(\theta_i^{-1} - 1) + \xi]\right], \tag{F-31}$$

$$\phi_i^{adjust} = \frac{(1+\varphi)(\gamma - 1)(1 - \hat{\Lambda}_L - \xi)}{\xi}(\theta_i^{-1} - 1)\tilde{\lambda}_i(1 - \chi_i^{-1}), \tag{F-32}$$

In a Cobb-Douglas economy, the output-gap stabilization policy is equivalent to $\sum_i \phi_i^{o.g.}\pi = 0$, with $\phi^{o.g.} = (\theta_i^{-1} - 1)\lambda_i \chi_i^{-1}$. This condition indicates that the monetary authority can exploit allocative efficiency by allowing higher inflation in sectors with higher network-adjusted markups (higher χ_i). Accordingly, the optimal policy assigns lower industry weights to sectors with higher network-adjusted markups. Moreover, Lemma 10 shows that sectors with higher network-adjusted markups generally correspond to higher initial markups.

G Optimal Policy in Example Economies

Example 1. Vertical Economy

The optimal monetary policy in a vertical economy can be simplified as

$$\left[\underbrace{\frac{\gamma + \varphi}{1 - \hat{\Lambda}_L}(\hat{\Psi}^n_{(L)})'\mathcal{H}_1}_{\text{Within-sector price dispersion}} + \underbrace{\Theta^{-1} - I}_{\text{Output gap}}\right]\pi = 1 - \prod_i \bar{\mu}_i^{-1} \tag{G-1}$$

In a vertical economy, cross-sectional resource allocation is always efficient regardless of initial wedges and price rigidities; therefore, the industry weights corresponding to cross-sector misallocation and adjustment from allocative efficiency should be zero: $\phi_i^{across} = \phi_i^{adjust} = 0$ for all $i \in \mathcal{N}$. Despite this, within-sector price dispersion persists due to pricing frictions, requiring the optimal policy to trade off variation in the output gap against within-sector misallocation, as emphasized in the standard New Keynesian literature. Equation in

(19) implies that the optimal price-stabilization target is given by $\sum_i \phi_i^* \pi_i = 1 - \prod_i \bar{\mu}_i^{-1}$, and

$$\phi_i^* \equiv \phi_i^{o.g.} + \phi_i^{within} \tag{G-2}$$

where

$$\phi_i^{o.g.} = 1/\theta_i - 1 \tag{G-3}$$

$$\phi_i^{within} = \frac{\gamma + \varphi}{1 - \prod_{k=1}^{N} \theta_k} (1/\theta_i - 1) \varepsilon_i \prod_{k=i}^{N} \theta_k \tag{G-4}$$

The optimal policy, therefore, allocates larger weights to industries with: (i) higher price stickiness; (ii) larger within-sector elasticities of substitution; and (iii) a more upstream position in the production chain. It is not surprising that our inflation index aligns with the findings of La'O and Tahbaz-Salehi (2022), as there is no cross-sector misallocation in the vertical economy, thus eliminating any supply side effect of monetary policy.

Example 2. Horizontal Economy

In this section, we use the horizontal economy from section 3.3 as an example to demonstrate how our model primitives characterize the optimal conduct of monetary policy. For simplicity, we assume that the elasticity of substitution in consumption is equal to one.

As illustrated in section 3.3, when initial wedges covary with price rigidities, monetary policy has a supply side effect. Consequently, the optimal policy component that accounts for the interaction between allocative efficiency and pure technology effect ϕ_i^{adjust} is nonzero. Next, in contrast to the vertical economy, a dispersion on price rigidities results in sectoral relative prices failing to fully reflect their corresponding productivities in response to productivity and monetary shocks, which implies the component of monetary policy targets cross-sector misallocation ϕ_i^{across} is also nonzero. Finally, combining the components of optimal policy aimed at reducing welfare losses arising from variation in the output gap and within-sector price dispersion, the optimal monetary policy in a horizontal economy consists of four components,

$$\phi_i^* \equiv \phi_i^{o.g.} + \phi_i^{within} + \phi_i^{across} + \phi_i^{adjust} \tag{G-5}$$

where

$$\phi_i^{o.g.} = (1/\theta_i - 1)\frac{b_i\bar{\mu}_i^{-1}}{\mathbb{E}_b(\bar{\mu}^{-1})} \tag{G-6}$$

$$\phi_i^{within} = \frac{\gamma + \varphi}{1 - \frac{\mathbb{E}_b(\theta\bar{\mu}^{-1})}{\mathbb{E}_b(\bar{\mu}^{-1})}}(1 - \theta_i)b_i\varepsilon_i \tag{G-7}$$

$$\phi_i^{across} = (\gamma + \varphi)(1/\theta_i - 1)\frac{\sum_k b_k\bar{\mu}_k^{-1}(\theta_k - \theta_i)}{\mathbb{E}_b(\bar{\mu}^{-1}) - \mathbb{E}_b(\theta\bar{\mu}^{-1})}\frac{b_i\bar{\mu}_i^{-1}}{\mathbb{E}_b(\bar{\mu}^{-1})} \tag{G-8}$$

$$\phi_i^{adjust} = -(1 + \varphi)(\gamma - 1)(1/\theta_i - 1)b_i\left(\frac{\bar{\mu}_i^{-1}}{\mathbb{E}_b(\bar{\mu}^{-1})} - 1\right)\frac{\mathrm{Cov}_b(\theta, \bar{\mu}^{-1})}{\mathbb{E}_b(\bar{\mu}^{-1}) - \mathbb{E}_b(\theta\bar{\mu}^{-1})}. \tag{G-9}$$

and the optimal inflation bias is determined by

$$\pi^* = \underbrace{1 - \mathbb{E}_b(\bar{\mu}^{-1})}_{\text{Aggregate wedge}} + \underbrace{[1 + \varphi + (\gamma - 1)\mathbb{E}_b(\bar{\mu}^{-1})]\frac{\mathrm{Cov}_b(\theta, \bar{\mu}^{-1})}{\mathbb{E}_b(\bar{\mu}^{-1}) - \mathbb{E}_b(\theta\bar{\mu}^{-1})}}_{\text{Supply side effect}} \tag{G-10}$$

In the horizontal economy, the optimal policy assigns a larger industry weight to industries with (i) higher price stickiness, (ii) larger consumption shares, and (iii) lower initial wedges.[8] It's also noteworthy that when initial wedges are uniform across sectors, the industry weight ϕ_i^* is independent of these initial wedges for all $i \in \mathcal{N}$ and the inflation bias arising from supply-side effects is zero. However, as long as initial markups are positive, the aggregate wedge $1 - \mathbb{E}_b(\bar{\mu}^{-1})$ still results in inflation bias.

[8]We can reasonably disregard ϕ_i^{adjust} due to its quantitatively minor significance.