



# Resuscitating the wage channel in models with unemployment fluctuations<sup>☆</sup>

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## ABSTRACT

Higher wages all else equal translate into higher inflation. More rigid wages imply a weaker response of inflation to shocks. This view of the wage channel is deeply entrenched in central banks' views and models of their economies. In this paper, we present a model with equilibrium unemployment which has three distinctive properties. First, using a search and matching model with right-to-manage wage bargaining a proper wage channel obtains. Second, accounting for fixed costs associated with maintaining an existing job greatly magnifies profit fluctuations for any given degree of wage fluctuations, which allows the model to reproduce the fluctuations of unemployment over the business cycle. And third, the model implies a reasonable elasticity of steady state unemployment with respect to changes in benefits. The calibration of the model implies low profits, but does not require a small gap between the value of working and the value of unemployment for the worker.

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## 1. Introduction

The channel from wages to inflation plays a key role in explaining aggregate price dynamics. All else equal, increased wages are associated with higher rates of inflation, and a slow adjustment of wages to shocks translates into inflation inertia<sup>1</sup>. This view appears to be shared by central banks around the globe and it is a central feature of their policy models.<sup>2</sup>

At the same time flows in and out of employment take center stage in policy discussions. This in mind, it is surprising that to date there appears to be no model which accounts both for the fluctuations in main labor market variables and for a wage channel to inflation. This paper is meant to fill the gap.

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<sup>1</sup> Here “all else equal” subsumes both the case in which wages increase due to a genuine “wage shock”, keeping other shocks constant, and the case in which a change in calibration makes wages more responsive to shocks in general, keeping constant those features of the calibration which are not linked to wage responsiveness.

<sup>2</sup> A non-exhaustive list of central bank models which feature a wage channel is given by the Federal Reserve Board's FRB/US and SIGMA models, the Bank of England Quarterly Model and the European Central Bank's old and New Area Wide Model.

In this paper, we develop a New Keynesian model with search and matching frictions in the labor market, which has three characteristic features: it incorporates a wage channel to inflation, it replicates the fluctuations of unemployment over the business cycle and it implies a reasonable response of unemployment rates to changes in the level of unemployment benefits.

Building on Trigari's (2006) right-to-manage (RTM, henceforth) wage bargaining framework, we account for fixed costs associated with maintaining an existing job.<sup>3</sup> These reduce average job-related profits and amplify fluctuations of profits in percentage terms. Since profits are the driving force behind hiring activity, the model can be calibrated to match the cyclical fluctuations of US labor market variables witnessed in the data. At the same time, the model preserves a channel from wages to inflation. We furthermore show that the model replicates second moments of the labor market data without having to rely on an implausibly high elasticity of unemployment with respect to benefits or a high degree of stickiness in wages of new hires.<sup>4</sup>

A wage channel, in our understanding, is present whenever wages have a direct influence on inflationary developments. As Trigari (2006) and Christoffel and Linzert (2005) have shown, this is the case under RTM.<sup>5</sup> Direct means that wages do not need to work through employment first to cause a reaction of inflation. In particular, in the search and matching setup which we use this means that also wages of existing matches have an impact on inflation. The argument is as follows: a job produces a labor good according to production function  $y_t^L = h_t^\alpha$ ,  $\alpha \in (0, 1)$ , where  $h_t$  are hours per worker. Given a bargained wage rate,  $w_t$ , and facing a real product price,  $x_t^L$ , labor firms set hours along their labor demand curves, so  $x_t^L \alpha h_t^{\alpha-1} = w_t$ . Price-setting firms acquire the labor good under perfect competition at price  $x_t^L$  and produce differentiated wholesale goods, their real marginal costs in equilibrium being  $mc_t = x_t^L = (1/\alpha)w_t h_t / y_t^L$ . The behavior of wages thus translates into marginal costs and therefore into the behavior of inflation.<sup>6</sup>

In models of search and matching, unemployment fluctuations are closely linked to labor firms' profits. In our model, these unemployment fluctuations are amplified as follows. Let  $\phi \geq 0$  be the fixed costs associated with maintaining an existing job. Period labor profits, which are given by  $\psi_t^L = x_t^L y_t^L - w_t h_t - \phi$ , can in equilibrium be expressed as  $\psi_t^L = ((1 - \alpha)/\alpha)w_t h_t - \phi$ . In the absence of fixed costs therefore, in equilibrium any 1% increase in profits also means a 1% increase in wages per employee. Since wages per employee do not fluctuate much over the business cycle labor profits do not fluctuate enough to induce significant fluctuations in hiring activity. We show that as a result unemployment does not fluctuate enough. If fixed costs of maintaining a job exist, however, the share of wages in profits is no longer constant over the business cycle. As we show algebraically in the paper, the larger the fixed cost the more do labor profits fluctuate in percentage terms for any given fluctuation in wages. Therefore even if wages per employee are relatively smooth, percentage job-related profits can fluctuate significantly. This reconciles the wage channel with labor market fluctuations.

It appears necessary to relate these results to the majority of literature which uses efficient bargaining (EB, henceforth) instead. Hagedorn and Manovskii (2007) clarify that under EB two properties must be met to replicate unemployment fluctuations. First, wages must not move one-to-one with labor revenue over the cycle. This provided, increases in revenue translate into more than proportional increases in profits. Second, labor profits in steady state must be small so as to induce sizeable cyclical fluctuations of profits in percentage terms. The proportionality of wages and revenue cannot be circumvented in our setup, while the condition that steady state profits need to be small carries over to our model with RTM. The per-period fixed cost,  $\phi > 0$ , ensures both that steady state profits are small and that the tight link between wages and revenue does not extend to profits. In influential papers, Hall (2005) and Shimer (2004) argue that if Nash-bargaining is efficient, smoother wages expose a firm's profits more to cyclical fluctuations in revenue. This helps to amplify unemployment fluctuations. With RTM instead the share of wages in revenue is constant over the business cycle. A smoother wage then would mean that revenues and profits would fluctuate by less. Indeed, absence of the fixed costs, in order to achieve vacancy and unemployment fluctuations of a realistic size, wages under RTM would need to be far more volatile than they are in the data. Furthermore the argument that sticky wages increase unemployment fluctuations requires in particular that the wages of new hires must be sticky, for which there is only scant empirical support, cp. Pissarides (2007) and Haefke et al. (2007).

On a final note, calibrations of matching models under EB similar to the one used in this paper tend to imply a large drop of the unemployment rate when benefits are reduced, see Costain and Reiter (2008) and Mortensen and Nagypal (2007).

<sup>3</sup> Cost items associated with a job which are independent of the actual hours worked include the cost of health insurance provided by the employer, costs associated with part of the supply of work-infrastructure (such as IT services and the rental of office space) as well as with the provision of overhead administrative services, or costs related to labor turnover. A few authors have pointed out in efficient bargaining frameworks that the presence of fixed costs or turnover costs makes a firm's net payoff (after paying the fixed costs) more responsive to productivity variation, see the references in Mortensen and Nagypal (2007).

<sup>4</sup> The recent literature on labor market matching has identified these two properties as potential shortcomings of models relying on efficient bargaining, which is the bargaining assumption most frequently used. Compare Costain and Reiter (2008) and Mortensen and Nagypal (2007) for a discussion of the elasticity of unemployment with respect to benefits as well as Pissarides (2007) and Haefke et al. (2007) for evidence on wages of new hires.

<sup>5</sup> RTM here is taken to mean that firms and workers bargain about the hourly wage rate only. At this wage rate, the firm is free to choose employment along the intensive (hours worked) margin. Through this, the marginal wage rate and the average wage rate coincide. The work-horse of the literature in contrast is efficient bargaining. There, firms and workers bargain simultaneously about both hours worked and wages.

<sup>6</sup> In an efficient bargaining setup, however, the marginal costs are determined by the marginal rate of substitution and the marginal product of labor. Krause and Lubik (2007) show that under this setup wages do not have a direct impact on marginal costs.

Instead when we calibrate the RTM model with fixed costs to US data, we obtain an elasticity of the unemployment rate to changes in benefits which is in line with empirical estimates, e.g. the estimates by Nickell and Layard (1999). The reason is that under RTM job-related profits can be small in steady state while the surplus of workers need not be negligible at the same time. This means that changes in benefits do not dramatically change the incentives to supply labor.

Apart from the hiring activity, the model adheres to the structure commonly employed in central bank models which follow the New Keynesian approach as in Smets and Wouters (2007). In particular, we show that RTM bargaining lends itself to staggered Calvo type wage-setting which induces real rigidities in the sense of Ball and Romer (1990). We view this structural similarity with the current vintage of policy models, the retention of a channel from wages to inflation and a reasonable empirical success of the model as key requirements to bring models with equilibrium unemployment closer to policy applications at central banks.

The remainder of the paper is structured as follows. We present a New Keynesian model with search and matching frictions in the labor market and staggered RTM bargaining in Section 2. Thereafter, in Section 3, we calibrate the model to US data. Section 4 makes the three points of this paper: First, it shows the existence of the wage channel algebraically and then by means of impulse responses. Second, it highlights the importance of fixed costs for unemployment fluctuations in the model in general and in the calibrated model economy in particular. Third, it illustrates that the model implies a reasonable reaction of the economy's steady state unemployment rate in response to changes in the level of benefits. A final section concludes. The Appendix collects the linearized model economy and the steady state.

