Bank of Japan Working Paper Series

# Supply Shocks, Employment Gap, and Monetary Policy

Takushi Kurozumi*
takushi.kurozumi@boj.or.jp

Willem Van Zandweghe**
willem.vanzandweghe@clev.frb.org

No.25-E-4
March 2025

Bank of Japan
2-1-1 Nihonbashi-Hongokucho, Chuo-ku, Tokyo 103-0021, Japan

* Research and Statistics Department, Bank of Japan
** Research Department, Federal Reserve Bank of Cleveland

# Supply Shocks, Employment Gap, and Monetary Policy*

Takushi Kurozumi† Willem Van Zandweghe‡

March 2025

**Abstract**

How should monetary policy respond to supply shocks in terms of inflation and employment stabilization? We introduce labor force entry and exit in an otherwise standard model with staggered price- and wage-setting to include employment in the model. A welfare-maximizing policy features wage growth stabilization with variation in the employment gap and inflation. Under staggered price- and wage-setting, the real wage adjustments to shocks entail a welfare cost, and variation in the employment gap contributes to reducing the welfare cost. Therefore, leaning against the employment gap induces substantial welfare losses for supply shocks compared to the welfare-maximizing policy.

*JEL Classification*: E24, E31, E52, J21

*Keywords*: Labor force entry and exit, Extensive margin of labor, Staggered price- and wage-setting, Wage growth stabilization

*The authors are grateful to Hassan Afrouzi, Kosuke Aoki, Mark Bils, Gian Luca Clementi, Paolo Gelain, Bariş Kaymak, Dirk Krueger, So Kubota, Jean-Paul L'Huillier, Pierlauro Lopez, André Luduvice, Kurt Lunsford, Junior Maih, Toshihiko Mukoyama, Juan Pablo Nicolini, Evi Pappa, Ricardo Reis, Juan Rubio-Ramírez, Ayşegül Şahin, Cynthia Wu, and participants at the 2023 AEA meeting, 2023 SNDE symposium, Spring 2024 Midwest Macro Meeting, and seminars at the Bank of Japan, the Federal Reserve Bank of Cleveland, and Tohoku University for valuable comments and discussions. Martin DeLuca provided excellent research assistance. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Bank of Japan, the Federal Reserve Bank of Cleveland, or the Federal Reserve System.

†Research and Statistics Department, Bank of Japan, 2-1-1 Nihonbashi-Hongokucho, Chuo-ku, Tokyo 103-8660, Japan (e-mail: takushi.kurozumi@boj.or.jp)

‡Research Department, Federal Reserve Bank of Cleveland, P.O. Box 6387, Cleveland, OH 44101, USA (e-mail: willem.vanzandweghe@clev.frb.org)

# 1 Introduction

The question of how monetary policy should respond to supply shocks has gained renewed relevance in the wake of the COVID-19 pandemic. The U.S. economy in its recovery from the pandemic-induced recession witnessed high inflation, shortages of materials inputs including semiconductors, and tight energy markets, developments resembling the effects of productivity shocks.[1] Moreover, high wage growth and low labor force participation indicated that labor supply shocks played an important role too.[2] Tellingly, anecdotes in the Federal Reserve's Beige Book contained 18 mentions of "supply chain disruptions" and 26 mentions of "labor shortage" in December 2021, up from, respectively, just one and four mentions in November 2019.

To address how monetary policy should be conducted under price and wage rigidities, Erceg et al. (2000) develop a model with staggered price- and wage-setting and show that the adjustments of real wages to shocks inevitably entail a welfare cost because prices, wages, or both have to adjust subject to their rigidities. These authors then suggest that merely pursuing price stability is an undesirable monetary policy strategy and that stabilizing wage growth is a better one. For shocks that raise the natural real wage (i.e., the real wage that would prevail under flexible prices and wages), the actual real wage rises preferably through a decline in inflation instead of an increase in wage growth.

The adjustments of real wages could be facilitated in the presence of employment in the model, since employment is another margin of labor, an extensive margin in addition to the intensive margin (i.e., hours worked), which influences wage growth. We thus introduce worker entry into and exit from the labor force in an otherwise standard model with staggered price- and wage-setting. In the model, individuals enjoy an exogenous benefit of nonparticipation in the labor market, which they weigh against a reward from market work. The labor force entry decision then gives rise to an equilibrium condition under which a marginal worker is indifferent between the reward from market work and the benefit of

[1] While supply shocks were likely substantial, there is disagreement about their importance relative to demand shocks. See, e.g., Bernanke and Blanchard (2025) and Giannone and Primiceri (2024) for different perspectives.

[2] During 2020–2021 the labor force participation rate remained about one percentage point below its pre-pandemic forecast from the U.S. Bureau of Labor Statistics (see Dubina et al., 2020, for the forecast).

nonparticipation.[3] As for supply shocks, we consider not only productivity shocks but also two types of labor supply shocks. The first type is the widely used labor supply shock to the intensive margin, which is a disturbance to the disutility of hours worked. The second type shifts the benefit of nonparticipation in the labor market and can thus be classified as a labor supply shock to the extensive margin.[4] In the adjustments of the real wage to these supply shocks, employment plays a crucial role through price and wage Phillips curves.

We use the model to examine how monetary policy should respond to supply shocks in terms of inflation and employment stabilization. We begin by deriving a welfare-maximizing policy as a benchmark against which to evaluate the performance of different monetary policy strategies. In the model, supply shocks shift the natural rate of output, which leads to shifts in the natural real wage.[5] The welfare-maximizing policy then calls for wage growth stabilization with variation in inflation and the employment gap (i.e., the gap between actual employment and its natural rate). As stressed by Erceg et al. (2000), staggered price- and wage-setting cause the adjustments of the real wage to shocks to entail a welfare cost. In response to supply shocks that raise the natural real wage, the welfare-maximizing policy leads the actual real wage to rise through decreases in the employment gap and inflation while keeping wage growth steady. The output gap also declines, as this is needed for the decrease in inflation. Then, the decrease in the employment gap contributes to reducing the welfare cost. If employment is maintained at its natural rate, then wage growth, inflation, and the output gap all decline more, inducing a larger welfare cost.

Next, we conduct a quantitative welfare comparison of different monetary policy strategies. One set of strategies consists of fully stabilizing inflation or wage growth. Full wage growth stabilization achieves a welfare level comparable to that attained under the welfare-

[3]The model assumes exogenous exits from the labor force. This assumption is in line with the evidence on the U.S. labor market, provided by, for example, Krusell et al. (2017), that the worker flows from nonparticipation to employment are more cyclical than those from employment to nonparticipation. Moreover, in the absence of unemployment in the model, the assumption is consistent with the exogenous job destruction supposed in the literature on labor market search.

[4]The extensive-margin labor supply shock may have become more relevant in recent years. Survey evidence supports the notion that the COVID-19 pandemic made some people less willing to work and had detrimental effects on labor force participation. Faberman et al. (2022) document a decline in the willingness to work during the pandemic, primarily by individuals out of the labor force. Consistently, Barrero et al. (2023) estimate that continuing social distancing was a substantial drag on labor force participation even in 2022.

[5]Extensive-margin labor supply shocks shift the natural rate of employment as well.

maximizing policy, which features wage growth stabilization with variation in inflation and the employment gap as noted above. Full inflation stabilization induces a substantial welfare loss compared to the welfare-maximizing policy. Moreover, the welfare loss conditional on productivity shocks exceeds that obtained in the case of a constant labor force, which is also large as emphasized by Erceg et al. (2000). Because a positive productivity shock puts downward pressure on the real marginal cost and hence inflation, accomplishing the desired rise in the real wage while keeping inflation constant requires a large rise in wage growth. This is attained partly through a large drop in labor force entry, which exacerbates the welfare loss compared to the case of a constant labor force.

Another set of monetary policy strategies consists of following a Taylor (1993)-type rule, which adjusts the interest rate in response to inflation and the output or employment gap. When the Taylor-type rule responds only to inflation, it generates substantial welfare losses for supply shocks compared to the welfare-maximizing policy. These losses can be mitigated if the rule responds additionally to the output gap. In contrast, if it responds alternatively to the employment gap, the welfare losses are exacerbated. This result confirms that variation in the employment gap contributes to reducing the welfare cost caused by the real wage adjustments to supply shocks under staggered price- and wage-setting. Therefore, we suggest that leaning against the employment gap induces substantial welfare losses for supply shocks compared to the welfare-maximizing policy.[6]

Our paper contributes to two strands of the literature: the implications of labor force fluctuations for monetary policy and the role of labor market shocks in sticky price and wage models. In the former literature, Galí (2011) develops a model with staggered price- and wage-setting, unemployment, and labor force participation, and analyzes a welfare-maximizing policy in the model conditional on only technology shocks. Labor market frictions that give rise to unemployment and nonparticipation in the model lead wage growth variability to generate a lower welfare cost than inflation variability. As a consequence, the welfare-maximizing policy is well characterized by a Taylor-type rule that puts weight on inflation and unemployment stabilization but not on wage growth stabilization. Erceg and Levin (2014) incorporate labor force participation and unemployment in a staggered price

[6]There is another argument against following a Taylor-type rule with responses to the employment gap: It shrinks the region of parameter values that ensure determinacy of equilibrium, as shown in Appendix C.

model, and show that the gradual adjustment of the labor force to changes in unemployment can justify a policy of letting the unemployment rate decline temporarily below its natural rate. Campolmi and Gnocchi (2016) construct a staggered price model with labor market search and matching frictions and labor force entry and exit, and examine the implications of productivity shocks and extensive-margin labor supply shocks—market-technology shocks and home-technology shocks in their terms—for monetary policy. Since their model assumes flexible wages, a welfare-maximizing policy calls for price stability.

A key distinction between our paper and the related literature is that our model abstracts from unemployment. Conceptually, unemployment is influenced by the institutional structure of the labor market, including search frictions and wage rigidities. Previous studies that embed unemployment in sticky price models then find that different specifications for the process of wage determination have distinct implications not only for business cycle fluctuations but also for monetary policy.[7] Leaving unspecified the labor market frictions that give rise to unemployment allows us to investigate the implications of employment in an otherwise standard model with sticky prices and wages.[8] Moreover, our paper proposes a novel way to introduce employment in the models, which is a complementary approach to those used in the previous studies.

As for the role of labor market shocks, previous literature focuses on disentangling (intensive-margin) labor supply shocks and wage markup shocks, which generate qualitatively similar impulse responses in standard models with sticky prices and wages but have different implications for monetary policy, as argued by Chari et al. (2009).[9] Our model considers the two types of labor supply shocks, to the intensive margin and to the extensive margin of labor. An impulse response analysis under the Taylor-type rule shows that both types generate qualitatively the same responses of output, inflation, wage growth, the real wage, and employment. Yet they give rise to opposite responses of per-worker hours worked,

[7]See, e.g., Thomas (2008), Faia (2009), Blanchard and Galí (2010), and Sunakawa (2015). Galí (2011) argues that the main role of introducing labor market frictions in sticky price models is to "make room" for wage rigidities.

[8]Our approach follows the spirit of Benhabib et al. (1991), who introduce nonparticipation in the labor market in an otherwise standard real business cycle model.

[9]See Galí et al. (2012) and Foroni et al. (2018) for two alternative ways to tackle the identification issue on (intensive-margin) labor supply shocks and wage markup shocks. Appendix A presents impulse responses to wage markup shocks in our model, and shows that intensive-margin labor supply shocks and wage markup shocks give rise to opposite responses of employment, which can help identify them separately.

which could help identify the two types of labor supply shocks separately.

Moreover, our model is isomorphic to those used in the literature on firm entry and exit on the product side.[10] As pointed out by Bilbiie et al. (2008), sticky price models involve monopolistically competitive product markets, which result in positive profits, and therefore assuming no firm entry or exit is theoretically unappealing. Our model applies their argument to the labor side in sticky price and wage models, which suppose monopolistically competitive labor markets.

The remainder of the paper proceeds as follows. Section 2 introduces labor force entry and exit in an otherwise standard model with staggered price- and wage-setting. Section 3 parameterizes the model and investigates its business cycle properties. Section 4 examines a welfare-maximizing policy in the model. Section 5 conducts a quantitative welfare comparison of different monetary policy strategies. Section 6 concludes.

# 2 Model with Labor Force Entry and Exit

In this section we introduce worker entry into and exit from the labor force in an otherwise standard model with staggered price- and wage-setting. As in the standard model, the economy consists of a representative household, a representative labor packer, a representative composite-good producer, firms, and a monetary authority. In what follows, we describe the behavior of each economic agent, beginning with that of the representative labor packer and the representative household, which is novel in the literature.

## 2.1 Labor packers

The representative labor packer combines the individual differentiated labor services of a continuum of workers $i \in [0, n_t]$ using the CES aggregator

$$l_t = \left[ \int_0^{n_t} (h_t(i))^{\frac{\theta_w - 1}{\theta_w}} \, di \right]^{\frac{\theta_w}{\theta_w - 1}} n_t^{-\frac{1-\psi}{\theta_w - 1}}, \tag{1}$$

[10]See, e.g., Bilbiie et al. (2008), Lewis and Poilly (2012), Cavallari (2013), Bilbiie et al. (2014), and Bilbiie (2021).

where $l_t$ is aggregate labor, $n_t \in (0,1]$ is the labor force or employment, $h_t(i)$ denotes worker $i$'s hours worked to provide one kind of differentiated labor service, $\theta_w > 1$ is the elasticity of substitution between individual labor services, and $\psi \in \{0,1\}$ is an indicator to admit ($\psi = 1$) or preclude ($\psi = 0$) a variety effect from the differentiated labor services.[11] As in Erceg et al. (2000), the labor packer combines each worker's hours worked in the same proportion as firms would choose. If $\psi = 1$, the resulting aggregate labor exceeds total labor (i.e., the product of the number of workers and per-worker labor presented later), reflecting that the variety in individual labor services makes the labor force more productive. If $\psi = 0$, such a variety effect is absent. Given the aggregate wage $P_t w_t$ and individual wages $\{P_t w_t(i)\}$, the labor packer maximizes profit $P_t w_t \, l_t - \int_0^{n_t} P_t w_t(i) \, h_t(i) \, di$ subject to the labor aggregator (1), where $P_t$ is the price level, i.e., the price of the composite good presented later. The first-order condition for profit maximization yields the demand curve for each individual labor service

$$h_t(i) = l_t n_t^{-(1-\psi)} \left( \frac{P_t w_t(i)}{P_t w_t} \right)^{-\theta_w}, \tag{2}$$

and thus the labor aggregator (1) leads to the aggregate wage

$$P_t w_t = \left[ \int_0^{n_t} \left( P_t w_t(i) \right)^{1-\theta_w} \, di \right]^{\frac{1}{1-\theta_w}} n_t^{-\frac{1-\psi}{1-\theta_w}}. \tag{3}$$

## 2.2 Households

The representative household consists of a large number of members. Some members are out of the labor force and receive a flow utility of nonparticipation in the labor market, while the others provide differentiated labor services and their wages are chosen in a staggered fashion.

At the beginning of each period, a fraction $1 - \rho$ of workers exits the labor force, so $\rho \in (0,1]$ denotes workers' survival probability. In each period a measure $n_{e,t}$ of household members joins the labor force and forgoes the benefit of nonparticipation. Thus the law of motion of employment is

$$n_t = \rho \, n_{t-1} + n_{e,t} \, . \tag{4}$$

[11] In the absence of unemployment in the model, the terms "labor force" and "employment" are used interchangeably.

