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Fixing the Phillips Curve: Implications of Firms' Monopsonistic Wage-setting for Inflation Dynamics*

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Abstract

Motivated by evidence documented in labor economics, we introduce *firms' monopsonistic* wage-setting in an otherwise standard DSGE model. Our model identifies shocks to the wage markdown as labor demand shocks—a feature absent from standard models. With both labor demand and supply shocks, our model empirically outperforms its standard counterpart model. Firms' monopsonistic wage-setting allows real unit labor cost to be decomposed into not only real marginal cost but also the wage markdown. This refined measure of real marginal cost enhances the Phillips curve's ability to describe inflation dynamics while obviating the need for price markup shocks.

Keywords: DSGE model, Labor market monopsony, Wage markdown, Labor demand shock, Real marginal cost

JEL Classification: E24, E31, J23, J42

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"It is not easy to obtain measures of marginal cost of which one can be certain."— Rotemberg and Woodford (1999, p. 1057).

1 Introduction

Since the seminal work of Erceg et al. (2000), the literature on dynamic stochastic general equilibrium (DSGE) models, typified by Christiano et al. (2005), Smets and Wouters (2007), and Justiniano et al. (2010, 2011), has widely adopted households' staggered wage-setting under monopolistic competition. However, households' monopolistic wage-setting disregards the evidence on labor market monopsony that has recently been documented in labor economics.[1] For instance, Yeh et al. (2022) present estimates of substantial markdowns of workers' wages from their marginal revenue product of labor (MPL). Benmelech et al. (2022) and Rinz (2022) empirically show that employer concentration lowers employees' wages. Langella and Manning (2021) observe that the mounting evidence of monopsony power in labor markets is stimulating research interest into the questions of how monopsony power varies over time and what are its consequences.

Motivated by the evidence, we examine the macroeconomic consequences of labor market monopsony. We introduce *firms'* staggered wage-setting under *monopsonistic* competition in an otherwise standard DSGE model of the sort developed in the literature.[2] In our model, monopsony power in labor markets arises from heterogeneity in workers' preferences for jobs, in an approach similar to, for example, Bhaskar et al. (2002) and Berger et al. (2022).[3] Wage growth is then driven by the *wage markdown*, that is, the gap between the real wage and the MPL in the wage Phillips curve that describes firms' wage-setting behavior, while labor is

[1]See, e.g., Manning (2021), Card (2022), and Azar and Marinescu (2024) for reviews of the related literature.

[2]Kurozumi et al. (2025) incorporate firms' staggered wage-setting under monopsonistic competition into a small-scale sticky-price model and show that firms' monopsonistic wage-setting gives rise to different implications for wage growth dynamics, welfare, and policy from those obtained in the standard counterpart model with households' monopolistic wage-setting. Bardóczy et al. (2025) examine how labor market power affects the transmission of monetary policy and develop a model with firms' staggered wage-setting under oligopsonistic competition.

[3]The assumption that jobs are imperfect substitutes captures the notion that jobs differ not only in wages but also in amenities and commuting costs. Another modeling approach involves search frictions in labor markets (e.g., Burdett and Mortensen, 1998; Postel-Vinay and Robin, 2002). Trottner (2025) demonstrates an equivalence between the two approaches.

determined on households' supply curves. Therefore, the wage Phillips curve turns out to be an aggregate labor *demand* curve. This contrasts with the standard counterpart model with households' monopolistic wage-setting. In that model, the driver of wage growth is the wage markup, that is, the gap between the real wage and the marginal rate of substitution (MRS) between consumption and labor in the wage Phillips curve that represents households' wage-setting behavior, whereas labor is determined on firms' demand curves. The wage Phillips curve is therefore an aggregate labor supply curve. It is well known that shocks to the wage markup and to preferences for labor supply cannot be identified because both shocks are disturbances to aggregate labor supply. Thus we embed only the wage markup shock in the counterpart model, as in standard DSGE models.

In our model, however, shocks to the wage markdown and to preferences for labor supply can be separately identified. While the latter shock is a disturbance to the aggregate labor supply curve in our model as well, the wage markdown shock is a disturbance to our wage Phillips curve—which is the aggregate labor demand curve in our model—and therefore the shock is identified as a labor *demand* shock. The observation that firms' monopsonistic wage-setting enables the separate identification of labor demand and supply shocks is novel in the literature.[4] By incorporating these two distinct shocks to labor markets, our model addresses the criticism made by Chari et al. (2009) that the labor market shocks of standard DSGE models have different policy implications, yet are observationally equivalent.

We estimate our model with firms' monopsonistic wage-setting as well as the counterpart model with households' monopolistic wage-setting, using full-information Bayesian methods and US macroeconomic time series during the period from 1984:Q1 through 2008:Q4. We then conduct a Bayesian comparison of the two estimated models to investigate which model better accounts for US business cycles and inflation dynamics.

The main results of the paper are twofold. First, our model with firms' monopsonistic wage-setting outperforms the counterpart model with households' monopolistic wage-setting in terms of marginal data density. The shocks to the wage markdown and to preferences for labor supply are both indispensable for the better empirical performance of our model.

[4] Dennery (2020) also indicates that firms' monopsonistic wage-setting leads the resulting wage Phillips curve to become an aggregate labor demand curve. However, this research considers no disturbances to the labor demand curve.

When we estimate our model with only one of the two shocks, its empirical performance fails to be better than that of the counterpart model. This result indicates that the separate identification of the labor demand and supply shocks is what makes firms' monopsonistic wage-setting relevant for DSGE models of the US economy.[5]

Second, our estimated model restores the relationship between inflation and real marginal cost, which has been elusive in empirical research that uses real unit labor cost as a proxy for real marginal cost. The model attributes fluctuations in the inflation rate to a broad mix of shocks that affect real marginal cost and transmit to inflation through the price Phillips curve, such as monetary policy shocks, total factor productivity shocks, consumption preference shocks, and marginal efficiency of investment shocks, while assigning only a marginal role to price markup shocks, which are disturbances to the Phillips curve. This result contrasts with that obtained in the estimated counterpart model, which attributes inflation fluctuations largely to price and wage markup shocks, consistent with the results of Smets and Wouters (2007) and Justiniano et al. (2010). Standard models including the counterpart model, where labor is determined on firms' demand curves, equate marginal cost to unit labor cost, but empirical studies with various approaches find that the data on real unit labor cost are not a useful indicator for explaining inflation dynamics (e.g., Bils et al., 2012; King and Watson, 2012; Angeletos et al., 2020).[6] Our model refines real marginal cost as the driver of inflation in the Phillips curve in the presence of the wage markdown. Firms' staggered wage-setting under monopsonistic competition allows real unit labor cost to be decomposed into not only real marginal cost but also the (variable) wage markdown.[7] The resulting measure of real marginal cost is strongly correlated with the data on inflation, whereas it has little correlation

[5]Alpanda (2025) obtains the opposite result: a DSGE model with monopsonistic wage-setting empirically underperforms its counterpart model with monopolistic wage-setting. We found that filtering out the COVID-19 pandemic period from the data of Alpanda (2025) aligns the results of the model comparison with our results, suggesting that the inclusion of extreme outliers biases the parameter estimates within the linearized models.

[6]King and Watson (2012) measure so-called fundamental inflation solely based on real unit labor cost and point to a disconnect between inflation and the cost. Angeletos et al. (2020) demonstrate a similar disconnect using a VAR-based method they call business cycle anatomy. Bils et al. (2012) show that a large role of price markup shocks and a flat Phillips curve in standard DSGE models are incompatible with micro evidence on firms' reset price inflation.

[7]The business cycle properties of the wage markdown in our estimated model are consistent with empirical evidence on labor market power (e.g., Webber, 2022). Previous empirical research primarily examines long-run trends in labor market power (e.g., Berger et al., 2022; Rinz, 2022; Ren and Zhang, 2025).

with the data on real unit labor cost. Therefore, it enhances the Phillips curve's ability to describe inflation dynamics while obviating the need for price markup shocks.[8]

Our results are consistent with empirical evidence on the labor wedge and provide a better understanding of fluctuations in the measured wedge.[9] As demonstrated by Chari et al. (2007) and Galí et al. (2007), accounting for the labor wedge is one of the key avenues for understanding business cycles. Karabarbounis (2014) empirically shows that fluctuations in the measured labor wedge predominantly reflect those in the household component of the wedge, that is, the gap between the real wage and the measured MRS. Labor preference shocks in our model and wage markup shocks in the counterpart model generate fluctuations in this gap. The fluctuations are observed in the macroeconomic data, and thus the empirical performance of our model with wage markdown shocks but no labor preference shocks is inferior to that of the counterpart model with wage markup shocks.[10]

In addition, our results extend those of Karabarbounis (2014) by uncovering a new role for the firm component of the measured labor wedge, that is, the gap between the measured MPL and the real wage, which corresponds to the negative of real unit labor cost. With monopsonistic wage-setting the firm component of the wedge is decomposed into real marginal cost and the wage markdown, thus improving the empirical performance of our model by better describing inflation dynamics as noted above. The wage markdown shock is a key driving force of fluctuations in the markdown, and hence the empirical performance of our model with labor preference shocks but no wage markdown shocks is inferior to that of the counterpart model.

The paper also contributes to the macroeconomic literature on the cyclical behavior of real marginal cost. Illustrating the opening quote, Rotemberg and Woodford (1999) review various refinements that lead marginal cost to deviate from unit labor cost: a CES production technology, overhead labor, labor adjustment costs, labor hoarding, variable capital utilization, and nonlinear wage bills that could reflect monopsony power in labor markets.

[8]Indeed, the two main results of the paper hold even if our model abstracts from price markup shocks.

[9]The labor wedge corresponds to the measured gap between the MPL and the MRS of prototype models with no rigidities in nominal prices and wages and no shocks to them.

[10]Moreover, our model has a worse empirical performance in the absence of labor preference shocks than in the absence of wage markdown shocks, suggesting that the labor preference shocks play a more important role in our model's fit to the macroeconomic data than the wage markdown shocks.

McAdam and Willman (2013) empirically investigate some of the refinements, including the CES production technology and variable capital utilization, although they do not tackle labor market monopsony.[11] Our paper considers firms' monopsonistic wage-setting and finds that marginal cost deviates from unit labor cost in the presence of the wage markdown. This enables the Phillips curve to better describe inflation dynamics, as noted above.[12]

The paper proceeds as follows. Section 2 introduces firms' monopsonistic wage-setting in an otherwise standard DSGE model. Section 3 explains the procedure for estimating the model. Section 4 presents the empirical results and Section 5 discusses a new measure of real marginal cost. Section 6 concludes.

2 Model

The model introduces firms' staggered wage-setting under monopsonistic competition in an otherwise standard DSGE model of the sort developed in the literature, such as Christiano et al. (2005), Smets and Wouters (2007), and Justiniano et al. (2010, 2011). In the model are several types of economic agents: a representative household with its members who are workers, a monetary authority, and four types of firms, namely a representative wholesaler, retailers, a representative composite-good producer, and a representative capital-service provider.[13] A notable feature of the model is that the household has preferences for an aggregate of all differentiated labor supplied by its members to the wholesaler, which sets their wages subject to their labor supply curves and produces its output using all labor and capital rented from the capital-service provider. Retailers then produce differentiated goods from the wholesale good and set their product prices subject to the composite-good producer's demand curves. In the presence of firms' monopsonistic wage-setting, the model can incorporate shocks to the wage markdown as well as to preferences for labor supply. As noted later, this contrasts with the standard counterpart model with households' monop-

[11] Nekarda and Ramey (2021) examine the conditional cyclicality of the average price markup, i.e., the reciprocal of real marginal cost.

[12] Krause et al. (2008) construct a measure of real marginal cost using the data on real wages and additional labor market factors suggested by labor market search models. This measure is strongly correlated with the data on real unit labor cost.

[13] The separation of wholesalers and retailers is the same modeling convention as that used in the literature on labor market search, such as Walsh (2005), Trigari (2009), and Kurozumi and Van Zandweghe (2010).

olistic wage-setting, where only one of two shocks to the wage markup and to preferences for labor supply can be embedded. The remaining part of the model is standard in the literature.

We describe the behavior of each economic agent in what follows.

2.1 Households

The representative household has many members $m \in [0,1]$. The household's preferences for composite-good consumption C_t and aggregate labor l_t are represented as the utility function with consumption habit formation H_t,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\log(C_t - h\, H_t) \exp \varepsilon_{c,t} - \frac{l_t^{1+\frac{1}{\chi}}}{1+\frac{1}{\chi}} \exp \varepsilon_{l,t} \right], \tag{1}$$

and its budget constraint is

$$P_t\, C_t + B_t = \int_0^1 P_t W_t(m)\, l_t(m) dm + r_{t-1}\, B_{t-1} + T_t\,,$$

where E_t is the expectation operator conditional on information available in period t, P_t is the price of the composite good, $l_t(m)$ and $W_t(m)$ are household member m's labor supply and real wage, B_t is the purchase of one-period (riskless) bonds, r_t is the interest rate on the bonds and is assumed to coincide with the monetary policy rate, T_t consists of lump-sum taxes and transfers as well as firms' profits received, $\varepsilon_{c,t}$ and $\varepsilon_{l,t}$ are shocks to preferences for consumption and labor supply, $\beta \in (0,1)$ is the subjective discount factor, $h \in [0,1]$ is the degree of (external) habit persistence in consumption preferences, and $\chi \geq 0$ is the household's elasticity of supply of aggregate labor l_t.

