Employment, Wages and Optimal Monetary Policy

Martin Bodenstein
Federal Reserve Board

Junzhu Zhao
Nanjing Audit University

April 6, 2018

Abstract

We study optimal monetary policy when the policymaker is uncertain whether the cyclical properties of employment and wages are determined by sticky nominal wages or by search and matching frictions in the labor market. Unless the policymaker is almost certain about the search and matching model being the true data-generating process, the policymaker chooses to stabilize wage inflation at the expense of price inflation, the policy resembling the optimal policy in the sticky wage model, regardless of the true model. This finding reflects the greater sensitivity of welfare losses in the sticky wage model to deviations from the model-specific optimal policy.

JEL classifications: E52
Keywords: optimal monetary policy; optimal targeting rules; search and matching; sticky wages; model uncertainty.

* The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or any other person associated with the Federal Reserve System. We are grateful to John Ham, Serene Tan, Christopher Gust, Robert Tetlow, Roger Farmer, and Albert Marcet for helpful comments and suggestions.
** Contact information: Martin Bodenstein (corresponding author), E-mail martin.r.bodenstein@frb.gov; Junzhu Zhao, E-mail junzhuzhao@gmail.com

1 Introduction

The key, if not the only, mandate of central banks is to maintain price stability—typically interpreted as low and stable (consumer price) inflation. Changes in nominal wages are of practical concern only to the extent that they affect price inflation through the marginal cost channel. This aspect of monetary policymaking contrasts with the normative recommendations of the empirical New Keynesian literature. Numerous contributions to this literature find that sticky nominal wages improve the fit of theoretical models to the data and in turn imply that monetary policy should place great emphasis on stabilizing wage inflation even at the expense of stabilizing price inflation. Policymakers' reluctance to embrace the normative recommendations derived from sticky wage models may reflect concerns about model misspecification. After all, economists have suggested other mechanisms that capture the cyclical properties of employment and wages such as search and matching frictions.

We incorporate these concerns into the study of optimal monetary policy by assuming that the policymaker is uncertain whether a model with sticky nominal wages or a model with search and matching frictions constitutes the true data-generating process. Unless the policymaker is almost certain about the search and matching model being the true data-generating process, the policymaker in our framework chooses to stabilize wage inflation at the expense of price inflation, the policy resembling the optimal policy in the sticky wage model, regardless of the true model. This finding reflects the greater sensitivity of welfare losses in the sticky wage model to deviations from the model-specific optimal policy. In light of these findings, real-life central banks should consider making wage inflation an explicit goal of stabilization policy even if doubts persist about the existence of a wage Philips curve.

Our analysis features two New Keynesian models with sticky nominal prices that differ only with respect to the details of the labor market. In the sticky wage model, we assume that wages are set in a staggered fashion as in Erceg, Henderson, and Levin (2000). The empirical New Keynesian literature has largely relied on this setup to generate empirically plausible labor market dynamics in monetary models.[1] By contrast, nominal wages are flexible in the search and matching models of the labor market pioneered by Diamond (1982), Mortensen (1982), and Pissarides (1985).[2] Firms post vacancies and workers search for jobs; when matched they

[1] Fine illustrations of this approach are Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007).

[2] Examples of New Keynesian models with search and matching frictions are Krause and Lubik (2007), Ravenna and Walsh (2008), and Christiano, Eichenbaum, and Trabandt (2016). Gertler and Trigari (2009) combine the search and matching framework with staggered multi-period wage contracts.

Nash bargain over wages and hours worked. Our setup builds on Faia (2009) and Ravenna and Walsh (2011), but we assume individual hours worked to be elastic to maintain comparability with the sticky wage model and to improve the model's ability to fit the empirical patterns of unemployment and vacancies.[3]

We confirm that both the sticky wage and the search and matching model can generate dynamics that are in line with evidence from structural vector autoregressions for reasonable parameter values when monetary policy follows an estimated interest rate rule. Other evidence aside, this exercise reflects the idea at the core of our analysis that policymakers can formulate multiple models that provide a good approximation to the true data-generating process given the available empirical evidence against which these models are assessed.

Without being able to settle on a unique model of the economy, conducting optimal monetary policy is complicated by the fact that the two models have vastly different normative implications. We consider optimal monetary policies under commitment from the timeless perspective when the policymaker's preferences coincide with those of the representative household as in Woodford (1999). In the model with search and matching frictions, the optimal policy keeps price inflation under tight control while nominal wages display large movements. Monetary policy cannot correct the labor market distortions generated by the search and matching process in our setting, and focuses on the dynamic distortions stemming from sticky prices in the product market. Stable inflation reduces relative price dispersion and inefficient shifts in relative demand. The degree of inflation stabilization is only constrained by the possible trade-off between inflation and resource utilization. By contrast, in the model with sticky nominal wages, the optimal policy needs to also balance price *and* wage inflation. Similar to the product market, wage inflation distorts relative real wages and labor demand; and price inflation supports the adjustment of real wages under staggered nominal wages. The near complete stabilization of wage inflation under the optimal policy reflects the high welfare costs associated with even minor relative wage differences in empirical sticky wage models.

Given these normative differences between the two models, how important is it for the policymaker to know which one represents the true data-generating process? We address this

[3] Shimer (2005) argues that search and matching models cannot generate labor market movements that are in line with the empirical evidence for plausible parameter choices—a view subsequently challenged by other authors. To address this criticism, we build on Hagedorn and Manovskii (2008) and model explicitly the opportunity costs of employment. Our conclusions are unchanged when we replace the assumption of Nash bargaining by the approach in Hall and Milgrom (2008) and Christiano, Eichenbaum, and Trabandt (2016) instead.

question using the concept of optimal targeting rules as in Giannoni and Woodford (2017).[4] Transplanting these rules from one model to the other induces welfare losses that are orders of magnitudes larger than the welfare costs of business cycles in Lucas (2003). The lack of robustness of the optimal targeting rules is not symmetric. The optimal targeting rule derived from the search and matching model stabilizes price inflation and induces excessive movements in wage inflation when applied to the sticky wage model. The resulting welfare costs are ten times larger than in the opposite case of excessive wage stabilization in the search and matching model under the optimal targeting rule of the sticky wage model.

This lack of robustness of the optimal targeting rules makes it unattractive to resolve model uncertainty via statistical model selection prior to the evaluation of monetary policy. Instead of opting for a specific model without conclusive evidence the policymaker can incorporate model uncertainty as a component in the evaluation of policy as advocated in Brock, Durlauf, and West (2007). We show that in this case, the policymaker selects a policy that resembles the optimal targeting rule *derived from the sticky nominal wage model* unless the policymaker is very certain about the search and matching model being the true data-generating process.

This result emerges under the two approaches for deriving optimal monetary policy under model uncertainty suggested in Levin, Wieland, and Williams (2003). Under the model averaging approach, the policymaker chooses a policy—implemented through an interest rate or a targeting rule—that minimizes the expected loss for a given probability distribution of the policymaker over the relevant reference models. When the policymaker adopts a minmax strategy, the policy minimizes the maximum expected loss; this second approach does not require the policymaker to specify a probability distribution over models. Under both approaches, the optimal policy mimics the optimal targeting rule derived from the sticky wage model and stabilizes wage inflation at the expense of price inflation, unless the policymaker attaches a low (or, under the minmax strategy, zero) probability on the sticky wage model being the true model. This finding reflects the lack of robustness of policies that are (close to) optimal in the search and matching model. Thus, uncertainty about the true model does not need to translate into uncertainty about the features of good monetary policy.

If we depart from the assumption that the policymaker adopts the preferences of the households, it is possible to derive policies that the policymaker deems (close to) optimal for both models. However, such policies are not robust from the perspective of households.

[4] The optimal targeting rule specifies the variables—including the relative importance and the dynamic structure of each variable—in a single target criterion that seeks to implement the optimal monetary policy. In other words, the optimal targeting rule is a commitment of the policymaker to respect a certain relationship between the model variables.

Assigning arbitrary preferences to the policymaker as often done in the literature is shown not to be innocuous when considering robustness of policies.

The remainder of the paper proceeds as follows. Section 2 discusses related literature. We present the two models in Section 3. In Section 4, we present the empirical strategy to parameterize the models. Section 5 derives optimal targeting rules for each model and assesses their robustness. Optimal policy under model uncertainty is analyzed in Section 6. We discuss alternative settings in Section 7 before concluding in Section 8.

2 Related literature

Our approach to model uncertainty is closest to Levin and Williams (2003) and Levin, Wieland, and Williams (2003) which also study robust monetary policy with competing reference models. Other related papers include Cogley and Sargent (2005) and Svensson and Williams (2005), but we abstract from the learning dynamics featured in these contributions. In sync with our work, these authors argue that policymakers should not tailor policies towards a model with recommendations that are not robust to misspecification and uncertainty even if the model is viewed likely to be (close to) the correct data-generating process.[5]

Our analysis differs from these contributions along several dimensions. First, we restrict attention to microfounded models with objective functions of the policymaker that are consistent with the preferences of the economic agents in the underlying models and that reflect the policymaker's probability distribution over the models. The aforementioned contributions assume that the policymaker's preferences are independent of the reference models, an approach we show to sometimes falsely suggest the existence of robust policies. Second, we parameterize the models to fit the same empirical evidence under empirical interest rate rules *before* deriving the optimal monetary policy. In Cogley and Sargent (2005) and Svensson and Williams (2005), model parameters are estimated conditional on the policymaker setting policy to maximize a given quadratic objective; no two models fit the data equally well over a given historical episode in their works and the ranking of the models by quality of fit switches between episodes. In Levin and Williams (2003) and Levin, Wieland, and Williams (2003) the models are not parameterized using the same empirical evidence. Third, we consider la-

[5] Research on model uncertainty and policy evaluation has taken several directions. One direction is to assume a given baseline model and consider all models within a given distance as in Hansen and Sargent (2007), Tetlow and von zur Muehlen (2001), and Giannoni (2002). The second approach, taken in this paper, does not require the models to be close to each other. Another recent example of this approach is Taylor and Wieland (2012). In addition to model uncertainty, data uncertainty and parameter uncertainty are other areas of concern for policymakers.

bor market aspects left out from earlier studies and stress the importance of smoothing wage inflation as the guiding principle for robust optimal monetary policy.

3 Two competing models of the labor market

The two reference models of the policymaker build on the New Keynesian model with sticky nominal prices; the models differ with regard to the details of the labor market. The first model features search and matching frictions in the labor market with flexible, but bargained wages as in Diamond (1982), Mortensen (1982), and Pissarides (1985). The second model introduces sticky nominal wages as in Erceg, Henderson, and Levin (2000). We provide brief model descriptions in the main text and refer to Appendix A for details.

3.1 New Keynesian model with search and matching frictions

The search and matching model follows Ravenna and Walsh (2011) with two key differences: (i) the steady state of the model is inefficient as we do not impose the conditions stated in Hosios (1990), (ii) the individual labor supply is elastic (as in the sticky wage model).

The share n_t of the household members is employed (w) and $1-n_t$ unemployed (u). Member share the same preferences and the household provides perfect consumption insurance as in Andolfatto (1996) and Merz (1995). The household maximizes the utility of its members

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(c_t - \mu c_{t-1})^{1-\sigma}}{1-\sigma} - n_t \phi_0 \frac{(h_t)^{1+\phi}}{1+\phi} \right] \tag{1}$$

subject to the budget constraint

$$c_t + \frac{B_{t+1}}{P_t} = w_t h_t n_t + b^u(1-n_t) + \frac{\mathrm{Pr}_t}{P_t} + \frac{T_t}{P_t} + \frac{R_{t-1} B_t}{P_t} \tag{2}$$

and the evolution of employment as defined below. $\mathbb{E}_0$ is the expectations operator conditional on all the information available up to period 0. β is the time discount factor. Consumption is denoted by c_t, and the hours worked by the employed household members are measured by h_t. Unemployed household members do not experience disutility from working. The real wage is given by w_t and unemployment benefits are measured by b^u. Bond holdings B_t, taxes and transfers T_t, and profits Pr_t are measured in nominal terms. The price level is denoted by P_t. R_t is the nominal interest rate on bonds. We denote by λ_t the Lagrange multiplier attached to the budget constraint when solving the household's problem. As in Walsh (2005) we assume that total consumption c_t consists of a manufactured good c_t^m and home production $b^u(1-n_t)$, i.e., $c_t = c_t^m + b^u(1-n_t)$.[6]

To hire workers, firms have to post vacancies v_t first. The share of household members searching for jobs is u_t. The matching function

$$m_t = \chi u_t^{\zeta} v_t^{1-\zeta} \tag{3}$$

determines the new matches m_t between firms and workers. Employment n_t evolves as

$$n_t = (1-\rho)\, n_{t-1} + m_t \tag{4}$$

where ρ is the breakup rate of existing matches. The number of job seekers in period t follows

$$u_t = 1 - n_{t-1} + \rho n_{t-1} = 1 - (1-\rho)\, n_{t-1}. \tag{5}$$

Taking the job finding rate $s_t = \frac{m_t}{u_t}$ as given, the household includes the evolution of employment in equation (4) written as $n_t = (1-\rho)\, n_{t-1} + s_t u_t$ into the constraint set.