The household's preferences over consumption of the composite good, hours worked, and nonparticipation in the labor market are represented as the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[ \int_0^1 \log\left(c_t(i) - b\, c_{t-1}\right) di \exp z_{c,t} - \int_0^{n_t} \frac{\left(h_t(i)\right)^{1+\chi}}{1+\chi}\, di \exp z_{h,t} + \int_{n_t}^1 v_t\, di - \frac{\gamma}{2}\left(\frac{n_{e,t}}{n_e}\right)^2 \right], \tag{5}$$

where $E_t$ is the expectation operator conditional on information available in period $t$, $c_t = \int_0^1 c_t(i)di$ is aggregate consumption, $z_{c,t}$ is a demand shock, $\beta \in (0,1)$ is the subjective discount factor, $b \in [0,1]$ is the degree of (external) habit persistence in consumption preferences, $\chi \geq 0$ is the inverse of the elasticity of labor supply, $v_t = v \exp z_{n,t}$ is a household member's benefit of nonparticipation in terms of utility, $v$ is its steady-state value, and $z_{h,t}$ and $z_{n,t}$ are shocks to the intensive and extensive margins of labor supply, respectively. Moreover, when a household member enters the labor force, the household experiences a temporary inconvenience cost in terms of utility, which could capture both time costs associated with making child care and other arrangements and psychic costs of adapting one's daily routine. The magnitude of the cost is governed by $\gamma \geq 0$.

The household's budget constraint is

$$\int_0^1 P_t\, c_t(i)\, di + B_t = \int_0^{n_t} P_t w_t(i)\, h_t(i)\, di + r_{t-1}\, B_{t-1} + D_t, \tag{6}$$

where $B_t$ is the stock of one-period (riskless) bonds, $r_t$ is the interest rate on the bonds and is assumed to coincide with the monetary policy rate, and $D_t$ consists of lump-sum taxes and transfers as well as firms' profits received.

The household maximizes the utility function (5) subject to the budget constraint (6), the law of motion of employment (4), and the labor demand curves (2). In particular, the household determines its members' labor force participation by considering per-worker labor $h_t$ and the per-worker wage $P_t\omega_t$ associated with the labor aggregator (1) and the aggregate wage (3):[12]

[12] The aggregate wage index $P_t w_t$ and the per-worker wage index $P_t\omega_t$ are labor-market counterparts of the consumer and producer price indexes in product markets with firm entry and exit (see Bilbiie et al., 2008).

$$h_t = \left[ \frac{1}{n_t} \int_0^{n_t} (h_t(i))^{\frac{\theta_w - 1}{\theta_w}} \, di \right]^{\frac{\theta_w}{\theta_w - 1}}, \quad P_t \omega_t = \left[ \frac{1}{n_t} \int_0^{n_t} (P_t w_t(i))^{1-\theta_w} \, di \right]^{\frac{1}{1-\theta_w}}.$$

Then it follows that

$$h_t = \frac{l_t}{n_t^{1+\frac{\psi}{\theta_w - 1}}}, \tag{7}$$

$$\omega_t = \frac{w_t}{n_t^{\frac{\psi}{1-\theta_w}}}. \tag{8}$$

Consequently, aggregate labor $l_t = h_t \, n_t \, n_t^{\frac{\psi}{\theta_w - 1}}$ consists of not only per-worker labor and the number of workers but also the variety effect $n_t^{\frac{1}{\theta_w - 1}}$ if it is present, i.e., $\psi = 1$. Correspondingly, if $\psi = 1$, the aggregate wage is $w_t = \omega_t n_t^{\frac{1}{1-\theta_w}}$, so that in the presence of the variety effect, a larger labor force reduces the aggregate wage, which increases the responsiveness of wage growth to employment as explained later. Moreover, substituting the labor demand curves (2) in the utility function (5) introduces a relative wage distortion

$$\Delta_{w,t} = \frac{1}{n_t} \int_0^{n_t} \left( \frac{P_t w_t(i)}{P_t \omega_t} \right)^{-\theta_w (1+\chi)} di. \tag{9}$$

In the presence of complete contingent claims for consumption and given the per-worker wage and the relative wage distortion, the first-order conditions for utility maximization with respect to consumption, bond holdings, and labor force participation are written as, respectively,

$$\lambda_t = \frac{\exp z_{c,t}}{c_t - b \, c_{t-1}}, \tag{10}$$

$$1 = \beta E_t \left( \frac{\lambda_{t+1}}{\lambda_t} \frac{r_t}{\pi_{t+1}} \right), \tag{11}$$

$$v \exp z_{n,t} = \lambda_t \omega_t h_t - \frac{h_t^{1+\chi} \Delta_{w,t}}{1+\chi} \exp z_{h,t} - \frac{\gamma}{[(1-\rho)n]^2} \left[ (n_t - \rho \, n_{t-1}) - \beta \rho \left( E_t n_{t+1} - \rho \, n_t \right) \right], \tag{12}$$

where $\lambda_t$ is the marginal utility of consumption and $\pi_t = P_t / P_{t-1}$ is the inflation rate of the composite good's price. The labor force entry condition (12) implies that the household increases its members' labor force participation until the marginal worker is indifferent between the benefit of nonparticipation $v_t$ $(= v \exp z_{n,t})$ and the reward from market work, which consists of per-worker labor earnings and labor disutility as well as the net cost of employment adjustment. Both types of labor supply shocks $z_{h,t}$ and $z_{n,t}$ affect the labor force entry decision.

Given the labor demand curves (2), individual wages $\{P_t w_t(i)\}$ are set on a staggered basis as in Erceg et al. (2000). In each period, a fraction $\xi_w \in (0,1)$ of wages is indexed to the steady-state wage growth rate $\pi_w$, while the remaining fraction $1 - \xi_w$ is chosen so as to maximize the relevant utility function

$$E_t \sum_{j=0}^{\infty} (\xi_w \beta \rho)^j \left[ -\frac{\left(h_{t+j|t}(i)\right)^{1+\chi}}{1+\chi} \exp z_{h,t+j} + \frac{\lambda_{t+j}}{P_{t+j}} P_t w_t(i)\, \pi_w^j\, h_{t+j|t}(i) \right]$$

subject to the labor demand curve

$$h_{t+j|t}(i) = l_{t+j}\, (n_{t+j})^{-(1-\psi)} \left( \frac{P_t w_t(i)\, \pi_w^j}{P_{t+j} w_{t+j}} \right)^{-\theta_w}.$$

The first-order condition for utility maximization with respect to the wage is

$$\begin{aligned} 0 = E_t \sum_{j=0}^{\infty} (\xi_w \beta \rho)^j \lambda_{t+j}\, l_{t+j}\, (n_{t+j})^{-(1-\psi)}\, (w_t^*)^{-\theta_w} \prod_{k=1}^{j} \left( \frac{\pi_{w,t+k}}{\pi_w} \right)^{\theta_w} \left\{ w_t^* \prod_{k=1}^{j} \left( \frac{\pi_{t+k}}{\pi_w} \right)^{-1} \right. \\ \left. - \frac{\theta_w}{\theta_w - 1} \left[ l_{t+j}\, (n_{t+j})^{-(1-\psi)}\, (w_t^*)^{-\theta_w} \prod_{k=1}^{j} \left( \frac{\pi_{w,t+k}}{\pi_w} \right)^{\theta_w} \right]^{\chi} \frac{\exp z_{h,t+j}}{\lambda_{t+j} w_{t+j}} \prod_{k=1}^{j} \frac{w_{t+k}}{w_{t+k-1}} \right\}, \end{aligned} \tag{13}$$

where $w_t^* = W_t^*/w_t$ is the optimized relative wage and $\pi_{w,t}$ is the wage growth rate, i.e.,

$$\pi_{w,t} = \frac{P_t w_t}{P_{t-1} w_{t-1}} = \pi_t \frac{w_t}{w_{t-1}}. \tag{14}$$

It is assumed, for simplicity, that the distribution of entrants' wages is the same as that of incumbent workers' wages. Under this assumption, staggered wage-setting implies that the aggregate wage (3) and the relative wage distortion (9) are written as, respectively,

$$\frac{1}{n_t^{\psi}} = \xi_w \left(\frac{\pi_{w,t}}{\pi_w}\right)^{\theta_w - 1} \frac{1}{n_{t-1}^{\psi}} + (1-\xi_w)(w_t^*)^{1-\theta_w}, \tag{15}$$

$$\frac{\Delta_{w,t}}{n_t^{\frac{\psi\theta_w(1+\chi)}{\theta_w-1}}} = \xi_w \left(\frac{\pi_{w,t}}{\pi_w}\right)^{\theta_w(1+\chi)} \frac{\Delta_{w,t-1}}{n_{t-1}^{\frac{\psi\theta_w(1+\chi)}{\theta_w-1}}} + (1-\xi_w)(w_t^*)^{-\theta_w(1+\chi)}. \tag{16}$$

It will be useful to consider the average wage markup of the real wage over the marginal rate of substitution between consumption and labor, defined as

$$\mu_{w,t} = \int_0^{n_t} s_t(i)\,\mu_{w,t}(i)\,di = \frac{\lambda_t w_t n_t^{\chi + \frac{\psi(1+\chi)}{\theta_w - 1}}}{l_t^{\chi}\,\Delta_{w,t}\exp z_{h,t}}, \tag{17}$$

where the weight $s_t(i)$ is worker $i$'s share of the household's labor disutility given by $s_t(i) = (h_t(i))^{1+\chi}/(n_t h_t^{1+\chi}\Delta_{w,t})$ and the worker's wage markup is $\mu_{w,t}(i) = \lambda_t w_t(i)/[(h_t(i))^{\chi}\exp z_{h,t}]$.[13]

## 2.3 Composite-good producers and firms

The setup of composite-good producers and firms is representative of the literature.

The representative composite-good producer combines the outputs of a continuum of firms $f \in [0,1]$ using the CES aggregator $y_t = \left[\int_0^1 (y_t(f))^{(\theta_p-1)/\theta_p}\,df\right]^{\theta_p/(\theta_p-1)}$, where $y_t$ is the output of the composite good, $y_t(f)$ is firm $f$'s output of an individual differentiated good, and $\theta_p > 1$ is the elasticity of substitution between individual goods. Given the composite good's price $P_t$ and individual goods' prices $\{P_t(f)\}$, the composite-good producer maximizes profit $P_t\,y_t - \int_0^1 P_t(f)\,y_t(f)\,df$ subject to the CES goods aggregator. The first-order condition for profit maximization yields the demand curve for each individual good

$$y_t(f) = y_t \left(\frac{P_t(f)}{P_t}\right)^{-\theta_p}, \tag{18}$$

and thus the goods aggregator leads to the composite good's price

$$P_t = \left[\int_0^1 (P_t(f))^{1-\theta_p}\,df\right]^{\frac{1}{1-\theta_p}}. \tag{19}$$

[13]This average wage markup and a simple arithmetic average are identical up to the first order in the model.

The composite good's market clearing condition requires that its output be equal to the household's consumption:

$$y_t = c_t \,. \tag{20}$$

Each firm $f$ produces output $y_t(f)$ using the technology

$$y_t(f) = (l_t(f))^{\alpha} \exp z_{a,t} \,, \tag{21}$$

where $z_{a,t}$ is a productivity shock, $l_t(f)$ is firm $f$'s labor input, and $\alpha > 0$ is the labor elasticity of output. Production cost minimization then implies that firm $f$ faces the real marginal cost

$$mc_t(f) = \frac{w_t l_t(f)}{\alpha\, y_t(f)} \,. \tag{22}$$

Taking into account the goods demand curves (18) and the real marginal cost (22), firms set their product prices on a staggered basis as in Calvo (1983). In each period, a fraction $\xi_p \in (0,1)$ of firms indexes prices to the steady-state inflation rate $\pi$, while the remaining fraction $1-\xi_p$ sets the price $P_t(f)$ so as to maximize relevant profit

$$E_t \sum_{j=0}^{\infty} \xi_p^j \, Q_{t,t+j} \left( P_t(f)\, \pi^j - P_{t+j} mc_{t+j}(f) \right) Y_{t+j} \left( \frac{P_t(f)\, \pi^j}{P_{t+j}} \right)^{-\theta_p},$$

where $Q_{t,t+j}$ is the nominal stochastic discount factor between period $t$ and period $t+j$. Using the equilibrium condition $Q_{t,t+j} = \beta^j (\lambda_{t+j}/\lambda_t)/(P_t/P_{t+j})$, the first-order condition for profit maximization is

$$0 = E_t \sum_{j=0}^{\infty} (\xi_p \beta)^j \lambda_{t+j} y_{t+j} \left\{ (p_t^*)^{-\theta_p} \prod_{k=1}^{j} \left( \frac{\pi_{t+k}}{\pi} \right)^{\theta_p} \left[ p_t^* \prod_{k=1}^{j} \left( \frac{\pi_{t+k}}{\pi} \right)^{-1} - \frac{\theta_p}{\theta_p - 1}\, mc_{t+j}^* \right] \right\}, \tag{23}$$

where $p_t^* = P_t^*/P_t$ is the optimized relative price and $mc_t^*$ is the associated real marginal cost.

Combining the goods demand curves (18), the production functions (21), and the labor market clearing condition $l_t = \int_0^1 l_t(f) df$ yields the aggregate production function

$$y_t \, \Delta_{p,t}^{\alpha} = l_t^{\alpha} \exp z_{a,t} \,, \tag{24}$$

where $\Delta_{p,t}$ denotes a relative price distortion that reflects inefficiency in producing the composite good due to dispersion in the relative prices of individual goods, given by

$$\Delta_{p,t} = \int_0^1 \left( \frac{P_t(f)}{P_t} \right)^{-\frac{\theta_p}{\alpha}} df. \tag{25}$$

Following Galí et al. (2001), the average real marginal cost is defined as

$$mc_t = \frac{w_t l_t}{\alpha \, y_t}. \tag{26}$$

Then, it follows that

$$mc^*_{t+j} = \frac{mc_{t+j}}{\Delta_{p,t+j}} \, (p^*_t)^{-\theta_p \frac{1-\alpha}{\alpha}} \prod_{k=1}^{j} \left( \frac{\pi_{t+k}}{\pi} \right)^{\theta_p \frac{1-\alpha}{\alpha}}. \tag{27}$$

Staggered price-setting implies that the composite good's price (19) and the relative price distortion (25) are written as, respectively,

$$1 = \xi_p \left( \frac{\pi_t}{\pi} \right)^{\theta_p - 1} + (1 - \xi_p)(p^*_t)^{1-\theta_p}, \tag{28}$$

$$\Delta_{p,t} = \xi_p \left( \frac{\pi_t}{\pi} \right)^{\frac{\theta_p}{\alpha}} \Delta_{p,t-1} + (1 - \xi_p)(p^*_t)^{-\frac{\theta_p}{\alpha}}. \tag{29}$$

## 2.4 Monetary authority and equilibrium

The monetary authority conducts policy according to a rule of the sort proposed by Taylor (1993). This rule adjusts the policy rate in response to the inflation rate, the output gap, and the employment gap:

$$\log r_t = \log r + \phi_p \, (\log \pi_t - \log \pi) + \phi_y \, (\log y_t - \log y^n_t) + \phi_n \, (\log n_t - \log n^n_t), \tag{30}$$

where $r$ is the steady-state interest rate; $\phi_p$, $\phi_y$, and $\phi_n$ are the policy responses to the inflation rate, the output gap, and the employment gap; and $y^n_t$ and $n^n_t$ are the natural rates of output and employment that would prevail in the absence of price and wage rigidities (i.e., $\xi_p = \xi_w = 0$), determined by

$$\frac{y_t^n}{\exp z_{a,t}} = \left(\alpha \frac{\theta-1}{\theta} \frac{\theta_w-1}{\theta_w} (n_t^n)^{\chi+\frac{\psi(1+\chi)}{\theta_w-1}} \frac{\exp z_{c,t}}{y_t^n - b\, y_{t-1}^n} \frac{\exp z_{a,t}}{\exp z_{h,t}}\right)^{\frac{\alpha}{1-\alpha+\chi}}, \tag{31}$$

$$v \exp z_{n,t} = \alpha \frac{\theta-1}{\theta} \frac{1+\theta_w\chi}{\theta_w(1+\chi)} \frac{\exp z_{c,t}}{y_t^n - b\, y_{t-1}^n} \frac{y_t^n}{n_t^n} - \frac{\gamma}{[(1-\rho)n]^2} \left[\left(n_t^n - \rho\, n_{t-1}^n\right) - \beta\rho \left(E_t n_{t+1}^n - \rho\, n_t^n\right)\right]. \tag{32}$$

The equilibrium conditions of the model consist of (4), (7), (8), (10)–(17), (20), (23), (24), (26)–(31), and (32), along with the four shocks' respective AR(1) processes

$$z_{i,t} = \rho_i z_{i,t-1} + \varepsilon_{i,t}, \quad i = a, c, h, n, \tag{33}$$

with the persistence parameter $\rho_i \in [0, 1)$ and the shock innovation $\varepsilon_{i,t} \sim$ i.i.d. $N(0, \sigma_i^2)$.