Household members have heterogeneous preferences for jobs. The aggregate labor index l_t is of the form used in, for example, Berger et al. (2022):

$$l_t = \left[\int_0^1 (l_t(m))^{\frac{1+\theta_{wd}}{\theta_{wd}}} dm \right]^{\frac{\theta_{wd}}{1+\theta_{wd}}}, \tag{2}$$

where $\theta_{wd} > 0$ is the elasticity of substitution between supply of individual differentiated labor. To allocate its members among the differentiated jobs, the household minimizes the aggregate labor index l_t for a given level of its labor income $\int_0^1 P_t W_t(m)\, l_t(m) dm$. This yields each member's labor supply curve

$$l_t(m) = l_t \left(\frac{P_t W_t(m)}{P_t W_t} \right)^{\theta_{wd}} \tag{3}$$

and the aggregate (nominal) wage index

$$P_t W_t = \left[\int_0^1 \left(P_t W_t(m)\right)^{1+\theta_{wd}} dm \right]^{\frac{1}{1+\theta_{wd}}}, \tag{4}$$

which imply that $P_t W_t\, l_t = \int_0^1 P_t W_t(m)\, l_t(m) dm$.

The household chooses aggregate labor supply, consumption, and bond purchases so as to maximize the utility function (1) subject to the budget constraint, which can be rewritten as

$$P_t\, C_t + B_t = P_t W_t\, l_t + r_{t-1}\, B_{t-1} + T_t\,.$$

Given the complete contingent claims for consumption and the consumption habit formation process $H_t = C_{t-1}$, the first-order conditions for utility maximization lead to

$$W_t = MRS_t\,, \tag{5}$$

$$\Lambda_t = \frac{\exp \varepsilon_{c,t}}{C_t - h\, C_{t-1}}, \tag{6}$$

$$1 = E_t \left(\frac{\beta\, \Lambda_{t+1}}{\Lambda_t} \frac{r_t}{\pi_{t+1}} \right), \tag{7}$$

where MRS_t denotes the marginal rate of substitution (MRS) between consumption and labor, given by

$$MRS_t \equiv \frac{l_t^{\frac{1}{\chi}} \exp \varepsilon_{l,t}}{\Lambda_t}, \tag{8}$$

Λ_t is the marginal utility of consumption, and $\pi_t = P_t / P_{t-1}$ is the inflation rate. The growth rate of the aggregate wage is

$$\pi_{w,t} \equiv \frac{P_t W_t}{P_{t-1} W_{t-1}} = \pi_t \frac{W_t}{W_{t-1}}. \tag{9}$$

2.2 Wholesalers

A representative wholesaler produces output $Y_{w,t}$ using the Cobb-Douglas production technology

$$Y_{w,t} = A_t \, l_{d,t}^{1-\alpha} \, K_{d,t}^{\alpha} \,, \tag{10}$$

where A_t denotes total factor productivity (TFP), $l_{d,t} = \int_0^1 l_t(m)dm$ and $K_{d,t}$ are labor and capital inputs, and $\alpha \in (0,1)$ is the capital elasticity of production. TFP consists of

$$A_t \equiv \tilde{A}_t^{1-\alpha} \exp \varepsilon_{a,t} \,, \tag{11}$$

where the deterministic component $\tilde{A}_t$ is governed by the nonstationary process

$$\log \tilde{A}_t = \log g_{\tilde{A}} + \log \tilde{A}_{t-1} \,, \tag{12}$$

so $g_{\tilde{A}}$ denotes the growth rate of $\tilde{A}_t$, and the stochastic component $\varepsilon_{a,t}$ is a TFP shock.

The present expected discounted value of the wholesaler's profit is

$$E_0 \sum_{t=0}^{\infty} S_{0,t} \left(P_t mc_t \, Y_{w,t} - \int_0^1 P_t W_t(m) \, l_t(m) \exp \tilde{\varepsilon}_{wd,t} \, dm - P_t R_{k,t} \, K_{d,t} \right),$$

where $S_{t,t+j}$ is the (nominal) stochastic discount factor between period t and period $t+j$, $P_t mc_t$ denotes the wholesale good's price, and $\tilde{\varepsilon}_{w,t}$ is a shock to the wage markdown explained later.

The wholesaler sets individual workers' wages $\{P_t W_t(m)\}$ on a staggered basis as in Calvo (1983). In each period, a fraction $\xi_w \in (0,1)$ of wages are indexed to a weighted average of the past wage growth rate $\pi_{w,t-1}$ and its steady-state rate π_w, while the remaining fraction of wages is set identically to maximize relevant profit

$$E_t \sum_{j=0}^{\infty} \xi_w^j \, S_{t,t+j} \left[P_{t+j} mc_{t+j} \, Y_{w,t+j} - P_t W_t(m) \prod_{k=1}^{j} \left(\pi_{w,t+k-1}^{\iota_w} \pi_w^{1-\iota_w} \right) l_{t+j|t}(m) \exp \tilde{\varepsilon}_{wd,t+j} \right]$$

subject to the production technology (10) and the individual labor supply curve

$$l_{t+j|t}(m) = l_{t+j}\left[\frac{P_t W_t(m)\prod_{k=1}^{j}\left(\pi_{w,t+k-1}^{\iota_w}\pi_w^{1-\iota_w}\right)}{P_{t+j}W_{t+j}}\right]^{\theta_{wd}},$$

where $\iota_w \in [0,1]$ is the weight on the past wage growth rate in the wage indexation. The first-order condition for wage setting is written as

$$\begin{aligned}0 = E_t\sum_{j=0}^{\infty}(\beta\xi_w)^j\,\Lambda_{t+j}W_{t+j}l_{t+j}\exp\tilde{\varepsilon}_{wd,t+j}\left[w_t^*\prod_{k=1}^{j}\frac{\pi_w}{\pi_{w,t+k}}\left(\frac{\pi_{w,t+k-1}}{\pi_w}\right)^{\iota_w}\right]^{\theta_{wd}}\\ \times\left[w_t^*\prod_{k=1}^{j}\frac{\pi_w}{\pi_{w,t+k}}\left(\frac{\pi_{w,t+k-1}}{\pi_w}\right)^{\iota_w}-\frac{\theta_{wd}}{1+\theta_{wd}}\exp(-\tilde{\varepsilon}_{wd,t+j})\,\frac{MPL_{t+j}}{W_{t+j}}\right],\end{aligned} \tag{13}$$

where the equilibrium condition for the discount factor $S_{t,t+j} = (\beta^j\Lambda_{t+j}/\Lambda_t)(P_t/P_{t+j})$ is used, $w_t^* \equiv W_t^*/W_t$, W_t^* is the real wage optimized by the wholesaler in period t, and

$$MPL_t \equiv (1-\alpha)\,mc_t\,\frac{Y_{w,t}}{l_{d,t}} \tag{14}$$

denotes the marginal revenue product of labor (MPL). Eq. (14) implies that real unit labor cost is decomposed into not only real marginal cost but also the wage markdown:

$$ulc_t \equiv \frac{W_t\,l_{d,t}}{Y_{w,t}} = (1-\alpha)\,mc_t\left(\frac{W_t}{MPL_t}\right). \tag{15}$$

Under staggered wage-setting, the aggregate wage index (4) can be reduced to

$$1 = \xi_w\left[\frac{\pi_w}{\pi_{w,t}}\left(\frac{\pi_{w,t-1}}{\pi_w}\right)^{\iota_w}\right]^{1+\theta_{wd}} + (1-\xi_w)(w_t^*)^{1+\theta_{wd}}\,. \tag{16}$$

Note that if all wages are flexible (i.e., $\xi_w = 0$), Eqs. (13) and (16) imply that

$$\frac{W_t}{MPL_t} = \frac{\theta_{wd}}{1+\theta_{wd}}\exp(-\tilde{\varepsilon}_{wd,t})\,,$$

so that $\theta_{wd}/\left(1+\theta_{wd}\right)$ represents the steady-state wage markdown and a positive markdown shock $\tilde{\varepsilon}_{wd,t}$ indeed increases the markdown of the wage from the MPL.

The first-order condition for capital input is

$$R_{k,t} = \alpha\, mc_t\, A_t\, l_{d,t}^{1-\alpha} K_{d,t}^{\alpha-1} = \alpha\, mc_t\, \frac{Y_{w,t}}{K_{d,t}},$$

which combined with the MPL (14) implies that

$$mc_t = \left(\frac{MPL_t}{(1-\alpha)\,\tilde{A}_t}\right)^{1-\alpha} \left(\frac{R_{k,t}}{\alpha}\right)^{\alpha} \exp(-\varepsilon_{a,t})\,. \tag{17}$$

Using the individual labor supply curves (3), the labor input equation $l_{d,t} = \int_0^1 l_t(m)dm$ can be rewritten as

$$l_t = l_{d,t}\, \Delta_{w,t}\,, \tag{18}$$

where

$$\Delta_{w,t} = \left[\int_0^1 \left(\frac{P_t W_t(m)}{P_t W_t}\right)^{\theta_{wd}} dm\right]^{-1}$$

represents a disutility from relative wage dispersion under staggered wage-setting. Larger relative wage dispersion raises the household's disutility of supplying a given amount of individual labor $\{l_t(m)\}$ by increasing the aggregate labor index l_t. That is because relative wage dispersion leads workers to concentrate more of their labor in jobs with higher wages, against the household's preferences for aggregate labor supply. If each worker receives the same wage $P_t W_t(m) = P_t W_t$, the disutility is minimized at $\Delta_{w,t} = 1$. Under staggered wage-setting, the disutility from relative wage dispersion can be rewritten as

$$\Delta_{w,t}^{-1} = \xi_w \Delta_{w,t-1}^{-1} \left[\frac{\pi_w}{\pi_{w,t}} \left(\frac{\pi_{w,t-1}}{\pi_w}\right)^{\iota_w}\right]^{\theta_{wd}} + (1-\xi_w)(w_t^*)^{\theta_{wd}}\,. \tag{19}$$

2.3 Composite-good producers

A representative composite-good producer combines the outputs of a continuum of retailers $f \in [0,1]$, each of which produces one kind of differentiated good $Y_t(f)$, according to

$$Y_t = \left[\int_0^1 Y_t(f)^{\frac{\theta_p - 1}{\theta_p}} df\right]^{\frac{\theta_p}{\theta_p - 1}}, \tag{20}$$

where $\theta_p > 1$ is the elasticity of substitution between demand for individual differentiated goods. The composite-good producer maximizes profit $P_t Y_t - \int_0^1 P_t(f) Y_t(f) df$ subject to the goods demand aggregator (20), given the composite good's price P_t and individual goods' prices $\{P_t(f)\}$. The first-order condition for profit maximization leads to the demand curve for each individual good

$$Y_t(f) = Y_t \left(\frac{P_t(f)}{P_t} \right)^{-\theta_p}. \tag{21}$$

Combining the aggregator (20) and the demand curve (21) yields the price index

$$P_t = \left[\int_0^1 P_t(f)^{1-\theta_p} df \right]^{\frac{1}{1-\theta_p}}. \tag{22}$$

2.4 Retailers

Each retailer $f \in [0, 1]$ produces one kind of differentiated good $Y_t(f)$ from the wholesale good and sets its product price $P_t(f)$ on a staggered basis as in Calvo (1983), given the demand curve (21) and the wholesale good's price $P_t mc_t$.

In each period, a fraction $\xi_p \in (0, 1)$ of retailers index prices to a weighted average of the past inflation rate π_{t-1} and its steady-state rate π, while the remaining fraction of retailers sets the price $P_t(f)$ identically so as to maximize relevant profit

$$E_t \sum_{j=0}^{\infty} \xi_p^j S_{t,t+j} \left[P_t(f) \prod_{k=1}^{j} \left(\pi_{t+k-1}^{\iota_p} \pi^{1-\iota_p} \right) - P_{t+j} mc_{t+j} \exp \tilde{\varepsilon}_{p,t+j} \right] Y_{t+j|t}(f)$$

subject to the demand curve

$$Y_{t+j|t}(f) = Y_{t+j} \left[\frac{P_t(f) \prod_{k=1}^{j} \left(\pi_{t+k-1}^{\iota_p} \pi^{1-\iota_p} \right)}{P_{t+j}} \right]^{-\theta_p},$$

where $\iota_p \in [0, 1]$ is the weight on the past inflation rate in the price indexation and $\tilde{\varepsilon}_{p,t}$ represents a shock to the price markup.