## 2. The New Keynesian model economy

We incorporate search and matching frictions à la Mortensen and Pissarides (1994) into an otherwise plain New Keynesian business cycle model. In order to make our point most clearly, we abstract from many of the frictions and features typically entertained in the recent empirical New Keynesian literature. In particular, we abstract from capital formation and the various frictions involved. We further abstract from firm-specific production factors and price and wage indexation. The model's production side features competitive factor markets in the only price-setting sector. Wages at the individual labor good firm are set in a Calvo-staggered manner. One time period in the model refers to a calendar time of 1 month.

### 2.1. Preferences and consumers' constraints

Consumers have time-additive expected utility preferences. Preferences of consumer  $i$  can be represented by

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t u(c_{i,t}, c_{t-1}, h_{i,t}) \right\}, \quad (1)$$

where  $E_0$  marks expectations conditional on period 0 information and  $\beta \in (0, 1)$  is the time-discount factor.  $u(c_{i,t}, c_{t-1}, h_{i,t})$  is a standard period utility function of the form

$$u(c_{i,t}, c_{t-1}, h_{i,t}) = \frac{(c_{i,t} - \varrho c_{t-1})^{1-\sigma}}{1-\sigma} - \kappa^L \frac{(h_{i,t})^{1+\varphi}}{1+\varphi}, \quad \sigma > 0, \quad \varphi > 0. \quad (2)$$

Here,  $c_{i,t}$  denotes consumption of member  $i$ ,  $c_{t-1}$  denotes aggregate consumption last period and  $h_{i,t}$  are hours worked by member  $i$ .  $\kappa^L$  is a positive scaling parameter of disutility of work,  $\varrho \in [0, 1)$  indicates an external habit motive.

#### 2.1.1. Family welfare and budget constraint

There is a large number of identical families in the economy with unit measure. Each family consists of a measure of  $1 - u_t$  employed members and  $u_t$  unemployed members both with above preferences. The family maximizes the sum of unweighted expected utilities of its individual members:

$$\int_0^1 E_0 \left\{ \sum_{t=0}^{\infty} \beta^t u(c_{i,t}, c_{t-1}, h_{i,t}) \right\} di. \quad (3)$$

Let  $U(c_t, c_{t-1}, u_t, \{h_{i,t}\})$  denote the aggregate per-period utility function of the family:

$$U(c_t, c_{t-1}, u_t, \{h_{i,t}\}) := \int_0^1 u(c_{i,t}, c_{t-1}, h_{i,t}) di, \quad (4)$$

where consumption  $c_t$  is the average consumption level of family members and  $\{h_{i,t}\}$  is shorthand for the distribution of hours worked. Given its arguments, the utility function  $U(\cdot, \cdot, \cdot, \cdot)$  gives the value of period family-utility when consumption spending  $c_t$  is optimally distributed among family members. The representative family pools the labor income of its working members, unemployment benefits of the unemployed members and financial income. Its budget constraint is

given by

$$c_t + t_t = \int_0^{1-u_t} w_{i,t} h_{i,t} di + u_t b + \frac{D_{t-1}}{P_t} R_{t-1} e_{t-1}^b - \frac{D_t}{P_t} + \psi_t, \quad (5)$$

where consumption per capita,  $c_t$ , is a choice variable of the family.  $t_t$  are lump-sum taxes per capita payable by the family.  $w_{i,t} h_{i,t}$  is the wage per hour times hours worked by individual family member  $i$ .  $b$  are real unemployment benefits paid to unemployed family members. The family holds  $D_t$  units of a risk-free one-period nominal bond (government debt) which pays a gross nominal return  $R_t e_t^b$  in period  $t+1$ .  $P_t$  is the aggregate price-level.  $e_t^b$  denotes a serially correlated shock to the risk premium, with  $\log(e_t^b) = \rho_b \log(e_{t-1}^b) + \zeta_t^b$ , where  $\rho_b \in [0, 1)$  and  $\zeta_t^b \stackrel{iid}{\sim} N(0, \sigma_b^2)$ . It drives a wedge between the return on bonds held by the families and the interest rate controlled by the central bank, see Smets and Wouters (2007). The family owns representative shares of all firms in the economy.  $\psi_t$  denotes real dividend income per member of the family arising from these firms' profits. Dividend income splits into

$$\psi_t = \psi_t^C + \int_0^{1-u_t} \psi_{i,t}^L di, \quad (6)$$

where  $\psi_t^C$  and  $\int_0^{1-u_t} \psi_{i,t}^L di$  are the profits arising in the differentiating industry and in the labor good industry, respectively; see Section 2.2.

### 2.1.2. The family's first-order conditions

The family maximizes welfare function (3) by choosing consumption,  $c_t$ , and bond-holdings,  $D_t$ , subject to its budget constraint (5).<sup>7</sup> The corresponding Euler equation is given by

$$1 = E_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \frac{R_t e_t^b}{P_{t+1}} \right\}, \quad (7)$$

where marginal utility of consumption is  $\lambda_t = (c_t - \varrho c_{t-1})^{-\sigma}$ . The optimal consumption plan also satisfies the transversality condition

$$\lim_{j \rightarrow \infty} E_t \left\{ \beta^j \frac{\lambda_{t+j}}{\lambda_t} \frac{D_{t+j}}{P_{t+j}} \right\} = 0, \quad \forall t. \quad (8)$$

## 2.2. Three sectors of production: firms

There are three sectors of production. Firms in the first sector produce a homogenous intermediate good, which we shall call the “labor good”. These firms need to find exactly one worker in order to produce. They take hours worked as their sole input into production. In the model, searching for a worker is a costly and time-consuming process due to matching frictions. Once a firm and a worker have met, they infrequently Nash-bargain over the hourly wage rate. We entertain the RTM framework of Trigari (2006). Given this wage rate, the firm decides in each period how many hours of work it wants to hire. Nominal wages in the labor sector are sticky à la Calvo (1983). Firms and workers cannot rebargain their nominal hourly wage rate in every period. This feature is deeply entrenched in New Keynesian macro-economic models in use at central banks, see for example Smets and Wouters (2005) and Edge et al. (2007).<sup>8</sup> Labor goods are sold to a wholesale sector in a perfectly competitive market. Firms in the wholesale sector take the intermediate labor good as their sole input and produce differentiated goods using a constant-returns-to-scale production technology. Subject to price-setting impediments à la Calvo, they sell under monopolistic competition to a final retail sector.<sup>9</sup> Retailers bundle differentiated goods into a homogenous consumption/investment basket,  $y_t$ . They sell this final good to consumers and to the government at price  $P_t$ . We next turn to a detailed description of the respective sectors. In the following, subscript index  $j$  will refer to wholesale good firm/product  $j$ . Subscript  $i$  will refer to labor good firm/firm-worker match  $i$ .

### 2.2.1. Retail firms

The retail sector operates in perfectly competitive factor markets. It takes wholesale goods of type  $j \in [0, 1]$ , labeled  $y_{j,t}$ , and aggregates all these varieties into the homogenous final good,  $y_t$ , according to

$$y_t = \left( \int_0^1 y_{j,t}^{(\varepsilon-1)/\varepsilon} dj \right)^{\varepsilon/(\varepsilon-1)}, \quad \varepsilon > 1. \quad (9)$$

<sup>7</sup> In fact, the family chooses  $\{c_{i,t}\}$  and  $D_t$ . Since utility of family members is additively separable in consumption and leisure, cf. (2), the optimal choice of the family involves full consumption insurance,  $c_{i,t} = c_t$ , for all family members.

<sup>8</sup> As argued in the Introduction, in our model environment sticky or unresponsive wages are not instrumental in generating labor market fluctuations. This contrasts the RTM setup with the case of efficient bargaining.

<sup>9</sup> Following most of the literature we part the markup pricing decision from the labor demand decision. Kuester (2007) highlights that search and matching frictions in principle make labor a temporarily firm-specific factor of production. When price-setting and labor market activity are conducted in the same sector, real rigidities arise even under efficient bargaining.

The cost-minimizing expenditure,  $P_t$ , needed to produce one unit of the final good is given by

$$P_t = \left( \int_0^1 P_{j,t}^{1-\varepsilon} dj \right)^{1/(1-\varepsilon)}, \quad (10)$$

where  $P_{j,t}$  marks the price of good  $y_{j,t}$ .  $P_t$  coincides with the consumer/GDP price index. The demand function for each single good  $y_{j,t}$  is given by

$$y_{j,t} = \left( \frac{P_{j,t}}{P_t} \right)^{-\varepsilon} y_t. \quad (11)$$

$\varepsilon > 1$  is thus the own-price elasticity of demand for differentiated goods.

### 2.2.2. Wholesale firms

Firms in the wholesale sector have unit mass and are indexed by  $j \in [0, 1]$ . Firm  $j$  produces variety  $j$  of a differentiated good,  $y_{j,t}$ , according to

$$y_{j,t} = y_{j,t}^{\text{Ld}}. \quad (12)$$

Here  $y_{j,t}^{\text{Ld}}$  denotes firm  $j$ 's demand for the intermediate labor good which it can acquire in a perfectly competitive market at real price  $x_t^{\text{L}}$ . Real period profits of firm  $j$ ,  $\psi_{j,t}^{\text{C}}$ , are given by

$$\psi_{j,t}^{\text{C}} = \frac{P_{j,t}}{P_t} y_{j,t} - y_{j,t}^{\text{Ld}} x_t^{\text{L}}.$$

The first term gives wholesale firm revenues, the second term marks real payments for the labor good. The real price for one unit of the labor good is  $x_t^{\text{L}}$ .