## 2.5 Log-linearized equilibrium conditions

Log-linearizing the equilibrium conditions around the steady state leads to the standard forms of the spending Euler equation, the Taylor-type rule, and the price Phillips curve:

$$\hat{\lambda}_t = E_t \hat{\lambda}_{t+1} + \hat{r}_t - E_t \hat{\pi}_{t+1}, \tag{34}$$

$$\hat{r}_t = \phi_p \hat{\pi}_t + \phi_y (\hat{y}_t - \hat{y}_t^n) + \phi_n (\hat{n}_t - \hat{n}_t^n), \tag{35}$$

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa_p \hat{mc}_t, \tag{36}$$

where hatted variables denote log-deviations from steady-state values and $\kappa_p = (1-\xi_p)(1-\xi_p\beta)/\{\xi_p[1+\theta_p(1-\alpha)/\alpha]\}$. The marginal utility of consumption, the real marginal cost, and the aggregate production function are described by[14]

$$\hat{\lambda}_t = -\frac{1}{1-b}\, \hat{y}_t + \frac{b}{1-b}\, \hat{y}_{t-1} + z_{c,t}\,, \tag{37}$$

$$\hat{mc}_t = \hat{w}_t - \left(\hat{y}_t - \hat{l}_t\right), \tag{38}$$

$$\hat{y}_t = \alpha\, \hat{l}_t + z_{a,t}\,. \tag{39}$$

[14] As in standard models with sticky prices and wages, the relative price and wage distortions have no first-order effects in the presence of price and wage indexation to the steady-state inflation and wage growth rates.

The wage Phillips curve in our model relates wage growth $\hat{\pi}_{w,t}$ $(= \hat{\pi}_t + \hat{w}_t - \hat{w}_{t-1})$ to not only expected future wage growth and the average wage markup but also changes in employment in the presence of the variety effect, i.e., $\psi = 1$:

$$\hat{\pi}_{w,t} = \beta\rho\, E_t \hat{\pi}_{w,t+1} - \kappa_w\, \hat{\mu}_{w,t} - \frac{\psi}{\theta_w - 1}\left[(\hat{n}_t - \hat{n}_{t-1}) - \beta\rho\,(E_t \hat{n}_{t+1} - \hat{n}_t)\right], \tag{40}$$

where $\kappa_w = (1-\xi_w)(1-\xi_w\beta\rho)/[\xi_w(1+\theta_w\chi)]$ and the average wage markup is given by

$$\hat{\mu}_{w,t} = \hat{w}_t - \left(\chi\, \hat{l}_t - \hat{\lambda}_t\right) + \left[\chi + \frac{\psi(1+\chi)}{\theta_w - 1}\right]\hat{n}_t - z_{h,t}\,. \tag{41}$$

Lower employment compresses the average wage markup, regardless of the variety effect. Moreover, our model includes the log-linearization of the labor force entry condition (12):

$$\begin{aligned}\frac{\theta_w}{1+\theta_w\chi}\hat{\mu}_{w,t} = {} & -\frac{1}{1+\chi}\, z_{h,t} + \left(\frac{1}{1+\chi} - \tilde{\gamma}\,\frac{1-\beta\rho}{1-\rho}\right) z_{n,t} - \hat{l}_t + \left(1 + \frac{\psi}{\theta_w - 1}\right)\hat{n}_t \\ & + \frac{\tilde{\gamma}}{(1-\rho)^2}\left[(\hat{n}_t - \rho\,\hat{n}_{t-1}) - \beta\rho\,(E_t\hat{n}_{t+1} - \rho\,\hat{n}_t)\right],\end{aligned} \tag{42}$$

where we use the average wage markup (41) and $\tilde{\gamma} = \gamma(1-b)\theta_p\theta_w/[\alpha(\theta_p - 1)(1+\theta_w\chi)]$. The entry condition relates the average wage markup to the two types of labor supply shocks as well as additional labor and employment terms. A positive intensive-margin labor supply shock $z_{h,t}$ reduces the average wage markup, making employment less attractive (with a partial offset on the right hand side of the equation). A positive extensive-margin labor supply shock $z_{n,t}$ makes nonparticipation more attractive. Then, employment declines to meet the condition. The model also contains the log-linearization of employment's law of motion (4): $\hat{n}_t = \rho\hat{n}_{t-1} + (1-\rho)\hat{n}_{e,t}$, which shows that the case of a constant labor force or, equivalently, the standard counterpart model with staggered price- and wage-setting, in which $\hat{n}_t = 0$, can be retrieved by setting $\rho = 1$.

In the case of a constant labor force, the wage Phillips curve (40) is reduced to the standard form

$$\hat{\pi}_{w,t} = \beta E_t \hat{\pi}_{w,t+1} - \kappa_w\, \hat{\mu}_{w,t}\,, \tag{43}$$

while the log-linearized labor force entry condition (42) becomes irrelevant.

# 3 Model's Business Cycle Properties

In this section we investigate the model's business cycle properties using variance decompositions and impulse responses to shocks. To parameterize the model, we calibrate its structural parameters and then estimate the remaining parameters.

## 3.1 Calibration of structural model parameters

We calibrate the structural parameters of the model so that their values are comparable with those used in related literature. Table 1 presents the quarterly calibration of the structural model parameters. For values of the structural parameters that are common across sticky price models, we follow Galí (2011) and Campolmi and Gnocchi (2016). Specifically, we set the subjective discount factor at $\beta = 0.99$, the inverse of the elasticity of labor supply at $\chi = 5$, and the labor elasticity of output at $\alpha = 2/3$, as in Galí (2011). We also choose the elasticity of substitution between individual goods at $\theta_p = 6$ and the degree of price rigidity at $\xi_p = 2/3$ as in Campolmi and Gnocchi (2016). We likewise set the elasticity of substitution between individual labor services at $\theta_w = 6$ and the degree of wage rigidity at $\xi_w = 2/3$. Moreover, we choose the degree of habit persistence in consumption preferences at $b = 0.7$ as in the estimate of Smets and Wouters (2007) and the monetary policy responses to inflation, the output gap, and the employment gap at $\phi_p = 1.5$, $\phi_y = 0.5/4$, and $\phi_n = 0$, respectively, as in Taylor (1993).

The remaining structural parameters of the model are $n$, $\rho$, and $\psi$. The steady-state employment-population rate is set at $n = 0.59$ as in Galí (2011). The workers' survival probability $\rho$ is chosen as follows. The exit rate from employment to nonparticipation has averaged 2.8 percent per month over the period 1991–2023 in the Current Population Survey, which implies that the average quarterly exit rate is 8.3 percent.[15] In the model steady state, there are $n_e$ exits in each quarter, so the quarterly exit rate is $n_e/n = 0.083$. Consequently, the survival probability is set at $\rho = 1 - n_e/n = 0.917$.

We admit the variety effect from differentiated labor services in the baseline parameter-

[15]The monthly exit rate is calculated as $EN_t/E_{t-1}$, where $EN_t$ represents the worker flows from employment to nonparticipation (BLS series LNS17800000) and $E_t$ denotes the employment level (BLS series LNS12000000). This calculation abstracts from unemployment, consistent with the model.

Table 1: Calibration of structural parameters in the quarterly model.

| Parameter | Description | Value |
|---|---|---|
| $\beta$ | Subjective discount factor | 0.99 |
| $\chi$ | Inverse of elasticity of labor supply | 5 |
| $\alpha$ | Labor elasticity of output | 2/3 |
| $\theta_p$ | Elasticity of substitution between goods | 6 |
| $\xi_p$ | Degree of price rigidity | 2/3 |
| $\theta_w$ | Elasticity of substitution between labor services | 6 |
| $\xi_w$ | Degree of wage rigidity | 2/3 |
| $b$ | Degree of habit persistence in consumption preferences | 0.7 |
| $\phi_p$ | Monetary policy response to inflation | 1.5 |
| $\phi_y$ | Monetary policy response to output gap | 0.5/4 |
| $\phi_n$ | Monetary policy response to employment gap | 0 |
| $n$ | Steady-state employment-population rate | 0.59 |
| $\rho$ | Workers' survival probability | 0.917 |
| $\psi$ | Labor service variety effect | 1 |

ization of the model. The CES labor aggregator can be viewed as succinctly capturing the notion that specialization improves productivity, which dates back at least to Smith (1776). It may also capture productivity gains from the return to in-person work after the COVID-19 pandemic. Recent micro evidence indicates that bringing workers together improves their productivity. For example, Battiston et al. (2021) find that face-to-face communication raises productivity. Consistently, more and more firms insist that workers return to the office after the shift to working from home during the pandemic (Barrero et al., 2024).[16] Thus we set $\psi = 1$ and examine the role of the variety effect in the quantitative welfare analysis presented in Section 5.

## 3.2 Estimation of remaining model parameters

Given the calibration of the structural parameters, we obtain values for the remaining parameters of the model using Bayesian estimation. We estimate the parameter of the employment adjustment cost, $\gamma$, and those of the four shock processes, $(\rho_i, \sigma_i)$, $i = a, c, h, n$, using the four US quarterly time series on output, employment, per-worker hours worked, and inflation during the sample period from 1984:Q1 to 2019:Q4. The first three time series for $\hat{y}_t$, $\hat{n}_t$,

[16] Empirical evidence provides stronger support for the variety effect if each worker is interpreted as representing an industry in the labor aggregate. Cingano and Schivardi (2004) show that greater sectoral variety of employment in localities increases total factor productivity.

and $\hat{h}_t$ are per-capita output, per-capita employment, and average weekly hours worked in the business sector that are detrended using the Hodrick-Prescott filter, and the last one for $\hat{\pi}_t$ is the inflation rate of the personal consumption expenditures deflator that is demeaned using the sample average.

Table 2: Prior and posterior distributions for parameters of employment adjustment cost and shock processes.

| | Prior distribution | | | Posterior distribution | |
|---|---|---|---|---|---|
| Parameter | Distribution | Mean | St. dev. | Mean | 90% interval |
| $\gamma$ | Gamma | 0.1 | 0.02 | 0.194 | $[0.153, 0.232]$ |
| $\rho_c$ | Beta | 0.5 | 0.2 | 0.870 | $[0.847, 0.894]$ |
| $\rho_a$ | Beta | 0.5 | 0.2 | 0.956 | $[0.919, 0.995]$ |
| $\rho_h$ | Beta | 0.5 | 0.2 | 0.849 | $[0.819, 0.879]$ |
| $\rho_n$ | Beta | 0.5 | 0.2 | 0.469 | $[0.341, 0.595]$ |
| $\sigma_c$ | Inv. gamma | 0.001 | 0.02 | 0.051 | $[0.046, 0.056]$ |
| $\sigma_a$ | Inv. gamma | 0.001 | 0.02 | 0.005 | $[0.005, 0.006]$ |
| $\sigma_h$ | Inv. gamma | 0.001 | 0.02 | 0.397 | $[0.350, 0.441]$ |
| $\sigma_n$ | Inv. gamma | 0.001 | 0.02 | 0.038 | $[0.027, 0.049]$ |

The prior distributions for the parameters to be estimated are presented in Table 2. We suppose a relatively small employment adjustment cost, so we agnostically set the prior for $\gamma$ to be the gamma distribution with mean 0.1 and standard deviation 0.02. The priors for the shock processes are based on Smets and Wouters (2007), that is, the beta distributions with mean 0.5 and standard deviation 0.2 for the shock persistence parameters $\rho_i$, $i = a, c, h, n$, and the inverse gamma distributions with mean 0.001 and standard deviation 0.02 for the shock innovations' standard deviations $\sigma_i$, $i = a, c, h, n$. Table 2 also reports each parameter's posterior mean and 90 percent highest posterior density interval.[17] The posterior mean estimates indicate that the productivity shock is more persistent than the other three shocks. Moreover, the product of the estimated standard deviation of the intensive-margin labor supply shock and the slope of the wage Phillips curve, $\kappa_w \sigma_h = 0.0025$, is close to the comparable standard deviation of the wage markup shock of 0.0024 estimated by Smets and Wouters (2007). In what follows, we set the values for the estimated parameters at their

[17] In the estimation, $200,000$ draws are generated and the first $100,000$ draws are discarded. The scale factor for the jumping distribution in the Metropolis-Hastings algorithm is adjusted so that the acceptance rate is approximately 24 percent.

posterior mean estimates, that is, $\gamma = 0.194$, $\rho_c = 0.870$, $\rho_a = 0.956$, $\rho_h = 0.849$, $\rho_n = 0.469$, $\sigma_c = 0.051$, $\sigma_a = 0.005$, $\sigma_h = 0.397$, and $\sigma_n = 0.038$.

## 3.3 Variance decompositions and impulse responses to shocks

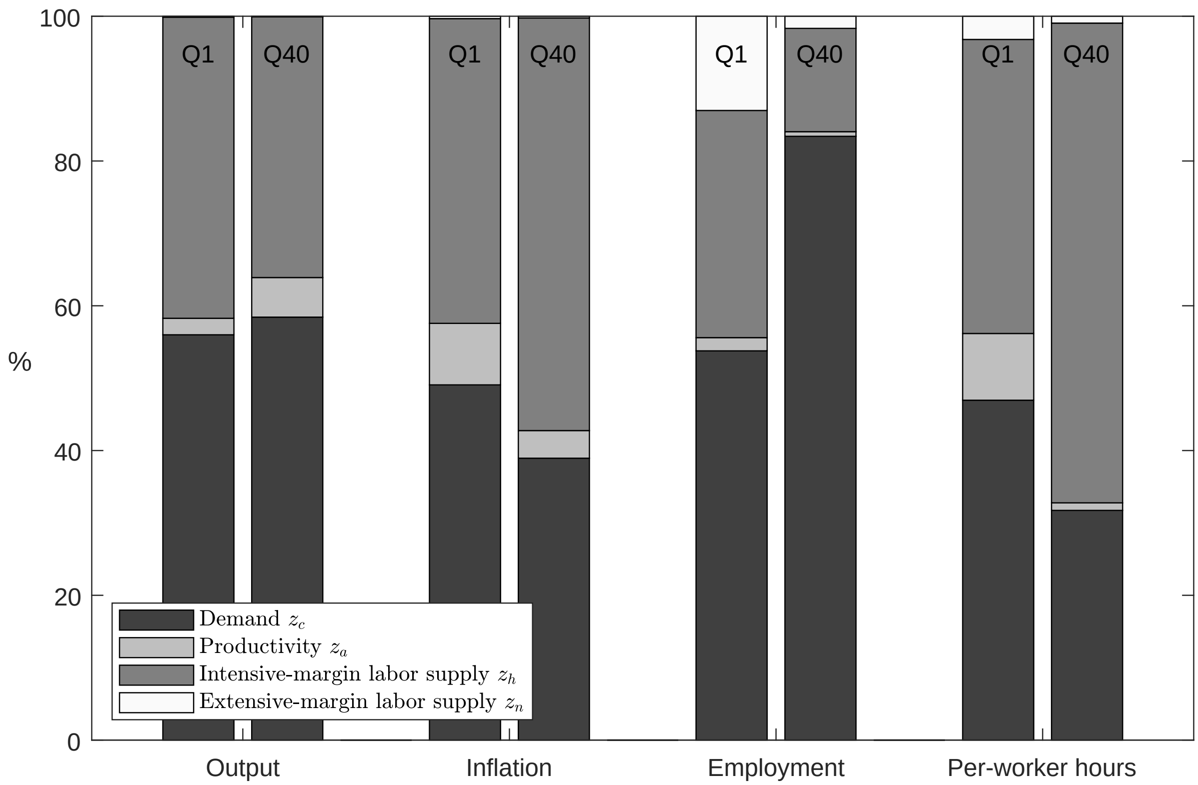
We analyze the estimated model using variance decompositions and impulse responses to shocks.