The first-order condition for price setting is written as

$$0 = E_t \sum_{j=0}^{\infty} (\beta\xi_p)^j \, \Lambda_{t+j} Y_{t+j} \left[p_t^* \prod_{k=1}^{j} \frac{\pi}{\pi_{t+k}} \left(\frac{\pi_{t+k-1}}{\pi} \right)^{\iota_p} \right]^{-\theta_p}$$
$$\times \left[p_t^* \prod_{k=1}^{j} \frac{\pi}{\pi_{t+k}} \left(\frac{\pi_{t+k-1}}{\pi} \right)^{\iota_p} - \frac{\theta_p}{\theta_p - 1} \exp(\tilde{\varepsilon}_{p,t+j}) \; mc_{t+j} \right], \tag{23}$$

where $p_t^* \equiv P_t^*/P_t$ and P_t^* is the price optimized by retailers in period t. Under staggered price-setting, eq. (22) can be reduced to

$$1 = \xi_p \left[\frac{\pi}{\pi_t} \left(\frac{\pi_{t-1}}{\pi} \right)^{\iota_p} \right]^{1-\theta_p} + (1 - \xi_p)(p_t^*)^{1-\theta_p}. \tag{24}$$

Using the individual goods demand curves (21), the wholesale-good market clearing condition can be written as

$$Y_{w,t} = \int_0^1 Y_t(f) \, df = Y_t \Delta_{p,t}, \tag{25}$$

where

$$\Delta_{p,t} = \int_0^1 \left(\frac{P_t(f)}{P_t} \right)^{-\theta_p} df$$

represents a relative price distortion, which can be reduced, under staggered price-setting, to

$$\Delta_{p,t} = \xi_p \, \Delta_{p,t-1} \left[\frac{\pi}{\pi_t} \left(\frac{\pi_{t-1}}{\pi} \right)^{\iota_p} \right]^{-\theta_p} + (1 - \xi_p)(p_t^*)^{-\theta_p} . \tag{26}$$

2.5 Capital-service providers

The representative capital-service provider adjusts the utilization rate u_t on capital K_{t-1} to supply capital services $u_t K_{t-1}$ to the wholesaler at the rental rate $P_t R_{k,t}$. Thus, the capital-service market clearing condition is

$$u_t K_{t-1} = K_{d,t} \, . \tag{27}$$

After the wholesaler's production, capital is depreciated at the rate $\delta(u_t)$. As in Greenwood et al. (1988), a higher utilization rate is assumed to result in a higher depreciation rate. Specifically, the depreciation rate is of the form $\delta(u_t) \equiv \delta + \delta_1 (u_t - 1) + (\delta_2/2) (u_t - 1)^2$

with $\delta \in (0,1)$, $\delta_1 > 0$, and $\delta_2 > 0$, following Schmitt-Grohé and Uribe (2012). Then, the capital-service provider makes a capital investment I_t using the technology that converts one unit of the composite good into Ψ_t units of capital, subject not only to an adjustment cost $O((I_t/I_{t-1})/(g_Z g_\Psi)) \equiv (\zeta/2)[(I_t/I_{t-1})/(g_Z g_\Psi) - 1]^2$ with $\zeta > 0$, advocated by Christiano et al. (2005), but also to a shock to the marginal efficiency of investment (MEI) $\varepsilon_{i,t}$, proposed by Greenwood et al. (1988). Thus, Ψ_t represents the level of investment-specific technology. The level Ψ_t is governed by the nonstationary deterministic process

$$\log \Psi_t = \log g_\Psi + \log \Psi_{t-1}, \tag{28}$$

where g_Ψ is the rate of investment-specific technological change.[14] The level Ψ_t and the TFP's deterministic component $\tilde{A}_t$ give rise to the level of composite technology

$$Z_t \equiv \tilde{A}_t \Psi_t^{\alpha/(1-\alpha)}, \tag{29}$$

which leads to a balanced growth path of the economy. The rate of the composite technological change Z_t/Z_{t-1} then meets $g_Z = g_{\tilde{A}} g_\Psi^{\alpha/(1-\alpha)}$. Consequently, the capital-service provider chooses the utilization rate u_t, investment I_t, and capital K_t so as to maximize its profit

$$E_0 \sum_{t=0}^{\infty} S_{0,t} \left(P_t R_{k,t}\, u_t K_{t-1} - P_t \frac{I_t}{\Psi_t} \right)$$

subject to the capital accumulation equation

$$K_t = (1 - \delta(u_t))\, K_{t-1} + \left[1 - O\left(\frac{I_t/I_{t-1}}{g_Z g_\Psi} \right) \right] I_t \exp \varepsilon_{i,t}\,. \tag{30}$$

The first-order conditions for profit maximization with respect to u_t, I_t, and K_t are given by

$$R_{k,t} = Q_t\, \delta'(u_t), \tag{31}$$

[14] Justiniano et al. (2011) find that MEI shocks are a much more important driver of US business cycles than investment-specific technology shocks. Thus our model abstracts from the latter shocks.

$$\frac{1}{\Psi_t} = Q_t \left[1 - O\left(\frac{I_t/I_{t-1}}{g_Z g_\Psi} \right) - O'\left(\frac{I_t/I_{t-1}}{g_Z g_\Psi} \right) \frac{I_t/I_{t-1}}{g_Z g_\Psi} \right] \exp \varepsilon_{i,t}$$
$$+ E_t \left[\frac{\beta \Lambda_{t+1}}{\Lambda_t} Q_{t+1} \, O'\left(\frac{I_{t+1}/I_t}{g_Z g_\Psi} \right) \frac{(I_{t+1}/I_t)^2}{g_Z g_\Psi} \exp \varepsilon_{i,t+1} \right], \tag{32}$$

$$1 = E_t \left[\frac{\beta \Lambda_{t+1}}{\Lambda_t} \frac{R_{k,t+1} u_{t+1} + Q_{t+1} \left(1 - \delta(u_{t+1})\right)}{Q_t} \right], \tag{33}$$

where Q_t is the real price of capital.

The composite-good market clearing condition is

$$Y_t = C_t + \frac{I_t}{\Psi_t} + G_t \, , \tag{34}$$

where G_t denotes exogenous spending other than consumption and investment, including government spending. The spending is determined by

$$G_t = \frac{G}{Y} Y_t \exp \tilde{\varepsilon}_{g,t} \, , \tag{35}$$

where G/Y is the steady-state output ratio of exogenous spending and $\tilde{\varepsilon}_{g,t}$ is an exogenous spending shock.

2.6 Monetary authority

The monetary authority adjusts its policy rate in response to inflation, output, and output growth in the presence of policy-rate smoothing. Specifically, the authority sets the rate according to a rule of the sort proposed by Taylor (1993):

$$\log r_t = \phi_r \log r_{t-1} + (1 - \phi_r) \left[\log r + \phi_\pi (\log \pi_t - \log \pi) + \phi_y \left(\log \frac{Y_t}{Z_t} - \log y \right) \right.$$
$$\left. + \phi_{gy} \left(\log \frac{Y_t}{Y_{t-1}} - \log g_Z \right) \right] + \varepsilon_{r,t} \, , \tag{36}$$

where r is the steady-state policy rate, y is the steady-state level of detrended output $y_t = Y_t/Z_t$, $\varepsilon_{r,t}$ is a shock to the policy rate, and $\phi_r \in [0, 1)$, $\phi_\pi > 0$, $\phi_y > 0$, and $\phi_{gy} > 0$ are the degrees of policy-rate smoothing and policy responses to inflation, output, and output growth, respectively.

2.7 Equilibrium conditions

The equilibrium conditions of the model consist of (5)–(14), (16)–(19), (23)–(35), and (36), along with the stationary processes of eight shocks $\varepsilon_{c,t}$, $\varepsilon_{a,t}$, $\varepsilon_{i,t}$, $\tilde{\varepsilon}_{g,t}$, $\varepsilon_{r,t}$, $\tilde{\varepsilon}_{p,t}$, $\tilde{\varepsilon}_{wd,t}$, and $\varepsilon_{l,t}$. The conditions are detrended using the composite technology level Z_t and the investment-specific technology level Ψ_t and then log-linearized for estimating parameters of the model.

In the log-linearized equilibrium conditions of the model, the aggregate wage growth rate $\hat{\pi}_{w,t}$ evolves according to the wage Phillips curve

$$\hat{\pi}_{w,t} = \frac{\iota_w}{1+\beta\iota_w}\,\hat{\pi}_{w,t-1} + \frac{\beta}{1+\beta\iota_w}\,E_t\hat{\pi}_{w,t+1} - \kappa_{wd}\left(\hat{w}_t - \hat{mpl}_t\right) - \varepsilon_{wd,t} \tag{37}$$

and aggregate labor $\hat{l}_t$ is determined on the aggregate labor supply curve

$$\hat{w}_t = \hat{mrs}_t\,, \tag{38}$$

where hatted variables denote log-deviations from steady-state values, $w_t \equiv W_t/Z_t$, $mpl_t \equiv MPL_t/Z_t$, and $mrs_t \equiv MRS_t/Z_t$. Therefore, the wage Phillips curve (37) turns out to be an aggregate labor demand curve and shows that wage growth is driven by the wage markdown $\hat{w}_t - \hat{mpl}_t$ with its coefficient (i.e., the slope of the curve) given by $\kappa_{wd} \equiv (1-\xi_w)(1-\beta\xi_w)/[\xi_w(1+\beta\iota_w)]$ and that $\varepsilon_{wd,t} \equiv \kappa_{wd}\,\tilde{\varepsilon}_{wd,t}$ is a rescaled shock to the markdown.

The remaining log-linearized equilibrium conditions are standard:

$$\hat{\pi}_t = \frac{\iota_p}{1+\beta\iota_p}\,\hat{\pi}_{t-1} + \frac{\beta}{1+\beta\iota_p}\,E_t\hat{\pi}_{t+1} + \kappa_p\,\hat{mc}_t + \varepsilon_{p,t}\,, \tag{39}$$

$$\hat{r}_t = \phi_r\hat{r}_{t-1} + (1-\phi_r)[\phi_\pi\hat{\pi}_t + \phi_y\hat{y}_t + \phi_{gy}(\hat{y}_t - \hat{y}_{t-1})] + \varepsilon_{r,t}\,, \tag{40}$$

$$\hat{\lambda}_t - E_t\hat{\lambda}_{t+1} = \hat{r}_t - E_t\hat{\pi}_{t+1}\,, \tag{41}$$

$$\hat{\lambda}_t = -\frac{g_Z}{g_Z - h}\,\hat{c}_t + \frac{h}{g_Z - h}\,\hat{c}_{t-1} + \varepsilon_{c,t}\,, \tag{42}$$

$$\hat{\pi}_{w,t} = \hat{\pi}_t + \hat{w}_t - \hat{w}_{t-1}\,, \tag{43}$$

$$\hat{mrs}_t = \frac{1}{\chi}\,\hat{l}_t - \hat{\lambda}_t + \varepsilon_{l,t}\,, \tag{44}$$

$$\hat{k}_t = \frac{1-\delta}{g_Z g_\Psi}\,\hat{k}_{t-1} - \left(\frac{1}{\beta} - \frac{1-\delta}{g_Z g_\Psi}\right)\hat{u}_t + \left(1 - \frac{1-\delta}{g_Z g_\Psi}\right)\left(\hat{i}_t + \varepsilon_{i,t}\right), \tag{45}$$

$$\hat{\lambda}_t - E_t\hat{\lambda}_{t+1} = \left(1 - \frac{\beta(1-\delta)}{g_Z g_\Psi}\right) E_t \hat{r}_{k,t+1} + \frac{\beta(1-\delta)}{g_Z g_\Psi} E_t \hat{q}_{t+1} - \hat{q}_t \,, \tag{46}$$

$$\hat{q}_t = \zeta\left(\hat{i}_t - \hat{i}_{t-1}\right) - \beta\zeta\left(E_t\hat{i}_{t+1} - \hat{i}_t\right) - \varepsilon_{i,t} \,, \tag{47}$$

$$\hat{r}_{k,t} = \hat{q}_t + \frac{\delta_2}{\delta_1}\,\hat{u}_t \,, \tag{48}$$

$$\hat{y}_t = (1-\alpha)\,\hat{l}_t + \alpha\left(\hat{u}_t + \hat{k}_{t-1}\right) + \varepsilon_{a,t} \,, \tag{49}$$

$$\hat{mpl}_t = \hat{y}_t - \hat{l}_t + \hat{mc}_t \,, \tag{50}$$

$$\hat{mc}_t = (1-\alpha)\,\hat{mpl}_t + \alpha\,\hat{r}_{k,t} - \varepsilon_{a,t} \,, \tag{51}$$

$$\left(1 - \frac{G}{Y}\right)\hat{y}_t = \frac{c}{y}\,\hat{c}_t + \frac{i}{y}\,\hat{i}_t + \varepsilon_{g,t} \,, \tag{52}$$

where $\varepsilon_{g,t} \equiv (G/Y)\,\tilde{\varepsilon}_{g,t}$ and $\varepsilon_{p,t} \equiv \kappa_p\,\tilde{\varepsilon}_{p,t}$ are rescaled shocks to exogenous spending and to the price markup, the slope of the price Phillips curve (39) is $\kappa_p \equiv (1-\xi_p)(1-\beta\xi_p)/[\xi_p(1+\beta\iota_p)]$, and the steady-state output ratios of consumption and investment are given by $c/y = 1 - G/Y - i/y$ and $i/y = \alpha[g_Z g_\Psi - (1-\delta)](mc/r_k)$ along with the steady-state values $r_k = g_Z g_\Psi/\beta - (1-\delta)$ and $mc = (\theta_p - 1)/\theta_p$.