We follow Calvo (1983) and Yun (1996) in assuming that in each period a random fraction  $\omega \in [0, 1]$  of firms cannot reoptimize their price. Those firms which reoptimize their price in period  $t$  face the problem of maximizing the value of their enterprise by choosing their sales price,  $P_{j,t}$ , taking into account the pricing frictions, demand function (11) and production function (12). Assuming that firms at least break even ex ante and realizing that for any given demand the optimal factor input choice leads to marginal costs which are independent of the production level, the price-setting problem simplifies to

$$\max_{P_{j,t}} E_t \left\{ \sum_{s=0}^{\infty} \omega^s \beta_{t,t+s} \left[ \frac{P_{j,t}}{P_{t+s}} - mc_{t+s} \right] y_{j,t+s} \right\}. \quad (13)$$

Here  $mc_t$  are real marginal costs, which are given by

$$mc_t = x_t^{\text{L}}. \quad (14)$$

$\beta_{t,t+s} := \beta^s \lambda_{t+s} / \lambda_t$  is the equilibrium stochastic discount factor. The typical reoptimizing wholesale firm's first-order condition for price-setting is

$$E_t \left\{ \sum_{s=0}^{\infty} \omega^s \beta_{t,t+s} \left[ \frac{P_t^*}{P_{t+s}} - \frac{\varepsilon}{\varepsilon-1} mc_{t+s} \right] y_{j,t+s} \right\} = 0, \quad (15)$$

where  $P_t^*$  marks the optimal price. Total real profits of the wholesale (Calvo) sector are  $\psi_t^{\text{C}} = \int_0^1 \psi_{j,t}^{\text{C}} dj$ , where

$$\psi_{j,t}^{\text{C}} = \left\{ \frac{P_{j,t}}{P_t} - mc_t \right\} y_{j,t} \quad (16)$$

denotes the period profits of firm  $j$ . These profits accrue to the representative family, cp. equations (5) and (6).

### 2.2.3. Labor good firms

The labor good is homogenous. Each firm in this sector consists of one and only one worker matched with an entrepreneur. In period  $t$  there is thus a mass  $(1 - u_t)$  of operative labor firms. Match  $i$  can produce amount  $y_{i,t}^{\text{L}}$  of the labor good using hours worked,  $h_{i,t}$ , according to

$$y_{i,t}^{\text{L}} = z_t h_{i,t}^{\alpha}, \quad \alpha \in (0, 1). \quad (17)$$

$z_t$  is a labor sector-wide technology shock, which follows an AR(1) process:

$$\log(z_t) - \log(z) = \rho_z (\log(z_{t-1}) - \log(z)) + \zeta_t^z,$$

where  $\rho_z \in [0, 1)$  and  $\zeta_t^z \stackrel{\text{iid}}{\sim} N(0, \sigma_z^2)$ . Here, as in the following, a reference to a variable, e.g.  $z_t$ , without time subscript, e.g.  $z$ , refers to that variable's steady state value. The technology shock is identical over the different matches.

### 2.3. Labor market—matching, bargaining and vacancy posting

We now turn to the specification of the labor market in our model. We first describe the matching technology and then focus on the bargaining and vacancy posting decisions.

#### 2.3.1. Matching the firms and workers

The matching process is governed by a Cobb–Douglas matching technology

$$m_t = \sigma_m (u_t)^\xi (v_t)^{1-\xi}, \quad \sigma_m > 0, \quad \xi \in (0, 1). \quad (18)$$

Here  $m_t$  is the number of new matches of workers with firms,  $v_t$  is the number of job vacancies. A searching firm finds a worker in period  $t$  with probability  $q_t = m_t/v_t$ . An unemployed worker will find a job with probability  $s_t = m_t/u_t$ .

In the US, according to Hall (2005), most of the variation of employment over the business cycle is explained by variations in vacancy posting while the separation rate appears to be rather stable. We therefore assume that separations occur with a constant, exogenous probability  $\vartheta \in (0, 1)$  in each period.<sup>10</sup> New matches in  $t$ ,  $m_t$ , become productive for the first time in  $t + 1$ . As a consequence of these assumptions, the employment rate  $n_t := 1 - u_t$  evolves according to

$$n_t = (1 - \vartheta)n_{t-1} + m_{t-1}. \quad (19)$$

#### 2.3.2. Wage bargaining

Due to a fixed cost of posting a vacancy,  $\kappa$ , and decreasing returns-to-scale at the individual labor firm level, formed matches entail economic rents. Firms and workers bargain about their share of the overall match surplus. The paper follows den Haan et al. (2000) in assuming that the family takes the labor supply decision for its workers. We start by describing the gain of a representative family from having an additional member  $i$  in employment.

The value (to the family) of a worker who is employed and receives nominal wage  $W_{i,t}$  is

$$V_t^E(W_{i,t}) = \frac{W_{i,t}}{P_t} h_{i,t} - \kappa^L \frac{h_{i,t}^{1+\varphi}}{(1+\varphi)\lambda_t} + E_t\{\beta_{t,t+1}(1-\vartheta)[\gamma V_{t+1}^E(W_{i,t}) + (1-\gamma)V_{t+1}^E(W_{t+1}^*)]\} \\ + E_t\{\beta_{t,t+1}\vartheta U_{t+1}\}. \quad (20)$$

The value of a worker in employment depends on his wage income, for which both the nominal hourly wage,  $W_{i,t}$ , and the hours worked,  $h_{i,t}$ , matter. The second term in the first row pertains to the utility loss from working. An employed worker retains his job with probability  $1 - \vartheta$ . In the next period, if he stays employed, he faces a probability  $\gamma$  that he will not be able to rebargain the nominal wage rate, in which case his value is  $V_{t+1}^E(W_{i,t})$ . Or he is able to rebargain, in which case his value reflects the optimal rebargained wage in  $t + 1$ :  $V_{t+1}^E(W_{t+1}^*)$ . With probability  $\vartheta$  he will be unemployed next period. The value of a worker when unemployed is given by

$$U_t = b + E_t\{\beta_{t,t+1}s_t[\gamma V_{t+1}^E(W_t) + (1-\gamma)V_{t+1}^E(W_{t+1}^*)]\} + E_t\{\beta_{t,t+1}(1-s_t)U_{t+1}\}. \quad (21)$$

Here  $b$  are real unemployment benefits. An unemployed worker has a chance of  $s_t$  of finding a new job. In that case, he enters the same Calvo scheme as the average currently employed worker. With probability  $(1 - \gamma)$  he can bargain over the wage in  $t + 1$ , with probability  $\gamma$  he will start working at the average nominal hourly wage rate of existing contracts in  $t$ ,  $W_t$ . These assumptions ensure a sufficient degree of homogeneity across workers, which is needed to keep the model tractable.

Let  $\Delta_t(W_{i,t}) := V_t^E(W_{i,t}) - U_t$  denote the family's surplus from having a worker in employment at wage  $W_{i,t}$  rather than having him unemployed. A few steps of algebra show that

$$\Delta_t(W_{i,t}) = \frac{W_{i,t}}{P_t} h_{i,t} - b - \kappa^L \frac{(h_{i,t})^{1+\varphi}}{(1+\varphi)\lambda_t} + E_t\{\beta_{t,t+1}(1-\vartheta)[V_{t+1}^E(W_{i,t}) - V_{t+1}^E(W_{t+1}^*)]\} \\ - E_t\{\beta_{t,t+1}s_t\gamma[V_{t+1}^E(W_t) - V_{t+1}^E(W_{t+1}^*)]\} + E_t\{\beta_{t,t+1}(1-\vartheta-s_t)\Delta_{t+1}(W_{t+1}^*)\}. \quad (22)$$

Firms are economically worthless when they separate from a worker. The market value of a labor firm matched to a worker who receives a nominal hourly wage of  $W_{i,t}$  is given by

$$J_t(W_{i,t}) = \Psi_t^L(W_{i,t}) + (1-\vartheta)E_t\{\beta_{t,t+1}[\gamma J_{t+1}(W_{i,t}) + (1-\gamma)J_{t+1}(W_{t+1}^*)]\}. \quad (23)$$

Here  $\Psi_t^L(W_{i,t})$  are real per-period profits of the firm when the nominal wage rate is  $W_{i,t}$  and  $h_{i,t}$  is the firm's labor input:

$$\Psi_t^L(W_{i,t}) = x_t^L z_t h_{i,t}^\alpha - \frac{W_{i,t}}{P_t} h_{i,t} - \Phi.$$

<sup>10</sup> This view is not uncontested in the literature. For example, Fujita and Ramey (2007) reject the view that variations in the separation rate are negligible for explaining variations in unemployment relative to variations in hiring activity. A similar point is made by Pissarides (2007) and Elsby et al. (2007). In the current paper we follow most of the literature, not least for the sake of clarity of exposition, and abstract from endogenous separation decisions.

$x_t^L$  is the competitive price for the labor good in real terms,  $\phi \geq 0$  denotes a per-period fixed cost of production. The second term in (23) reflects that firms which survive until the next period are subject to Calvo staggering: only with a certain probability,  $1 - \gamma$ , will they be able to rebargain the hourly wage.