Figure 1 reports the forecast error variance decompositions for the estimated model. The decompositions account for each shock's relative contribution to the four observable variables (i.e., output, inflation, employment, and per-worker hours worked) at the forecast horizons of one (left bar) and 40 (right bar) quarters ahead. The demand shock explains slightly more than half of output fluctuations and the largest portion of employment fluctuations in the estimated model. The supply shocks, such as the productivity shock and the two types of labor supply shocks, dominate the variability of inflation and per-worker hours. Among the labor supply shocks, the extensive-margin shock plays some more role for fluctuations in employment and per-worker hours at shorter forecast horizons. Overall, however, the intensive-margin shock is substantially more important than the extensive-margin shock in accounting for business cycle fluctuations in the estimated model.

We turn next to the impulse responses to shocks in the estimated model with a twofold goal. First, comparing the impulse responses with the existing empirical evidence can validate the model both qualitatively and quantitatively. Second, the impulse responses illustrate the main distinction between the extensive- and intensive-margin labor supply shocks. Figure 2 shows the impulse responses to one-standard-deviation positive innovations to the demand shock $z_{c,t}$, the productivity shock $z_{a,t}$, and the intensive- and extensive-margin labor supply shocks $z_{h,t}$ and $z_{n,t}$.

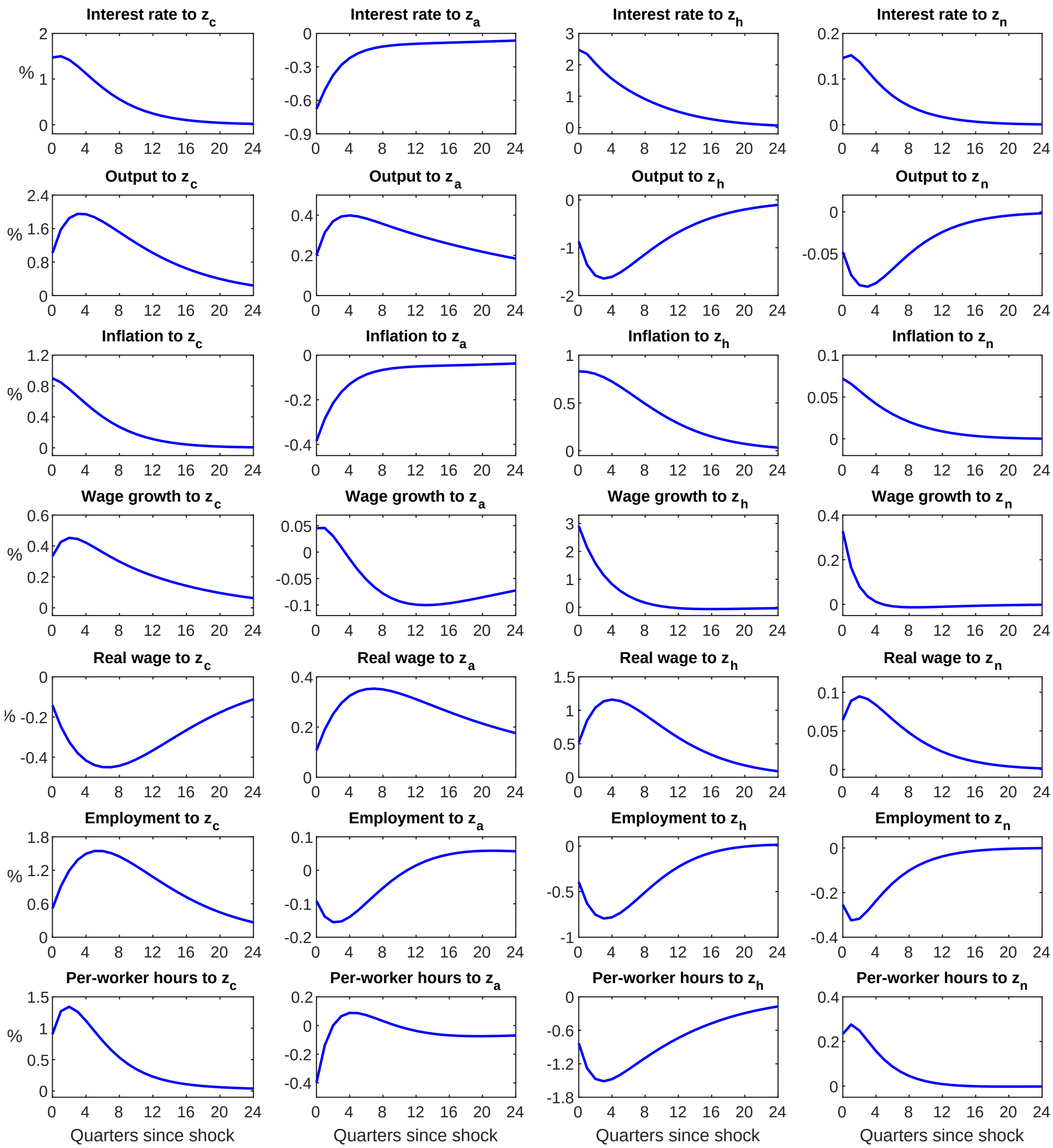
Starting in the first column of the figure, a positive demand shock raises output, inflation, and hence the interest rate. To meet an increase in demand, employment and per-worker hours worked rise. The additional labor force entry puts downward pressure on the real wage, which declines gradually. These responses align qualitatively with evidence on the responses to demand shocks from VARs. Christiano et al. (2015) show that an expansionary monetary policy shock raises output and inflation but reduces the real wage with a lag. The vector autoregression (VAR) literature has focused on the dynamics of aggregate hours worked,

Figure 1: Forecast error variance decomposition.




*Notes*: The figure presents the forecast error variance decompositions of output, inflation, employment, and per-worker hours worked at the forecast horizons of one and 40 quarters ahead, labeled "Q1" and "Q40," respectively. The values of model parameters used are those reported in Table 1 and the posterior mean estimates reported in Table 2.

Figure 2: Impulse responses to shocks.




*Notes*: The panels in each column display the impulse responses of the interest rate $r$, output $y$, the inflation rate $\pi$, the wage growth rate $\pi_w$, the real wage $w$, employment $n$, and per-worker hours $h$, respectively, to one-standard-deviation positive innovations to the demand shock $z_c$ (first column), the productivity shock $z_a$ (second column), and the intensive- and extensive-margin labor supply shocks $z_h$ (third column) and $z_n$ (fourth column) in the model. All responses are expressed as percentages; the responses of the interest, inflation, and wage growth rates are displayed at annualized rates. The values of model parameters used are those reported in Table 1 and the posterior mean estimates reported in Table 2.

with scant evidence on the separate dynamics of employment and per-worker hours worked. An exception is Ma (2024), who estimates a VAR and shows that an expansionary monetary policy shock increases per-worker hours rapidly and raises employment with a lag, consistent with the dynamics shown in the figure.

The second column of the figure displays the impulse responses to a positive productivity shock. The shock increases output and the real wage while decreasing inflation, consistent with VAR evidence (e.g., Christiano et al., 2015). Because prices are sticky, higher productivity leads firms to reduce their labor demand in the short run, so employment and per-worker hours worked initially decline. Empirical evidence on the response of aggregate hours worked (and the labor force) to productivity shocks is mixed, with some studies reporting increases and others reporting decreases.[18]

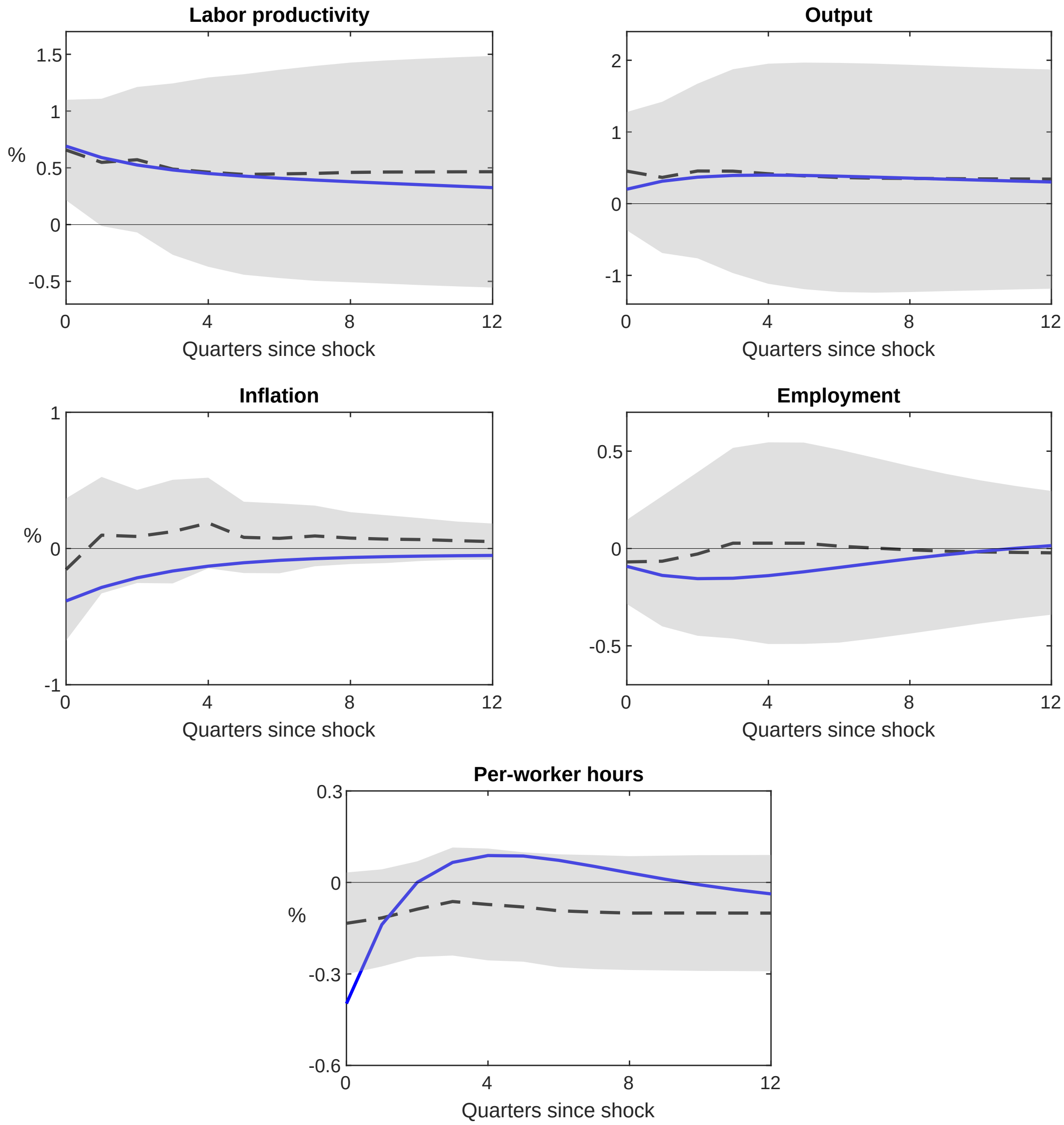
The third column of the figure presents the impulse responses to a positive intensive-margin labor supply shock $z_{h,t}$. The shock raises the marginal disutility of market work, which reduces per-worker hours worked and, by increasing the marginal rate of substitution between consumption and labor, compresses the average wage markup. The lower wage markup raises wage growth and hence the real wage, resulting in a higher real marginal cost, higher inflation, and lower output. The lower wage markup also induces a decline in employment via the labor force entry condition (42).

The fourth column illustrates the impulse responses to a positive extensive-margin labor supply shock $z_{n,t}$. The shock raises the benefit of nonparticipation and reduces employment via the labor force entry condition (42). The decline in employment compresses the average wage markup (41), triggering qualitatively the same responses of wage growth, the real wage, inflation, and output as those to the positive intensive-margin labor supply shock $z_{h,t}$ displayed in the third column. Contrary to the response to the latter shock, however, per-worker hours worked increase due to a higher marginal utility of consumption. The opposite responses of per-worker hours suggest that the extensive-margin shock $z_{n,t}$ and the intensive-margin shock $z_{h,t}$ can be identified separately.

For a quantitative model validation, we compare the impulse responses to a one-standard-

[18] Galí (1999) famously argued that positive technology shocks decrease aggregate hours worked in the short run, whereas Christiano et al. (2015) report that the shocks increase them. Fernald (2007) points out that a positive response of aggregate hours worked to technology shocks reflects positive low-frequency comovement between productivity and aggregate hours worked in the data.

Figure 3: Impulse responses to productivity shocks: model vs. VAR.




*Notes*: The figure displays impulse responses to a one-standard-deviation positive innovation to the productivity shock $z_a$ in the model (solid lines) and in a structural VAR (dashed lines). The VAR is estimated on data from 1950:Q2 to 2019:Q4 for the growth rate of output per hours (i.e., productivity growth), log employment per capita, log average weekly hours worked, and the inflation rate of the personal consumption expenditures deflator. The estimation method follows Fernald (2007), by adjusting productivity growth for trend breaks identified by a Bai and Perron (1998) break test at 1973:Q2, 1997:Q2, and 2005:Q2, and identifying productivity shocks with long-run restrictions. The lag length of the VAR is four quarters. The gray bands are two-standard-deviations confidence intervals obtained from 1,000 bootstrap replications. All responses are expressed as percentages; the responses of the inflation rate are displayed at the annualized rate. The values of model parameters used are those reported in Table 1 and the posterior mean estimates reported in Table 2.

deviation positive productivity shock in the estimated model with its counterpart obtained in a structural VAR. Figure 3 displays the responses of labor productivity, output, employment, per-worker hours worked, and inflation in the estimated model (solid lines) and in the VAR (dashed lines). The shock raises labor productivity and output persistently and reduces inflation. Employment and per-worker hours both decline in the short run. The impulse responses of the model remain within the confidence bands of the VAR, except for the impact response of per-worker hours. While per-worker hours in the model are more volatile than their empirical counterpart, employment in the model is somewhat more persistent than its empirical counterpart. Overall, the model impulse responses quantitatively match their empirical counterparts reasonably closely, suggesting that the model can be a useful tool for monetary policy analysis.