Wholesale firms employ labor to produce the good y_t^w which is sold at the competitive market price P_t^w. To post a vacancy, wholesale firms have to pay the cost κ^v. These firms maximize profits given the law of motion for employment and the production technology

$$\begin{aligned} \max_{\{n_t, y_t^w, v_t\}_{t=0}^{\infty}} \; & \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \lambda_t \left(\frac{P_t^w}{P_t} y_t^w - \frac{W_t}{P_t} n_t h_t - \kappa^v v_t \right) \\ s.t. \quad & n_t = (1-\rho)\, n_{t-1} + q_t v_t \\ & y_t^w = a_t n_t h_t \end{aligned} \tag{6}$$

where firms take the probability of filling an open vacancy $q_t = \frac{m_t}{v_t}$ as given. Total factor productivity a_t follows an AR(1) process $\log(a_t) = \rho_a \log(a_{t-1}) + \varepsilon_t^a$ with normally distributed innovations $\varepsilon_t^a \sim \mathcal{N}(0, \sigma_a^2)$.

When an agent and a firm are matched, they engage in Nash bargaining over wages and

[6] With this assumption the search and matching process can be efficient under the conditions in Hosios (1990). If unemployment benefits are modeled as tax-financed, imposing the conditions in Hosios (1990) is not sufficient to achieve efficiency for $b^u > 0$. Our results are not affected by the specifics of modeling the unemployment benefits.

hours worked. The solution to the bargaining problem is obtained from

$$\max_{w_t,h_t} J_t^{1-\xi} H_t^{\xi} \tag{7}$$

where ξ stands for the bargaining power of the worker. The marginal value of employment to the firm J_t is the period profit of the additional worker, i.e., the excess of the marginal product over the real wage, plus the continuation value if the match survives into the future

$$J_t = \left(\frac{P_t^w}{P_t}a_t - \frac{W_t}{P_t}\right) h_t + (1-\rho)\, E_t \beta \frac{\lambda_{t+1}}{\lambda_t} J_{t+1}. \tag{8}$$

The marginal value of employment to the household H_t satisfies

$$H_t = \left(\frac{W_t}{P_t}h_t - b^u - \frac{\phi_0}{1+\phi}\frac{h_t^{1+\phi}}{\lambda_t}\right) + (1-\rho)\, E_t \beta \frac{\lambda_{t+1}}{\lambda_t}\left(1 - s_{t+1}\right) H_{t+1} \tag{9}$$

and consists of the increase in household income $\frac{W_t}{P_t}h_t - b^u$ of having an additional member employed over the monetary equivalent to compensate that member for the loss in leisure $\frac{\phi_0}{1+\phi}\frac{h_t^{1+\phi}}{\lambda_t}$ and the continuation value if the match persists.

Retail firm i produces a differentiated good and sets its price to maximize

$$\max_{\tilde{P}_t(i)} \mathbb{E}_t \sum_{s=0}^{\infty} (\xi^p \beta)^s \frac{\lambda_{t+s}}{\lambda_t} \left[\left((1+\bar{\tau}^p)\tilde{P}_t(i)\left(\prod_{l=1}^{s} \Pi_{t+l-1}^{\iota^p} \bar{\Pi}^{1-\iota^p}\right) - MC_{t+s}\right)\right] y_{t+s}(i)$$

$$s.t. \quad y_{t+s}(i) = \left(\frac{\tilde{P}_t(i)\left(\prod_{l=1}^{s} \Pi_{t+l-1}^{\iota^p} \bar{\Pi}^{1-\iota^p}\right)}{P_{t+s}}\right)^{-\dfrac{\lambda^p}{\lambda^p - 1}} y_{t+s}. \tag{10}$$

Each period, retailer i adjusts its price $P_t(i)$ with the fixed probability $1-\xi^p$ as in Calvo (1983). If not, the price adjusts by the geometric average of past inflation and the steady state value of the inflation rate $\bar{\Pi}$. The subsidy $\bar{\tau}^p$ offsets the distortions due to monopolistic competition in the steady state. We introduce a markup shock into the first order condition of the retailer which is first-order equivalent to variations in $\bar{\tau}^p$ or λ^p. The profit maximization is subject to the demand curve which in turn is derived from the problem of the producers of the final consumption good y_t. The final consumption good consists of the differentiated goods $y_t = \left[\int_0^1 y_t(i)^{\frac{1}{\lambda^p}} \mathrm{d}i\right]^{\lambda^p}$. The term $\frac{\lambda^p}{\lambda^p-1}$ measures the elasticity of substitution between retail varieties. y_t is used for consumption c_t^m and for posting vacancies v_t. Finally, the retailer's cost minimization problem

$$\begin{aligned}
&\min_{y_t^w(i), y_t(i)} P_t^w y_t^w(i) \\
&s.t. \quad y_t(i) = y_t^w(i).
\end{aligned} \tag{11}$$

delivers an expression for real marginal costs $mc_t = \dfrac{P_t^w}{P_t}$.

3.2 New Keynesian model with sticky nominal wages

Each household j chooses consumption and asset holdings by maximizing the inter-temporal utility function

$$E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} \left[\frac{(c_t(j) - \mu c_{t-1}(j))^{1-\sigma}}{1-\sigma} - \phi_0 \frac{h_t(j)^{1+\phi}}{1+\phi} \right] \tag{12}$$

subject to the budget constraint

$$P_t c_t(j) + B_{t+1}(j) = (1 + \bar{\tau}^w) W_t(j) h_t(j) + R_{t-1} B_t(j) + Pr_t(j) + T_t(j). \tag{13}$$

All members of each household j are always employed and supply differentiated labor services $h_t(j)$. As in Calvo (1983), the household adjusts its nominal wage optimally with fixed probability $1 - \xi^w$ each period. If not, the wage changes by the weighted geometric average of past and steady state inflation. The household sets its wage to solve

$$\begin{aligned}
& \max_{\tilde{W}_t(j)} \mathbb{E}_t \sum_{s=0}^{\infty} (\xi^w \beta)^s \left[\frac{(c_{t+s}(j) - \mu c_{t-1+s}(j))^{1-\sigma}}{1-\sigma} - \phi_0 \frac{h_{t+s}(j)^{1+\phi}}{1+\phi} \right] \\
s.t. \quad & P_{t+s} c_{t+s} + B_{t+s+1} = (1 + \bar{\tau}^w) W_{t+s}(j) h_{t+s}(j) + R_{t+s-1} B_{t+s} + Pr_{t+s} + T_{t+s} \\
& W_{t+s}(j) = \tilde{W}_t(j) \left(\prod_{l=1}^{s} \Pi_{t+l-1}^{\iota^w} \bar{\Pi}^{1-\iota^w} \right) \\
& h_{t+s}(j) = \left(\frac{W_{t+s}(j)}{W_{t+s}} \right)^{-\dfrac{\lambda^w}{\lambda^w - 1}} h_{t+s}
\end{aligned} \tag{14}$$

where the subsidy $\bar{\tau}^w$ is set to eliminate the labor supply distortions arising from monopolistic competition in the steady state. The profit maximization problem of labor bundlers that package the differentiated labor services $h_t(j)$ into the aggregate labor service, $h_t =$

$\left[\int_0^1 h_t(j)^{\frac{1}{\lambda^w}}\mathrm{d}j\right]^{\lambda^w}$, delivers the labor demand function.

Wholesale firms purchase aggregate labor services h_t from the labor bundler. Retail firms purchase the wholesale good, differentiate it, and set prices using staggered contracts, just as in the model with search and matching frictions.

4 Setting up the policy environment

At the core of our analysis lies the idea that the policymaker can formulate multiple models that provide a good approximation to the true data-generating process given the empirical evidence against which the models are assessed. Given the large number of free parameters in most theoretical models, it is basically impossible to reduce the set of candidate models to a single one and obtain model certainty. The large variety of business cycle models found in the academic literature (that all try to explain similar aspects of the data) and the diverse set of models used within central banks attest this view.

4.1 Empirical strategy

To arrive at a setting in which the policymaker wants to consider both our models for setting policy, we find parameterizations for which the two models provide a good empirical fit under an interest rate rule of the type

$$i_t = \rho_R i_{t-1} + \rho_\pi \pi_t + \rho_x x_t. \tag{15}$$

Such a policy rule is commonly argued to provide a good approximation to actual policy decisions, see Taylor (1993). Price inflation π_t is measured in deviation from its long-run target value, and i_t denotes the short term nominal interest rate in deviation from steady state. The output gap is x_t. The coefficient ρ_R governs the degree of interest rate smoothing.

For each model, we divide the parameters into two groups: calibrated (Γ^c) and estimated (Γ) parameters. Following Rotemberg and Woodford (1997), our parameter estimates minimize the distance between selected impulse response functions generated from the model, denoted by $G(\Gamma,\Gamma^c)^{model}$, and their empirical counterparts, G.[7] We match the responses after

[7] Formally, the estimated parameters satisfy $\hat{\Gamma} = \arg\min_\Gamma \left(G - G(\Gamma,\Gamma^c)^{model}\right)' \left(\Psi^0\right)^{-1} \left(G - G(\Gamma,\Gamma^c)^{model}\right)$. The diagonal weighting matrix Ψ^0 is the variance-covariance matrix of the empirical impulse response functions Ψ with all off-diagonal elements set to zero.

the neutral technology shock from the SVAR in Christiano, Eichenbaum, and Trabandt (2016) over the first 15 periods.

An alternative to our approach would be full information estimation as in Smets and Wouters (2007). Full information estimation would deliver an empirical specification of all the shocks in each model. However, this approach requires additional modeling features and assumptions about the stochastic disturbances of varying economic plausibility.

4.2 Parameterzing the model and estimation

For each model we estimate the coefficients in the interest rate rule, ρ_R and ρ_π, the degree of internal consumption habits μ, and the degree of price indexation ι^p. In the search and matching model, we also estimate the replacement ratio r^u. While we fix the persistence of the technology shock at $\rho_a = 0.9999$, we estimate the standard deviation of the shock σ_a. All other parameters are assigned standard values found in the literature. We follow Christiano, Eichenbaum, and Trabandt (2016) as closely as possible, see Table 1, and we assign identical values to parameters that appear in both models. As they do, we abstract from wage indexation in the sticky wage model. For the sticky wage model, the estimation includes the impulse responses of output, inflation, the short-term interest rate as measured by the federal funds rate, hours worked, real wages, and consumption. In the case of the search and matching model, we also include the responses of the unemployment rate, vacancies, and the job finding rate.

Table 2 shows the parameter estimates and Figure 1 plots the empirical responses and the impulse responses for the estimated models. With the exception of hours worked, the model responses lie within the confidence bands of the empirical responses and the responses are reasonably close to the SVAR point estimates and to each other.

The estimates for the coefficients in the interest rate rule, the variance of the technology shock, price indexation, and consumption habits are almost identical across models. Both estimated rules feature similarly high degrees of interest rate smoothing and long-run responses of the interest rate to inflation; the Taylor principle, e.g., $\rho_\pi/(1-\rho_R) > 1$, is satisfied in both cases. When assuming the same interest rate rule for both models the estimates of the remaining parameters stayed stable. Across specifications, price indexation is estimated at zero; when we relaxed the assumption of no indexation in wages, the fit of the sticky wage model improved and was closed to the search and matching model, see Appendix F. Overall, our estimates and the theoretical impulse responses resemble those in Christiano, Eichenbaum, and Trabandt (2016) despite the greater simplicity of our models and the different bargaining protocol in the search and matching model.[8]

Our estimate for the replacement ratio in the search and matching model with Nash bargaining r^u at 0.5345 is well below the implausibly high estimate of 0.88 in Christiano, Eichenbaum, and Trabandt (2016). The ability of search and matching models to fit labor market data has been hotly debated since Shimer (2005).[9] By modeling the disutility from working explicitly, we build on the ideas in Hagedorn and Manovskii (2008) to resolve the Shimer (2005) puzzle as detailed in Appendix B. In building our analysis on a search and matching model that can replicate the volatility of unemployment and vacancies in the data our work is distinct from earlier contributions on optimal policy in search and matching models such as Ravenna and Walsh (2011) or Faia (2009).

4.3 Additional shocks

While we used identified neutral technology shocks to determine free parameters, we are also interested in the effects of markup shocks. Absent a broadly accepted identification scheme for markup shocks for SVAR analysis, we specify a transitory markup shock with a standard deviation of 0.0135 in the sticky wage model. The standard deviation of the markup shock in the search and matching model of 0.0104 minimizes the distance between the impulse responses for the markup shocks in the two models given the parameters in Tables 1 and 2. The smaller value of the standard deviation in the search and matching model reflects the stronger impact of an equal-sized markup shock on output and inflation in the search and matching model compared to the sticky wage model.