For those firms which bargain in a given period, nominal hourly wages are determined by means of Nash-bargaining over the match surplus:

$$\arg \max_{W_{i,t}} [A_t(W_{i,t})]^{\eta_t} [J_t(W_{i,t})]^{1-\eta_t} \Rightarrow W_t^*, \quad (24)$$

where  $\eta_t \in (0, 1)$  denotes the family's bargaining power.<sup>11</sup> The optimization above takes into account that in each period each firm sets hours worked optimally according to the usual marginal profit condition by which the marginal value product of labor is equated to the real wage rate

$$x_t^L z_t \alpha h_{i,t}^{\alpha-1} = \frac{W_{i,t}}{P_t}. \quad (25)$$

The first-order condition for the wage can then be written as

$$\eta_t J_t^* \underbrace{\frac{\partial A(W_{i,t})}{\partial W_{i,t}}}_{\approx \delta_t^W} W_t^* = (1 - \eta_t) A_t^* \underbrace{\frac{-\partial J(W_{i,t})}{\partial W_{i,t}}}_{\approx \delta_t^F} W_t^*. \quad (26)$$

### 2.3.3. Vacancy posting decision

Free entry into the vacancy posting market drives the value of a vacancy to zero. In equilibrium therefore real vacancy posting costs,  $\kappa > 0$ , equal the discounted expected value of a firm, so

$$\kappa = q_t E_t \{ \beta_{t,t+1} [\gamma J_{t+1}(W_t) + (1 - \gamma) J_{t+1}(W_{t+1}^*)] \}. \quad (27)$$

The term in square brackets reflects our assumption that newly started jobs face the same Calvo rigidities as incumbent jobs. This is similar to the assumptions made in [Gertler and Trigari \(2006\)](#), who appeal to wage structures in multi-worker firms. With probability  $(1 - \gamma)$  the firm-worker pair can reset its wage rate. With the remaining probability, the wage rate is set to the average hourly wage rate prevailing in the previous period.<sup>12</sup>

### 2.4. Government: monetary and fiscal policy

The monetary authority controls the one-month risk-free interest rate on nominal bonds,  $R_t$ . The empirical literature (see, e.g. [Clarida et al., 2000](#)) finds that simple generalized Taylor-type rules of the form

$$\begin{aligned} \log(R_t) = & \log\left(\frac{\bar{\Pi}}{\beta}\right) (1 - \phi_R) + \phi_R \log(R)_{t-1} \\ & + (1 - \phi_R) \left[ \frac{\phi_\pi}{12} \log\left(\frac{\Pi_{t-1}^a}{\bar{\Pi}^{12}}\right) + \frac{\phi_y}{12} \log\left(\frac{y_t}{\bar{y}}\right) \right] + \log(\varepsilon_t^{\text{money}}), \end{aligned} \quad (28)$$

once linearized, are a good representation of monetary policy in recent decades. Here  $\Pi_t^a = P_t/P_{t-12}$  is year-on-year inflation, and  $\bar{\Pi} = 1$  is the month-on-month gross target inflation rate.  $\phi_R \in [0, 1)$ ,  $\phi_\pi > 1$  and  $\phi_y \geq 0$  are response coefficients to lagged interest rates, inflation and output, respectively.  $\log(\varepsilon_t^{\text{money}}) = \zeta_t^{\text{money}} \stackrel{\text{iid}}{\sim} N(0, \sigma_{\text{money}}^2)$  is an iid log-normal shock to the monetary policy stance.

Government spending,  $g_t$ , is exogenous and evolves according to

$$\log(g_t) - \log(\bar{g}) = \rho_g (\log(g_{t-1}) - \log(\bar{g})) + \zeta_t^g,$$

where  $\rho_g \in [0, 1)$  and  $\zeta_t^g \stackrel{\text{iid}}{\sim} N(0, \sigma_g^2)$ .  $\bar{g}$  is the government's long-run target level for government expenditure. The government budget constraint is given by

$$t_t + \frac{D_t}{P_t} = u_t b + \frac{D_{t-1}}{P_t} R_{t-1} + g_t. \quad (29)$$

The government generates revenue from lump-sum taxes. It also earns income through new debt issues,  $D_t/P_t$ . On the expenditure-side appear unemployment benefits (the term involving  $b$ ), debt repayment and coupon as well as government spending. We assume that fiscal policy is Ricardian.

<sup>11</sup> Throughout the paper the bargaining power will be constant. The exception is Section 4.2 where variations in the bargaining power are used to illustrate the existence, respectively, absence of a wage channel under RTM and EB.

<sup>12</sup> Note that in our setup the assumption of wage stickiness for new hires is not essential for explaining unemployment fluctuations though.

## 2.5. Market clearing

The aggregate retail good is used for private and government consumption. In addition, vacancy posting activity requires resources and so do the fixed costs of producing labor goods. Total demand is thus given by

$$y_t = c_t + g_t + \kappa v_t + n_t \Phi. \quad (30)$$

Market clearing in the retail market requires that above demand of retail goods equals total supply, which is given by  $y_t = [\int_0^1 (y_{j,t})^{(\varepsilon-1)/\varepsilon} dj]^{1/(\varepsilon-1)}$ .

For each firm  $j$  in the wholesale sector, its supply  $y_{j,t} = y_{j,t}^{L,d}$ , must be matched by the corresponding demand  $y_{j,t} = (P_{j,t}/P_t)^{-\varepsilon} y_t$  in order to clear the wholesale market.

The total demand for the labor good is given by  $y_t^L = \int_0^1 y_{j,t}^{L,d} dj$ , where  $y_{j,t}^{L,d}$  marks demand for the labor good by individual wholesale firm  $j$ . Market clearing requires that total demand for the labor good equals the supply of the labor good which is given by  $y_t^L = z_t \int_0^1 h_{i,t}^2 di$ .

## 3. Calibration to the US

We calibrate the model to the US using data from 1964:q1 to 2006:q3. The sample start coincides with the samples used in [Gertler and Trigari \(2006\)](#) and [Krause and Lubik \(2007\)](#). All data are taken from the Federal Reserve Bank of St. Louis' database FRED II except for the Help Wanted Advertising Index which was obtained from the Conference Board. We use the Hodrick–Prescott filter with a conventional filter weight of 1,600 to extract the business cycle component from the data in logs.

As to the underlying data, output is measured by nominal output in the business sector divided by the GDP deflator. Total hours worked are hours worked in the business sector. Total wages are the compensation in the business sector divided by the GDP deflator, and wages per employee are obtained by dividing the former by the number of employees in the business sector. Real hourly wages are measured by the real compensation per hour in the business sector, again obtained by dividing the nominal quantity by the GDP deflator. Vacancies are measured by the Conference Board's index of Help-Wanted Advertising. We use the civilian unemployment rate among those 16 years old and older. The inflation rate is the (quarter-on-quarter) GDP inflation rate. The interest rate is the quarterly average of the FED funds rate. We note that both the interest rate and the inflation rate are not annualized in the figures reported below. The model runs at a monthly frequency in order to be able to match stocks and flows in the US labor market. The calibrated parameter values and the targets are summarized in [Table 1](#). Turning first to preferences, the time-discount factor,  $\beta$ , is chosen so as to match an annual real rate of 2.45%. The curvature of disutility of work,  $\varphi = 2$ , follows the estimates of [Domeij and Flodén \(2006\)](#). The coefficient of relative risk aversion,  $\sigma = 1.5$ , follows the estimates in [Smets and Wouters \(2007\)](#). Habit persistence,  $\varrho$ , is set to a value of 0.7, in line with [Smets and Wouters \(2007\)](#). Scaling parameter  $\kappa^L$  is set so as to meet our target for hours worked per employee of  $h = \frac{1}{3}$ .

Turning to the labor good sector and the labor markets, we set  $\alpha = 0.99$ , implying only mildly decreasing returns to hours worked per worker. We set the elasticity of matches with respect to unemployment to  $\zeta = 0.5$ , which is in the range of reasonable values suggested by [Petrongolo and Pissarides \(2001\)](#). The bargaining power is set to a conventional value of  $\eta = 0.5$ . The monthly separation rate of  $\vartheta = 0.03$  follows [Shimer \(2005\)](#). The degree of nominal rigidity of wages is set to  $\gamma = 0.8$ . This amounts to the same contract duration for wages which we use for prices, namely 5 months. This wage duration is roughly consistent with panel data when not adjusting for possible reporting errors, cp. [Gottschalk \(2005\)](#). The same author, however, also shows that the duration of wage contracts considerably increases when eliminating possibly spurious statements. Doing so, the hazard rate of a wage change peaks at 12 months, leading us to consider also more wage rigidity in the impulse responses reported in Section 4.

As regards the labor market steady state, we target an unemployment rate of  $u = 0.0588$  in line with the data average and a quarterly probability of finding a worker of 70%. The latter figure follows ([den Haan et al., 2000](#)) and implies a monthly job filling probability of  $q = 0.33$ . The efficiency parameter of the matching function is set to  $\sigma_m = 0.398$  in order to match the above two assumptions regarding the labor market steady state. With the same target, the cost of posting a vacancy is set to  $\kappa = 0.0051$ . The technology parameter is set to  $z = 3.152$ , which ensures that output is equal to unity in steady state. All steady state values reported can thus be interpreted as ratios to GDP.

We calibrate the fixed costs to  $\Phi = 0.0092$ . This amounts to 0.86% of steady state output of an individual labor firm being absorbed by fixed costs or, alternatively, 0.95% of the value of its revenue. In choosing this number, we target the degree of fluctuations in unemployment in the data.<sup>13</sup>

<sup>13</sup> To obtain empirical evidence for the size of overhead labor costs, [Ramey \(1991\)](#) uses the proportion of non-productive workers in total manufacturing employment as a proxy. Using BLS data from 1985 to 2006 the proportion of non-productive workers varies between 27% and 30%. [Basu \(1996\)](#) argues that even higher values are plausible if more general overhead costs would be taken into account. These numbers, though indicative of possibly substantial fix costs, are not directly interpretable as parameter  $\Phi$  in our calibration but rather constitute upper bounds. In our model,  $\Phi$  indicates costs which are fixed with respect to hours worked per employee. The measures just cited define fixed costs more broadly and also include costs which are to a certain extent fixed with respect to the number of employees, for example.