# 4 Welfare-Maximizing Policy

In this section, we examine a welfare-maximizing policy in the model using impulse responses to shocks. To illuminate the role of the employment gap in the welfare-maximizing policy, we abstract from the sources of short-run dynamics that capture business cycle properties presented in the preceding section but could obscure key mechanisms in the model. That is, we assume no consumption habit persistence, variety effect, or employment adjustment cost (i.e., $b = \psi = \gamma = 0$), each of which embeds a lagged endogenous variable in the model. In the next section, we reinstate these frictions in conducting a quantitative welfare comparison of different monetary policy strategies.

## 4.1 Natural rates and shocks

Staggered price- and wage-setting imply that the adjustments of real wages to shocks entail a welfare cost because prices, wages, or both have to adjust subject to their rigidities. Shocks shift the natural rate of output $y_t^n$ and thereby possibly the natural real wage $w_t^n$. We obtain the latter from Eqs. (24), (26), (28), and (29) under flexible prices and wages, i.e., $\xi_p = \xi_w = 0$:

$$w_t^n = \alpha \frac{\theta_p - 1}{\theta_p} \left( \frac{1}{y_t^n} \right)^{\frac{1-\alpha}{\alpha}} (\exp z_{a,t})^{\frac{1}{\alpha}}. \tag{44}$$

Hence, the natural real wage rises with positive productivity shocks and declines for a higher natural rate of output as long as $\alpha < 1$. Under the simplifying assumptions of $b = \psi = \gamma = 0$, the natural rates of output (31) and employment (32) are log-linearized as

$$\hat{y}_t^n = z_{a,t} + \frac{\alpha}{1+\chi} (\chi \, \hat{n}_t^n + z_{c,t} - z_{h,t}), \tag{45}$$

$$\hat{n}_t^n = z_{c,t} - z_{n,t} \, . \tag{46}$$

Therefore, a positive demand shock $z_{c,t}$ increases the natural rates of output and employment and decreases the natural real wage as long as $\alpha < 1$. A positive productivity shock $z_{a,t}$ raises not only the natural rate of output but also the natural real wage. A positive (contractionary) intensive-margin labor supply shock $z_{h,t}$ decreases the natural rate of output and thereby increases the natural real wage as long as $\alpha < 1$, and so does a positive extensive-margin labor supply shock $z_{n,t}$. The latter labor supply shock also reduces the natural rate of employment.

Using Eqs. (38) and (45), we can write the average wage markup (41) in the case of $b = \psi = \gamma = 0$ as

$$\hat{\mu}_{w,t} = \hat{mc}_t - \frac{1+\chi}{\alpha} (\hat{y}_t - \hat{y}_t^n) + \chi \, (\hat{n}_t - \hat{n}_t^n). \tag{47}$$

The price and wage Phillips curves (36) and (40) link inflation and wage growth to the real marginal cost and the average wage markup, respectively. Therefore, Eq. (47) implies that the monetary authority must balance the employment gap along with the output gap, inflation, and wage growth.

## 4.2 Impulse responses to shocks under welfare-maximizing policy

We analyze a welfare-maximizing policy to address how monetary policy should respond to each of the four shocks in the model. Such a policy maximizes the representative household's utility function (5) subject to the equilibrium conditions (4), (10)–(16), (20), (23), (24), (26)–(28), and (29) in terms of aggregate labor $l_t$ and the aggregate wage $w_t$.[19] The Lagrangian of the welfare maximization problem and the resulting equilibrium conditions are presented in Appendix B. After log-linearizing the equilibrium conditions under the policy, we obtain

[19]Eqs. (7) and (8) are used to remove per-worker labor $h_t$ and the per-worker wage $\omega_t$ from the welfare maximization problem.

the impulse responses displayed in Figure 4. This figure plots the responses of the output gap, inflation, wage growth, the real marginal cost, the average wage markup, and the employment gap to one-standard-deviation positive innovations to the demand shock $z_{c,t}$, the productivity shock $z_{a,t}$, and the intensive- and extensive-margin labor supply shocks $z_{h,t}$ and $z_{n,t}$.[20]

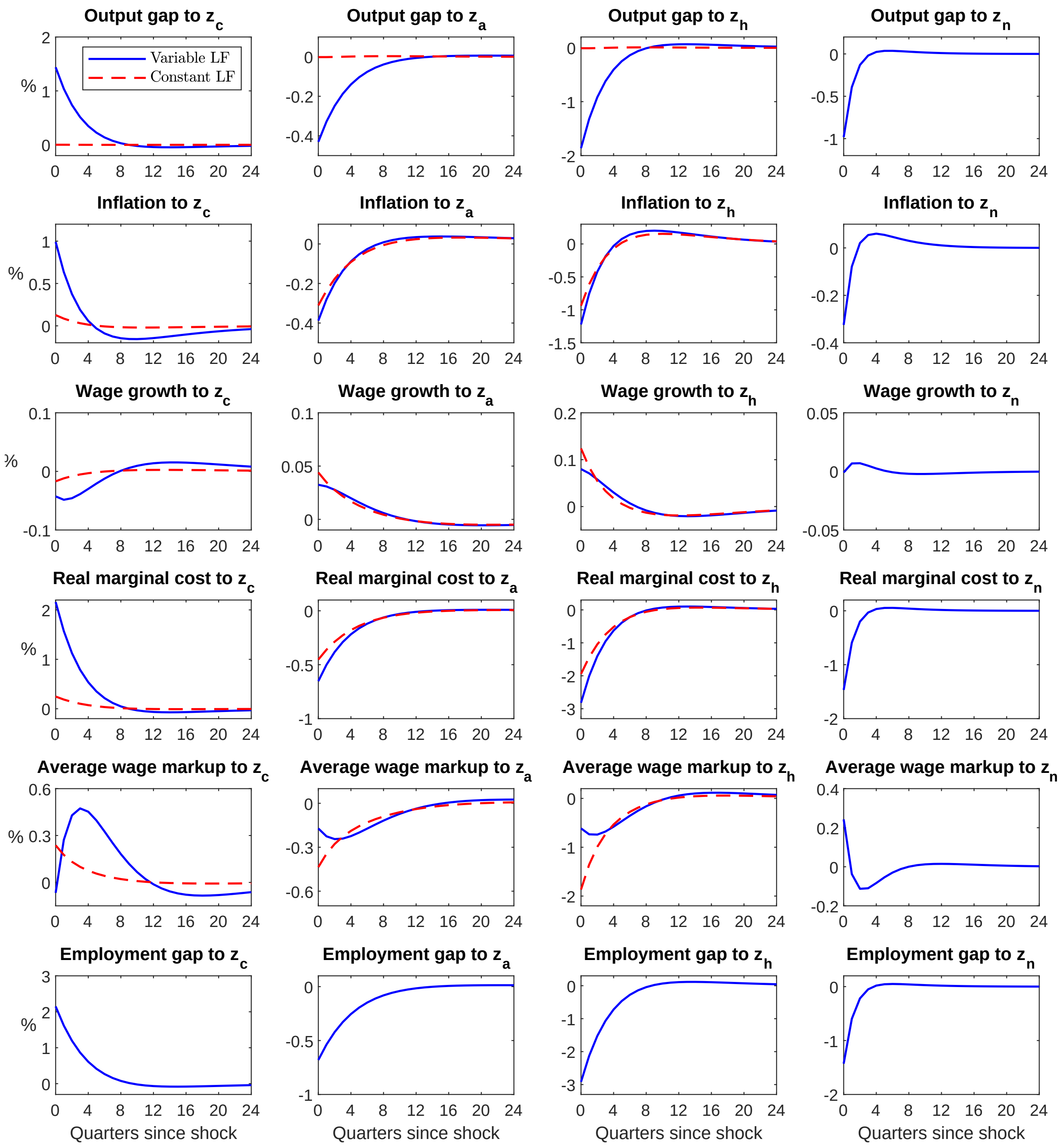
We discuss the impulse responses to each shock (solid lines), starting with a positive demand shock $z_{c,t}$ in the first column of the figure. This shock increases the natural rate of output and decreases the natural real wage. In response to the shock, the welfare-maximizing policy raises the output gap (top panel), inflation (second panel), and the employment gap (bottom panel), while inducing a small, ambiguous response of wage growth (third panel). By boosting output above its natural rate, the policy leads to increases in the real marginal cost and inflation and thus erodes the real wage. Moreover, the increase in the employment gap raises the average wage markup, which dampens wage growth in the wage Phillips curve (40) and the real wage. Hence, the increases in the employment gap and inflation work together to achieve the desired decrease in the real wage.

The second column of the figure displays the responses to a positive productivity shock $z_{a,t}$. This shock increases not only the natural rate of output but also the natural real wage. The welfare-maximizing policy then keeps the rise in output below the increase in its natural rate and thus reduces the output gap, which decreases the real marginal cost and hence inflation. The policy also decreases the employment gap and hence the average wage markup, resulting in a modest increase in wage growth. Again, the decreases in the employment gap and inflation contribute to achieving the desired increase in the real wage.

The last two columns of the figure present the responses to positive intensive- and extensive-margin labor supply shocks $z_{h,t}$ and $z_{n,t}$, respectively. Each of the labor supply shocks decreases the natural rate of output and increases the natural real wage. The welfare-maximizing policy then calls for declines in the output gap, inflation, and the employment gap, with a small rise in wage growth. The decline in the output gap lowers the real marginal cost and hence inflation. In turn, the declines in inflation and the employment gap both contribute to the desired increase in the real wage, the latter by raising wage growth.

[20]The figure omits per-worker hours, since their relevance for welfare is captured by the output and employment gaps.

Figure 4: Impulse responses under welfare-maximizing policy.

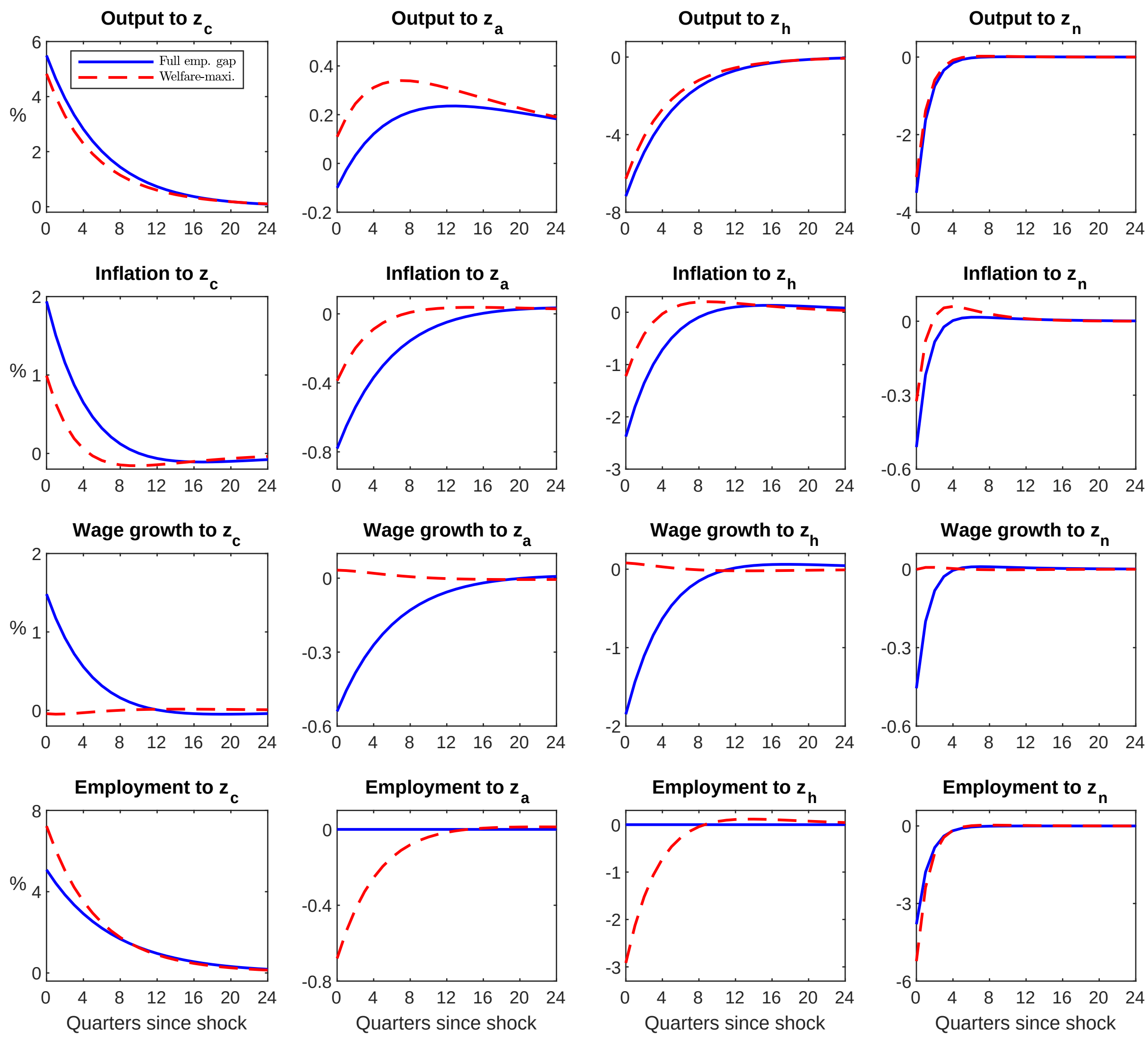



*Notes*: The solid lines ("Variable LF") display the impulse responses under the welfare-maximizing policy in the model with labor force entry and exit, and the dashed lines ("Constant LF") plot those in its counterpart model with a constant labor force. The panels in each column show the responses of the output gap $y/y^n$, the inflation rate $\pi$, the wage growth rate $\pi_w$, the real marginal cost $mc$, the average wage markup $\mu_w$, and the employment gap $n/n^n$, respectively, to one-standard-deviation positive innovations to the demand shock $z_c$, the productivity shock $z_a$, and the intensive- and extensive-margin labor supply shocks $z_h$ and $z_n$. All responses are expressed as percentages; the responses of the inflation and wage growth rates are displayed at annualized rates. The values of model parameters used are those reported in Table 1 and the posterior mean estimates reported in Table 2, except for $b = \psi = \gamma = 0$.

Two observations emerge from these impulse responses. First, the welfare-maximizing policy features wage growth stabilization with variation in the employment gap and inflation. Erceg et al. (2000) analyze a welfare-maximizing policy with staggered price- and wage-setting in the case of a constant labor force and productivity shocks. These authors find that stabilizing wage growth is a better monetary policy strategy than stabilizing inflation from a welfare viewpoint, that is, to achieve the desired adjustments of the real wage to productivity shocks. The minor responses of wage growth under the welfare-maximizing policy displayed in Figure 4 suggest that their policy prescription extends to the model with labor force entry and exit and shocks to demand and the intensive and extensive margins of labor supply.

Second, variation in the employment gap plays a substantial role in the welfare-maximizing policy, that is, reducing the welfare cost caused by the adjustments of the real wage to shocks under staggered price- and wage-setting. This observation is confirmed in Figure 5, which displays the impulse responses of output, inflation, wage growth, and employment to each of the four shocks under a policy strategy of fully stabilizing the employment gap, i.e., $\hat{n}_t - \hat{n}_t^n = 0$ (solid lines). The responses under the welfare-maximizing policy are added for reference (dashed lines). Under full employment gap stabilization, a positive demand shock $z_{c,t}$ (first column) increases employment in tandem with its natural rate, which entails a smaller increase than that under the welfare-maximizing policy. Consequently, the average wage markup rises less, putting less downward pressure on wage growth. Higher wage growth, by boosting the real wage and the real marginal cost, ultimately leads inflation and output to rise past their levels attained under the welfare-maximizing policy. In the case of a positive productivity shock $z_{a,t}$ (second column), preventing employment from declining leads to a higher average wage markup, which reduces wage growth and results in weaker output and a larger fall in inflation. Similarly, positive labor supply shocks $z_{h,t}$ and $z_{n,t}$ (last two columns), when met with the mandate of a zero employment gap, result in falls in wage growth and larger declines in output and inflation. Since the positive extensive-margin labor supply shock reduces the natural rate of employment, actual employment must fall to keep the employment gap closed. In short, full employment gap stabilization results in suboptimally large variability of both inflation and wage growth, thus confirming a substantial role of variation in the employment gap for reducing the welfare cost.