In our model, the labor preference shock $\varepsilon_{l,t}$ and the wage markdown shock $\varepsilon_{wd,t}$ are separately identified. The former shock is a disturbance to the aggregate labor supply curve (38), as can be seen from the MRS (44). The wage markdown shock is a disturbance to the wage Phillips curve (37), which is the aggregate labor demand curve as noted above, and thus the shock is identified as a labor *demand* shock.

3 Model Estimation Procedure

This section explains the procedure for estimating the log-linearized model presented in the preceding section.

The model is estimated with full-information Bayesian methods using quarterly US time series. For the estimation, we assume as in the literature that the price markup and wage markdown shocks are governed by the ARMA(1,1) processes

$$\varepsilon_{n,t} = \rho_n\,\varepsilon_{n,t-1} + \zeta_{n,t} - \nu_n\,\zeta_{n,t-1}, \quad n \in \{p, wd\},$$

while the other shocks are governed by the AR(1) processes

$$\varepsilon_{n,t} = \rho_n \, \varepsilon_{n,t-1} + \zeta_{n,t}, \quad n \in \{c, a, i, g, r, l\}, \tag{53}$$

where $\rho_n \in [0, 1)$, $\nu_n \in [0, 1)$, and $\zeta_{n,t} \sim$ i.i.d. $N(0, \sigma_n^2)$.

3.1 Data

The data used in the model estimation are seven US quarterly time series on the output growth rate $\Delta \log Y_t$, the consumption growth rate $\Delta \log C_t$, the investment growth rate $\Delta \log I_t$, the real wage growth rate $\Delta \log W_t$, labor or, equivalently, hours worked $\log l_t$, the inflation rate $\log \pi_t$, and the interest rate $\log r_t$ during the period from 1984:Q1 through 2008:Q4.[15] These time series are the same as those of Smets and Wouters (2007), except that our paper uses the data on per capita real investment growth because of the presence of investment-specific technological change.[16] Thus the observation equations that relate the data to the corresponding variables in the model are given by

$$\begin{bmatrix} 100\Delta \log Y_t \\ 100\Delta \log C_t \\ 100\Delta \log I_t \\ 100\Delta \log W_t \\ 100 \log l_t \\ 100 \log \pi_t \\ 100 \log r_t \end{bmatrix} = \begin{bmatrix} \overline{g_Z} \\ \overline{g_Z} \\ \overline{g_Z} + \overline{g_\Psi} \\ \overline{g_Z} \\ \bar{l} \\ \overline{\pi} \\ \overline{r} \end{bmatrix} + \begin{bmatrix} \hat{y}_t - \hat{y}_{t-1} \\ \hat{c}_t - \hat{c}_{t-1} \\ \hat{i}_t - \hat{i}_{t-1} \\ \hat{w}_t - \hat{w}_{t-1} \\ \hat{l}_t \\ \hat{\pi}_t \\ \hat{r}_t \end{bmatrix},$$

where $\overline{g_Z} \equiv 100(g_Z - 1)$, $\overline{g_\Psi} \equiv 100(g_\Psi - 1)$, $\bar{l} \equiv 100 \log l$, $\overline{\pi} \equiv 100(\pi - 1)$, and $\overline{r} \equiv 100(r - 1)$.

[15]The sample period starts after the Great Inflation era during which equilibrium is likely to be indeterminate in standard DSGE models as argued in the literature, including Lubik and Schorfheide (2004) and Hirose et al. (2020). Moreover, the sample period ends before the (nominal) interest rate reaches its effective lower bound (ELB), so the estimation is not subject to the nonlinearity arising from the ELB. The Appendix presents the estimation results for the longer sample period until 2019:Q4 (before the COVID-19 pandemic), using the shadow federal funds rate of Wu and Xia (2016) when the interest rate is at the ELB, and shows that the results remain qualitatively the same.

[16]Smets and Wouters (2007) employ the data on the growth rate of nominal investment per capita deflated by the GDP deflator in the absence of investment-specific technological change.

Before estimation, the values of four parameters in the model are fixed. We set the capital elasticity of production at $\alpha = 1/3$, the (quarterly) depreciation rate of capital at $\delta = 0.1/4 = 0.025$ (i.e., 10 percent annually), and the parameter governing the elasticity of substitution between demand for individual goods at $\theta_p = 7$. These values are widely used in the macroeconomic literature. The steady-state output ratio of exogenous spending is set at the average of the GDP ratio of spending other than consumption and investment over the sample period 1984:Q1–2008:Q4, i.e., $G/Y = 0.172$.

3.2 Prior distributions

Table 1: Prior distributions for estimated parameters of the quarterly model

Parameter		Distribution	Mean	St. dev.
$\overline{g_Z}$	Steady-state output growth rate	Normal	0.444	0.100
$\overline{g_\Psi}$	Steady-state rate of investment-specific technological change	Normal	0.114	0.100
$\overline{l}$	Normalized log steady-state labor	Normal	0.000	0.100
$\overline{r}$	Steady-state interest rate	Gamma	1.294	0.100
$\overline{\pi}$	Steady-state inflation rate	Normal	0.610	0.100
h	Consumption habit persistence	Beta	0.700	0.100
χ	Elasticity of aggregate labor supply	Gamma	1.000	0.200
δ_2/δ_1	Parameter governing capital utilization adjustment costs	Gamma	0.750	0.100
ζ	Elasticity of investment adjustment costs	Gamma	4.000	1.500
ξ_p	Degree of price rigidity	Beta	0.500	0.100
ι_p	Degree of price indexation	Beta	0.500	0.150
ξ_w	Degree of nominal wage rigidity	Beta	0.500	0.100
ι_w	Degree of nominal wage indexation	Beta	0.500	0.150
ϕ_r	Monetary policy-rate smoothing	Beta	0.750	0.100
ϕ_π	Monetary policy response to inflation	Gamma	1.500	0.250
ϕ_y	Monetary policy response to output	Gamma	0.125	0.050
ϕ_{gy}	Monetary policy response to output growth	Gamma	0.125	0.050
ρ_j	AR(1) coefficient of shock $\varepsilon_{j,t}$, $j \in \{c, a, i, g, r, p, l, wd\}$	Beta	0.500	0.200
ν_j	MA(1) coefficient of shock $\varepsilon_{j,t}$, $j \in \{p, wd\}$	Beta	0.500	0.200
σ_j	St. dev. of shock innovation $\zeta_{j,t}$, $j \in \{c, a, i, g, r, p, l, wd\}$	Inv. gamma	0.100	2.000

All the other parameters of the model are estimated.[17] Their prior distributions are presented in Table 1. The prior mean of the steady-state quarterly rates of output growth, investment-specific technological change, interest, and inflation ($\overline{g_Z}$, $\overline{g_\Psi}$, $\overline{r}$, and $\overline{\pi}$) is set at the respective averages of the growth rate of real GDP per capita, the rate of change in the ratio of the investment deflator to the GDP deflator, the federal funds rate, and the

[17]For the discount factor β, the steady-state condition $\beta = \pi g_Z / r$ is used in the estimation.

inflation rate of the GDP deflator over the sample period 1984:Q1–2008:Q4. The prior mean of log steady-state labor $\bar{l}$ is chosen at zero as the data on log hours worked are demeaned for normalization. The prior distributions for the remaining parameters are the same as those used in Smets and Wouters (2007), except for the following two. We set the prior mean of the elasticity of aggregate labor supply at $\chi = 1$, a standard value used in the macroeconomic literature, and the prior mean of the parameter governing adjustment costs of capital utilization at $\delta_2/\delta_1 = 0.75$ as in Schmitt-Grohé and Uribe (2012).

4 Empirical Results

To explain the empirical results of the model, we compare them to those of its standard counterpart model with households' monopolistic wage-setting.

4.1 Counterpart model with households' monopolistic wage-setting

We begin by describing the counterpart model with households' staggered wage-setting under monopolistic competition. In the model, a representative household sets its members' wages subject to a representative wholesaler's demand curves for their differentiated labor, while the wholesaler produces its output using an aggregate of its demand for all household members' labor $\{l_t(m)\}$:

$$l_t = \left[\int_0^1 (l_t(m))^{\frac{\theta_{wu}-1}{\theta_{wu}}} \, dm \right]^{\frac{\theta_{wu}}{\theta_{wu}-1}}, \tag{54}$$

where $\theta_{wu} > 1$ denotes the elasticity of substitution between the wholesaler's demand for individual differentiated labor and also represents the wage elasticity of labor demand. This aggregator leads to the wholesaler's demand curve for each individual labor $l_t(m) = l_t \left[(P_t W_t(m)) \, / \, (P_t W_t) \right]^{-\theta_{wu}}$ and hence the aggregate wage index

$$P_t W_t = \left[\int_0^1 (P_t W_t(m))^{1-\theta_{wu}} \, dm \right]^{\frac{1}{1-\theta_{wu}}}. \tag{55}$$

The representative household's preferences are represented as the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\log(C_t - h\, H_t) \exp \varepsilon_{c,t} - \int_0^1 \frac{(l_t(m))^{1+\frac{1}{\chi}}}{1+\frac{1}{\chi}} \exp \varepsilon_{l,t}\, dm \right].$$

Its members' wages $\{P_t W_t(m)\}$ are set on a staggered basis as in Calvo (1983). In each period, a fraction $\xi_w \in (0,1)$ of wages are indexed to a weighted average of the past wage growth rate $\pi_{w,t-1}$ and its steady-state rate π_w, while the remaining fraction of wages is set identically so as to maximize the relevant utility function

$$E_t \sum_{j=0}^{\infty} (\beta \xi_w)^j \left[-\frac{\left(l_{t+j|t}(m)\right)^{1+\frac{1}{\chi}}}{1+\frac{1}{\chi}} \exp \varepsilon_{l,t+j} + \frac{\Lambda_{t+j}}{P_{t+j}} P_t W_t(m) \prod_{k=1}^{j} \left(\pi_{w,t+k-1}^{\iota_w} \pi_w^{1-\iota_w} \right) l_{t+j|t}(m) \exp\left(-\tilde{\varepsilon}_{wu,t+j}\right) \right]$$

subject to the wholesaler's labor demand curve

$$l_{t+j|t}(m) = l_{t+j} \left[\frac{P_t W_t(m) \prod_{k=1}^{j} \left(\pi_{w,t+k-1}^{\iota_w} \pi_w^{1-\iota_w} \right)}{P_{t+j} W_{t+j}} \right]^{-\theta_{wu}},$$

where $\tilde{\varepsilon}_{wu,t}$ is a shock to the wage markup.

In the equilibrium conditions of the model with households' monopolistic wage-setting, the following four equations are included instead of eqs. (5), (13), (16), (18), and (19):

$$\begin{aligned} 0 = E_t \sum_{j=0}^{\infty} (\beta \xi_w)^j \Lambda_{t+j} l_{t+j|t}(m) \exp\left(-\tilde{\varepsilon}_{wu,t+j}\right) &\left\{ w_t^* \prod_{k=1}^{j} \frac{\pi_w}{\pi_{t+k}} \left(\frac{\pi_{w,t+k-1}}{\pi_w} \right)^{\iota_w} \right. \\ &\left. - \frac{\theta_{wu} \exp \tilde{\varepsilon}_{wu,t+j}}{\theta_{wu}-1} \frac{MRS_{t+j}}{W_{t+j}} \left[w_t^* \prod_{k=1}^{j} \frac{\pi_w}{\pi_{w,t+k}} \left(\frac{\pi_{w,t+k-1}}{\pi_w} \right)^{\iota_w} \right]^{-\frac{\theta_{wu}}{\chi}} \prod_{k=1}^{j} \frac{W_{t+k}}{W_{t+k-1}} \right\}, \end{aligned} \tag{56}$$

$$W_t = MPL_t\,, \tag{57}$$

$$1 = \xi_w \left[\frac{\pi_w}{\pi_{w,t}} \left(\frac{\pi_{w,t-1}}{\pi_w} \right)^{\iota_w} \right]^{1-\theta_{wu}} + (1-\xi_w)(w_t^*)^{1-\theta_{wu}}\,, \tag{58}$$

$$l_t = l_{d,t}\,. \tag{59}$$

Consequently, in the log-linearized equilibrium conditions of the model, the following two equations are included instead of eqs. (37) and (38). The aggregate wage growth rate $\hat{\pi}_{w,t}$