5 Optimal policy and robustness

As both models match the relevant SVAR evidence well for reasonable parameter values under the estimated interest rate rule, the policymaker has little guidance for choosing one model

[8] Christiano, Eichenbaum, and Trabandt (2016) include investment, capacity utilization, and the relative price of investment as well as shocks to monetary policy and investment-specific technology into the impulse response function matching exercise. They require an estimate of μ between 0.7 and 0.8 to match the hump-shaped response of consumption in the VAR after the monetary policy shock, a feature not shared by the neutral technology shock. When we fixed μ at a strictly positive value the parameters reported in Table 2 changed marginally.

[9] Numerous authors have offered candidate solutions: Hall (2005) and Shimer (2005) propose real wage rigidities; Hagedorn and Manovskii (2008) argue in favor of high opportunity costs of employment; Hall and Milgrom (2008) suggest departures from Nash bargaining over wages.

over the other. In addition, the two models have conflicting normative implications: In the search and matching model, the optimal monetary policy seeks to stabilize price inflation at the expense of wage inflation whereas the optimal monetary policy in the sticky wage model pursues the opposite goal. If the policymaker formulates policies on the assumption that the search and matching model is the true data-generating process when in fact the sticky wage model constitutes the true process, the policymaker implements a policy that may result in big welfare losses and vice versa. Hence, the policymaker should shy away from selecting a single model prior to the evaluation of monetary policy and instead make model uncertainty a component of policy evaluation.

To compute the optimal policy under model uncertainty the policymaker seeks to minimize the loss function of the form

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \mathcal{L} \left(\tilde{y}_t, \Omega_t \right) \right\} \tag{16}$$

where the vector $\tilde{y}_t$ contains the variables of all the reference models including their relevant leads and lags. The loss function depends explicitly on the policymaker's probability distribution Ω_t over models to reflect the fact that the policymaker's preferences over economic outcomes may differ across models. In principle, the policymaker updates Ω_t in response to the observed outcomes under his choices. The modelling of this updating process can take on different degrees of complexity with no learning about the true data-generating process and Bayesian optimal learning defining the extremes of possible setups.

Four scenarios shed light on the policymaker's decision problem under model uncertainty:

1. the policymaker knows the correct model and implements a policy that is optimal given the preferences of the representative household (standard assumption),
2. the policymaker selects policy on the assumption that model 1 is true, when in fact model 2 is true and the other way around,
3. the policymaker has a time-invariant probability distribution over models and fixes a policy rule at the beginning of time that is consistent with a weighted-average over the preferences of the representative household in the reference models,
4. the policymaker chooses a policy rule that minimizes the maximum welfare losses of the representative household given the reference models.

We discuss the first two scenarios in this section, and the remaining two in Section 6.

5.1 Optimal policy and targeting rules

To implement scenarios 1 and 2, we derive optimal targeting rules. Following Giannoni and Woodford (2017), and citations therein, an optimal targeting rule specifies the variables—including the relative importance and the dynamic structure of each variable—in a single target criterion that seeks to implement the optimal monetary policy.

When the preferences of the policymaker coincide with those of the representative household in the model, obtainaing optimal targeting rules requires us to: (1) derive the objective function of the policymaker as a purely quadratic approximation to the preferences of the representative household;[10] (2) obtain the first order conditions associated with the policymaker's optimization problem; (3) combine these first order conditions into a single equation.

This equation describes the relationship between the endogenous and exogenous variables under the optimal policy and when used as the policy rule it implements the optimal monetary policy in the underlying model. Written in terms of economically relevant model variables only, the optimal targeting rule is ideally suited to investigate the robustness of the optimal policy implied by one model in any other model as in our second scenario.

To derive the optimal targeting rule in the sticky wage model consider the problem

$$\min_{\{\pi_t,\pi_t^w,\hat{y}_t,i_t,\hat{w}_t\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \mathcal{L}_t^{sw} \tag{17}$$

$s.t.$

$$\pi_t = \beta E_t \pi_{t+1} + \kappa^p \left(\hat{w}_t - \hat{a}_t\right) + \hat{\theta}_{p,t} \tag{18}$$

$$\pi_t^w = \beta E_t \pi_{t+1}^w + \kappa^w \left(\sigma+\phi\right)\left(\hat{y}_t - \frac{1+\phi}{\sigma+\phi}\hat{a}_t\right) - \kappa^w \left(\hat{w}_t - \hat{a}_t\right) \tag{19}$$

$$\hat{y}_t = E_t \hat{y}_{t+1} - \frac{1}{\sigma}\left(i_t - E_t \pi_{t+1}\right) \tag{20}$$

$$\hat{w}_t = \hat{w}_{t-1} + \pi_t^w - \pi_t. \tag{21}$$

and pre-commitments for period 0 (timeless perspective).

The second order approximation of household preferences is given by the loss function

$$\mathcal{L}_t^{sw} = \frac{\sigma+\phi}{2}\left(\hat{y}_t - \frac{1+\phi}{\sigma+\phi}\hat{a}_t\right)^2 + \frac{1+\theta^p}{2\theta^p\kappa^p}\pi_t^2 + \frac{1+\theta^w}{2\theta^w\kappa^w}(\pi_t^w)^2. \tag{22}$$

Equations (18)-(21) are obtained from the equilibrium conditions of the sticky wage model

[10] We follow Woodford (1999) and Benigno and Woodford (2012) in adopting the concept of "optimality from the timeless perspective"—a necessary assumption to obtain the correct linear quadratic approximation to our nonlinear model.

by linearization around the deterministic steady state. Variables are expressed in deviations from steady state; "hatted" variables are in log-deviations. Consistent with our estimation results, we abstract from consumption habits and indexation of prices and wages.

Theorem 1 *The optimal targeting rule for the sticky wage model associated with the optimization problem in (17)-(22) satisfies*

$$\begin{aligned} 0 &= \left(\frac{1+\theta^p}{\theta^p}\pi_t + x_t - x_{t-1}\right) + \frac{1+\beta+\kappa^p}{\kappa^w}\left(\frac{1+\theta^w}{\theta^w}\pi_t^w + x_t - x_{t-1}\right) \\ &\quad -\frac{\beta}{\kappa^w}\left(\frac{1+\theta^w}{\theta^w}\pi_{t+1}^w + x_{t+1} - x_t\right) - \frac{1}{\kappa^w}\left(\frac{1+\theta^w}{\theta^w}\pi_{t-1}^w + x_{t-1} - x_{t-2}\right) \end{aligned} \tag{23}$$

with the output gap defined as $x_t = \hat{y}_t - \frac{1+\phi}{\sigma+\phi}\hat{a}_t$.

Proof. See Appendix E. ■

The stickier nominal wages are, i.e., a lower value for κ^w, the less concerned is the policymaker with the deviations of price inflation from its long-run target. Absent sticky wages, i.e., $\kappa^w \to \infty$, equation (23) reduces to

$$\frac{1+\theta^p}{\theta^p}\pi_t + x_t - x_{t-1} = 0, \tag{24}$$

optimal targeting rule in the textbook New Keynesian model with flexible wages.

Optimal targeting rules for models with search and matching frictions are absent from the literature. Blanchard and Galí (2010), Thomas (2008), and Ravenna and Walsh (2011) derive purely quadratic objectives for the policymaker from household preferences under the assumption that the search and matching process does not induce inefficiencies as in Hosios (1990). None of these papers derives the implied optimal targeting rule. Furthermore, if the Hosios condition is not imposed, even the first step of obtaining a second order approximation to the preferences of the representative household is missing in the literature.

We employ the numerical approach described in Bodenstein, Guerrieri, and LaBriola (2014) to derive the purely quadratic objective for the policymaker in the search and matching model with a distorted steady state as

$$\begin{aligned} \mathcal{L}_t^{s\&m} &= P_{\pi,\pi}\pi_t^2 + P_{y,y}\hat{y}_t^2 + P_{n,n}\hat{n}_t^2 + P_{n^-,n^-}\hat{n}_{t-1}^2 + P_{y,n}\hat{n}_t\hat{y}_t + P_{y,n^-}\hat{y}_t\hat{n}_{t-1} \\ &\quad + P_{n,n^-}\hat{n}_t\hat{n}_{t-1} + P_{n,a}\hat{n}_t\hat{a}_t + P_{n,p}\hat{n}_t\hat{\theta}_{p,t} + P_{y,a}\hat{y}_t\hat{a}_t + P_{y,p}\hat{y}_t\hat{\theta}_{p,t}. \end{aligned} \tag{25}$$

Appendix D shows how to simplify the loss function to include those variables only that enter the linear model in equations (27)-(29) below.[11] The problem of the policymaker is

$$\min_{\{\pi_t, i_t, \hat{n}_t, \hat{y}_t\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \mathcal{L}_t^{s\&m} \tag{26}$$

$s.t.$

$$\pi_t = \beta E_t \pi_{t+1} + \kappa^p \left[\left(\phi + \sigma \frac{\varpi^{y_{ss}}}{1-\kappa^c} \right) \hat{y}_t - (1+\phi)\, \hat{a}_t - (\theta_1 \hat{n}_t + \theta_2 \hat{n}_{t-1}) \right] + \hat{\theta}_{p,t} \tag{27}$$

$$\hat{y}_t = E_t \hat{y}_{t+1} - \frac{1-\kappa^c}{\sigma \varpi^{y_{ss}}} \left(i_t - E_t \pi_{t+1} + (\theta_1 - \phi)\,(E_t \hat{n}_{t+1} - \hat{n}_t) + \theta_2\,(\hat{n}_t - \hat{n}_{t-1}) \right) \tag{28}$$

$$\gamma_1 E_t \hat{n}_{t+1} + \gamma_2 \hat{n}_t + \gamma_3 \hat{n}_{t-1} = \left(1 + \phi + \frac{\sigma \varpi^{y_{ss}}}{1-\kappa^c} \right) \hat{y}_t - (1+\phi)\, \hat{a}_t$$
$$- \frac{(1-\rho)\beta}{\nu} (1 - \xi q_{ss} \theta_{ss}) \left(\frac{\kappa^v}{q_{ss}} \right) (i_t - E_t \pi_{t+1}) \tag{29}$$

and pre-commitments for period 0 (timeless perspective).

Theorem 2 *The optimal targeting rule in the search and matching model associated with the optimization problem in (25)-(29) satisfies:*

$$\varpi_1 \hat{n}_t + \varpi_2 \hat{n}_{t-1} + \varpi_3 \hat{n}_{t+1} + \varpi_4 \hat{y}_t + \varpi_5 \hat{y}_{t+1} + \varpi_6 \hat{a}_t + \varpi_7 \hat{\theta}_{p,t} + \varpi_8 \pi_t + \varpi_9 \pi_{t+1} + \varpi_{10} \hat{P}_{t-1}$$
$$+ \varpi_{11} \hat{y}_t^{WA} + \varpi_{12} \hat{n}_t^{WA} + \varpi_{13} \hat{a}_t^{WA} + \varpi_{14} \hat{\theta}_{p,t}^{WA} + \varpi_{15} \hat{P}_t^{WA} = 0 \tag{30}$$

with the weighted infinite-moving averages for output (y), employment (n), the price level (P), and the shocks (a, θ) for $X = \{y, n, P, a, \theta\}$ being defined as

$$\hat{X}_t^{WA} = \beta_\delta \hat{X}_{t-1}^{WA} + \hat{X}_t. \tag{31}$$

Proof. See Appendix D. ■

The markup shock $\hat{\theta}_{p,t}$ appears in the targeting rule due to our decision not to impose the efficiency condition by Hosios (1990)—a necessary choice to obtain a good fit of the search and matching model to the data as discussed in Section 4.[12]

We express the targeting rules in variables that are common to both models before exchanging them between models. When implementing the rule in equation (30) in the sticky wage model we substitute out for employment $\hat{n}_t$ in terms of hours worked, output, and tech-

[11] See Appendix C for the derivations of the linearized equilibrium conditions.

[12] In the sticky wage model the markup shock does not enter equation (23) since the steady state is assumed to be efficient; otherwise the markup shock would appear in the targeting rule as well. See also Benigno and Woodford (2005).

nology using the aggregate production function and we define the price level in the sticky wage model. When solving the search and matching model under the optimal targeting rule derived from the sticky wage model, equation (23), we add a definition of wage inflation.