Figure 5: Impulse responses under full employment gap stabilization.




*Notes*: The solid lines ("Full emp. gap") display the impulse responses in the model under full employment gap stabilization, and the dashed lines ("Welfare-maxi.") plot those under the welfare-maximizing policy. The panels in each column show the responses of output $y$, the inflation rate $\pi$, the wage growth rate $\pi_w$, and employment $n$, respectively, to one-standard-deviation positive innovations to the demand shock $z_c$, the productivity shock $z_a$, and the intensive- and extensive-margin labor supply shocks $z_h$ and $z_n$. All responses are expressed as percentages; the responses of the inflation and wage growth rates are displayed at annualized rates. The values of model parameters used are those reported in Table 1 and the posterior mean estimates reported in Table 2, except for $b = \psi = \gamma = 0$.

# 5 Implications for Monetary Policy Strategies

In the preceding section, we have shown that the welfare-maximizing policy features wage growth stabilization with variation in the employment gap and inflation and that variation in the employment gap contributes to reducing a welfare cost caused by the real wage adjustment to shocks under staggered price- and wage-setting.

In this section, we conduct a welfare comparison of different monetary policy strategies in the quantitatively specified model with the parameter values reported in Tables 1 and 2, including $b = 0.7$, $\psi = 1$, and $\gamma = 0.194$. Two sets of monetary policy strategies are considered. The first set consists of fully stabilizing inflation (i.e., $\hat{\pi}_t = 0$), wage growth (i.e., $\hat{\pi}_{w,t} = 0$), and the employment gap (i.e., $\hat{n}_t - \hat{n}_t^n = 0$). The second set consists of following variants of the Taylor-type rule (35).

We quantify the welfare loss from adopting a monetary policy strategy by comparing the welfare cost incurred under the policy strategy to that under the welfare-maximizing policy. To that end, the representative household's utility function (5) is written recursively as

$$\mathcal{W}_t = \log\left(c_t - b\, c_{t-1}\right) \exp z_{c,t} - \frac{1}{1+\chi}\, l_t^{1+\chi}\, n_t^{-\left[\chi + \frac{\psi(1+\chi)}{\theta_w - 1}\right]} \Delta_{w,t} \exp z_{h,t} + (1 - n_t)\, v \exp z_{n,t} - \frac{\gamma}{2}\left(\frac{n_t - \rho n_{t-1}}{(1-\rho)n}\right)^2 + \beta E_t \mathcal{W}_{t+1}, \quad (48)$$

where $\mathcal{W}_t$ represents the welfare of the household in period $t$. The stochastic mean of the household's welfare, denoted by $E(\mathcal{W})$, is obtained from a second-order solution to the system of equilibrium conditions of the model, following Schmitt-Grohé and Uribe (2004). Let $E(\mathcal{W}_a)$ and $E(\mathcal{W}_b)$ represent the mean of the household's welfare under a monetary policy strategy in question and under the welfare-maximizing policy benchmark, respectively, and let $\delta$ denote the permanent consumption loss induced by the policy strategy as a fraction of consumption under the welfare-maximizing policy. This welfare loss depends on the two welfare levels as follows:

$$\delta = 1 - \exp\left[(1-\beta)\left(E(\mathcal{W}_a) - E(\mathcal{W}_b)\right)\right].$$

Table 3 presents the welfare losses from adopting each of the monetary policy strategies,

Table 3: Welfare losses from adopting different monetary policy strategies (%).

| | Productivity shock $z_{a,t}$ | | Labor supply shocks $z_{h,t}$, $z_{n,t}$ | |
|---|---|---|---|---|
| | Variable LF | Constant LF | Variable LF | Constant LF |
| (a) *Baseline parameterization* | | | | |
| $\hat{\pi}_{w,t} = 0$ | 0.015 | 0.002 | 0.269 | 0.180 |
| $\hat{\pi}_t = 0$ | 0.366 | 0.268 | 1.516 | 1.551 |
| $\hat{n}_t - \hat{n}_t^n = 0$ | 0.369 | — | 3.728 | — |
| $\phi_p = 1.5$ | 0.099 | 0.128 | 7.825 | 5.700 |
| $\phi_p = 1.5,\ \phi_y = 0.125$ | 0.070 | 0.092 | 5.205 | 3.510 |
| $\phi_p = 1.5,\ \phi_n = 0.125$ | 0.302 | — | 10.072 | — |
| (b) *No variety effect* ($\psi = 0$) | | | | |
| $\hat{\pi}_{w,t} = 0$ | 0.003 | 0.002 | 0.566 | 0.180 |
| $\hat{\pi}_t = 0$ | 0.400 | 0.268 | 1.539 | 1.551 |
| $\hat{n}_t - \hat{n}_t^n = 0$ | 0.360 | — | 3.845 | — |
| $\phi_p = 1.5$ | 0.090 | 0.128 | 6.904 | 5.700 |
| $\phi_p = 1.5,\ \phi_y = 0.125$ | 0.051 | 0.092 | 4.277 | 3.510 |
| $\phi_p = 1.5,\ \phi_n = 0.125$ | 0.258 | — | 8.398 | — |
| (c) *Higher degrees of price and wage rigidities* ($\xi_p = \xi_w = 3/4$) | | | | |
| $\hat{\pi}_{w,t} = 0$ | 0.029 | 0.002 | 0.307 | 0.192 |
| $\hat{\pi}_t = 0$ | 0.471 | 0.342 | 2.057 | 1.912 |
| $\hat{n}_t - \hat{n}_t^n = 0$ | 0.408 | — | 3.631 | — |
| $\phi_p = 1.5$ | 0.157 | 0.207 | 9.211 | 5.375 |
| $\phi_p = 1.5,\ \phi_y = 0.125$ | 0.096 | 0.117 | 5.846 | 3.047 |
| $\phi_p = 1.5,\ \phi_n = 0.125$ | 3.368 | — | 17.120 | — |
| (d) *Flexible wages* ($\xi_w = 0$) | | | | |
| $\hat{\pi}_{w,t} = 0$ | 0.016 | 0.013 | 0.662 | 0.203 |
| $\hat{\pi}_t = 0$ | 0.004 | 0.001 | 0.353 | 0.061 |
| $\hat{n}_t - \hat{n}_t^n = 0$ | 0.004 | — | 0.353 | — |
| $\phi_p = 1.5$ | 0.027 | 0.061 | 2.426 | 5.576 |
| $\phi_p = 1.5,\ \phi_y = 0.125$ | 0.018 | 0.054 | 1.454 | 4.778 |
| $\phi_p = 1.5,\ \phi_n = 0.125$ | 0.016 | — | 1.291 | — |

*Notes*: The numbers in the table represent the permanent consumption losses from adopting the monetary policy strategies listed in the first column, as a percentage of consumption under the welfare-maximizing policy. "Variable LF" and "Constant LF" refer to the model with labor force entry and exit and its counterpart model with a constant labor force, respectively. The values of model parameters used are those reported in Table 1 and the posterior mean estimates reported in Table 2, except when indicated otherwise.

compared to the welfare-maximizing policy.[21] Panel (a) shows the welfare losses under the baseline parameterization of the model that consists of the values of model parameters reported in Table 1 and the posterior mean estimates reported in Table 2.[22] The magnitude of the welfare losses is generally smaller for the productivity shock than for the two types of labor supply shocks, which induce larger fluctuations in the output gap, the employment gap, inflation, and wage growth, given the estimated parameter values of the shocks.[23] The different magnitudes notwithstanding, the rows in the table indicate a clear welfare ranking of the policy strategies in the face of supply shocks.

The first three rows display the welfare losses under full wage growth stabilization, full inflation stabilization, and full employment gap stabilization, respectively. Fully stabilizing wage growth achieves welfare levels comparable to those attained under the welfare-maximizing policy, which features wage growth stabilization with variation in inflation and the employment gap as noted above. Compared to the welfare-maximizing policy, fully stabilizing inflation or the employment gap induces substantial welfare losses, an order of magnitude larger than the losses under the full wage growth stabilization. The welfare loss from fully stabilizing inflation for the productivity shock is relatively large (0.37 percent) and exceeds that obtained in the case of a constant labor force (0.27 percent), which is also relatively large as emphasized by Erceg et al. (2000). Because a positive productivity shock puts downward pressure on the real marginal cost and hence inflation, keeping inflation constant requires a large jump in wage growth. This is achieved partly through a large drop in labor force entry, which exacerbates the welfare loss compared to the case of a constant labor force. Likewise, the welfare loss from fully stabilizing the employment gap for the productivity shock is sizable (0.37 percent).

[21]This paper supposes an inefficient steady state in the model. This, however, would have little effect on the main results of the paper because we focus on the dynamic responses of the model variables to shocks in terms of deviations from their steady-state values and on the welfare difference between the welfare-maximizing policy and each of the monetary policy strategies. Moreover, the presence of price and wage indexation to steady-state inflation and wage growth rates ensures the validity of the natural rate hypothesis in the model, as in standard models with sticky prices and wages.

[22]Results for the demand shock are omitted from the table. Although the qualitative effects of the demand shock resemble those of the productivity and labor supply shocks, the quantitative welfare effects of deviating from the welfare-maximizing policy to the different monetary policy strategies considered are close to zero.

[23]If the welfare losses are divided by the variances of relevant shock innovations, as in Erceg et al. (2000), the magnitude conditional on the productivity shock would exceed that conditional on the intensive-margin labor supply shock.

The last three rows in panel (a) present the welfare losses from following the Taylor-type rule (35). When the rule responds only to inflation, it generates moderate to large welfare losses compared to the welfare-maximizing policy depending on the type of supply shocks: 0.10 percent for the productivity shock and 7.83 percent for the two types of labor supply shocks. These losses can be mitigated if the Taylor-type rule responds additionally to the output gap (0.07 percent for the productivity shock and 5.21 percent for the two types of labor supply shocks). In contrast, if the rule responds alternatively to the employment gap, the welfare losses are exacerbated (0.30 percent for the productivity shock and 10.07 percent for the two types of labor supply shocks).

The results for full employment gap stabilization and for the Taylor-type rule with responses to the employment gap confirm that variation in the employment gap contributes to reducing the welfare cost caused by the real wage adjustments to supply shocks under staggered price- and wage-setting. As shown in Figure 5, fully stabilizing the employment gap encounters large adjustments of wage growth that are needed to rein in larger variability of inflation. Therefore, the results in the table indicate that leaning against the employment gap induces substantial welfare losses for supply shocks compared to the welfare-maximizing policy.

The middle and bottom panels of Table 3 present the welfare losses in the cases of no variety effect (panel b), higher degrees of price and wage rigidities (panel c), and flexible wages (panel d). As reported in panel (b), the absence of the variety effect increases the welfare loss from fully stabilizing inflation for the productivity shock (0.40 percent), while it mitigates the welfare losses from following the Taylor-type rule with responses to the employment gap (0.26 percent for the productivity shock and 8.40 percent for the two types of labor supply shocks). Panel (c) shows that higher degrees of price and wage rigidities greatly exacerbate the welfare losses from following the Taylor-type rule that responds to the employment gap in the presence of labor force entry and exit (3.37 percent for the productivity shock and 17.12 percent for the two types of labor supply shocks). The higher the degree of wage rigidity, the larger the adverse welfare effect of the interest rate adjustments to variation in the employment gap. Consequently, if wages are perfectly flexible, all of the monetary policy strategies considered are relatively effective in achieving a welfare level close to that under the welfare-maximizing policy, as seen in panel (d).[24]

# 6 Concluding Remarks

We have examined how monetary policy should respond to supply shocks in terms of inflation and employment stabilization, motivated by the U.S. macroeconomic developments observed during the COVID-19 pandemic. Our model includes employment by introducing worker entry into and exit from the labor force in an otherwise standard model with staggered price- and wage-setting. The presence of price and wage rigidities induces a well-known trade-off for monetary policy between stabilizing inflation and wage growth, which is optimally resolved in the direction of stabilizing wage growth. Labor force entry and exit influences employment and wage growth. If a shock prompts fewer workers to enter the labor force, employment falls and reduces the average wage markup, which raises wage growth. The welfare-maximizing policy involves substantial variation in the employment gap, thus dampening fluctuations of wage growth and requiring smaller variability of inflation to achieve desired changes in the real wage. A welfare comparison of different monetary policy strategies suggests that monetary policy should not lean against the employment gap.

Our model features two types of labor supply shocks to the intensive and extensive margins of labor. A distinction between them could be relevant for the implementation of monetary policy because only the extensive-margin labor supply shock involves fluctuations in the natural rate of employment. In our estimated model the extensive-margin shock is less important than the intensive-margin shock in accounting for business cycle fluctuations, as it generates a countercyclical response of per-worker hours worked.

Fiscal policy likely played a key role in the recovery of the U.S. economy from the pandemic-induced recession along with monetary policy. Accordingly, using the model with labor force entry and exit to analyze welfare-maximizing fiscal and monetary policy in response to supply shocks along the lines of Schmitt-Grohé and Uribe (2006) could be a fruitful agenda for future research.

[24] In panel (d), the case of a constant labor force displays the well-known result in sticky price models that the Taylor-type rule induces modest welfare losses compared to full inflation stabilization. Such welfare losses are mitigated in our model with labor force entry and exit, consistent with the results of Campolmi and Gnocchi (2016).