evolves according to the wage Phillips curve

$$\hat{\pi}_{w,t} = \frac{\iota_w}{1+\beta\iota_w}\,\hat{\pi}_{w,t-1} + \frac{\beta}{1+\beta\iota_w}\,E_t\hat{\pi}_{w,t+1} - \kappa_{wu}\left(\hat{w}_t - \hat{mrs}_t\right) + \varepsilon_{wu,t} \tag{60}$$

and aggregate labor $\hat{l}_t$ is determined on the aggregate labor demand curve

$$\hat{w}_t = \hat{mpl}_t\,, \tag{61}$$

where the slope of the curve is $\kappa_{wu} \equiv (1-\xi_w)(1-\beta\xi_w)/[\xi_w(1+\beta\iota_w)(1+\theta_{wu}/\chi)]$ and $\varepsilon_{wu,t} \equiv \kappa_{wu}\,\tilde{\varepsilon}_{wu,t}$ is a rescaled shock to the wage markup. Hence, the wage Phillips curve (60) is the aggregate labor supply curve. Then, it is worth noting that combining the MRS (44) and the wage Phillips curve (60) yields

$$\hat{\pi}_{w,t} = \frac{\iota_w}{1+\beta\iota_w}\,\hat{\pi}_{w,t-1} + \frac{\beta}{1+\beta\iota_w}\,E_t\hat{\pi}_{w,t+1} - \kappa_{wu}\left(\hat{w}_t - \frac{1}{\chi}\,\hat{l}_t + \hat{\lambda}_t\right) + \kappa_{wu}\,\varepsilon_{l,t} + \varepsilon_{wu,t}\,, \tag{62}$$

which implies that the labor preference shock $\varepsilon_{l,t}$ and the wage markup shock $\varepsilon_{wu,t}$ cannot be identified.[18] To avoid overfitting, we disregard the labor preference shock $\varepsilon_{l,t}$ in estimating the log-linearized model with households' monopolistic wage-setting, and assume that the wage markup shock $\varepsilon_{wu,t}$ is governed by the ARMA(1,1) process, as in Smets and Wouters (2007) and Justiniano et al. (2010, 2011). We set the same prior distributions of the AR(1) and MA(1) coefficients and the shock innovations' standard deviation for the wage markup shock $\varepsilon_{wu,t}$ as those for the price markup shock $\varepsilon_{p,t}$, and fix the elasticity of substitution between demand for individual differentiated labor θ_{wu} at 7.

4.2 Model estimation results

We can now proceed to the estimation results of the models presented in the preceding sections. Table 2 reports the posterior estimates of the parameters of our model, the one without the wage markdown shock $\varepsilon_{wd,t}$, the one without the labor preference shock $\varepsilon_{l,t}$, and the counterpart model with households' monopolistic wage-setting that includes the wage

[18] Both shocks are disturbances to aggregate labor supply. The labor preference shock $\varepsilon_{l,t}$ is a disturbance to the disutility of labor, while the wage markup shock $\varepsilon_{wu,t}$ is a disturbance to the wage Phillips curve (60), which is the aggregate labor supply curve in the counterpart model.

Table 2: Posterior estimates of parameters of our model and the counterpart model

	Our model		w/o markdown ε_{wd}		w/o labor preference ε_l		Counterpart model	
Parameter	Mean	90% interval	Mean	90% interval	Mean	90% interval	Mean	90% interval
$\overline{g_Z}$	0.454	[0.419, 0.491]	0.482	[0.452, 0.515]	0.423	[0.358, 0.487]	0.491	[0.466, 0.518]
$\overline{g_\Psi}$	0.287	[0.212, 0.366]	0.321	[0.244, 0.394]	0.273	[0.183, 0.365]	0.306	[0.230, 0.382]
$\bar{l}$	-0.002	[-0.162, 0.161]	-0.004	[-0.168,0.164]	-0.011	[-0.176, 0.148]	0.007	[-0.152, 0.165]
$\bar{r}$	1.320	[1.191, 1.445]	1.319	[1.191, 1.442]	1.332	[1.192, 1.473]	1.301	[1.177, 1.424]
$\bar{\pi}$	0.628	[0.540, 0.716]	0.630	[0.541, 0.713]	0.599	[0.470, 0.728]	0.615	[0.504, 0.729]
h	0.769	[0.608, 0.947]	0.810	[0.670, 0.942]	0.993	[0.990, 0.996]	0.808	[0.701, 0.920]
χ	0.547	[0.388, 0.693]	0.565	[0.414, 0.716]	0.521	[0.369, 0.674]	0.949	[0.639, 1.245]
δ_2/δ_1	0.727	[0.570, 0.875]	0.733	[0.579, 0.877]	0.740	[0.577, 0.906]	0.746	[0.588, 0.890]
ζ	6.717	[3.760, 9.544]	7.164	[4.008, 10.053]	4.603	[2.237,6.885]	6.515	[3.863, 8.913]
ξ_p	0.772	[0.713, 0.827]	0.829	[0.777, 0.881]	0.847	[0.799, 0.890]	0.932	[0.910, 0.953]
ι_p	0.425	[0.204, 0.644]	0.432	[0.208, 0.648]	0.425	[0.163, 0.675]	0.408	[0.168, 0.630]
ξ_w	0.493	[0.357, 0.615]	0.366	[0.246, 0.485]	0.820	[0.676, 0.944]	0.587	[0.409, 0.777]
ι_w	0.341	[0.131, 0.547]	0.355	[0.130, 0.582]	0.158	[0.048, 0.257]	0.227	[0.085, 0.372]
ϕ_r	0.728	[0.671, 0.788]	0.756	[0.707, 0.804]	0.673	[0.597, 0.750]	0.753	[0.701, 0.808]
ϕ_π	2.359	[1.991, 2.736]	2.224	[1.836, 2.591]	2.177	[1.835, 2.514]	1.443	[1.054, 1.791]
ϕ_y	0.063	[0.026, 0.098]	0.064	[0.027, 0.101]	0.060	[0.025, 0.095]	0.144	[0.077, 0.217]
ϕ_{gy}	0.134	[0.061, 0.208]	0.161	[0.075, 0.243]	0.138	[0.071, 0.216]	0.161	[0.069, 0.248]
ρ_c	0.492	[0.223, 0.747]	0.493	[0.265, 0.729]	0.098	[0.022, 0.171]	0.618	[0.432, 0.802]
ρ_a	0.887	[0.819, 0.952]	0.737	[0.635, 0.842]	0.996	[0.992, 1.000]	0.820	[0.737, 0.909]
ρ_i	0.637	[0.543, 0.735]	0.670	[0.585, 0.759]	0.669	[0.584, 0.759]	0.670	[0.583, 0.764]
ρ_g	0.963	[0.946, 0.980]	0.962	[0.944, 0.980]	0.951	[0.935, 0.967]	0.974	[0.959, 0.989]
ρ_r	0.487	[0.377, 0.600]	0.421	[0.313, 0.534]	0.572	[0.467, 0.682]	0.512	[0.390, 0.639]
ρ_p	0.427	[0.095, 0.740]	0.906	[0.841, 0.975]	0.924	[0.826, 0.999]	0.693	[0.466, 0.902]
ν_p	0.528	[0.235, 0.828]	0.607	[0.421, 0.784]	0.632	[0.442, 0.811]	0.558	[0.291, 0.803]
ρ_{wd} or ρ_{wu}	0.952	[0.907, 0.996]	–	–	0.994	[0.989, 0.999]	0.877	[0.771, 0.961]
ν_{wd} or ν_{wu}	0.624	[0.469, 0.783]	–	–	0.870	[0.723, 0.980]	0.730	[0.574, 0.883]
ρ_l	0.977	[0.960, 0.995]	0.970	[0.951, 0.990]	–	–	–	–
σ_c	3.721	[1.340, 6.636]	4.356	[1.593, 7.269]	55.371	[38.041, 73.386]	4.182	[2.063, 6.350]
σ_a	0.468	[0.384, 0.550]	0.581	[0.472, 0.686]	0.467	[0.383, 0.554]	0.448	[0.390, 0.506]
σ_i	6.095	[3.455, 8.652]	6.037	[3.494, 8.402]	4.366	[2.644, 6.140]	5.843	[3.491, 7.752]
σ_g	0.447	[0.397, 0.499]	0.448	[0.395, 0.497]	0.450	[0.395, 0.503]	0.448	[0.396, 0.498]
σ_r	0.131	[0.110, 0.151]	0.122	[0.104, 0.139]	0.139	[0.115, 0.162]	0.112	[0.097, 0.127]
σ_p	0.059	[0.030, 0.089]	0.091	[0.072, 0.111]	0.102	[0.070, 0.132]	0.086	[0.067, 0.105]
σ_{wd} or σ_{wu}	1.012	[0.657, 1.347]	–	–	0.574	[0.443, 0.697]	0.545	[0.443, 0.650]
σ_l	1.374	[1.108, 1.609]	1.412	[1.182, 1.646]	–	–	–	–
log *MDD*	-519.961		-530.283		-574.009		-522.011	

Notes: The table reports the posterior mean and 90 percent highest posterior density interval of each estimated parameter of our model, the one without the wage markdown shock ε_{wd}, the one without the labor preference shock ε_l, and the counterpart model with households' monopolistic wage-setting and the wage markup shock ε_{wu}. The last line of the table presents the log marginal data density (log *MDD*) for each of the four model specifications.

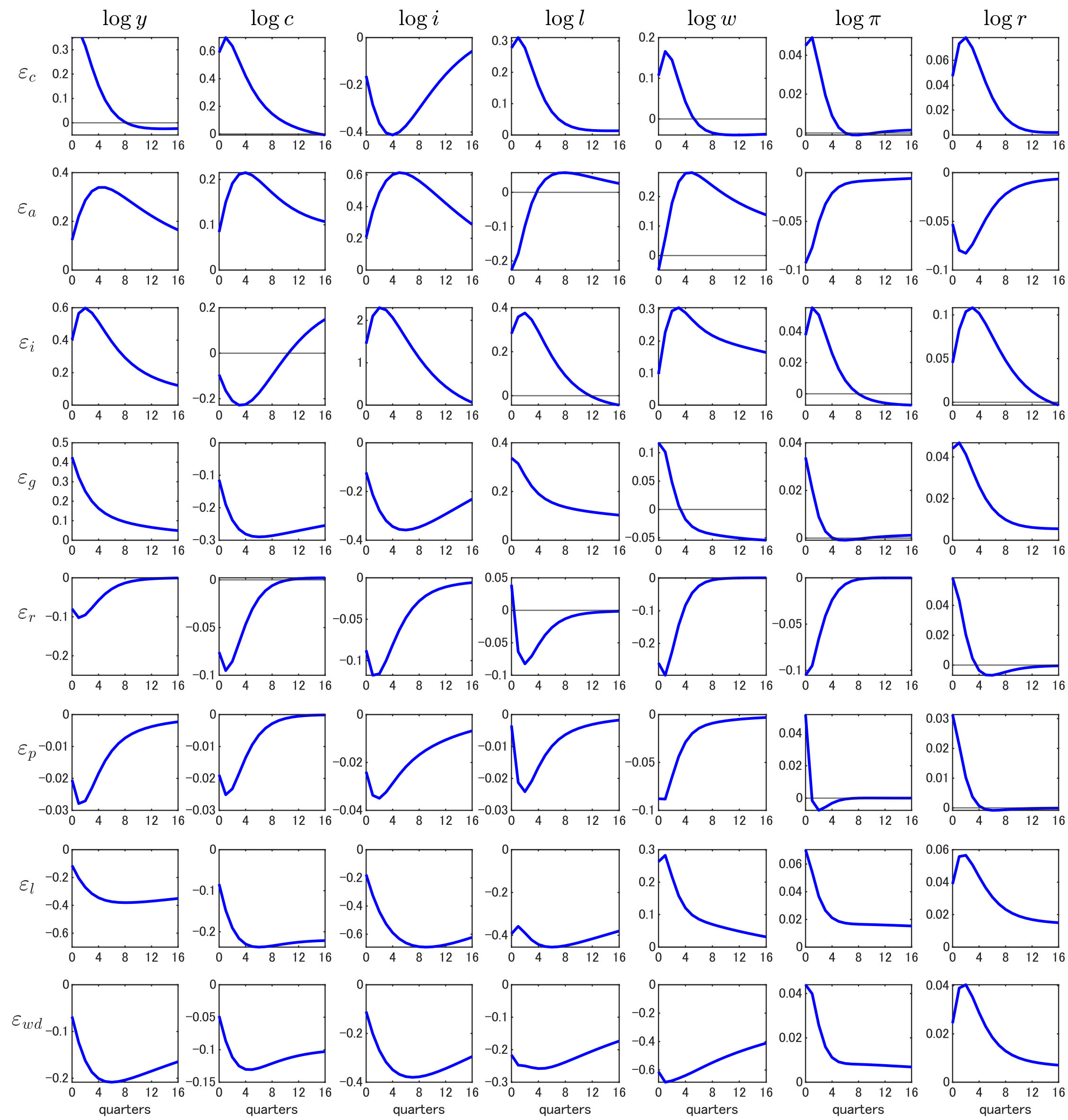
markup shock $\varepsilon_{wu,t}$. We can see that the posterior estimates of only two parameters are distinct between our model and the counterpart model in that the 90 percent highest posterior density intervals of the parameters do not overlap. First, the posterior mean estimate of the degree of price rigidity ξ_p in our model is 0.77, below that of 0.93 in the counterpart model. With firms' more frequent price optimization taking into account real marginal cost in our model, the posterior mean estimates of parameters imply that the slope (i.e., the coefficient on real marginal cost) of the price Phillips curve of $\kappa_p = 0.048$ is an order of magnitude larger than the slope of $\kappa_p = 0.004$ in the counterpart model. Second, the posterior mean estimate of the policy response to inflation ϕ_π in our model is 2.36, which is higher than that of 1.44 in the counterpart model. Hence, in our model, the more aggressive policy response to inflation is able to reconcile fluctuations of the inflation rate related to the steeper slope of the Phillips curve with the data on inflation. These results suggest that our estimated model and the estimated counterpart model have distinct implications for inflation dynamics.