5.2 Robustness of optimal targeting rules

We first assess the robustness of the optimal targeting rules in the search and matching model. Figure 2 depicts the case of the technology shock $\hat{a}_t$ in the top two rows of panels and the case of the price markup shock $\hat{\theta}_{p,t}$ in the bottom two rows. Under the technology shock, the optimal targeting rule derived from the search and matching model, equation (30), calls for almost full stabilization of price inflation. No meaningful trade-offs arise as the welfare-relevant gaps move in the same direction: the technology shock exerts downward pressure on prices, and upward pressure on output and employment with sticky prices holding back the expansion. An interest rate cut reduces the downward pressure on prices and speeds up the expansion in output and employment. As a result, the real variables follow closely their paths in an economy with flexible prices. Under the optimal policy, the labor market adjusts promptly to the shock in sharp contrast to the empirical responses in Figure 1, as the pronounced spurt in wage inflation facilitates swift adjustment of the real wage. The movements in wages reflect the persistent jump in the marginal value of employment to the firm that gives rise to the front-loaded response in vacancies and the fall in unemployment.

By contrast, when we apply the optimal targeting rule derived from the sticky wage model, equation (23), to the search and matching model, the policymaker keeps nominal wages basically constant in response to the technology shock. Price inflation falls below its target value to facilitate the adjustment in the real wage. As firms and households cannot reap immediately all benefits of the improved technology and of higher real wages, vacancy postings, employment, and unemployment display inertia relative to the optimal responses. Adjustments in output and consumption are delayed, as well. Obviously, the targeting rule that is optimal in the sticky wage model does not induce the optimal responses in the search and matching model after a technology shock.

In the case of the markup shock, similar differences emerge between the two policy rules in the search and matching model. With the exception of price inflation, all other variables react more strongly to the shock under the optimal policy, equation (30). As the markup shock induces a trade-off between variables, price inflation is not fully stabilized under the optimal policy to temper the fluctuations in the other variables. Again, when the targeting rule derived from the sticky wage model is imposed instead, equation (23), wage inflation is almost fully stabilized at the expense of higher price inflation and the responses of all other variables are greatly muted compared to the optimal policy.

The lack of robustness of the targeting rules across models also applies to the sticky wage model as shown in Figure 3. The optimal policy under sticky nominal wages, implemented by equation (23), stabilizes wage inflation in response to the technology and the markup shock. This policy avoids welfare-costly wage dispersion in the sticky wage model, whereas price inflation induces movements in the real wage that in turn facilitate the adjustment process for all other variables. The targeting rule derived from the search and matching model (30) overly stabilizes price inflation and causes more wage inflation than is optimal in the sticky wage model. Hours worked, output, and consumption exceed their optimal responses.

To sum up, optimal targeting rule derived from the search and matching model, favours stabilizing prices over stabilizing wages irrespective of the model in which the rule is implemented. The optimal targeting rule derived from the sticky wage model, favours stabilizing wages over stabilizing prices irrespective of the model under consideration. Exchanging targeting rules between models induces welfare losses that are much larger than the welfare costs of business cycles in Lucas (2003). For the sticky wage model the welfare loss is higher than for the search and matching model (1.3033 versus 0.1133 in CEV) reflecting the sensitivity of welfare losses to deviations from the model-specific optimal policy in the sticky wage model. As discussed in the Appendix F, the welfare losses are even bigger when wages are indexed.

6 Robust policy

Analyzing optimal policy under model uncertainty requires specifying the policymaker's preferences under uncertainty and his probability distribution over models. We consider the two approaches introduced in Section 5: model averaging (scenario 3) and minmax (scenario 4).

Under model averaging, the policymaker's preferences over economic outcomes are

$$L^{av}(\Theta) = \omega \left(\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \mathcal{L}_t^{s\&m}(\Theta) \right) + (1-\omega) \left(\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \mathcal{L}_t^{sw}(\Theta) \right) \tag{32}$$

where Θ indicates the monetary policy strategy common to both models. The parameters ω and $1-\omega$ denote the policymaker's time-invariant probability distribution over the two models and hence the relevant weights attached to the preferences of the representative households in the two models, the loss functions $\mathcal{L}_t^{sw}$ (equation 22) and $\mathcal{L}_t^{s\&m}$ (equation 25).[13]

This approach can be viewed literally as the case of a single policymaker assigning a probability distribution over the reference models based on statistical analysis; the weighted average of the reference models is the policymaker's model. An alternative interpretation is to assume that each member of a committee has a single model in mind and the optimal policy under uncertainty produces outcomes that might be acceptable to all members.

When the policymaker pursues the minmax approach, the loss under policy Θ is the maximum welfare loss across the two reference models

$$L^{minmax}(\Theta) = \max \left\{ \left(\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \mathcal{L}_t^{s\&m}(\Theta) \right), \left(\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \mathcal{L}_t^{sw}(\Theta) \right) \right\}. \tag{33}$$

In this case, models with greater normative sensitivity to deviations from their model-specific optimal policies have disproportionate impact on the optimal policy under model uncertainty to avoid worst-case scenarios. The probability distribution over models matters only to the extent that the policymaker attaches non-zero probability to each model.

To characterize optimal monetary policy under model uncertainty we assume that the policymaker follows a parametric rule. We consider a simple instrument rule of the form

$$i_t = \rho_R i_{t-1} + \rho_\pi \pi_t + \rho_\pi^w \pi_t^w + \rho_x x_t \tag{34}$$

with its coefficients stacked in the vector $\Theta = \left\{ \rho_R, \rho_\pi, \rho_\pi^w, \rho_x \right\}$ and a simple targeting rule

$$\begin{aligned} 0 \;=\; & \rho_{tr} \left(\frac{1+\theta^p}{\theta^p} \pi_t + x_t - x_{t-1} \right) + \frac{1+\beta+\kappa^p}{\kappa^w} \left(\frac{1+\theta^w}{\theta^w} \pi_t^w + x_t - x_{t-1} \right) \\ & - \frac{\beta}{\kappa^w} \left(\frac{1+\theta^w}{\theta^w} \pi_{t+1}^w + x_{t+1} - x_t \right) - \frac{1}{\kappa^w} \left(\frac{1+\theta^w}{\theta^w} \pi_{t-1}^w + x_{t-1} - x_{t-2} \right) \end{aligned} \tag{35}$$

with $\Theta = \left\{ \rho_{tr} \right\}$. The output gap is measured as the difference between actual output and the output that would have prevailed absent nominal rigidities. Given the policymaker's objective, the optimal parameterization Θ of a rule minimizes the policymaker's welfare loss under the policymaker's beliefs over the reference models and their implied dynamics as in Levin and Williams (2003) and Levin, Wieland, and Williams (2003).[14]

[13] Levin and Williams (2003) and Taylor and Williams (2010) refer to this approach as Bayesian strategy.

[14] As the discount factor is close to 1, we approximate conditional welfare by unconditional welfare and thus eliminate the impact of arbitrary initial conditions. A correction term accounts for violations of the pre-commitment conditions imposed in deriving the loss functions by the rules, see Benigno and Woodford (2012). We discard rules leading to indeterminacy.

Using simple rules to describe policy reduces the search for optimal policy under model uncertainty to determining a small number of coefficients. In addition to facilitating computations and transparency of the analysis, these rules can closely approximate the optimal policy for both our models absent model uncertainty. For example, the simple targeting rule (35) replicates the optimal targeting rule from the sticky wage model for $\rho_{tr} = 1$ and it approximates well the optimal targeting rule from the search and matching model when ρ_{tr} is large.[15] Similarly, there is also little room to simplify these rules any further. Appendix F documents how, for example, the performance of the simple instrument rule (34) deteriorates as we restrict any of its parameters to zero.

6.1 Monetary policy rules under model uncertainty

6.1.1 Instrument rule

Table 3 reports in Panel (a) the optimal simple rules under the benchmark parameterization of the search and matching model and the sticky wage model. For the model averaging approach, we consider multiple specifications of the policymaker's probability distribution with ω, the probability that the policymaker assigns to the search and matching model being the true data-generating process, ranging from 0 to 1. We refer to the optimal simple rule associated with a given probability distribution as the "ω-optimal simple rule." Welfare is reported in terms of consumption equivalent variations (CEV). In Panel (b), we report the findings when the policymaker follows the simple targeting rule. Finally, for comparison, the table repeats in Panel (c) the welfare implications of implementing the optimal targeting rules derived in the previous section across models.

In Panel (a), we distinguish three regions for the probability ω under model averaging: low ($\omega \leq 0.2$), intermediate ($0.3 \leq \omega \leq 0.8$), and high ($\omega \geq 0.9$). The ω-optimal simple rule varies distinctly across these regions. In the first region with little probability weight on the search and matching model, the nominal interest rate responds primarily to wage inflation in line with the optimal policy prescriptions of the sticky wage model. In the second region, the rule responds to wage and price inflation with the coefficients assigned to the two variables being of similar magnitude. In the third region the ω-optimal simple rule displays significant interest rate inertia. The coefficient on wage inflation basically drops to zero whereas the nominal

[15] For the parameters in Tables 1 and 2, the weights ϖ_j with $j = 1, ..., 15$ in equation (30) are such that the optimal targeting rule from the textbook model in equation (24) is a good approximation to the optimal targeting rule derived from the search and matching model.

interest rate responds to price inflation. With the policymaker assigning a high probability to the search and matching model, the importance of wage inflation stabilization fades. Consequently, in the sticky wage model the welfare loss (relative to the optimal monetary policy in that model) under the ω-optimal simple rule is larger for higher values of ω and the welfare loss in the search and matching model is reduced.

To illustrate the dynamic implications of these rules, we plot in Figure 4 the impulse responses of output, price and wage inflation in both models to the technology shock and the markup shock for $\omega = 0, 0.2, 0.3, 0.8, 0.9, 1$. In the sticky wage model (bottom two rows of panels), the ω-optimal simple rules with $\omega < 0.9$ induce impulse responses that are reasonably close to those under $\omega = 0$, the optimal simple rule if the policymaker is certain about the sticky wage model being the true data-generating process. For the search and matching model (top two rows of panels), ω-optimal simple rules with $\omega < 0.9$ induce responses that differ noticeably from those under $\omega = 1$, the optimal simple rule if the policymaker is certain about the search and matching model being the true data-generating process.[16] The effective policy is biased towards the optimal policy in the sticky wage model for the low and the intermediate region of ω despite the differences in the rule parameters.

The welfare losses induced by the ω-optimal simple rules reported in Table 3 confirm this conclusion from a normative perspective. When moving from the 0.8-optimal simple rule to the 0.9-optimal simple rule the CEV value for the sticky wage model goes from negligible to 0.2. While the welfare losses in the search and matching model are generally small, the CEV value is practically zero under the 0.9-optimal simple rule.

The reason for the apparent bias of the optimal policy under model uncertainty towards the sticky wage model lies in the high welfare costs associated with even minor relative wage differences in the sticky wage model. The desire to avoid bad economic outcomes caused by bad monetary policy is even more explicit when the policymaker adopts a minmax strategy. In this case, the optimal simple rule coincides with the 0-optimal simple rule, which despite its simplicity mimics the optimal targeting rule derived from the sticky wage model closely.

[16] For the search and matching model, the Euclidean distance between the impulse responses of price inflation, wage inflation and output to the price markup shock for the rules $\omega = 0.8$ and $\omega = 0.9$ measured against the case of $\omega = 1$, respectively, drops from 0.0347 to 0.019. For the sticky wage model, by contrast, the Euclidean distance for the rules $\omega = 0.8$ and $\omega = 0.9$ measured against the case of $\omega = 0$, respectively, more than doubles from 0.0116 to 0.0245.

6.1.2 Targeting rule

To complement the findings for the optimal simple rules, Panel (b) reports the optimal parameterization of the simple targeting rule proposed in equation (35). In the case of model averaging, when the policymaker holds the sticky wage model reasonably likely, the coefficient ρ_{tr} is set near 1 and the rule allows for wage inflation to be a primary concern of monetary policy. Only for ω close to 1 does the policymaker switch to stabilizing price inflation aggressively: ρ_{tr} exceeds 6e+05 for $\omega = 1$, but it assumes a value around 15 for $\omega = 0.9$. It is in the interval $\omega \in [0.9, 1]$ that the welfare loss in the search and matching model under the simple targeting rule drops to almost zero, whereas the welfare loss in the sticky wage model soars. Under the minmax approach, the policymaker chooses $\rho_{tr} = 1$ and implements the optimal targeting rule of the sticky wage.

6.2 Shock persistence and consumption habits

Table 4 assess the role of persistence in the markup shock and of consumption habits. Panel (a) shows that in the case of mildly persistent markup shocks ($\rho_u = 0.2$) the results are similar to those in Table 3, if not stronger. Under model averaging, the ω-optimal simple rule is biased towards improving the outcomes in the sticky wage model: the welfare loss in the sticky wage model is smaller than in the search and matching model as long as $\omega \leq 0.8$ and negligible for $\omega \leq 0.4$ (compared to $\omega \leq 0.2$ in Table 3). The minmax strategy picks again the ω-optimal simple rule for $\omega = 0$. Our results also withstand the introduction of habit persistence ($\mu = 0.6$) shown in Panel (b). With this real rigidity the bias of the optimal policy under model uncertainty towards the sticky wage model is slightly less pronounced.