# Appendix

## A Impulse Responses to Wage Markup Shocks

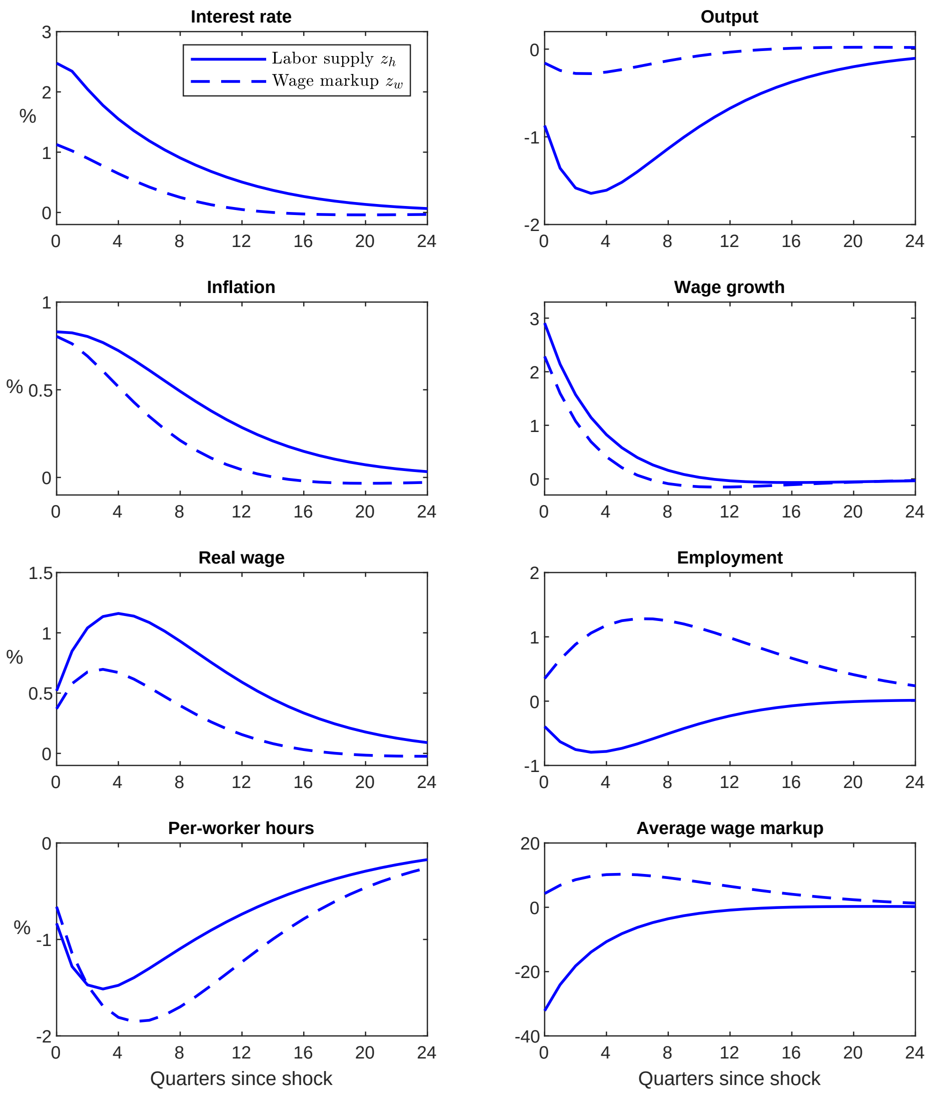
This appendix presents the impulse responses to an ad hoc shock to the wage markup denoted by $z_{w,t}$, which appears in the wage Phillips curve (40):

$$\hat{\pi}_{w,t} = \beta\rho E_t \hat{\pi}_{w,t+1} - \kappa_w \left(\hat{\mu}_{w,t} - z_{w,t}\right) - \frac{\psi}{\theta_w - 1}\left[\left(\hat{n}_t - \hat{n}_{t-1}\right) - \beta\rho\left(E_t \hat{n}_{t+1} - \hat{n}_t\right)\right].$$

Foroni et al. (2018) employ a DSGE model with labor market search and matching frictions, and show that intensive-margin labor supply shocks and wage bargaining shocks bring about opposite responses of unemployment, thus allowing to tackle the issue of separately identifying the labor supply shocks and wage bargaining shocks. Their approach carries over to our model, by substituting employment for unemployment and wage markup shocks for wage bargaining shocks.

A positive wage markup shock increases the average wage markup, thereby stimulating worker entry into the labor force. In contrast, a positive intensive-margin labor supply shock reduces the average wage markup and discourages labor force entry. Figure A1 displays the impulse responses to one-standard-deviation positive innovations to the wage markup shock $z_{w,t}$ and the intensive-margin labor supply shock $z_{h,t}$, and shows that both shocks elicit qualitatively the same responses of output, inflation, wage growth, and the real wage. However, the shocks induce opposite responses of employment and the average wage markup and thus the presence of labor force entry and exit helps identify the labor supply shocks separately from wage markup shocks in our model.

Figure A1: Impulse responses to labor market shocks.




*Notes*: The figure shows the impulse responses of the interest rate $r$, output $y$, the inflation rate $\pi$, the wage growth rate $\pi_w$, the real wage $w$, employment $n$, per-worker hours $h$, and the average wage markup $\mu_w$, respectively, to one-standard-deviation positive innovations to the intensive-margin labor supply shock $z_h$ (solid lines) and the wage markup shock $z_w$ (dashed lines). All responses are expressed as percentages; the responses of the interest, inflation, and wage growth rates are displayed at annualized rates. The persistence of the shock $z_w$ and the standard deviation of its innovations are set at the same values as for the shock $z_h$, that is, $\rho_w = 0.849$ and $\sigma_w = 0.397$. The values of other model parameters used are those reported in Table 1 and the posterior mean estimates reported in Table 2.

# B Derivation of Welfare-Maximizing Policy

This appendix derives a welfare-maximizing policy in the model. The first-order conditions for the optimized wage (13) and price (23) are written recursively so that they can be included in the Lagrangian of the welfare maximization problem. The Lagrangian is given by

$$\begin{aligned}
L = E_0 \sum_{t=0}^{\infty} \beta^t \Bigg\{ & \log\left(y_t - b\, y_{t-1}\right) - \frac{1}{1+\chi} l_t^{1+\chi}\, n_t^{-\left[\chi + \frac{\psi(1+\chi)}{\theta_w - 1}\right]} \Delta_{w,t} \exp z_{h,t} + (1-n_t)\, v \exp z_{n,t} \\
& - \frac{\gamma}{2}\left(\frac{n_t - \rho\, n_{t-1}}{(1-\rho)n}\right)^2 + M_{1,t}\left[(p_t^*)^{1+\theta_p \frac{1-\alpha}{\alpha}} V_{p1,t} - V_{p2,t}\right] + M_{2,t}\left[\lambda_t y_t + \xi_p \beta E_t \left(\frac{\pi_{t+1}}{\pi}\right)^{\theta_p - 1} V_{p1,t+1} - V_{p1,t}\right] \\
& + M_{3,t}\left[\frac{\theta_p}{\alpha(\theta_p - 1)} \frac{w_t l_t \lambda_t}{\Delta_{p,t}} + \xi_p \beta E_t \left(\frac{\pi_{t+1}}{\pi}\right)^{\frac{\theta_p}{\alpha}} V_{p2,t+1} - V_{p2,t}\right] + M_{4,t}\left[(w_t^*)^{1+\theta_w \chi} V_{w1,t} - V_{w2,t}\right] \\
& + M_{5,t}\left[\lambda_t l_t n_t^{-(1-\psi)} + \xi_w \beta \rho E_t \left(\frac{\pi_{w,t+1}}{\pi_w}\right)^{\theta_w} \left(\frac{\pi_{t+1}}{\pi}\right)^{-1} V_{w1,t+1} - V_{w1,t}\right] \\
& + M_{6,t}\left[\frac{\theta_w}{\theta_w - 1}\left(l_t n_t^{-(1-\psi)}\right)^{1+\chi} \exp z_{h,t} + \xi_w \beta \rho E_t \left(\frac{\pi_{w,t+1}}{\pi_w}\right)^{\theta_w(1+\chi)} w_{t+1} V_{w2,t+1} - w_t V_{w2,t}\right] \\
& + M_{7,t}\left(l_t^{\alpha} \exp z_{a,t} - y_t \Delta_{p,t}^{\alpha}\right) + M_{8,t}\left[\xi_p \left(\frac{\pi_t}{\pi}\right)^{\theta_p - 1} + (1-\xi_p)\left(p_t^*\right)^{1-\theta_p} - 1\right] \\
& + M_{9,t}\left[\xi_p \left(\frac{\pi_t}{\pi}\right)^{\frac{\theta_p}{\alpha}} \Delta_{p,t-1} + (1-\xi_p)\left(p_t^*\right)^{-\frac{\theta_p}{\alpha}} - \Delta_{p,t}\right] + M_{10,t}\left(\pi_t \frac{w_t}{w_{t-1}} - \pi_{w,t}\right) \\
& + M_{11,t}\Bigg[\frac{w_t l_t \lambda_t}{n_t} - \frac{1}{1+\chi} l_t^{1+\chi}\, n_t^{-(1+\chi)\left(1+\frac{\psi}{\theta_w - 1}\right)} \Delta_{w,t} \exp z_{h,t} \\
& \qquad - \frac{\gamma}{[(1-\rho)n]^2}\left[(n_t - \rho\, n_{t-1}) - \beta\left(E_t n_{t+1} - \rho\, n_t\right)\right] - v \exp z_{n,t}\Bigg] \\
& + M_{12,t}\left[\xi_w \left(\frac{\pi_{w,t}}{\pi_w}\right)^{\theta_w - 1} \frac{1}{n_{t-1}^{\psi}} + (1-\xi_w)\left(w_t^*\right)^{1-\theta_w} - \frac{1}{n_t^{\psi}}\right] \\
& + M_{13,t}\left[\xi_w \left(\frac{\pi_{w,t}}{\pi_w}\right)^{\theta_w(1+\chi)} \frac{\Delta_{w,t-1}}{n_{t-1}^{\frac{\psi\theta_w(1+\chi)}{\theta_w - 1}}} + (1-\xi_w)\left(w_t^*\right)^{-\theta_w(1+\chi)} - \frac{\Delta_{w,t}}{n_t^{\frac{\psi\theta_w(1+\chi)}{\theta_w - 1}}}\right] \\
& + M_{14,t}\left(\frac{\exp z_{c,t}}{y_t - b\, y_{t-1}} - \lambda_t\right)\Bigg\},
\end{aligned}$$

where $M_{i,t},\ i = 1, \ldots, 14$ are Lagrange multipliers and the constraints associated with the multipliers $M_{i,t},\ i = 1,2,3$ and $M_{i,t},\ i = 4,5,6$ consist of the first-order conditions for the optimized price and wage, respectively.

The equilibrium under the welfare-maximizing policy satisfies the constraints of the Lagrangian and the following first-order conditions:

$$\partial\pi_t: -M_{10,t}\pi_{w,t} = (\theta_p-1)\xi_p\left(\frac{\pi_t}{\pi}\right)^{\theta_p-1}\left(V_{p1,t}M_{2,t-1}+M_{8,t}\right)$$
$$+\theta_p\xi_p\left(\frac{\pi_t}{\pi}\right)^{\frac{\theta_p}{\alpha}}\left(V_{p2,t}M_{3,t-1}+M_{9,t}\Delta_{p,t-1}\right)-\xi_w\rho\left(\frac{\pi_{w,t}}{\pi_w}\right)^{\theta_w}\left(\frac{\pi_t}{\pi}\right)^{-1}V_{w1,t}M_{5,t-1},$$

$$\partial\pi_{w,t}: M_{10,t}\pi_{w,t} = \theta_w\xi_w\rho\left(\frac{\pi_{w,t}}{\pi_w}\right)^{\theta_w}\left(\frac{\pi_t}{\pi}\right)^{-1}V_{w1,t}M_{5,t-1}+(\theta_w-1)\xi_w\left(\frac{\pi_{w,t}}{\pi_w}\right)^{\theta_w-1}\frac{1}{n_{t-1}^{\psi}}M_{12,t}$$
$$+\theta_w(1+\chi)\xi_w\left(\frac{\pi_{w,t}}{\pi_w}\right)^{\theta_w(1+\chi)}\left[\rho w_t V_{w2,t}M_{6,t-1}+M_{13,t}\left(\frac{n_t}{n_{t-1}}\right)^{\frac{\psi\theta_w(1+\chi)}{\theta_w-1}}\Delta_{w,t-1}\right],$$

$$\partial p_t^*: \left(1+\theta_p\frac{1-\alpha}{\alpha}\right)M_{1,t}V_{p1,t}\left(p_t^*\right)^{1+\frac{\theta_p}{\alpha}} = (\theta_p-1)(1-\xi_p)p_t^*M_{8,t}+\frac{\theta_p}{\alpha}(1-\xi_p)\left(p_t^*\right)^{-\theta_p\frac{1-\alpha}{\alpha}}M_{9,t},$$

$$\partial V_{p1,t}: M_{2,t} = M_{1,t}\left(p_t^*\right)^{1+\theta_p\frac{1-\alpha}{\alpha}}+\xi_p\left(\frac{\pi_t}{\pi}\right)^{\theta_p-1}M_{2,t-1},$$

$$\partial V_{p2,t}: M_{3,t} = -M_{1,t}+\xi_p\left(\frac{\pi_t}{\pi}\right)^{\frac{\theta_p}{\alpha}}M_{3,t-1},$$

$$\partial w_t^*: (1+\theta_w\chi)\left(w_t^*\right)^{\theta_w(1+\chi)}V_{w1,t}M_{4,t}$$
$$= (\theta_w-1)(1-\xi_w)M_{12,t}+\theta_w(1+\chi)(1-\xi_w)\left(w_t^*\right)^{-(1+\theta_w\chi)}n_t^{\frac{\psi\theta_w(1+\chi)}{\theta_w-1}}M_{13,t},$$

$$\partial V_{w1,t}: M_{5,t} = \left(w_t^*\right)^{1+\theta_w\chi}M_{4,t}+\xi_w\rho\left(\frac{\pi_{w,t}}{\pi_w}\right)^{\theta_w}\left(\frac{\pi_t}{\pi}\right)^{-1}M_{5,t-1},$$

$$\partial V_{w2,t}: M_{6,t} = -\frac{M_{4,t}}{w_t}+\xi_w\rho\left(\frac{\pi_{w,t}}{\pi_w}\right)^{\theta_w(1+\chi)}M_{6,t-1},$$

$$\partial\Delta_{w,t}: n_t^{\frac{\psi\theta_w(1+\chi)}{\theta_w-1}}M_{13,t}-\xi_w\beta E_t\left(\frac{\pi_{w,t+1}}{\pi_w}\right)^{\theta_w(1+\chi)}n_{t+1}^{\frac{\psi\theta_w(1+\chi)}{\theta_w-1}}M_{13,t+1} = -\left(\frac{l_t}{n_t^{1-\psi}}\right)^{1+\chi}\frac{\exp z_{h,t}}{1+\chi}\left(n_t+M_{11,t}\right),$$

$$\partial n_t: \left[\frac{w_t l_t\lambda_t}{n_t}-(1-\psi)\,l_t^{1+\chi}n_t^{-(1+\chi)}\Delta_{w,t}\exp z_{h,t}\right]\left(n_t+M_{11,t}\right)$$
$$= -(1-\psi)\left[\lambda_t l_t n_t^{-(1-\psi)}M_{5,t}+\frac{\theta_w(1+\chi)}{\theta_w-1}\left(l_t n_t^{-(1-\psi)}\right)^{1+\chi}\exp z_{h,t}M_{6,t}\right]$$
$$+\psi\frac{1}{n_t^{\psi}}\left[M_{12,t}-\xi_w\beta E_t\left(\frac{\pi_{w,t+1}}{\pi_w}\right)^{\theta_w-1}M_{12,t+1}\right]$$
$$-\frac{\gamma}{[(1-\rho)n]^2}\left[M_{11,t}-\rho M_{11,t-1}-\beta E_t\left(M_{11,t+1}-\rho M_{11,t}\right)\right]n_t,$$

$$\partial y_t: \Delta_{p,t}^{\alpha}M_{7,t} = \lambda_t M_{2,t}-\left(\frac{\lambda_t}{\exp z_{c,t}}M_{14,t}-1\right)\lambda_t+b\beta E_t\left(\frac{\lambda_{t+1}}{\exp z_{c,t+1}}M_{14,t+1}-1\right)\lambda_{t+1},$$

$$\partial\lambda_t: M_{14,t} = y_t M_{2,t}+\frac{\theta_p}{\alpha(\theta_p-1)}\frac{w_t l_t}{\Delta_{p,t}}M_{3,t}+l_t n_t^{-(1-\psi)}M_{5,t}+\frac{w_t l_t}{n_t}M_{11,t},$$

$$\partial l_t : l_t^{1+\chi} n_t^{-(1+\chi)\left(1+\frac{\psi}{\theta_w-1}\right)} \Delta_{w,t} \exp z_{h,t} \left(n_t + M_{11,t}\right) = \frac{\theta_p}{\alpha(\theta_p-1)} \frac{w_t l_t \lambda_t}{\Delta_{p,t}} M_{3,t} + l_t \lambda_t n_t^{-(1-\psi)} M_{5,t}$$

$$+ \frac{\theta_w(1+\chi)}{\theta_w-1} \left(l_t n_t^{-(1-\psi)}\right)^{1+\chi} \exp z_{h,t} M_{6,t} + \alpha y_t \Delta_{p,t}^{\alpha} M_{7,t} + \frac{w_t l_t \lambda_t}{n_t} M_{11,t},$$

$$\partial w_t : \left[M_{6,t} - \xi_w \rho \left(\frac{\pi_{w,t}}{\pi_w}\right)^{\theta_w(1+\chi)} M_{6,t-1}\right] w_t V_{w2,t}$$

$$= \frac{\theta_p}{\alpha(\theta_p-1)} \frac{w_t l_t \lambda_t}{\Delta_{p,t}} M_{3,t} + \pi_{w,t} M_{10,t} - \beta E_t \pi_{w,t+1} M_{10,t+1} + \frac{w_t l_t \lambda_t}{n_t} M_{11,t},$$

$$\partial \Delta_{p,t} : \Delta_{p,t} \left[M_{9,t} - \xi_p \beta E_t \left(\frac{\pi_{t+1}}{\pi}\right)^{\frac{\theta_p}{\alpha}} M_{9,t+1}\right] = -\frac{\theta_p}{\alpha(\theta_p-1)} \frac{w_t l_t \lambda_t}{\Delta_{p,t}} M_{3,t} - \alpha y_t \Delta_{p,t}^{\alpha} M_{7,t}.$$

# C Another Pitfall of Leaning against Employment Gap

This appendix analyzes the implications of leaning against the employment gap for determinacy of equilibrium. We show that replacing the policy response to the output gap with that to the employment gap in the Taylor-type rule (35) shrinks the region of parameter values that ensure equilibrium determinacy.