**Table 1**  
Parameters and their calibrated values

Parameter	Value	Explanation; target/reference
<i>Preferences</i>		
$\beta$	0.998	Time-discount factor; matches annual real rate of 2.45%
$\varphi$	2	Labor supply elasticity of 0.5; <a href="#">Domeij and Flodén (2006)</a>
$\sigma$	1.50	Risk aversion; <a href="#">Smets and Wouters (2007)</a>
$\varrho$	0.70	External habit persistence; <a href="#">Smets and Wouters (2007)</a>
$\kappa^L$	372.31	Scaling factor to disutility of work; targets $h = 1/3$
<i>Bargaining and labor good</i>		
$\alpha$	0.99	Labor elasticity of production; close to constant returns to scale
$\xi$	0.50	Elasticity of matches w.r.t. unempl.; <a href="#">Petrongolo and Pissarides (2001)</a>
$\eta$	0.50	Bargaining power of workers; conventional value
$\vartheta$	0.03	Monthly rate of separation; <a href="#">Shimer (2005)</a>
$\gamma$	0.80	Avg. duration of wages of 5 mths; same stickiness as for prices
$\sigma_m$	0.398	Efficiency of matching; reconciles $m$ with target for $u, q$
$\kappa$	0.0051	Vacancy posting costs; reconciles $m$ with target for $u, q$
$z$	3.1526	Technology; targets output $y = 1$
$\Phi$	0.0092	Fixed cost associated with labor; targets $std(\hat{u}_t)$
<i>Wholesale sector</i>		
$\varepsilon$	11	Markup; conventional price-markup of 10% over marginal costs
$\omega$	0.80	Calvo stickiness of prices; avg. duration of 5 mths; <a href="#">Bils and Klenow (2004)</a>
<i>Government</i>		
$\phi_\pi$	1.50	Response to inflation; conventional Taylor rule
$\phi_y$	0.50	Response to output; conventional Taylor rule
$\phi_R$	$0.85^{1/3}$	Interest rate smoothing; 0.85 at quarterly frequency
$\bar{g}$	0.347	Government spending; targets consumption—GDP ratio of 0.65
$b$	0.3825	Unemployment benefits; targets replacement rate $b/(wh) = 0.4$
<i>Correlation of shocks and size of innovations</i>		
$\rho_g$	0.89	Autocorr. of government spending; 0.79 in quarterly data
$\rho_z$	0.82	Autocorr. of technology shock; 0.67 in quarterly data (identified using the model's resource constraint)
$\rho_b$	0.95	Autocorr. of premium shock; 0.90 in quarterly terms
$\sigma_{money}$	0.043	Standard deviation of innovation to Taylor rule; data
$\sigma_g$	0.674	Std. dev. of innov. to gov. spending; match std. dev. (0.87) in qtrly data
$\sigma_z$	0.571	Std. dev. of innov. to tech. shock; match std. dev. of techn. (0.69) in qtrly data
$\sigma_b$	0.102	Std. dev. of innov. to premium shock; targets $std(\hat{y}_t)$

*Notes:* The table reports calibrated parameter values. The model is calibrated to the US using data from 1964:q1 to 2006:q3; see the main text for details. As to the shocks, the government spending and technology shocks are estimated using quarterly data. The autocorrelation coefficients and the standard deviation of the respective innovation at a monthly frequency were chosen such that the resulting series would imply the same first-order autocorrelation coefficient and the same standard deviation as the quarterly estimates if the monthly series were to be time-aggregated to a quarterly frequency. See the main text for details.

The markup in the wholesale sector is set to a conventional value of 10%, implying  $\varepsilon = 11$ . Following [Bils and Klenow \(2004\)](#) the average contract duration of prices is set to 5 months, so  $\omega = 0.8$ .

We rely on a monthly adaptation of a standard Taylor rule (i.e. a long-run response to inflation with  $\phi_\pi = 1.5$  and to output with  $\phi_y = 0.5$ ), with the coefficient on interest rate smoothing being set to  $\phi_R = 0.85^{1/3}$ . This roughly corresponds to a quarterly interest rate smoothing coefficient of 0.85 which is standard in the literature. In order to determine the steady state level of “government spending”, we target a consumption output ratio of 65% which is the data average over the sample period. We take  $c/(c + g)$  as the model counterpart of this ratio. By this and Eq. (30),  $\bar{g} = 0.347$  (some resources are also used for vacancy posting costs and for job-related fixed costs). We target a steady state replacement rate of  $b/wh = 0.4$ , a conventional value which is used for example in [Shimer \(2005\)](#) and which is close to the evidence reported in [Engen and Gruber \(2001\)](#). Our target for the replacement rate implies  $b = 0.382$ .

The resulting steady state for some of the model variables is reported in [Table 2](#). As argued, profits in the labor sector are small. As a result, the value of labor firms,  $J$ , amounts to only 1.5% of monthly output. The surplus of workers is an order of magnitude larger,  $\Delta = 0.3589$ , which amounts to about 38% of the monthly wage per employee. This has implications for the elasticity of unemployment with respect to benefits, on which Section 4.4 will comment.

Returning to the calibration, the technology process is modeled as an AR(1) process, so  $\hat{z}_t = \rho_z \hat{z}_{t-1} + \zeta_t^z$ , where a hat denotes the percent deviation of the corresponding series from steady state, and  $\zeta_t^z \stackrel{\text{iid}}{\sim} N(0, \sigma_z^2)$ . We first use the model's inverted production function  $\hat{z}_t = \hat{y}_t - (\alpha \hat{h}_t + \hat{n}_t)$  to identify the time series for the technology shock from the data as follows. Time-aggregation implies that  $\hat{z}_{t_q}^q = \hat{y}_{t_q}^q - (\alpha \hat{h}_{t_q}^q + \hat{n}_{t_q}^q)$ , where superscript  $q$  denotes quarterly averages and time

**Table 2**  
Steady state

Variable	Value	Description
$y$	1	Output
$c$	0.6439	Consumption
$wh$	0.9562	Wage per employee
$u$	0.0588	Unemployment rate
$v$	0.0854	Vacancies (as share of labor force)
$s$	0.4802	Probability of finding a job within a month
$q$	0.3306	Probability of finding a worker within a month
$b/(wh)$	0.40	Unemployment insurance replacement rate
$\kappa v/y \cdot 100$	0.0432	Percent share of output lost to vacancy posting
$\Phi/(x^L z h^r)$	0.0095	Share of a labor firm's revenue lost to fixed costs
$\psi^C/y$	0.0909	Profit share (wholesale sector) in total output
$\psi^L n/y$	0.0005	Profit share (labor sector) in total output
$J$	0.0153	Value of a labor firm
$\Delta$	0.3589	Surplus of the worker from working

Notes: Steady state for some variables implied by the calibration in Table 1.

**Table 3**  
Second moments of the model compared to the data

Variable	Meaning	Std.	Std. to std( $y$ )	Corr. with $y$	AR(1)
$\hat{y}_t$	Output	1.91 (1.92)	1.00 (1.00)	1.00 (1.00)	0.92 (0.86)
$\hat{R}_t$	Nominal rate	0.41 (0.41)	0.21 (0.21)	0.02 (0.37)	0.89 (0.83)
$\hat{\pi}_t$	Inflation	0.23 (0.29)	0.12 (0.15)	0.21 (0.15)	0.36 (0.47)
$\hat{h}_t + \hat{n}_t$	Total hours	2.08 (1.74)	1.09 (0.91)	0.89 (0.88)	0.87 (0.92)
$\hat{w}_t + \hat{h}_t + \hat{n}_t$	Total compensation	2.00 (1.90)	1.05 (0.99)	0.95 (0.85)	0.87 (0.91)
$\hat{w}_t + \hat{h}_t$	Compens. per empl.	1.37 (0.90)	0.72 (0.47)	0.90 (0.49)	0.82 (0.81)
$\hat{h}_t$	Hours per worker	1.49 (0.49)	0.78 (0.25)	0.79 (0.72)	0.82 (0.77)
$\hat{w}_t$	Hourly compensation	0.43 (0.85)	0.22 (0.45)	0.09 (0.11)	0.88 (0.78)
$\hat{u}_t$	Unemployment	10.93 (11.01)	5.74 (5.74)	−0.98 (−0.87)	0.91 (0.92)
$\hat{v}_t$	Vacancies	13.77 (13.15)	7.23 (6.85)	0.88 (0.90)	0.76 (0.91)

Notes: The table reports summary statistics of the model and compares those to the data (values in the data are given in brackets). All statistics refer to the variables being measured at a quarterly frequency. Model variables are averaged/aggregated over the quarter so as to bring their measurement in line with the data. The data are hp(1,600) filtered. The third column reports the standard deviation of the series, the fourth its standard deviation relative to that of GDP. The fifth column shows the contemporaneous cross-correlation with GDP. The final column reports first-order autocorrelation coefficients. These refer to the autocorrelation measured quarter-on-quarter. The computations for the data are performed on the sample from 1964:q1 to 2006:q3.

index  $t_q$  indicates that one time step is one quarter.<sup>14</sup> The monthly autocorrelation parameter,  $\rho_z$ , and the standard deviation of the innovation,  $\sigma_z$ , are then obtained as follows. We estimate an AR(1) process on the quarterly average of  $\hat{z}_t$ , i.e.  $\hat{z}_{t_q}^q = \rho_z^q \hat{z}_{t_q-1}^q + \zeta_{t_q}^{z,q}$ , by ordinary least squares. Here  $\hat{z}_{t_q-1}^q$  denotes the average of the technology shock during the previous quarter. We then choose  $\rho_z$  and  $\sigma_z$  such that the first-order autocorrelation of the quarterly average of this monthly technology process matches the counterparts in the estimated quarterly process.