7 Alternative settings

As the list of plausible extensions to our work is long, we comment on few aspects only. To facilitate our exposition, we abstracted from capital accumulation and investment dynamics. As these features hardly alter the policymaker's trade-offs, we expect our findings to hold in a model augmented with these features.

Our two reference models incorporate two polar views about the labor market. Gertler and Trigari (2009) bridge these views by introducing staggered multiperiod wage contracting into the search and matching framework. Thomas (2008) shows that the optimal policy in such a model resembles the recommendations derived from the sticky wage model. Adding this hybrid framework to our set of reference models would therefore not fundamentally alter the considerations of monetary policy under model uncertainty.

Replacing the sticky wage model with the framework by Gertler and Trigari (2009) could be an attractive alternative if we employed Bayesian estimation rather than impulse response function matching to create an environment with multiple reference models. With the hybrid model being informative about the same labor market variables as the standard search and matching model, posterior odds ratios could provide empirical guidance about the policymaker's probability distribution over the reference models as in Levine, McAdam, and Pearlman (2012). Given the range and sensitivity of the additional assumptions needed to obtain a good fit of DSGE models to the data and the predominance of the sticky wage framework in empirical monetary economics, we view this way as complementary to ours.

Models with heterogenous consumers constitute another class of alternative reference models. Kaplan, Moll, and Violante (2016) and Ravn and Sterk (2016) have incorporated household heterogeneity into New Keynesian models. From a normative perspective, the policymaker needs to trade off real economic activity, inflation, and the degree of heterogeneity in such models. However, the results in Debortoli and Galí (2017) suggest that the optimal policy prescriptions from a model with this kind of household heterogeneity may resemble those from representative agent models with sticky prices but flexible wages. Quantitatively, heterogeneity in their two-agent model barely alters the policymaker's desire to focus on stabilizing inflation unless the policymaker is highly averse to heterogeneity.[17] We expect our conclusions to hold even in a model with heterogenous agents.

7.1 Policymaker's preferences

Previous works on policymaking under model uncertainty assume that the policymaker's preferences are given by the widely-used simple quadratic loss function

$$\mathcal{L}_t^{sql} = \pi_t^2 + \lambda_x x_t^2. \tag{36}$$

At least in our case, this simple loss function is unrelated to the preferences of the agents in the models and it fails to account for the possibility that the policymaker's preferences over

[17] In the heterogenous agent model with rigid real wages of Gornemann, Kuester, and Nakajima (2016), the policymaker optimally shifts focus away from inflation stabilization towards stabilizing unemployment. However, a similar finding emerges in the representative agent model with rigid real wages presented in Blanchard and Galí (2010).

outcomes might differ between models, see equations (22) and (25). To explore the role of the policymaker's preferences, we revisit our analysis for two parameterizations of (36) that place different emphasis on stabilizing price inflation: $\lambda_x = 0.0429$ and $\lambda_x = 1$.[18]

Figure 5 examines the robustness of optimal targeting rules across models when the targeting rules are derived under the simple loss function for each model (scenarios 1 and 2). We show the impulse responses to the price markup shock. In the search and matching model, the optimal policy consistent with preferences $\mathcal{L}_t^{sql}$ for $\lambda_x = 0.0429$ resembles the optimal policy derived under the preferences $\mathcal{L}_t^{s\&m}$ in equation (25)—the first row of panels. With the exception of price inflation all variables react by less to the markup shock than in Figure 2, indicating that under this parameterization of $\mathcal{L}_t^{sql}$ the policymaker prefers price inflation to bear more of the burden of adjustment than in Section 5. When imposing onto the search and matching model the optimal targeting rule derived from the sticky wage model under preferences $\mathcal{L}_t^{sql}$, the same qualitative differences emerge relative to the optimal policy as in Figure 2 despite the policymaker's preferences being constant across models. In the sticky wage model the gaps between the impulse responses under the two targeting rules derived for preferences $\mathcal{L}_t^{sql}$ remain large albeit smaller than in Figure 3. Thus, holding the policymaker's preferences constant across models does not necessarily yield robust optimal targeting rules.

However, if the policymaker assigns even lower relative importance to price inflation, the optimal targeting rules *are* robust. The last two rows of panels in Figure 5 show the impulse responses for $\lambda_x = 1$. In both the search and matching model and the sticky wage model, the gaps between the impulse responses generated by the optimal targeting rules derived for $\lambda_x = 1$ are minor. Whether optimal targeting rules turn out to be robust can be highly sensitive to the preferences assigned to the policymaker!

This unexpected robustness of optimal policies for $\lambda_x = 1$ carries over to the full analysis of monetary policy under model uncertainty (scenarios 3 and 4) in Table 5. The ω-optimal simple rules computed for $\mathcal{L}_t^{sql}$ with $\lambda_x = 1$ induce very similar dynamics in both models (not shown) despite the differences in their parameterization. Further evidence along these lines stems from the observation that the welfare losses in each model under the model-specific true loss functions (as opposed to $\mathcal{L}_t^{sql}$) are stable across values of ω; the low CEVs computed for the sticky wage model indicate that all the rules resemble closely the optimal monetary policy in the sticky wage model under its true loss function.

[18] The choice $\lambda_x = 0.0429$ is consistent with the weight on the output gap in the loss function derived for the textbook New Keynesian model with flexible wages under the parameters in Tables 1 and 2. The alternative specification of $\lambda_x = 1$ is popular in the literature.

The results for $\lambda_x = 1$ could be viewed as evidence for the existence of robust monetary policies. Yet, this conclusion is true only from the perspective of the policymaker whose preferences are described by the simple loss function $\mathcal{L}_t^{sql}$. From the perspective of the representative household with preferences $\mathcal{L}_t^{s\&m}$ and $\mathcal{L}_t^{sw}$ the results are suboptimal: the policies are unnecessarily biased towards the sticky wage model when ω is close to 1 compared to Table 3. To the extent that the welfare implications of microfounded models are of interest, this result discourages the use of arbitrary loss functions for policy analysis.

8 Conclusion

We analyze optimal monetary policy when the policymaker is uncertain whether the true data-generating process is given by a search and matching model or a sticky wage model. While the two models produce similar impulse responses to shocks under estimated policy rules, the responses differ importantly when monetary policy is chosen optimally.

Under sticky wages, the optimal policy induces little variation in nominal wages and the dynamics of the real wage are determined by the adjustment in prices. In the search and matching model, it is optimal to stabilize prices and to allow for real wage adjustment be brought about by changes in nominal wages. The optimal targeting rule associated with the search and matching model is not robust, in the sense that it induces large welfare losses when applied to the sticky wage model. While the optimal targeting rule derived for the sticky wage model alters the dynamics in the search and matching model relative to the model-specific optimal monetary policy, the welfare consequences are less dramatic.

Given the models' sensitivity to the optimal targeting rules, we assume that the policymaker makes model uncertainty a direct component of policy evaluation. A model averaging and a minmax approach both imply optimal simple instrument and targeting rules that are biased towards stabilizing wage inflation—the distinct feature of the optimal monetary policy in the sticky wage model—unless the policymaker places high probability weight on the search and matching model being the true data-generating process.

References

Andolfatto, D. (1996). Business Cycles and Labor-Market Search. *American Economic Review 86*(1), 112–32. [6]

Benigno, P. and M. Woodford (2005). Inflation Stabilization And Welfare: The Case Of A Distorted Steady State. *Journal of the European Economic Association 3*(6), 1185–1236. [16]

Benigno, P. and M. Woodford (2012). Linear-quadratic approximation of optimal policy problems. *Journal of Economic Theory 147*(1), 1–42. [14, 19]

Blanchard, O. and J. Galí (2010). Labor Markets and Monetary Policy: A New Keynesian Model with Unemployment. *American Economic Journal: Macroeconomics 2*(2), 1–30. [15, 23]

Bodenstein, M., L. Guerrieri, and J. LaBriola (2014). Macroeconomic Policy Games. Finance and Economics Discussion Series 2014-87, Board of Governors of the Federal Reserve System (U.S.). [15]

Brock, W. A., S. N. Durlauf, and K. D. West (2007). Model uncertainty and policy evaluation: Some theory and empirics. *Journal of Econometrics 136*(2), 629–664. [4]

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics 12*(3), 383–398. [8, 9]

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005). Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy 113*(1), 1–45. [2]

Christiano, L. J., M. S. Eichenbaum, and M. Trabandt (2016). Unemployment and Business Cycles. *Econometrica 84*, 1523–1569. [2, 3, 11, 12, 30, 31]

Cogley, T. and T. J. Sargent (2005). The conquest of US inflation: Learning and robustness to model uncertainty. *Review of Economic Dynamics 8*(2), 528–563. [5]

Debortoli, D. and J. Galí (2017). Monetary Policy with Heterogeneous Agents: Insights from TANK models. mimeo. [23]

Diamond, P. A. (1982). Aggregate Demand Management in Search Equilibrium. *Journal of Political Economy 90*(5), 881–94. [2, 6]

Erceg, C. J., D. W. Henderson, and A. T. Levin (2000). Optimal monetary policy with staggered wage and price contracts. *Journal of Monetary Economics 46*(2), 281–313. [2, 6]

Faia, E. (2009). Ramsey monetary policy with labor market frictions. *Journal of Monetary Economics 56*(4), 570–581. [3, 12]

Gertler, M. and A. Trigari (2009). Unemployment Fluctuations with Staggered Nash Wage Bargaining. *Journal of Political Economy 117*(1), 38–86. [2, 22, 23]

Giannoni, M. (2002). Does Model Uncertainty Justify Caution? Robust Optimal Monetary Policy In A Forward-Looking Model. *Macroeconomic Dynamics 6*(01), 111–144. [5]

Giannoni, M. P. and M. Woodford (2017). Optimal target criteria for stabilization policy. *Journal of Economic Theory 168*(C), 55–106. [4, 14]

Gornemann, N., K. Kuester, and M. Nakajima (2016). Doves for the Rich, Hawks for the Poor? Distributional Consequences of Monetary Policy. CEPR Discussion Papers 11233, C.E.P.R. Discussion Papers. [23]

Hagedorn, M. and I. Manovskii (2008). The Cyclical Behavior of Equilibrium Unemployment and Vacancies Revisited. *American Economic Review 98*(4), 1692–1706. [3, 12]

Hall, R. E. (2005). Employment Fluctuations with Equilibrium Wage Stickiness. *American Economic Review 95*(1), 50–65. [12]

Hall, R. E. and P. R. Milgrom (2008). The Limited Influence of Unemployment on the Wage Bargain. *American Economic Review 98*(4), 1653–1674. [3, 12]

Hansen, L. P. and T. J. Sargent (Eds.) (2007). *Robustness*. Princeton University Press. [5]

Hosios, A. J. (1990). On The Efficiency of Matching and Related Models of Search and Unemployment. *Review of Economic Studies 57*(2), 279–298. [6, 7, 15, 16]

Kaplan, G., B. Moll, and G. L. Violante (2016). Monetary Policy According to HANK. Working Papers 1602, Council on Economic Policies. [23]

Krause, M. U. and T. A. Lubik (2007). The (ir)relevance of real wage rigidity in the New Keynesian model with search frictions. *Journal of Monetary Economics 54*(3), 706–727. [2]

Levin, A. T., V. Wieland, and J. C. Williams (2003). The Performance of Forecast-Based Monetary Policy Rules Under Model Uncertainty. *American Economic Review 93*(3), 622–645. [4, 5, 19]

Levin, A. T. and J. C. Williams (2003). Robust monetary policy with competing reference models. *Journal of Monetary Economics 50*(5), 945–975. [5, 19]

Levine, P., P. McAdam, and J. Pearlman (2012). Probability models and robust policy rules. *European Economic Review 56*(2), 246–262. [23]

Lucas, R. E. (2003). Macroeconomic Priorities. *American Economic Review 93*(1), 1–14. [4, 18]

Merz, M. (1995). Search in the Labor Market and the Real Business Cycle. *Journal of Monetary Economics 36*(2), 269–300. [6]

Mortensen, D. T. (1982). Property Rights and Efficiency in Mating, Racing, and Related Games. *American Economic Review 72*(5), 968–79. [2, 6]

Pissarides, C. A. (1985). Short-run Equilibrium Dynamics of Unemployment Vacancies, and Real Wages. *American Economic Review 75*(4), 676–90. [2, 6]

Pissarides, C. A. and B. Petrongolo (2001). Looking into the Black Box: A Survey of the Matching Function. *Journal of Economic Literature 39*(2), 390–431. [30]

Ramey, G., W. J. den Haan, and J. Watson (2000). Job Destruction and Propagation of Shocks. *American Economic Review 90*(3), 482–498. [30]

Ravenna, F. and C. E. Walsh (2008). Vacancies, unemployment, and the Phillips curve. *European Economic Review 52*(8), 1494–1521. [2]

Ravenna, F. and C. E. Walsh (2011). Welfare-Based Optimal Monetary Policy with Unemployment and Sticky Prices: A Linear-Quadratic Framework. *American Economic Journal: Macroeconomics 3*(2), 130–162. [3, 6, 12, 15]