The last line of Table 2 presents the log marginal data density (log MDD) for each of the four model specifications. The log marginal data density of our model is -520, which is larger than the counterpart model's log marginal data density of -522. The Bayes factor (i.e., the ratio of the marginal data densities) is 7.8, a value that indicates substantial evidence and strong evidence in favor of our model according to the scales of Jeffreys (1961) and Kass and Raftery (1995), respectively. Thus, our model with firms' monopsonistic wage-setting empirically outperforms the counterpart model with households' monopolistic wage-setting. The table also shows that our model's log marginal data density decreases to -530 in the absence of the wage markdown shock $\varepsilon_{wd,t}$ and to -574 in the absence of the labor preference shock $\varepsilon_{l,t}$. This demonstrates that for the better empirical performance of our model compared to that of the counterpart model, both labor preference and wage markdown shocks are indispensable.[19]

To confirm that the labor preference and wage markdown shocks are distinct disturbances to, respectively, aggregate labor supply and demand in our model, we plot the impulse re-

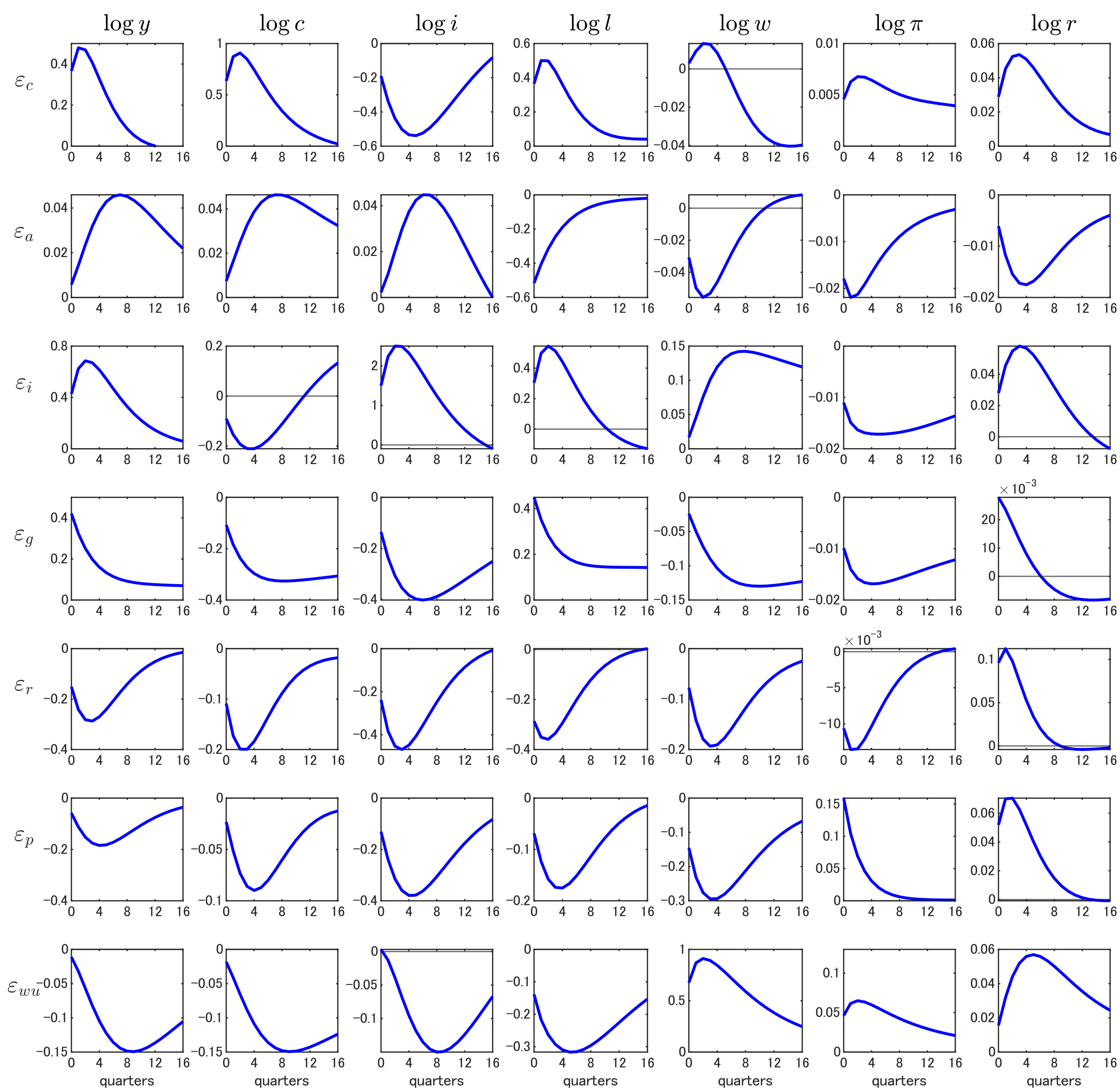
[19] The result of the comparison between our model and the counterpart model holds even if one more shock is added to the counterpart model by incorporating an error in the observation equation for labor—which relaxes the constraint on real marginal cost in the model imposed by the data on real unit labor cost—so that the number of shocks becomes the same between the two models, i.e., eight shocks. Moreover, the result survives even if our model abstracts from the price markup shock so that both models have seven shocks.

Figure 1: Impulse responses of key macroeconomic variables to shocks in our model



Notes: The panels in each row display the impulse responses of seven variables (i.e., output $\log y$, consumption $\log c$, investment $\log i$, hours worked $\log l$, the real wage $\log w$, the inflation rate $\log \pi$, and the interest rate $\log r$) to a one-standard-deviation positive innovation to one of eight shocks (i.e., the consumption preference shock ε_c, the TFP shock ε_a, the MEI shock ε_i, the exogenous spending shock ε_g, the monetary policy shock ε_r, the price markup shock ε_p, the labor preference shock ε_l, and the wage markdown shock ε_{wd}) in our model parameterized with the posterior mean estimates reported in Table 2. All responses are expressed as percentages.

Figure 2: Impulse responses of key macroeconomic variables to shocks in the counterpart model



Notes: The panels in each row display the impulse responses of seven variables (i.e., output $\log y$, consumption $\log c$, investment $\log i$, hours worked $\log l$, the real wage $\log w$, the inflation rate $\log \pi$, and the interest rate $\log r$) to a one-standard-deviation positive innovation to one of seven shocks (i.e., the consumption preference shock ε_c, the TFP shock ε_a, the MEI shock ε_i, the exogenous spending shock ε_g, the monetary policy shock ε_r, the price markup shock ε_p, and the wage markup shock ε_{wu}) in the counterpart model parameterized with the posterior mean estimates reported in Table 2. All responses are expressed as percentages.

sponses of key macroeconomic variables related to the seven observables. Figure 1 displays the responses of output $\log y_t$, consumption $\log c_t$, investment $\log i_t$, hours worked $\log l_t$, the real wage $\log w_t$, the inflation rate $\log \pi_t$, and the interest rate $\log r_t$, to one-standard-deviation positive innovations to the eight shocks (i.e., the consumption preference shock $\varepsilon_{c,t}$, the TFP shock $\varepsilon_{a,t}$, the MEI shock $\varepsilon_{i,t}$, the exogenous spending shock $\varepsilon_{g,t}$, the monetary policy shock $\varepsilon_{r,t}$, the price markup shock $\varepsilon_{p,t}$, the labor preference shock $\varepsilon_{l,t}$, and the wage markdown shock $\varepsilon_{wd,t}$) in our model parameterized with the posterior mean estimates reported in Table 2. In the last two rows of the figure, we can see that the responses of the real wage $\log w_t$ to the labor preference shock $\varepsilon_{l,t}$ and the wage markdown shock $\varepsilon_{wd,t}$ are opposite, while the responses of the other six variables to the two shocks are qualitatively the same. Thus, the impulse responses confirm that the labor preference shock $\varepsilon_{l,t}$ and the wage markdown shock $\varepsilon_{wd,t}$ are separately identified in our estimated model with firms' monopsonistic wage-setting.

Figure 2 displays the impulse responses of the seven variables to one-standard-deviation positive innovations to the seven shocks (i.e., the first six shocks and the wage markup shock $\varepsilon_{wu,t}$) in the counterpart model parameterized with the posterior mean estimates reported in Table 2. Comparing Figures 1 and 2, we can see that most of the impulse responses to the six shocks $\varepsilon_{c,t}$, $\varepsilon_{a,t}$, $\varepsilon_{i,t}$, $\varepsilon_{g,t}$, $\varepsilon_{r,t}$, and $\varepsilon_{p,t}$, which are not disturbances to labor markets, are the same, since our model and the counterpart model (in terms of the log-linearization) differ only in the two equations, the wage Phillips curve and the equilibrium condition for labor.

4.3 Variance decomposition

We turn next to variance decompositions of the seven key macroeconomic variables (i.e., output, consumption, investment, hours worked, the real wage, the inflation rate, and the interest rate) to understand the sources of fluctuations in the variables. The upper panel of Table 3 shows variance decompositions of the seven variables into components with the eight shocks (i.e., the consumption preference shock $\varepsilon_{c,t}$, the TFP shock $\varepsilon_{a,t}$, the MEI shock $\varepsilon_{i,t}$, the exogenous spending shock $\varepsilon_{g,t}$, the monetary policy shock $\varepsilon_{r,t}$, the price markup shock $\varepsilon_{p,t}$, the labor preference shock $\varepsilon_{l,t}$, and the wage markdown shock $\varepsilon_{wd,t}$) at frequencies with cycles between 6 and 32 quarters in our model parameterized with the posterior mean estimates reported in Table 2. The lower panel of Table 3 presents the variance decompositions into components with the seven shocks (i.e., the first six shocks and the wage markup shock $\varepsilon_{wu,t}$) in the counterpart model parameterized with the posterior mean estimates reported in Table 2.

Table 3: Variance decompositions at business cycle frequencies in our model and the counterpart model

(a) Our model (%)

Series\Shock	ε_c	ε_a	ε_i	ε_g	ε_r	ε_p	ε_l	ε_{wd}
Output	27.8	11.1	38.0	9.9	1.1	0.1	8.4	3.5
Consumption	72.8	4.6	10.9	5.5	1.0	0.1	3.7	1.4
Investment	3.3	3.9	87.5	1.0	0.1	0.0	2.8	1.3
Hours worked	24.7	6.9	26.2	11.1	0.9	0.1	20.5	9.6
Real wage	7.9	9.8	8.5	1.7	9.3	0.7	7.6	54.6
Inflation rate	16.2	20.9	12.5	2.1	32.0	1.7	9.3	5.3
Interest rate	29.6	17.5	31.0	4.8	4.6	1.1	7.2	4.2

(b) Counterpart model (%)

Series\Shock	ε_c	ε_a	ε_i	ε_g	ε_r	ε_p	ε_{wu}
Output	32.5	0.1	46.3	8.4	8.3	3.0	1.4
Consumption	84.4	0.1	6.3	3.9	3.6	0.8	0.9
Investment	3.7	0.0	90.8	1.1	2.6	1.4	0.3
Hours worked	28.5	12.4	30.0	7.5	11.3	2.6	7.7
Real wage	0.2	0.4	0.8	0.6	3.6	7.7	86.8
Inflation rate	0.2	2.4	1.9	1.2	1.1	67.5	25.6
Interest rate	13.5	0.9	12.2	2.4	41.3	19.8	10.0

Notes: The upper panel of the table shows variance decompositions of seven variables (i.e., output $\log y$, consumption $\log c$, investment $\log i$, hours worked $\log l$, the real wage $\log w$, the inflation rate $\log \pi$, and the interest rate $\log r$) into components with eight shocks (i.e., the consumption preference shock ε_c, the TFP shock ε_a, the MEI shock ε_i, the exogenous spending shock ε_g, the monetary policy shock ε_r, the price markup shock ε_p, the labor preference shock ε_l, and the wage markdown shock ε_{wd}) at frequencies with cycles between 6 and 32 quarters in our model parameterized with the posterior mean estimates reported in Table 2. The lower panel of the table presents variance decompositions of the seven variables into components with the first six shocks and the wage markup shock ε_{wu} in the counterpart model parameterized with the posterior mean estimates reported in Table 2.