Government spending is represented by an AR(1) process estimated on the HP(1,600) filtered government consumption data for the sample period (detrended by the GDP deflator). Just as with the technology shock, we adjust the autocorrelation parameter and the standard deviation of the innovation in the model in such a way, that the monthly series for government spending once aggregated to quarterly numbers would fit the serial correlation and standard deviation as estimated from the quarterly data.

The standard deviation of the monetary policy shock is obtained as follows. We obtain the residual (plus a constant term) by using actual data in Taylor rule (28). We use monthly observations of the Federal funds rate and its one month lagged value. The 1 month lagged year-on-year GDP inflation rate in that formula is proxied for by year-on-year CPI

<sup>14</sup> So for example  $\hat{y}_{2005,q1}^q = \frac{1}{3}(\hat{y}_{2005:m1} + \hat{y}_{2005:m2} + \hat{y}_{2005:m3})$ .

inflation, which is available at a monthly frequency. The deviation of output from steady state in each month of the sample is proxied by the seasonal component of hp(14,400) filtered data of the index of industrial production. The standard deviation,  $\sigma_{\text{money}}$ , is computed as the standard deviation of the residual in (28) such obtained.

Finally, the standard deviation of the risk premium shock is set such that the standard deviation of the output series in our model coincides with the standard deviation of hp-filtered output in the data. This implies  $\sigma_b = 0.102$ . The serial correlation of the risk premium shock is set to 0.95, which translates into an autocorrelation of a quarterly aggregate of this shock of around 0.9.

Table 3 shows the second moments of endogenous variables as implied by the model, namely unconditional standard deviations, the contemporaneous correlation with output as well as the serial correlation coefficients. This information can be compared to the moments implied by the data which are given in brackets.

The model captures both the standard deviations and the overall co-movement in the data. The compensation per employee is still more volatile than in the data, while real hourly wages are not volatile enough. As a consequence, total hours worked and, especially, hours per worker fluctuate more than their counterparts in the data. Most importantly, however, the model reproduces the substantial fluctuations in unemployment and vacancies in the data. In percentage terms wages per employee are only about  $\frac{3}{4}$  as volatile as output in the data. Yet the model matches the unemployment fluctuations despite the tight link that, in the RTM model, exists between labor profits and the relatively smooth wages per employee.

Using this calibration, we next turn to illustrating the wage channel to inflation, the importance of the per-period fixed costs associated with jobs and the implications of the model for the response of unemployment to changes in benefits.

#### 4. Wage channel, unemployment fluctuations and benefits

In the Introduction we identified three main features of our model: (a) that the model contains a proper wage channel, (b) that it reproduces the fluctuations of unemployment over the business cycle and (c) that it implies a reasonable elasticity of steady state unemployment with respect to changes in benefits.

This section analyzes the three features in detail: Section 4.1 presents key equations of the model to illustrate the model's wage channel and to explain the mechanism which induces unemployment fluctuations. A wage channel, in our understanding, is present whenever wages and the wage-setting process have a direct influence on inflation. In our model this materializes itself primarily in two observations which we corroborate in Section 4.2: First, a higher degree of wage rigidity induces a weaker response of inflation to aggregate shocks. Second, higher wages all else equal translate directly into higher inflation. We note that this is the case even if a shock to wages does not affect the wages of prospective new hires but only affects the wages of existing matches. Section 4.2 also clarifies in which respect these defining characteristics of the wage channel are present under RTM bargaining but not under efficient bargaining (EB). Moving to point (b) above, Table 3 already showed that the model can reproduce the fluctuations of unemployment over the business cycle under a suitable calibration. Section 4.3 makes clear that the value of fixed costs is crucial for this result. Finally, Section 4.4 examines by how much unemployment would rise in the long-run if unemployment benefits were to rise in our model environment.

##### 4.1. Wage channel and unemployment fluctuations—key equations

This section builds intuition for why there exists a wage channel in our model economy and for why fixed labor costs are important for unemployment fluctuations in the model. In order to keep the exposition tractable and clear, in this subsection we abstract from wage rigidity and set the wage stickiness parameter  $\gamma$  to zero. Therefore all firms pay the same wage rate and all workers work the same number of hours. This allows us to drop superscript  $*$  and subscript index  $i$  in the following exposition. Under RTM, workers and firms bargain only about the hourly wage. At this wage rate a labor firm faces a perfectly elastic labor supply. The first-order condition for hours worked equates the marginal value product of labor and the real hourly wage<sup>15</sup>:

$$x_t^L \alpha z_t h_t^{\alpha-1} = w_t.$$

Since the marginal cost of a price-setting firm is  $mc_t = x_t^L$  and  $z_t h_t^\alpha = y_t^L$ , rewriting above equation yields

$$mc_t = \frac{1}{\alpha} \frac{w_t h_t}{y_t^L}. \quad (31)$$

Eq. (31) implies that higher wages all else equal induce higher inflation and that stickiness in wages all else equal translates into stickiness of the marginal costs of price-setting firms. This stickiness translates into a muted response of inflation to shocks (when compared to a model with more flexible wages) via the New Keynesian Phillips curve. Wages and anything affecting the wage-setting process thereby have a direct effect on inflation.

<sup>15</sup> Under efficient bargaining, a firm and a worker jointly bargain over the wage and hours worked:  $\arg \max_{w_t, h_t} [A_t]^\eta [J_t]^{1-\eta}$ . The corresponding first-order conditions under efficient bargaining are as follows. For the wage:  $\eta J_t = (1 - \eta) A_t$ , and for hours worked:  $x_t^L \alpha z_t h_t^{\alpha-1} = \kappa^L h_t^\alpha / \lambda_t$ . Under EB hours are set so as to equate the marginal value product of labor and the worker's marginal rate of substitution between leisure and consumption. (Average) wages therefore do not directly influence production and thus they do not play a direct role in influencing marginal costs of price-setting firms under EB.

We next clarify the relation between the introduction of a period-by-period fixed cost associated with jobs,  $\phi$ , and the fluctuation of unemployment over the business cycle. Under the assumption of no wage rigidity, vacancy posting condition (27) simplifies to

$$\kappa = q_t E_t \{ \beta_{t,t+1} J_{t+1} \}. \quad (32)$$

Using this in the definition of the market value of the firm (the simplified version of (23)) yields an expression for  $J_t$  which depends on contemporaneous variables only. Reinserting this expression in (32) yields

$$\frac{\kappa}{q_t} = E_t \left\{ \beta_{t,t+1} \left[ \psi_{t+1}^L + \frac{\kappa}{q_{t+1}} \right] \right\}.$$

Linearizing that around the steady state, one obtains

$$-\hat{q}_t = E_t \{ \hat{\beta}_{t,t+1} \} + [1 - (1 - \vartheta)\beta] E_t \{ \hat{\psi}_{t+1}^L \} - \beta(1 - \vartheta) E_t \{ \hat{q}_{t+1} \}.$$

There is, neglecting fluctuations in the pricing kernel, a one-to-one relationship between percentage fluctuations in expected per-period labor profits,  $E_t \{ \hat{\psi}_{t+1}^L \}$ , and percentage fluctuations in the probability of finding a worker,  $\hat{q}_t$ . The more per-period profits react to the business cycle, the more will the vacancy posting activity react to the business cycle—and thus the more will unemployment react.

Fixed costs in period profits amplify fluctuations in labor profits in percentage terms. The revenue of a labor firm is given by  $x_t^L z_t h_t^\alpha$ . Using the first-order condition for hours worked,  $\alpha x_t^L z_t h_t^{\alpha-1} = w_t$ , the share of *revenue* of the firm that is paid to labor is given by  $\alpha \in (0, 1)$  and thus constant over the business cycle. As a result, per-period profits of a labor firm can be expressed as

$$\psi_t^L = \frac{1 - \alpha}{\alpha} w_t h_t - \phi. \quad (33)$$

Once fixed costs associated with a job are positive, wage costs are still proportional to revenue as in the previous literature, e.g. Trigari (2006), but they are no longer proportional to *profits*. Percentage fluctuations in profits can then be larger than percentage fluctuations in wages. In particular, linearizing (33) around steady state gives

$$\hat{\psi}_t^L = A(\hat{w}_t + \hat{h}_t) \quad \text{where } A \geq 1. \quad (34)$$

In percentage terms, fluctuations in labor profits are linked to percentage fluctuations in wages per employee by a factor of proportionality  $A = ((1 - \alpha)/\alpha) \cdot wh / [(1 - \alpha)/\alpha) \cdot wh - \phi]$  which is larger than unity if  $\phi > 0$ . For any given level of fluctuations in wages per employee, labor profits associated with a job will be the more volatile in percentage terms, the more the fixed costs consume of a firm's revenue, i.e. the lower the labor firm's steady state profit is. With a suitable choice of calibration for the size of fixed costs  $\phi$ , unemployment rates exhibit the desired amplitude over the business cycle. In our calibration  $A = 19.72$ .