Ravn, M. O. and V. Sterk (2016). Macroeconomic Fluctuations with HANK & SAM: An Analytical Approach. Discussion Papers 1633, Centre for Macroeconomics (CFM). [23]

Rotemberg, J. and M. Woodford (1997). An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy. In *NBER Macroeconomics Annual 1997, Volume 12*, NBER Chapters, pp. 297–361. National Bureau of Economic Research, Inc. [10]

Shimer, R. (2005). The Cyclical Behavior of Equilibrium Unemployment and Vacancies. *American Economic Review 95*(1), 25–49. [3, 12]

Smets, F. and R. Wouters (2007). Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach. *American Economic Review 97*(3), 586–606. [2, 11, 30]

Svensson, L. and N. Williams (2005). Monetary Policy with Model Uncertainty: Distribution Forecast Targeting. NBER Working Papers 11733, National Bureau of Economic Research, Inc. [5]

Taylor, J. B. (1993). Discretion versus policy rules in practice. *Carnegie-Rochester Conference Series on Public Policy 39*(1), 195–214. [10]

Taylor, J. B. and V. Wieland (2012). Surprising Comparative Properties of Monetary Models: Results from a New Model Database. *The Review of Economics and Statistics 94*(3), 800–816. [5]

Taylor, J. B. and J. C. Williams (2010). Simple and Robust Rules for Monetary Policy. In B. M. Friedman and M. Woodford (Eds.), *Handbook of Monetary Economics*, Volume 3 of *Handbook of Monetary Economics*, Chapter 15, pp. 829–859. Elsevier. [19]

Tetlow, R. and P. von zur Muehlen (2001). Robust monetary policy with misspecified models: Does model uncertainty always call for attenuated policy? *Journal of Economic Dynamics and Control 25*(6-7), 911–949. [5]

Thomas, C. (2008). Search and matching frictions and optimal monetary policy. *Journal of Monetary Economics 55*(5), 936–956. [15, 22]

Walsh, C. E. (2005). Labor Market Search, Sticky Prices, and Interest Rate Policies. *Review of Economic Dynamics 8*(4), 829–849. [7]

Woodford, M. (1999). Commentary : how should monetary policy be conducted in an era of price stability? *Proceedings - Economic Policy Symposium - Jackson Hole*, 277–316. [3, 14]

Table 1: Calibrated Parameters

Description	Parameter	Search and Matching	Sticky Wage
discount factor	β	0.99	0.99
exogenous seperation rate	ρ	0.1	-
matching function share of unemployment[1]	ζ	0.54	-
steady state inflation rate	$\bar{\pi}$	1	1
Calvo price stickiness	ξ^p	0.75	0.75
steady state price markup	λ^p	1.2	1.2
Calvo wage stickiness	ξ^w	-	0.75
steady state wage markup	λ^w	-	1.2
invers consumption elasticity[2]	σ	1	1
inverse labor supply elasticity	ϕ	2	2
hiring flow cost / output	η_s	0.0066	-
steady state unemployment rate	$\tilde{u}_{ss}$	0.055	-
steady state vacancy filling rate[3]	q_{ss}	0.7	-
steady state working hour	h_{ss}	1/3	1/3
wage indexation	ι^w	-	0
Shock Process			
technology shock: AR	ρ_a	0.9999	0.9999
markup shock: AR	ρ_u	0	0
markup shock: Std	σ_u	0.0104	0.0135
Implied Deep Parameter Value			
hiring fixed cost	$\bar{\kappa}$	0	-
hiring flow cost	κ^v	0.0154	-
unemployment benefit	b^u	0.1769	-
worker's share of surplus	ξ	0.7438	-
matching efficiency	χ	0.6625	-
scaling of working hour disutility	ϕ_0	27.8940	27

Note: Table 1 summarizes the parameters and calibration targets for the model with search and matching frictions and the model with sticky wages. Unless indicated otherwise, our choices coincide with Christiano, Eichenbaum, and Trabandt (2016); [1] Pissarides and Petrongolo (2001), [2] Smets and Wouters (2007), [3] Ramey, den Haan, and Watson (2000).

Table 2: Estimated Parameters

Description	Estimated Parameter	Search	Sticky Wage
interest rate smoothing	ρ_R	0.8555	0.8379
		[0.0294]	[0.0450]
weights on inflation	ρ_π	0.1445	0.1622
		[1.5e-05]	[3.12e-05]
std technology shock	σ_a	0.0031	0.0033
		[0.0002]	[0.0002]
habit persistence	μ	0	0
		[0.5148]	[0.4394]
replacement ratio	r^u	0.5345	-
		[0.0185]	-
price indexation	ι^p	0	0
		[0.3123]	[0.3204]

Note: The top panel of Table 2 summarizes the estimated parameters for the model with search and matching frictions. The parameters are estimated using impulse response function matching under neutral technology shocks. The empirical impulse responses against which the performance of the theoretical models is assessed are taken from the SVAR estimation in Christiano, Eichenbaum, and Trabandt (2016). The numbers in the square bracket are the standard deviations of the estimates.

Table 3: Optimal Simple Rules and Optimal Simple Targeting Rules

Panel a: Optimal Simple Rules

Approach	Prior	Coefficients				Welfare Loss				
		ρ_R	ρ_π	ρ_π^w	ρ_x	Objective	$\mathcal{L}_t^{s\&m}(\Theta^*)$	$CEV^{s\&m}(\Theta^*)$	$\mathcal{L}_t^{sw}(\Theta^*)$	$CEV^{sw}(\Theta^*)$
Model Averaging	$(0,1)$	0	0	66.6844	2.3852	3.1047	2.1568	0.1094	3.1047	0.0010
	$(0.1,0.9)$	0	0	61.5860	2.0019	3.0099	2.1566	0.1092	3.1048	0.0010
	$(0.2,0.8)$	0	0	56.4038	1.6763	2.9151	2.1565	0.1091	3.1048	0.0011
	$(0.3,0.7)$	0	0.6240	0.5226	0	2.8139	2.1028	0.0554	3.1186	0.0149
	$(0.4,0.6)$	0	0.6368	0.5160	0	2.7123	2.1025	0.0551	3.1188	0.0151
	$(0.5,0.5)$	0	0.6558	0.5131	0	2.6106	2.1022	0.0548	3.1190	0.0153
	$(0.6,0.4)$	0	0.7005	0.5158	0	2.5088	2.1014	0.0540	3.1199	0.0162
	$(0.7,0.3)$	0	0.8135	0.5231	0	2.4067	2.0994	0.0520	3.1240	0.0202
	$(0.8,0.2)$	0	1.1725	0.5245	0	2.3031	2.0920	0.0446	3.1475	0.0438
	$(0.9,0.1)$	0.8177	0.8860	0	0	2.1870	2.0623	0.0149	3.3098	0.2061
	$(1,0)$	0.9366	2.1197	0	0	2.0477	2.0477	0.0003	4.0851	0.9814
Minmax	N.A.	0	0	66.6844	2.3852	3.1047	2.1568	0.1094	3.1047	0.0010

Panel b: Optimal Simple Targeting Rules

Approach	Prior	Coefficients	Welfare Loss				
		ρ_{tr}	Objective	$\mathcal{L}_t^{s\&m}(\Theta^*)$	$CEV^{s\&m}(\Theta^*)$	$\mathcal{L}_t^{sw}(\Theta^*)$	$CEV^{sw}(\Theta^*)$
Model Averaging	$(0,1)$	1.0000	3.1037	2.1602	0.1128	3.1037	0.0000
	$(0.1,0.9)$	1.0847	3.0094	2.1601	0.1127	3.1037	0.0000
	$(0.2,0.8)$	1.2319	2.9150	2.1600	0.1126	3.1038	0.0000
	$(0.3,0.7)$	1.4166	2.8206	2.1598	0.1124	3.1038	0.0001
	$(0.4,0.6)$	1.6773	2.7262	2.1595	0.1121	3.1040	0.0003
	$(0.5,0.5)$	2.0417	2.6317	2.1591	0.1117	3.1043	0.0006
	$(0.6,0.4)$	2.6065	2.5371	2.1585	0.1111	3.1050	0.0013
	$(0.7,0.3)$	3.5951	2.4423	2.1576	0.1102	3.1068	0.0031
	$(0.8,0.2)$	5.7812	2.3471	2.1557	0.1083	3.1129	0.0091
	$(0.9,0.1)$	15.0510	2.2499	2.1495	0.1021	3.1534	0.0497
	$(1,0)$	6.1979e+05	2.0488	2.0488	0.0014	4.3001	1.1964
Minmax	N.A.	1.0000	3.1037	2.1607	0.1133	3.1037	0.0000

Panel c: Optimal Targeting Rules

Optimal Targeting Rule	Welfare Loss			
	$\mathcal{L}_t^{s\&m}$	$CEV^{s\&m}$	$\mathcal{L}_t^{sw}$	CEV^{sw}
s&m	2.0474	0.0000	4.4070	1.3033
sw	2.1607	0.1133	3.1037	0.0000

Note: Table 3 reports the optimal parameterizations of the simple rule in (34) in Panel (a) and simple targeting rule (35) in Panel (b) when the policymaker has two reference model, the model with search and matching frictions (s&m) and the model with sticky wages (sw). The model is parameterized as in Tables 1 and 2. Under model averaging, the policymaker minimizes the expected loss given a probability distribution (prior). Under the minmax strategy, the policymaker searches for a policy rule that minimizes the maximum loss. "Objective" measures the value of the policymaker's objective function at the optimum. The columns $\mathcal{L}_t^{s\&m}(\Theta^*)$ and $\mathcal{L}_t^{sw}(\Theta^*)$ give the value of the expected loss in each model, the columns $CEV^{s\&m}(\Theta^*)$ and $CEV^{sw}(\Theta^*)$ translate these losses into consumption equivalent variations. Panel (c) displays the welfare costs of implementing the optimal targeting rules in each model.

Table 4: Sensitivity of Optimal Simple Rules

Panel a: persistent markup shock $\rho_u = 0.2$

Approach	Prior	Optimal Simple Rule				Welfare Loss				
		ρ_R	ρ_π	ρ_π^w	ρ_x	Objective	$\mathcal{L}_t^{s\&m}(\Theta^*)$	$CEV^{s\&m}(\Theta^*)$	$\mathcal{L}_t^{sw}(\Theta^*)$	$CEV^{sw}(\Theta^*)$
Model Averaging	$(0, 1)$	0	0	66.6812	1.6100	3.2524	2.2305	0.1520	3.2524	0.0014
	$(0.1, 0.9)$	0	0	62.1310	1.3100	3.1501	2.2302	0.1518	3.2524	0.0014
	$(0.2, 0.8)$	0	0	57.0042	1.0663	3.0479	2.2300	0.1516	3.2524	0.0015
	$(0.3, 0.7)$	0	0	51.9820	0.8663	2.9457	2.2299	0.1514	3.2524	0.0015
	$(0.4, 0.6)$	0	0	47.4445	0.6725	2.8434	2.2297	0.1513	3.2525	0.0016
	$(0.5, 0.5)$	0	0.6436	0.5084	0	2.7087	2.1448	0.0663	3.2726	0.0217
	$(0.6, 0.4)$	0	0.6743	0.5110	0	2.5958	2.1441	0.0656	3.2735	0.0226
	$(0.7, 0.3)$	0	0.7419	0.5165	0	2.4827	2.1424	0.0639	3.2768	0.0259
	$(0.8, 0.2)$	0	0.9590	0.5250	0	2.3683	2.1361	0.0576	3.2973	0.0463
	$(0.9, 0.1)$	0.8744	0.5682	0	0	2.2419	2.0993	0.0208	3.5253	0.2744
	$(1, 0)$	0.9789	1.4644	0	0	2.0785	2.0785	0.0000	4.7228	1.4719
Minmax	N.A.	0	0	66.6812	1.6100	3.2524	2.2305	0.1520	3.2524	0.0014