Our estimated model indicates that the labor preference and wage markdown shocks account for a modest portion of US business cycles. The main source of output fluctuations in our model is the MEI shock $\varepsilon_{i,t}$, which is also the main source in the counterpart model in line with the findings of Justiniano et al. (2010, 2011). Moreover, in both models, the

MEI shock accounts for the bulk of the fluctuations in investment, while the consumption preference shock $\varepsilon_{c,t}$ drives most of the fluctuations in consumption.

However, firms' monopsonistic wage-setting yields notable implications for the driving forces of labor market variables and the inflation rate in US business cycles. In the labor market, the labor preference shock $\varepsilon_{l,t}$ and the wage markdown shock $\varepsilon_{wd,t}$ account for a substantial portion of fluctuations in hours worked (about 30 percent). Moreover, the markdown shock is the primary source of fluctuations in the real wage. Because it is a disturbance to the aggregate labor demand curve, the markdown shock causes a positive comovement between the real wage and hours worked and can thus induce fluctuations in real unit labor cost. In contrast, the counterpart model attributes real wage fluctuations largely to the wage markup shock $\varepsilon_{wu,t}$, which has a limited influence on real unit labor cost because it is a disturbance to the aggregate labor supply curve and thus has offsetting effects on the real wage and hours worked.

As for fluctuations in the inflation rate, our estimated model shows that a broad mix of shocks contribute to them. In the model, the monetary policy shock $\varepsilon_{r,t}$ is the primary driver of inflation, accounting for about one third of the fluctuations, consistent with the larger response of inflation displayed in Figure 1 compared to that in Figure 2 for the counterpart model. The TFP shock $\varepsilon_{a,t}$, the consumption preference shock $\varepsilon_{c,t}$, and the MEI shock $\varepsilon_{i,t}$ also explain substantial portions of inflation fluctuations. However, the contribution of the price markup shock $\varepsilon_{p,t}$ is negligible.[20] Shocks other than the price markup shock affect real marginal cost and transmit to the inflation rate through the price Phillips curve, a transmission that is amplified by the steeper curve in our estimated model compared to the counterpart model.[21] In the latter model, in contrast, the price and wage markup shocks mostly account for inflation fluctuations, mirroring the results of Smets and Wouters (2007) and Justiniano et al. (2010).

[20] We can obtain similar estimation results and hence similar variance decompositions even if our model abstracts from the price markup shock.

[21] Our estimated model also shows that fluctuations in wage growth are attributed to a broad mix of shocks, such as the wage markdown shock $\varepsilon_{wd,t}$ (33.4%), the monetary policy shock $\varepsilon_{r,t}$ (19.6%), the consumption preference shock $\varepsilon_{c,t}$ (14.6%), the MEI shock $\varepsilon_{i,t}$ (13.1%), and the labor preference shock $\varepsilon_{l,t}$ (13.0%). In contrast, the estimated counterpart model attributes wage growth fluctuations mostly to wage markup shocks $\varepsilon_{wu,t}$ (93.6%).

5 New Measure of Real Marginal Cost

Our estimated model revives the Phillips curve by restoring real marginal cost as a prominent driver of inflation while obviating the need for the price markup shock. In this section, we show that accounting for firms' staggered wage-setting under monopsonistic competition changes the measure of real marginal cost substantially.

5.1 Decomposition of real unit labor cost

In our model, real unit labor cost can be decomposed into not only real marginal cost but also the wage markdown as in (15):

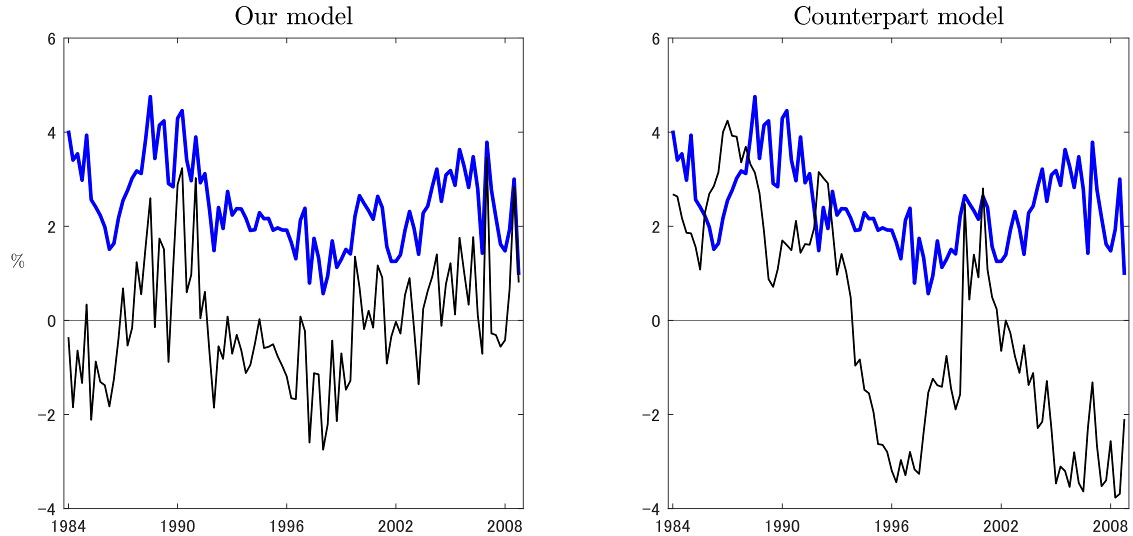
$$\hat{ulc}_t = \hat{mc}_t + \left(\hat{w}_t - \hat{mpl}_t\right).$$

This decomposition contrasts with that in the counterpart model, where real unit labor cost consists of only real marginal cost (i.e., $\hat{ulc}_t = \hat{mc}_t$) in the presence of the aggregate labor demand curve (61). It is then worth noting that real unit labor cost $\hat{ulc}_t = \hat{w}_t + \hat{l}_t - \hat{y}_t$ is pinned down by the data on the real wage, hours worked, and output.

In estimating the counterpart model, the estimation procedure requires reconciling the data on inflation and real unit labor cost, because the cost is equal to real marginal cost, the driver of inflation in the Phillips curve (39). However, as shown by empirical studies with various approaches, real unit labor cost is not a useful indicator for explaining inflation dynamics. King and Watson (2012) show that in the model of Smets and Wouters (2007), so-called fundamental inflation, which is based solely on the behavior of real unit labor cost, differs substantially from the actual inflation rate. Angeletos et al. (2020) compute VAR-based main business cycle shocks and find that the shock that accounts for the largest possible share of inflation does not explain the labor share or, equivalently, real unit labor cost and vice versa.[22] Standard DSGE models, including the counterpart model, rely on a flat price Phillips curve and a large role of price markup shocks to reconcile the data on inflation and real unit labor cost. Yet such models ignore the influence of the wage markdown on real unit labor cost and hence on real marginal cost.

[22] Galí and Gertler (1999) and Sbordone (2002) provide more favorable assessments on the role of real unit labor cost in inflation dynamics for sample periods that end in the 1990s.

Figure 3: Inflation and real marginal cost measure



Notes: The thick blue lines and the thin black lines denote, respectively, the inflation rate and (smoothed) real marginal cost in our estimated model with firms' monopsonistic wage-setting (left panel) and the estimated counterpart model with households' monopolistic wage-setting (right panel).

In our model, real marginal cost is affected by the wage markdown as well as real unit labor cost, while firms' staggered wage-setting makes the markdown time-varying. Firms' monopsonistic wage-setting thus refines the measure of real marginal cost by accounting for the influence of the wage markdown. The left panel of Figure 3 plots the time series of inflation and real marginal cost in our estimated model. These two series are highly correlated (0.72). Consequently, the estimation procedure can better reconcile the measure of real marginal cost with the data on inflation, leading to a steeper Phillips curve and leaving only a marginal role for the price markup shock. The smaller posterior mean estimates of the parameters pertaining to the price markup shock $\{\rho_p, \nu_p, \sigma_p\}$ reported in Table 2 and the larger slope κ_p of the Phillips curve imply that the standard deviation of the original price markup shock $\tilde{\varepsilon}_{p,t}$ is an order of magnitude smaller in our estimated model (1.81) than in the estimated counterpart model (46.88).[23] For the latter model, the right panel of Figure 3

[23] Arguably, the standard deviation of the original price markup shock $\tilde{\varepsilon}_{p,t}$ is unreasonably large in the estimated counterpart model—more than 212 times larger than the standard deviation of the inflation rate, versus 8 times larger in our estimated model. L'Huillier and Phelan (2025) argue that only unreasonably large price markup shocks $\tilde{\varepsilon}_{p,t}$ can affect the inflation rate in standard DSGE models with a flat Phillips curve. Our estimated model mitigates that concern because it has a steeper Phillips curve and assigns only a marginal role to price markup shocks in inflation fluctuations.

shows that the inflation rate and real marginal cost exhibit a mild correlation (0.34), as the cost is equal to real unit labor cost.

5.2 Roles of wage markdown and labor preference shocks

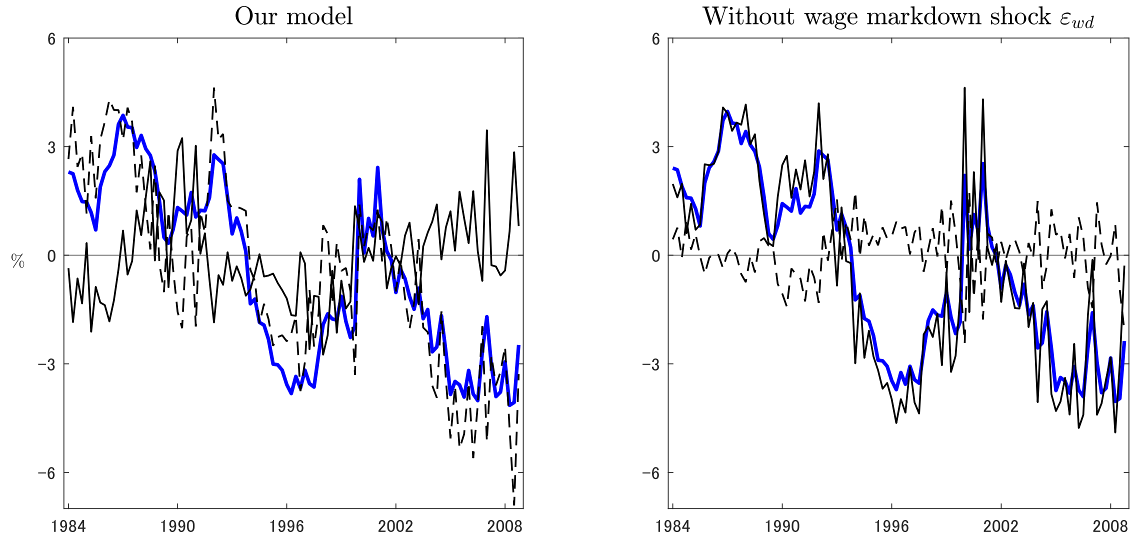
We have shown that both labor demand and supply shocks are indispensable for our model with firms' monopsonistic wage-setting to outperform the counterpart model with households' monopolistic wage-setting. In this subsection, we show that the wage markdown shock shapes the behavior of the markdown and hence of real marginal cost.

As a disturbance to the aggregate labor demand curve, the wage markdown shock gives rise to a positive comovement between the real wage and hours worked, as noted above. Hence, the shock has a similar effect on the wage markdown and real unit labor cost. Because the markdown shock is the main driving force of the real wage as shown in Table 3, it can generate a strong association of real unit labor cost with the wage markdown, while at the same time weakening its association with real marginal cost. Figure 4 plots real unit labor cost (thick blue lines) along with real marginal cost (solid black lines) and the wage markdown (dashed black lines) in our estimated model and the one without the wage markdown shock. Indeed, in the presence of the markdown shock, the wage markdown is strongly correlated with real unit labor cost, as shown in the left panel of the figure—the correlation is 0.88. Like real unit labor cost, the wage markdown is mildly countercyclical—the correlation of output and the markdown is -0.23—consistent with the empirical evidence of Webber (2022) that labor market competition as measured by the labor supply elasticity to the firm is procyclical.[24] However, if the shock is absent, the wage markdown is no longer closely associated with real unit labor cost, so the latter's behavior is mostly inherited by real marginal cost, as shown in the right panel. The correlation between unit labor cost and marginal cost becomes 0.96, that is, almost 1 as in the counterpart model. Thus, the wage markdown shock is important for the decomposition of real unit labor cost into real marginal cost and the wage markdown and hence for inflation dynamics.

To summarize the cyclical behavior of real marginal cost and the wage markdown, Table 4

[24] Furthermore, the empirical measure of the average wage markdown constructed from micro data as the reciprocal of our markdown variable by Ren and Zhang (2025, Figure 2) rose above trend during the business cycle expansions of the 1990s and the 2010s, while labor market concentration calculated by Rinz (2022, Figure 1) increased during the Great Recession, both consistent with a countercyclical wage markdown.