#### 4.2. The wage channel—simulations

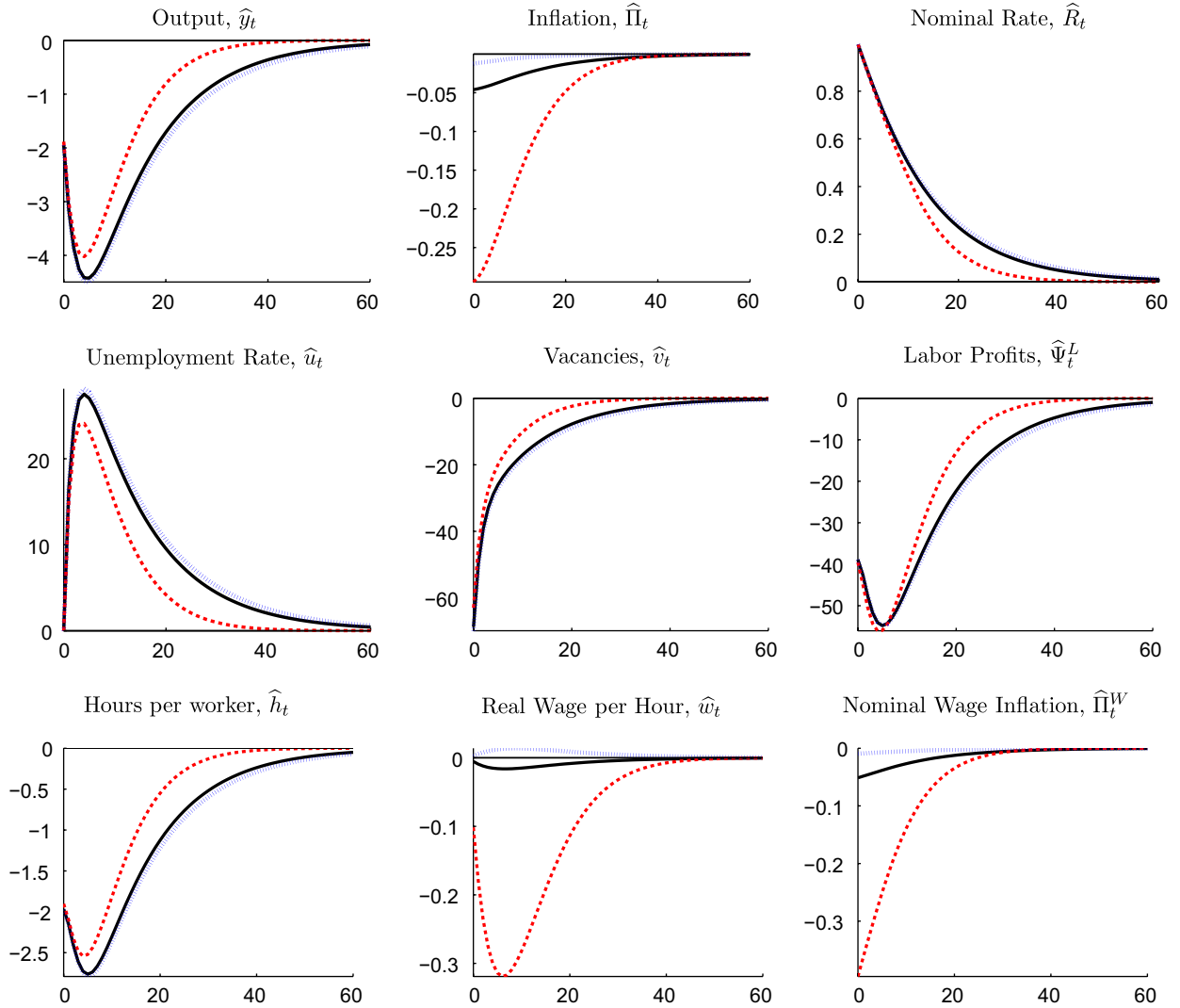
We next turn to graphically illustrate the wage channel. Fig. 1 shows impulse responses to a monetary policy shock for different degrees of nominal wage rigidity. All graphs refer to variables measured at the monthly frequency implied by the model. The black solid line marks the baseline calibration which features a wage rigidity parameter of  $\gamma = 0.8$  implying an average wage duration of 5 months. The red dashed line shows impulse responses in an economy with lower wage rigidity ( $\gamma = 0.5$ , so wages are optimized on average every second month). A blue dotted line reports the impulse responses when  $\gamma = \frac{11}{12}$ , which implies an average wage duration of 12 months. The response of the real wage rate,  $\hat{w}_t$ , to a monetary tightening is less pronounced when nominal wages are more rigid.<sup>16</sup> As a consequence also inflation falls less sharply—illustrating one of the defining properties of the wage channel. The same is not true under efficient bargaining (EB), as Krause and Lubik (2007) show.<sup>17</sup>

Fig. 2 illustrates that in our model with RTM all else equal higher wages *directly* induce higher inflation while again this is not the case under EB. In the simulation underlying the figure the bargaining power of workers unexpectedly rises from  $\eta = 0.5$  to  $0.6$  in  $t = 0$ . The bargaining power is known to return to its steady state level,  $\eta = 0.5$ , for all following periods. We abstract from wage rigidity.<sup>18</sup> Under both bargaining schemes the rise in the bargaining power of workers triggers a

<sup>16</sup> With  $\gamma = \frac{11}{12}$  nominal wages are more rigid than prices. Despite falling nominal wages (see bottom right panel in Fig. 1), real wages can therefore rise. Inflation nevertheless falls since marginal costs are given by  $\hat{m}c_t = \hat{w}_t - [\hat{z}_t + (\alpha - 1)\hat{h}_t]$  and since hours worked per employee fall (bottom left panel).

<sup>17</sup> The reason being that under EB in equilibrium marginal costs are related to the marginal rate of substitution of the worker between consumption and leisure and not to the wage rate, cf. also footnote 14.

<sup>18</sup> The very purpose of Fig. 2, and also of Fig. 3, is to show that under EB wages affect inflation only to the extent that they affect employment while under RTM there exists a direct channel from wages to inflation. For technical reasons, in this paper we do not distinguish between wage rigidity for existing hires and wage rigidity for new hires, but rather assume similar wage rigidity for all matches. Under RTM, whether wage rigidity affects all matches or only existing matches hardly affects results, see e.g. Christoffel et al. (2008). In contrast, under EB results would be affected. Wage rigidity modeled the way we do would lead to spill-overs from wages of existing matches to the surplus of new matches. It would thus cause spill-overs to employment even if the bargaining shock itself only affects existing matches.

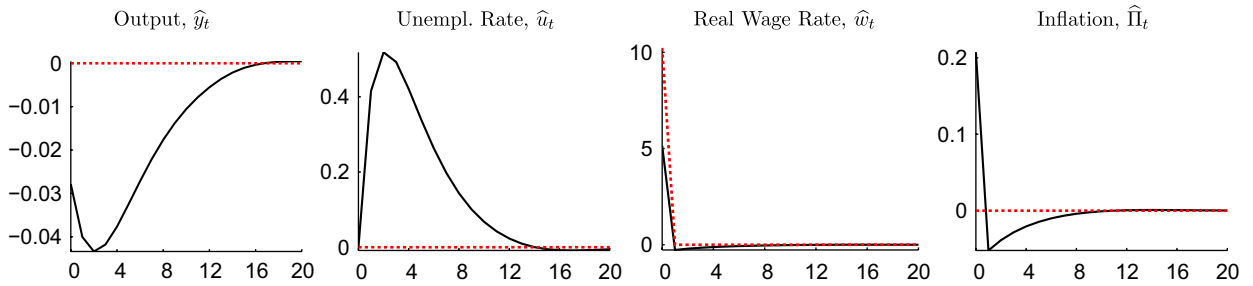


**Fig. 1.** Impulse responses to a monetary policy shock—the effect of wage rigidity. *Notes:* The figure shows percentage responses (1 in the plots corresponds to a 1% increase over the respective steady state value) of endogenous variables to a 1% monetary policy shock. All variables are measured at a monthly frequency. A time period in the graphs is 1 month. The black solid line marks the calibrated benchmark model (the average contract duration is 5 months). The red dashed line shows the case of lower wage rigidity (the average contract duration is 2 months). The blue dotted line corresponds to the case of higher wage rigidity (the average contract duration is 12 months). The wage rigidity in the model is a rigidity in nominal hourly wage rates. Nominal wage inflation is defined as  $\hat{\Pi}_t^W := (\hat{W}_t / \hat{W}_{t-1})$ .