Following Galí (2008), the Taylor-type rule is generalized, for this exercise, to allow for a policy response to wage growth:

$$\hat{r}_t = \phi_p \hat{\pi}_t + \phi_w \hat{\pi}_{w,t} + \phi_y (\hat{y}_t - \hat{y}_t^n) + \phi_n (\hat{n}_t - \hat{n}_t^n), \tag{49}$$

where $\phi_w$ denotes the degree of the policy response to wage growth. Moreover, the exercise assumes, for simplicity, no consumption habit persistence, employment adjustment cost, or variety effect, i.e., $b = \psi = \gamma = 0$.

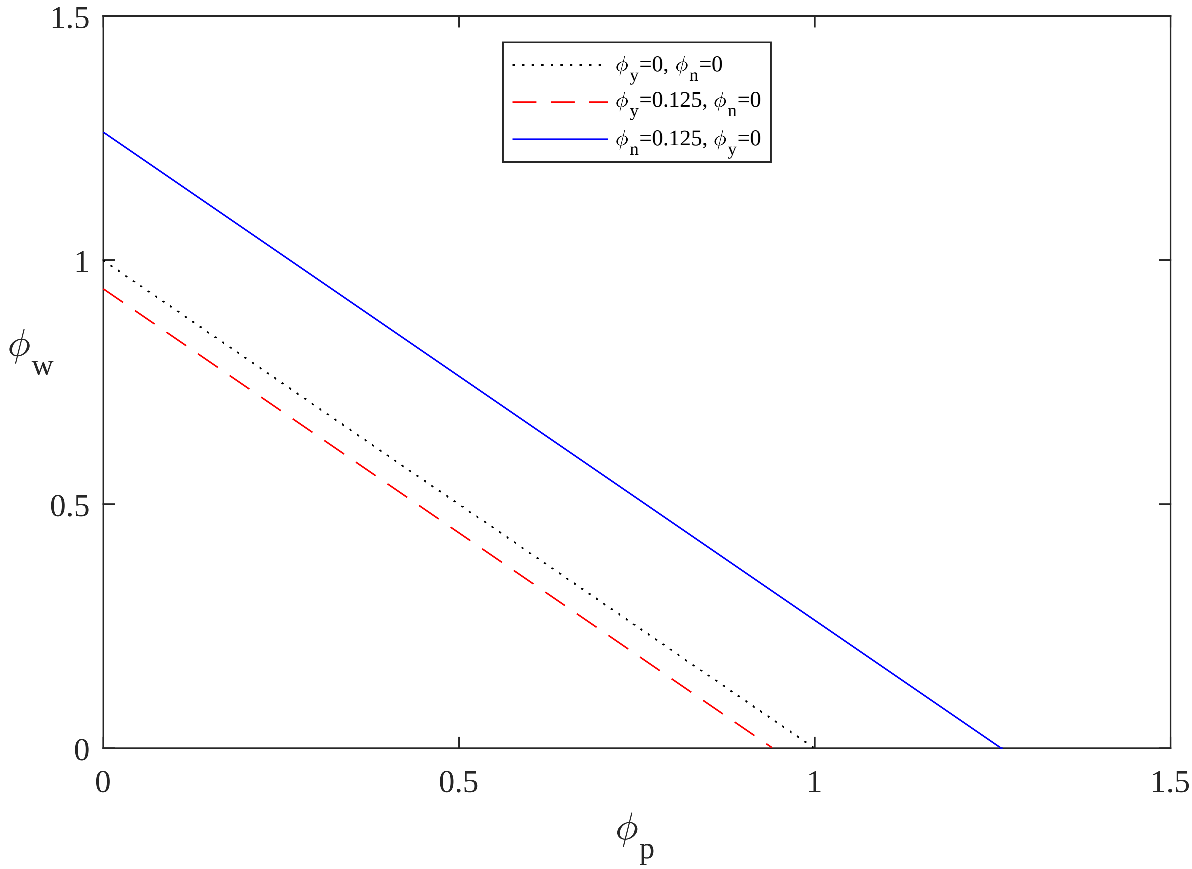
By combining the long-run log-linearized equilibrium conditions (36)–(42) and the long-run wage growth equation, we can obtain the long-run version of the Taylor principle, which holds that the interest rate should respond more than one-for-one with inflation in the long run. In the model with labor force entry and exit and the policy rule (49), the principle requires that:

$$\phi_p + \phi_w + \alpha \left(\frac{1-\beta}{\kappa_p} + \frac{1-\beta\rho}{\kappa_w(1+\theta_w)}\right) \phi_y + \left(\frac{1-\beta}{\kappa_p} - \frac{(1-\beta\rho)(\theta_w-1)}{\kappa_w(1+\theta_w)}\right) \phi_n > 1. \tag{50}$$

This condition shows that a policy response to the output gap (i.e., $\phi_y > 0$) lowers the minimum values of $\phi_p$ and $\phi_w$ that are required for determinacy of equilibrium. In contrast, a policy response to the employment gap (i.e., $\phi_n > 0$) *raises* the minimum values of $\phi_p$ and $\phi_w$ that ensure equilibrium determinacy, if the coefficient on $\phi_n$ in the condition (50) is negative.

Figure A2 displays the determinacy and indeterminacy regions for three types of the policy rule (49) under the calibration of model parameters reported in Table 1, except for $b = \psi = \gamma = 0$. First, the dotted line is the boundary between the determinacy and indeterminacy regions of the parameter space obtained for the policy rule that responds only to inflation and/or wage growth (i.e., $\phi_y = \phi_n = 0$). This line shows that any values of $\phi_p$ and $\phi_w$ such that $\phi_p + \phi_w > 1$ ensures determinacy. Second, the dashed line is the boundary obtained for the policy rule that also includes a response to the output gap (i.e., $\phi_y = 0.125$, $\phi_n = 0$). The policy response to the output gap enlarges the determinacy region slightly in the calibrated model. Third, the solid line is the boundary obtained for the policy rule that alternatively includes a response to the employment gap (i.e., $\phi_n = 0.125$, $\phi_y = 0$). The policy response to the employment gap shrinks the determinacy region noticeably in the calibrated model by shifting the boundary in the northeast direction. Due to the policy response to the employment gap, only values of $\phi_p$ and $\phi_w$ such that $\phi_p + \phi_w > 1.26$ ensure determinacy. The boundaries plotted in the figure are obtained numerically, but coincide with the boundaries implied by the long-run version of the Taylor principle (50).

Figure A2: Equilibrium determinacy region of the model parameter space.




*Notes*: Each line plots the boundary between the regions of equilibrium determinacy in the northeast area of the figure and indeterminacy in the southwest area. The dotted line is the boundary obtained for the policy rule (49) that responds only to inflation and/or wage growth (i.e., $\phi_y = \phi_n = 0$). The dashed line is the boundary obtained for the policy rule that also includes a response to the output gap (i.e., $\phi_y = 0.125$, $\phi_n = 0$). The solid line is the boundary obtained for the policy rule that alternatively includes a response to the employment gap (i.e., $\phi_n = 0.125$, $\phi_y = 0$). The values of model parameters used here are those reported in Table 1, except for $b = \psi = 0$, and $\gamma = 0$.

# References


Bai, Jushan and Pierre Perron (1998). "Estimating and testing linear models with multiple structural changes." *Econometrica*, 66(1), pp. 47–78.

Barrero, Jose Maria, Nicholas Bloom, Shelby Buckman, and Steven J. Davis (2024). "SWAA September 2024 updates." Technical report, WFH Research.

Barrero, Jose Maria, Nicholas Bloom, and Steven J. Davis (2023). "Long social distancing." *Journal of Labor Economics*, 41(S1), pp. S129–S172.

Battiston, Diego, Jordi Blanes I Vidal, and Tom Kirchmaier (2021). "Face-to-face communications in organizations." *Review of Economic Studies*, 88, pp. 574–609.

Benhabib, Jess, Richard Rogerson, and Randall Wright (1991). "Homework in macroeconomics: Household production and aggregate fluctuations." *Journal of Political Economy*, 99(6), pp. 1166–1187.

Bernanke, Ben and Olivier Blanchard (2025). "What caused the U.S. pandemic-era inflation?" *American Economic Journal: Macroeconomics*, forthcoming.

Bilbiie, Florin O. (2021). "Monetary neutrality with sticky prices and free entry." *Review of Economics and Statistics*, 103(3), pp. 492–504.

Bilbiie, Florin O., Ippei Fujiwara, and Fabio Ghironi (2014). "Optimal monetary policy with endogenous entry and product variety." *Journal of Monetary Economics*, 64, pp. 1–20.

Bilbiie, Florin O., Fabio Ghironi, and Marc J. Melitz (2008). "Monetary policy and business cycles with endogenous entry and product variety." In Daron Acemoglu, Kenneth Rogoff, and Michael Woodford, editors, *NBER Macroeconomics Annual 2007*, pp. 299–353. University of Chicago Press.

Blanchard, Olivier and Jordi Galí (2010). "Labor markets and monetary policy: A New Keynesian model with unemployment." *American Economic Journal: Macroeconomics*, 2(2), pp. 1–30.

Calvo, Guillermo A. (1983). "Staggered prices in a utility-maximizing framework." *Journal of Monetary Economics*, 12(3), pp. 383–398.

Campolmi, Alessia and Stefano Gnocchi (2016). "Labor market participation, unemployment, and monetary policy." *Journal of Monetary Economics*, 79, pp. 17–29.

Cavallari, Lilia (2013). "Firms' entry, monetary policy and the international business cycle." *Journal of International Economics*, 91, pp. 263–274.

Chari, V.V., Patrick Kehoe, and Ellen McGrattan (2009). "New Keynesian models: Not yet useful for policy analysis." *American Economic Journal: Macroeconomics*, 1(1), pp. 242–266.

Christiano, Lawrence J., Martin S. Eichenbaum, and Mathias Trabandt (2015). "Understanding the Great Recession." *American Economic Journal: Macroeconomics*, 7(1), pp. 110–167.

Cingano, Federico and Fabiano Schivardi (2004). "Identifying the sources of local productivity growth." *Journal of the European Economic Association*, 2(4), pp. 720–742.

Dubina, Kevin S., Janie-Lynn Kim, Emily Rolen, and Michael J. Rieley (2020). "Projections overview and highlights, 2019-29." *Monthly Labor Review*, September, pp. 1–33.

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

Erceg, Christopher J. and Andrew T. Levin (2014). "Labor force participation and monetary policy in the wake of the Great Recession." *Journal of Money, Credit and Banking*, 46(2), pp. 3–49.

Faberman, R. Jason, Andreas I. Mueller, and Ayşegül Şahin (2022). "Has the willingness to work fallen during the Covid pandemic?" *Labour Economics*, 79(102275).

Faia, Ester (2009). "Ramsey monetary policy with labor market frictions." *Journal of Monetary Economics*, 56(4), pp. 570–581.

Fernald, John G. (2007). "Trend breaks, long-run restrictions, and contractionary technology improvements." *Journal of Monetary Economics*, 54, pp. 2467–2485.

Foroni, Claudia, Francesco Furlanetto, and Antoine Lepetit (2018). "Labor supply factors and economic fluctuations." *International Economic Review*, 59(3), pp. 1491–1510.

Galí, Jordi (1999). "Technology, employment, and the business cycle: Do technology shocks explain aggregate fluctuations?" *American Economic Review*, 89(1), pp. 249–271.

Galí, Jordi (2008). *Monetary Policy, Inflation, and the Business Cycle*. Princeton University Press.

Galí, Jordi (2011). "Monetary policy and unemployment." In Benjamin M. Friedman and Michael Woodford, editors, *Handbook of Monetary Economics*, volume 3, chapter 10, pp. 487–546. Elsevier.

Galí, Jordi, Mark Gertler, and J. David López-Salido (2001). "European inflation dynamics." *European Economic Review*, 45, pp. 1237–1270.

Galí, Jordi, Frank Smets, and Rafael Wouters (2012). "Unemployment in an estimated New Keynesian model." In Daron Acemoglu and Michael Woodford, editors, *NBER Macroeconomics Annual 2011*, pp. 329–360. University of Chicago Press.

Giannone, Domenico and Giorgio E. Primiceri (2024). "The drivers of post-pandemic inflation." *ECB Forum on Central Banking*.

Krusell, Per, Toshihiko Mukoyama, Richard Rogerson, and Ayşegül Şahin (2017). "Gross worker flows over the business cycle." *American Economic Review*, 107(11), pp. 3447–3476.

Lewis, Vivien and Céline Poilly (2012). "Firm entry, markups and the monetary transmission mechanism." *Journal of Monetary Economics*, 59, pp. 670–685.

Ma, Eunseong (2024). "Intensive and extensive margins of labor supply in HANK: Aggregate and disaggregate implications." *Journal of Money, Credit and Banking*, forthcoming.

Schmitt-Grohé, Stephanie and Martín Uribe (2004). "Solving dynamic general equilibrium models using a second-order approximation to the policy function." *Journal of Economic Dynamics and Control*, 28, pp. 755–775.

Schmitt-Grohé, Stephanie and Martín Uribe (2006). "Optimal fiscal and monetary policy in a medium-scale macroeconomic model." In Mark Gertler and Kenneth Rogoff, editors, *NBER Macroeconomics Annual 2005*, pp. 383–425. MIT Press.

Smets, Frank and Rafael Wouters (2007). "Shocks and frictions in US business cycles: A Bayesian DSGE approach." *American Economic Review*, 97(3), pp. 586–606.

Smith, Adam (1776). *An Inquiry into the Nature and Causes of The Wealth of Nations*. W. Strahan and T. Cadell.

Sunakawa, Takeki (2015). "Optimal monetary policy with labor market frictions: The role of the wage channel." *Journal of Money, Credit and Banking*, 47(6), pp. 1119–1147.

Taylor, John B. (1993). "Discretion versus policy rules in practice." *Carnegie-Rochester Conference Series on Public Policy*, 39, pp. 195–214.

Thomas, Carlos (2008). “Search and matching frictions and optimal monetary policy.” *Journal of Monetary Economics*, 55(5), pp. 936–956.