Figure 4: Real unit labor cost and its components



Notes: The thick blue lines denote the (smoothed) real unit labor cost in our estimated model with firms' monopsonistic wage-setting (left panel) and the one model without the wage markdown shock (right panel). The cost is decomposed into the (smoothed) real marginal cost (solid black lines) and the (smoothed) wage markdown (dashed black lines).

displays their correlations with the inflation rate $\hat{\pi}_t$, real unit labor cost $\hat{ulc}_t$, and output $\hat{y}_t$ in our estimated model and the estimated counterpart model. As noted above, our model generates a strong correlation of 0.72 between inflation and the refined measure of real marginal cost by accounting for the influence of the wage markdown. Real unit labor cost is essentially uncorrelated with the real marginal cost (0.05) and is highly correlated with the wage markdown (0.88). These patterns differ greatly from those observed in the estimated counterpart model, which features a mild correlation of 0.34 between inflation and real marginal cost as this cost is equal to real unit labor cost. While the wage markdown is mildly countercyclical in our model as noted above, real marginal cost is weakly or mildly procyclical in both of the models.

Table 4: Correlations with real marginal cost and the wage markdown

	Real marginal cost			Wage markdown	
	$\hat{\pi}_t$	$\hat{ulc}_t$	$\hat{y}_t$	$\hat{ulc}_t$	$\hat{y}_t$
Our model	0.719	0.047	0.086	0.877	-0.229
Counterpart model	0.339	1.000	0.216	–	–

Next to the novel role of the wage markdown shock, the labor preference shock in our model and the wage markup shock in the counterpart model play a familiar role of generating fluctuations in the household component of the measured labor wedge, that is, the gap between the real wage $\hat{w}_t$ and the measured MRS $(1/\chi)\,\hat{l}_t - \hat{\lambda}_t$. Without the labor preference shock, our model generates no fluctuations in this gap and as a consequence, its empirical performance in terms of the log marginal data density declines sharply from -520 to -574 and is inferior to that of the counterpart model with the wage markup shock (-522), as shown in the last line of Table 2. Moreover, our model has a worse empirical performance in the absence of the labor preference shock (-574) than in the absence of the wage markdown shock (-530), suggesting that the labor preference shock plays a more important role in our model's fit to the macroeconomic data than the wage markdown shock. This finding is consistent with the evidence of Karabarbounis (2014) showing that fluctuations in the measured labor wedge primarily reflect those in its household component. At the same time, our results extend those of Karabarbounis (2014) by uncovering a new role of the firm component of the measured wedge, that is, the gap between the measured MPL and the real wage, which corresponds to the negative of real unit labor cost. With monopsonistic wage-setting the firm component of the wedge is decomposed into real marginal cost and the wage markdown, thus improving the empirical performance of our model by better describing for inflation dynamics in the presence of the wage markdown shock.

6 Conclusion

This paper has introduced firms' staggered wage-setting under monopsonistic competition in an otherwise standard DSGE model, motivated by the evidence on monopsony power in labor markets that has recently been documented in labor economics. In our model, shocks to preferences for labor supply and to the wage markdown can be separately identified because the former is a disturbance to the aggregate labor supply curve while the latter is a disturbance to the aggregate labor demand curve. Such a labor demand shock is absent from the standard counterpart model with households' staggered wage-setting under monopolistic competition, where both shocks to preferences for labor supply and to the wage markup are disturbances to the aggregate labor supply curve. The paper shows that in the presence of both labor preference and wage markdown shocks our model with firms' monopsonistic wage-setting empirically outperforms the counterpart model with households' monopolistic wage-setting.

Our estimated model restores the relationship between inflation and real marginal cost that has been elusive in empirical research, by downplaying price markup shocks while emphasizing other shocks that affect real marginal cost and hence inflation through the Phillips curve. Firms' staggered wage-setting under monopsonistic competition allows real unit labor cost to be decomposed into not only real marginal cost but also the wage markdown and thus refines the measure of real marginal cost by accounting for the influence of the wage markdown. The magnitude of the refinement is quantitatively meaningful because the wage markdown shock generates joint movements in the markdown and real unit labor cost. The markdown shocks can be viewed equivalently as disturbances to the elasticity of substitution between the supply of individual differentiated labor. An exogenous decline in this elasticity makes workers more attached to their jobs, a preference shift that may capture a variety of factors, such as workers' greater appreciation of their job-specific amenities or their greater pessimism about labor markets. Our estimated model indicates that such preference shifts are important for understanding inflation dynamics. This finding suggests that empirical investigations into the cyclical properties of wage markdowns could be a fruitful avenue for future research.

Appendix: Estimation Results for Longer Sample Period

This appendix presents the estimation results for the longer sample period from 1984:Q1 until 2019:Q4, which ends immediately before the COVID-19 pandemic. The shadow federal funds rate of Wu and Xia (2016) is used to proxy for the monetary policy stance when the nominal interest rate was at the ELB. For that sample period, the steady-state output ratio of exogenous spending is set at $G/Y = 0.168$. The prior mean of the steady-state quarterly rates of output growth, investment-specific technological change, nominal interest, and inflation is chosen at the respective averages over the sample period of the growth rate of real GDP per capita ($\overline{g_Z} = 0.404$ percent), the rate of change in the ratio of the investment deflator to the GDP deflator ($\overline{g_\Psi} = 0.206$ percent), the federal funds rate ($\bar{r} = 0.942$ percent), and the inflation rate of the GDP deflator ($\bar{\pi} = 0.538$ percent). All other priors are unchanged.

The estimation results are presented in Table A1. For brevity, the table shows the posterior estimates of the structural parameters and omits those of the shock parameters. The log marginal data density of our model is -772, which is larger than the counterpart model's log marginal data density of -780. The Bayes factor is $4,275$, a value that indicates decisive evidence and very strong evidence in favor of our model according to the scales of Jeffreys (1961) and Kass and Raftery (1995), respectively. This confirms for the longer sample period that our model with firms' monopsonistic wage-setting empirically outperforms the counterpart model with households' monopolistic wage-setting. The log marginal data density of our model decreases to -798 in the absence of the wage markdown shock $\varepsilon_{wd,t}$ and to -832 in the absence of the labor preference shock $\varepsilon_{l,t}$, confirming for the longer sample period that both labor preference and wage markdown shocks are indispensable for the better empirical performance of our model compared to the counterpart model.

Table A2 shows the variance decompositions of the seven key macroeconomic variables. It remains qualitatively unchanged for the longer sample period. In particular, the driving forces of fluctuations in the inflation rate are broad-based, including monetary policy shocks $\varepsilon_{r,t}$, MEI shocks $\varepsilon_{i,t}$, and TFP shocks $\varepsilon_{a,t}$, although the role of consumption preference shocks $\varepsilon_{c,t}$ is diminished compared to that for the baseline sample period up to 2008:Q4. In the counterpart model, in contrast, price and wage markup shocks, $\varepsilon_{p,t}$ and $\varepsilon_{wu,t}$, continue to account for most of the inflation fluctuations.

Table A1: Posterior estimates of structural parameters of our model and the counterpart model for the sample period 1984:Q1–2019:Q4

	Our model		w/o markdown ε_{wd}		w/o labor preference ε_l		Counterpart model	
Parameter	Mean	90% interval	Mean	90% interval	Mean	90% interval	Mean	90% interval
$\overline{g_Z}$	0.389	[0.345, 0.436]	0.431	[0.399, 0.463]	0.337	[0.286, 0.390]	0.431	[0.405, 0.458]
$\overline{g_\Psi}$	0.277	[0.215, 0.339]	0.316	[0.258, 0.374]	0.265	[0.208, 0.322]	0.317	[0.255, 0.379]
$\bar{l}$	-0.003	[-0.167, 0.165]	-0.012	[-0.171, 0.149]	-0.003	[-0.163, 0.154]	-0.009	[-0.170, 0.164]
$\bar{r}$	1.012	[0.870, 1.148]	1.020	[0.882, 1.154]	1.048	[0.899, 1.192]	0.993	[0.866, 1.124]
$\bar{\pi}$	0.539	[0.443, 0.632]	0.537	[0.443, 0.628]	0.500	[0.371, 0.635]	0.468	[0.343, 0.601]
h	0.944	[0.905, 0.988]	0.962	[0.940, 0.985]	0.994	[0.993, 0.996]	0.905	[0.808, 0.973]
χ	0.564	[0.399, 0.736]	0.610	[0.441, 0.775]	0.752	[0.498, 0.994]	1.009	[0.721, 1.304]
δ_2/δ_1	0.746	[0.594, 0.890]	0.847	[0.681, 1.012]	0.692	[0.541, 0.833]	0.813	[0.661, 0.966]
ζ	7.180	[4.234, 9.941]	7.871	[4.931, 10.652]	6.091	[3.730, 8.370]	7.137	[4.544,9.622]
ξ_p	0.782	[0.743, 0.821]	0.835	[0.801, 0.872]	0.854	[0.817, 0.892]	0.948	[0.942, 0.953]
ι_p	0.222	[0.082, 0.353]	0.307	[0.138, 0.467]	0.209	[0.073, 0.339]	0.301	[0.152, 0.450]
ξ_w	0.383	[0.256, 0.504]	0.240	[0.152, 0.332]	0.553	[0.387, 0.718]	0.599	[0.464, 0.752]
ι_w	0.291	[0.093, 0.478]	0.307	[0.104, 0.505]	0.171	[0.039, 0.304]	0.121	[0.039, 0.200]
ϕ_r	0.778	[0.737, 0.820]	0.812	[0.780, 0.846]	0.721	[0.658, 0.787]	0.801	[0.761 0.845]
ϕ_π	2.336	[2.003, 2.673]	2.154	[1.823, 2.476]	2.117	[1.779, 2.458]	1.073	[0.947, 1.214]
ϕ_y	0.042	[0.022, 0.065]	0.033	[0.015, 0.051]	0.030	[0.014, 0.046]	0.097	[0.066, 0.127]
ϕ_{gy}	0.110	[0.045, 0.170]	0.129	[0.055, 0.199]	0.103	[0.044, 0.163]	0.200	[0.092, 0.307]
log *MDD*	-771.730		-798.231		-832.179		-780.090	

Notes: The table reports the posterior mean and 90 percent highest posterior density interval of each estimated structural parameter of our model, the one without the wage markdown shock ε_{wd}, the one without the labor preference shock ε_l, and the counterpart model with households' monopolistic wage-setting and the wage markup shock ε_{wu}. The last line of the table presents the log marginal data density (log *MDD*) for each of the four model specifications.

Table A2: Variance decompositions at business cycle frequencies in our model and the counterpart model for the sample period 1984:Q1–2019:Q4

(a) Our model (%)

Series\Shock	ε_c	ε_a	ε_i	ε_g	ε_r	ε_p	ε_l	ε_{wd}
Output	15.3	8.3	54.1	13.2	0.9	0.0	6.6	1.6
Consumption	92.1	1.3	3.4	1.3	0.4	0.0	1.1	0.4
Investment	3.5	6.8	80.5	2.2	0.5	0.0	5.3	1.2
Hours worked	16.4	8.3	39.4	14.5	0.9	0.0	16.5	4.0
Real wage	2.9	10.0	14.8	3.0	15.9	0.2	14.9	38.3
Inflation rate	4.6	16.5	24.2	3.0	35.5	1.1	11.5	3.6
Interest rate	8.4	14.3	48.1	5.6	10.3	0.6	9.8	2.9

(b) Counterpart model (%)

Series\Shock	ε_c	ε_a	ε_i	ε_g	ε_r	ε_p	ε_{wu}
Output	30.5	0.0	51.0	7.0	9.7	1.3	0.3
Consumption	93.7	0.0	2.1	1.8	1.9	0.2	0.2
Investment	4.4	0.0	86.4	1.5	6.1	1.3	0.3
Hours worked	29.6	12.0	36.6	6.4	13.1	1.3	1.0
Real wage	0.1	0.9	2.1	1.6	7.4	6.1	81.7
Inflation rate	0.5	2.7	1.6	5.0	0.9	72.0	17.3
Interest rate	9.9	0.7	11.1	2.1	60.1	11.2	4.9

Notes: The upper panel of the table shows variance decompositions of seven variables (i.e., output $\log y$, consumption $\log c$, investment $\log i$, hours worked $\log l$, the real wage $\log w$, the inflation rate $\log \pi$, and the interest rate $\log r$) into components with eight shocks (i.e., the consumption preference shock ε_c, the TFP shock ε_a, the MEI shock ε_i, the exogenous spending shock ε_g, the monetary policy shock ε_r, the price markup shock ε_p, the labor preference shock ε_l, and the wage markdown shock ε_{wd}) at frequencies with cycles between 6 and 32 quarters in our model parameterized with the posterior mean estimates reported in Table 2. The lower panel of the table presents variance decompositions of the seven variables into components with the first six shocks and the wage markup shock ε_{wu} in the counterpart model parameterized with the posterior mean estimates reported in Table 2.

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