Panel b: habit persistence $\mu = 0.6$

Approach	Prior	Optimal Simple Rule				Welfare Loss				
		ρ_R	ρ_π	ρ_π^w	ρ_x	Objective	$\mathcal{L}_t^{s\&m}(\Theta^*)$	$CEV^{s\&m}(\Theta^*)$	$\mathcal{L}_t^{sw}(\Theta^*)$	$CEV^{sw}(\Theta^*)$
Model Averaging	$(0, 1)$	0	0	68.1424	1.4345	3.1519	2.1796	0.1347	3.1519	0.0007
	$(0.1, 0.9)$	0	0.6175	1.3949	0	3.0546	2.1689	0.1240	3.1530	0.0018
	$(0.2, 0.8)$	0	0.6561	1.3497	0	2.9561	2.1678	0.1229	3.1532	0.0020
	$(0.3, 0.7)$	0	0.7064	1.3276	0	2.8575	2.1664	0.1215	3.1537	0.0025
	$(0.4, 0.6)$	0	0.7754	1.3139	0	2.7586	2.1646	0.1197	3.1547	0.0035
	$(0.5, 0.5)$	0	0.8786	1.3099	0	2.6594	2.1621	0.1172	3.1568	0.0056
	$(0.6, 0.4)$	0.9882	1.4557	0	0.2369	2.5576	2.1205	0.0756	3.2132	0.0620
	$(0.7, 0.3)$	0.9198	2.4368	0	0.3228	2.4461	2.1042	0.0593	3.2438	0.0926
	$(0.8, 0.2)$	0.8178	4.0965	0	0.4114	2.3289	2.0867	0.0418	3.2976	0.1464
	$(0.9, 0.1)$	0.6763	6.9621	0	0.4346	2.2020	2.0677	0.0228	3.4110	0.2598
	$(1, 0)$	0	41.4453	1.6503	0	2.0465	2.0465	0.0016	5.0518	1.9006
Minmax	N.A.	0	0	68.1424	1.4345	3.1519	2.1796	0.1347	3.1519	0.0007

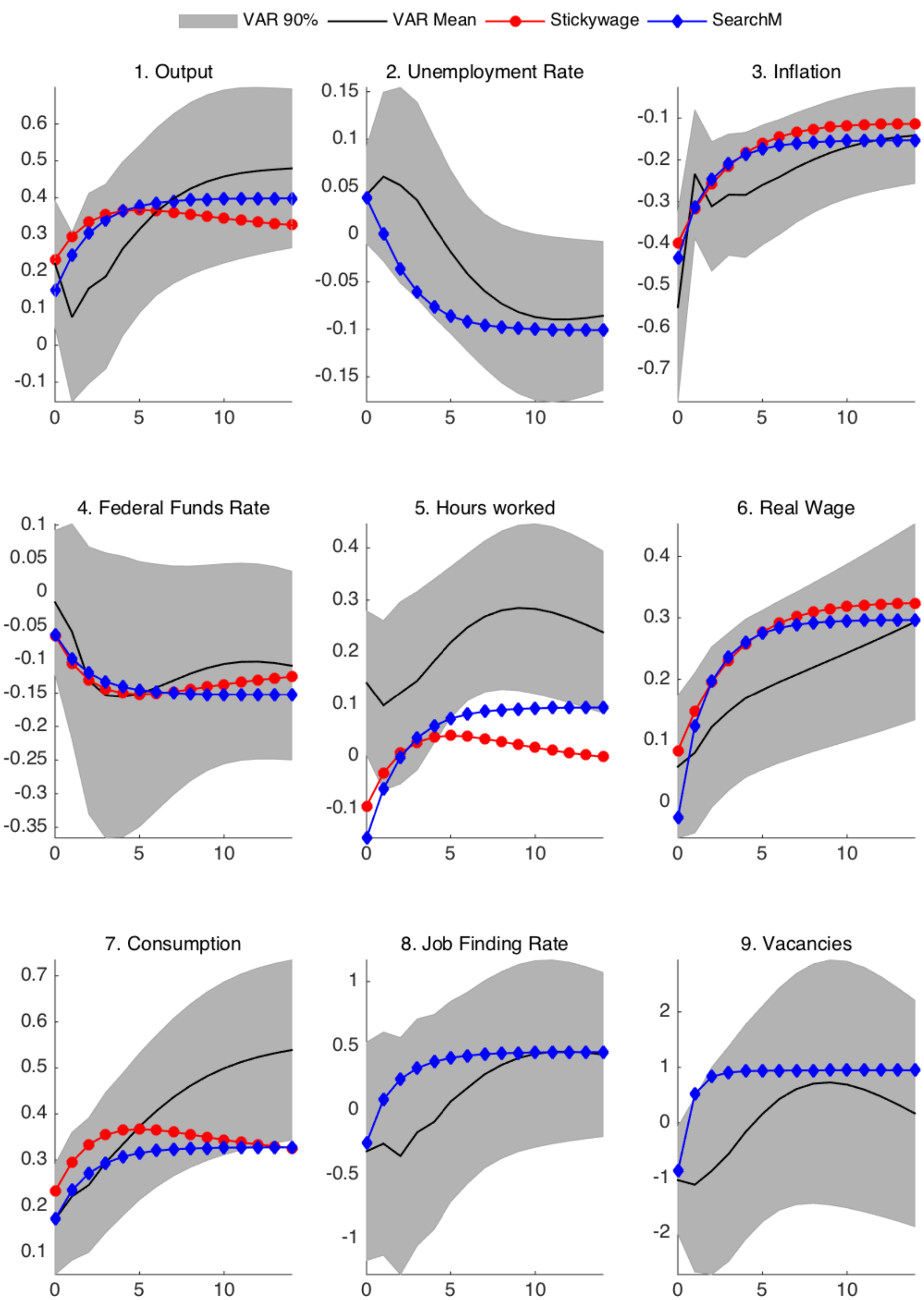
Note: Table 4 reports the optimal parameterizations of the simple rule in (34) when the policymaker has two reference model, the model with search and matching frictions (s&m) and the model with sticky wages (sw) for two alternative specifications of the model. The model is parameterized as in Tables 1 and 2, with the exception that we raise the persistence of the price markup shock from zero to $\rho_u = 0.2$ in Panel (a), and we raise the degree of habit persistence from zero to $\mu = 0.6$ (Panel b). Under model averaging, the policymaker minimizes the expected loss given a probability distribution (prior). Under the minmax strategy, the policymaker searches for a policy rule that minimizes the maximum loss. "Objective" measures the value of the policymaker's objective function at the optimum. The columns $\mathcal{L}_t^{s\&m}(\Theta^*)$ and $\mathcal{L}_t^{sw}(\Theta^*)$ give the value of the expected loss in each model, the columns $CEV^{s\&m}(\Theta^*)$ and $CEV^{sw}(\Theta^*)$ translate these losses into consumption equivalent variations.

Table 5: Optimal Simple Rules under a Simple Loss Function $\mathcal{L}_t^{sql}$

Approach	Prior	Optimal Simple Rule				Welfare Loss				
		ρ_R	ρ_π	ρ_π^w	ρ_x	Objective	$\mathcal{L}_t^{s\&m}(\Theta^*)$	$CEV^{s\&m}(\Theta^*)$	$\mathcal{L}_t^{sw}(\Theta^*)$	$CEV^{sw}(\Theta^*)$
Model Averaging	$(0,1)$	0	0	0	41.8350	0.0120	2.2892	0.2418	3.1106	0.0069
	$(0.1,0.9)$	0.4376	0	4.0245	20.1245	0.0118	2.2708	0.2234	3.1104	0.0067
	$(0.2,0.8)$	0.9269	0	4.1139	20.1418	0.0117	2.2703	0.2229	3.1107	0.0070
	$(0.3,0.7)$	0.9999	0	4.0938	19.9256	0.0116	2.2702	0.2228	3.1107	0.0070
	$(0.4,0.6)$	0.9999	0	2.1613	10.2326	0.0114	2.2697	0.2223	3.1108	0.0071
	$(0.5,0.5)$	0.9999	0	1.3662	6.2492	0.0113	2.2691	0.2217	3.1109	0.0072
	$(0.6,0.4)$	0.9999	0	0.8275	3.5735	0.0112	2.2681	0.2207	3.1111	0.0074
	$(0.7,0.3)$	0.9999	0	0.4872	1.9215	0.0110	2.2665	0.2191	3.1114	0.0077
	$(0.8,0.2)$	0.9999	0	0.2646	0.9015	0.0109	2.2636	0.2162	3.1123	0.0086
	$(0.9,0.1)$	0.9999	0	0.1128	0.3014	0.0107	2.2582	0.2108	3.1148	0.0111
	$(1,0)$	0.9999	0.05	0	0.1003	0.0104	2.2501	0.2027	3.1236	0.0199
Minmax	N.A.	0	0	0	41.8350	0.0120	2.2892	0.2418	3.1106	0.0069

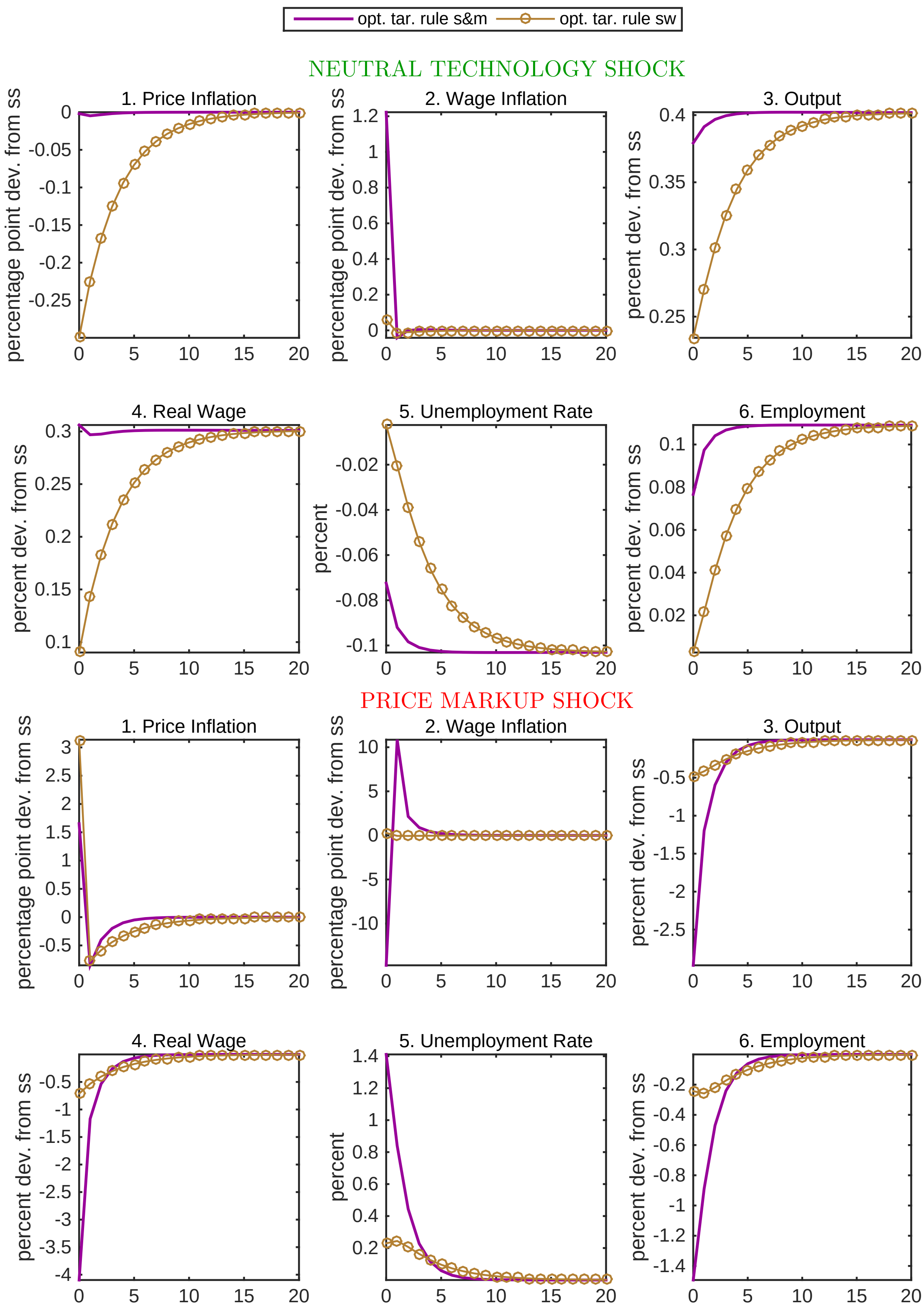
Note: Table 5 reports the optimal parameterizations of the simple rule in (34) when the policymaker has two reference model, the model with search and matching frictions (s&m) and the model with sticky wages (sw). In contrast to Table 3, the policymaker's preferences are described by the simple loss function of the form $\mathcal{L}_t = \pi_t^2 + x_t^2$ in both models. The model is parameterized as in Tables 1 and 2. Under model averaging, the policymaker minimizes the expected loss given a probability distribution (prior). Under the minmax strategy, the policymaker searches for a policy rule that minimizes the maximum loss. "Objective" measures the value of the policymaker's objective function at the optimum, i.e., the simple loss function. The columns $\mathcal{L}_t^{s\&m}(\Theta^*)$ and $\mathcal{L}_t^{sw}(\Theta^*)$ give the values of the expected loss in each model from the perspective of the representative household, the columns $CEV^{s\&m}(\Theta^*)$ and $CEV^{sw}(\Theta^*)$ translate these losses into consumption equivalent variations.

Figure 1: Impulse response function matching under neutral technology shock



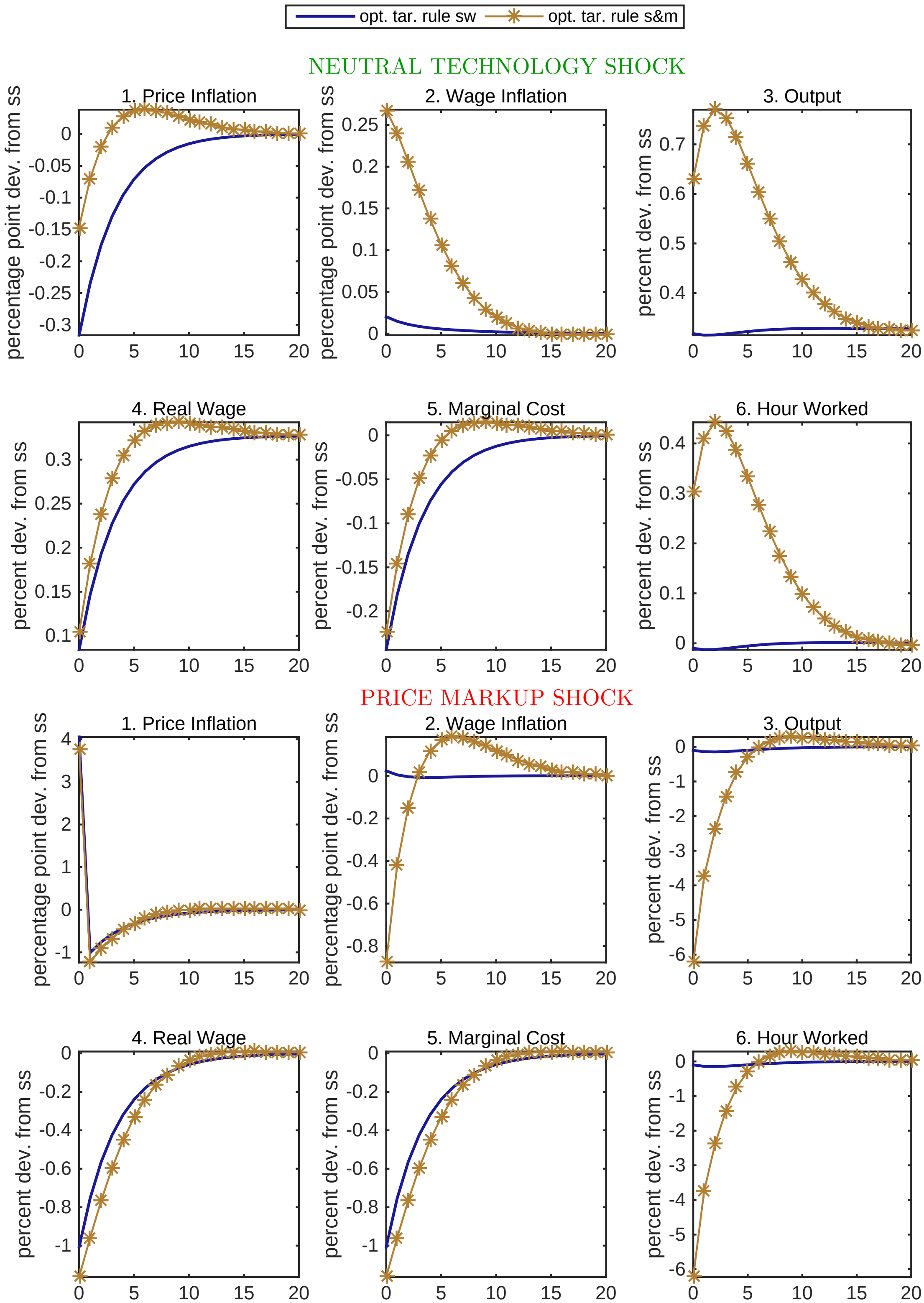
Note: Figure 1 depicts the impulse responses to a neutral technology shock in the search and matching model (blue) and the sticky wage model (red). The solid black lines show the point estimates of the empirical impulse responses along with the 90% confidence interval, the grey shaded area. Inflation rates and the federal fund rate are annualized.

Figure 2: Targeting rules in the search and matching model



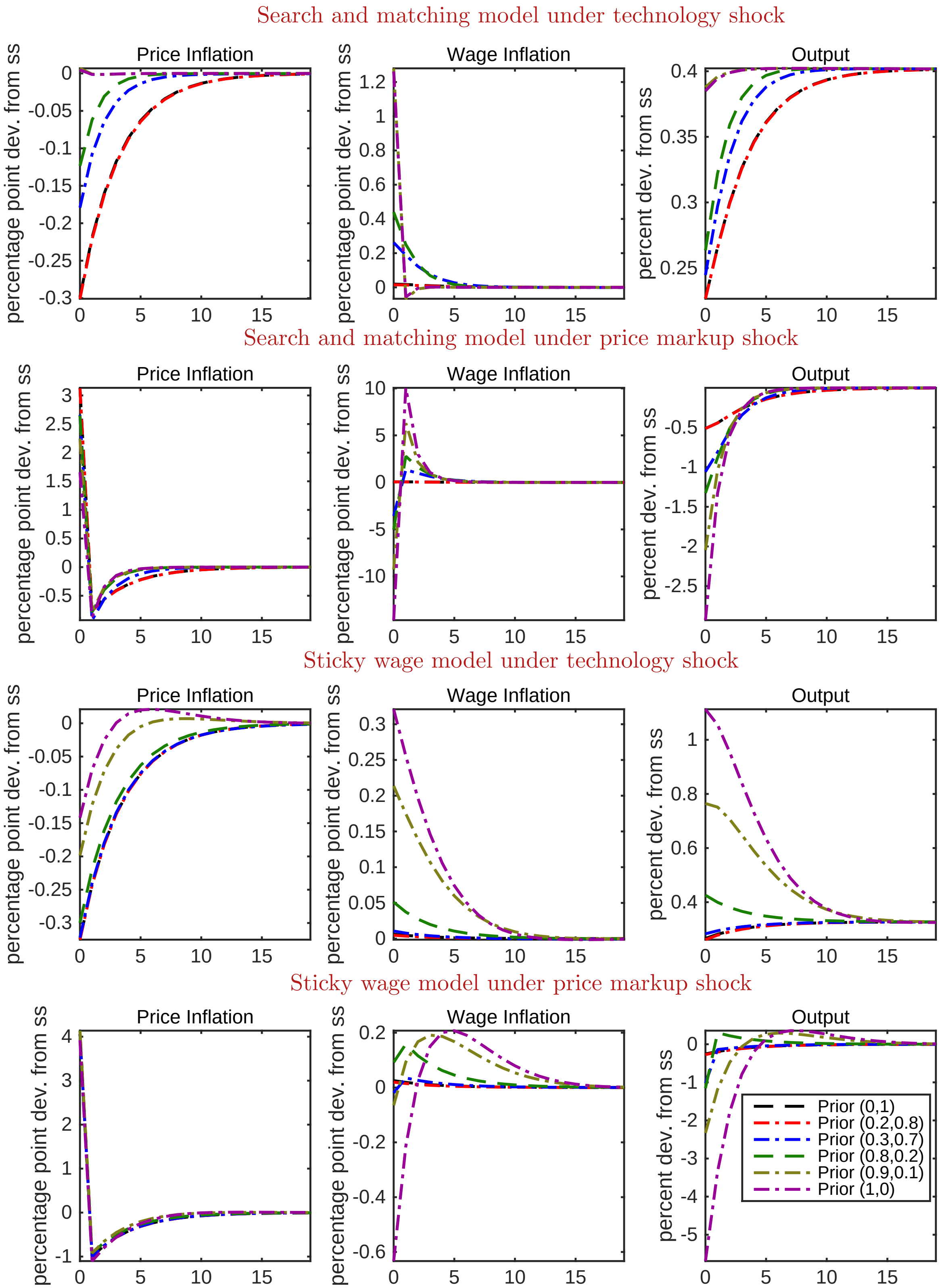
Note: Figure 2 plots the impulse responses in the search and matching model to a neutral technology shock and a price markup shock when policy follows the optimal targeting rule from the search and matching model (purple) and the sticky wage model (yellow).

Figure 3: Targeting rules in the sticky wage model



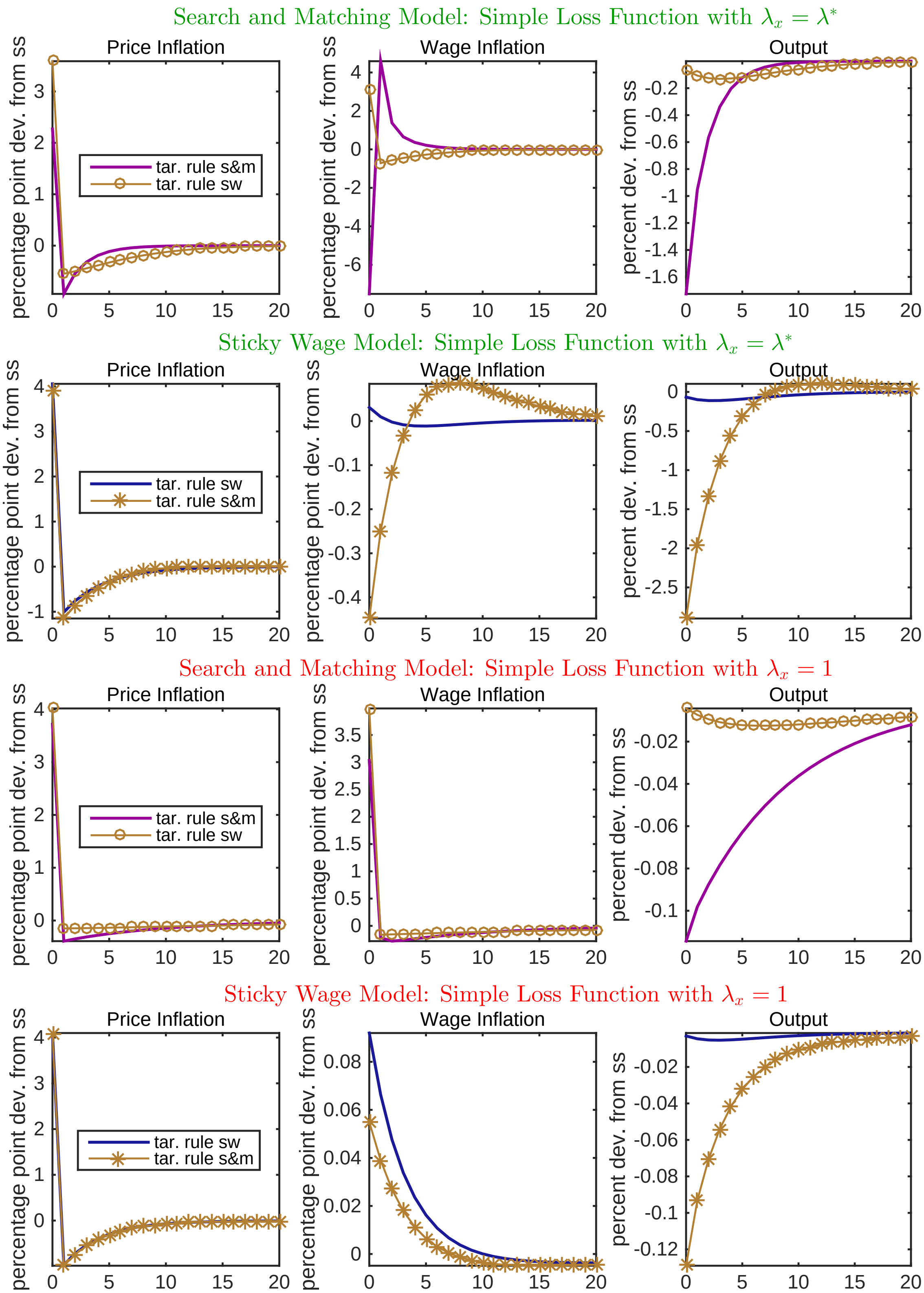
Note: Figure 3 plots the impulse responses in the sticky wage model to a neutral technology shock and a price markup shock when policy follows the optimal targeting rule from the sticky wage model (blue) and the search and matching model (yellow).

Figure 4: Impulse responses under optimal simple rules



Note: Figure 4 compares the performance of the search and matching and the sticky wage model under ω-optimal simple rules $(0, 1)$, $(0.2, 0.8)$, $(0.3, 0.7)$, $(0.8, 0.2)$, $(0.9, 0.1)$, and $(1, 0)$ for the neutral technology shock and the price markup shock.

Figure 5: Targeting rules with simple loss function: price markup shock



Note: Figure 5 compares the performance of optimal targeting rules derived from the loss function $\left(\pi_t^2 + \lambda_x x_t^2\right)$ for both the search and matching model and the sticky wage model in response to a *price markup shock*. In the upper six panels, it is $\lambda_x = \lambda^* = 0.0429$; in the lower six panels it is $\lambda_x = 1$.