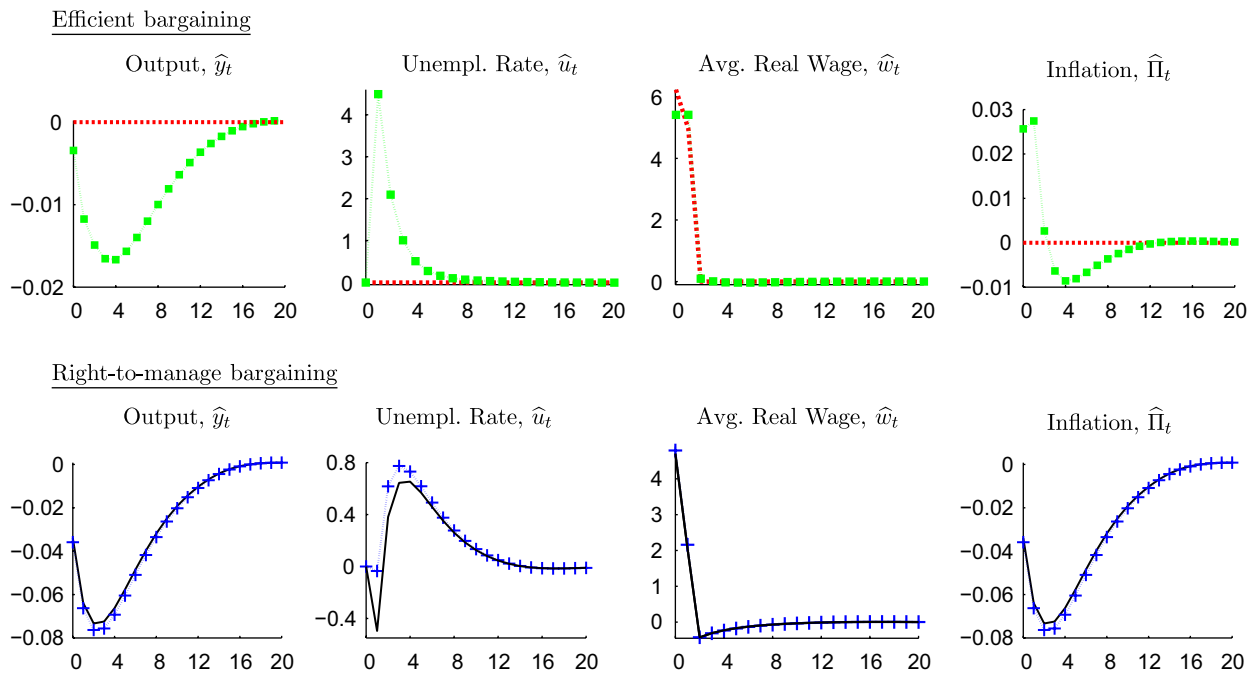
sharp increase in hourly wages. Under RTM this immediately translates into a rise in inflation, just as Eq. (31) would have suggested (black solid line). As a consequence of the monetary tightening, output falls and employment falls in subsequent periods, too. This response of inflation is absent under EB (red dashed line) where movements in wages, unless they affect the hiring decisions of firms, affect nothing else but the distribution of the joint surplus of workers and firms. In above scenario, the bargaining power rises only in period  $t = 0$ , so there is no effect on future wages and profits. The vacancy posting decisions today are therefore not affected under EB. As a consequence, even though wages of 94% of the labor force sharply rise in  $t = 0$ , under EB there is no effect on inflation.<sup>19</sup>

These results do not rest on the lack of persistence of the bargaining power shock in Fig. 2. Instead, under EB even a persistent “wage shock” may not affect production and inflation. Unless the shock affects the bargaining of prospective new matches, under EB there is no impact on the price of the labor good,  $x_t^L$ , and therefore no impact on marginal costs or on inflation. Fig. 3 illustrates this claim, assuming that the bargaining power shock is persistent. The bargaining power rises to

<sup>19</sup> Appendix A.3 reports details for the steady state and the linearized model underlying the impulse responses with EB.

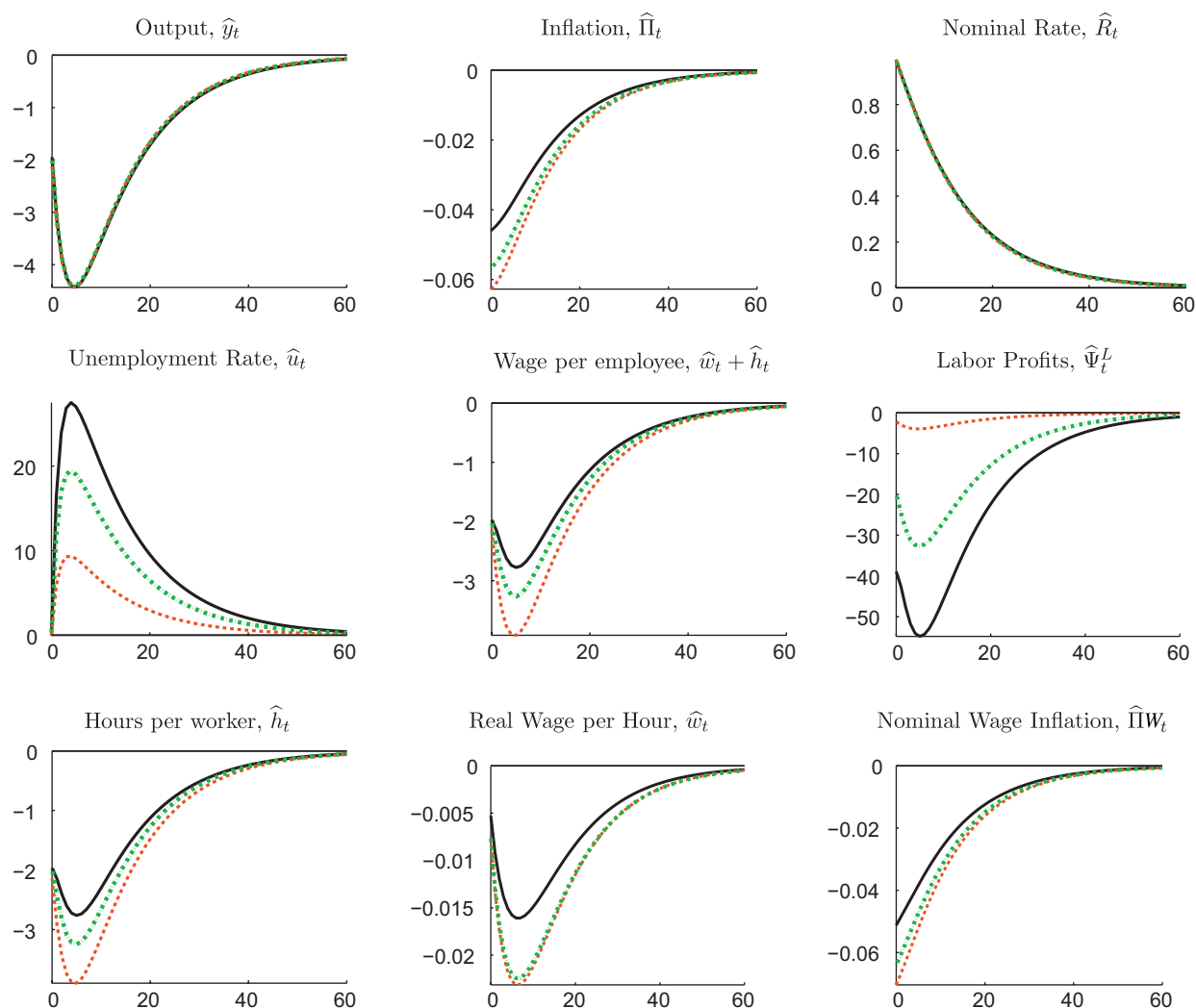


**Fig. 2.** Increase in bargaining power—right-to-manage vs. efficient bargaining. *Notes:* The figure shows percentage responses to a one-time increase in the worker's bargaining power. The workers' bargaining power increases from 0.5 to 0.6 in  $t = 0$ . All variables are measured at a monthly frequency. A black solid line refers to the benchmark model under right-to-manage bargaining. The red dashed line reports impulse responses for the same model but with efficient bargaining. For comparability, both models do not feature any nominal wage rigidity ( $\gamma = 0$ ). The calibration for EB uses the same targets as the calibration for RTM in Table 1. See Table 5 in the Appendix for the steady state and the parameters under EB.



**Fig. 3.** Persistent increase in bargaining power—new vs. existing matches. *Notes:* The figure shows percentage responses to a persistent increase in the worker's bargaining power. The workers' bargaining power increases from 0.5 to 0.6 under the baseline calibration in month 0 and stays at 0.55 in month 1, returning to baseline thereafter. As of month 0, the bargaining power in month 1 is known. A time period in the graphs is 1 month. The first row of panels refers to efficient bargaining. A red dashed line reports impulse responses for the model with efficient bargaining when only matches formed prior to  $t = 0$  are subject to the bargaining power shock. A dotted green line marked by squares indicates the response under EB when also those matches which were newly formed in  $t = 0$  are subject to the  $t = 1$  bargaining power shock. The second row of panels refers to the model with right-to-manage bargaining. A black solid line refers to the benchmark model under right-to-manage bargaining when only matches formed prior to  $t = 0$  ("existing" matches) are subject to the bargaining power shock. Blue crosses mark the model with RTM bargaining when also those matches which were formed in  $t = 0$  (so also "new" matches) are subject to the  $t = 1$  bargaining power shock. Both the RTM and the EB model do not feature nominal wage rigidity ( $\gamma = 0$ ).

$\eta = 0.6$  in  $t = 0$  and is known as of  $t = 0$  to be still halfway between that level and the baseline in  $t = 1$ . The bargaining power returns to the baseline thereafter (from  $t = 2$  onwards). We first assume that only the bargaining power of workers in matches that already produce in  $t = 0$  is affected. Under efficient bargaining this persistent bargaining shock, which affects the wages of 94% of the labor force in  $t = 0$  and of 91% of the labor force in  $t = 1$ , does not have any bearing on inflation (see the red dashed line in the first row of panels in Fig. 3). We next explore the case in which the bargaining power shock affects the bargaining of all matches, including those who start to work only in  $t = 1$ . The responses under EB change considerably (cp. the green squares to the red dashed line in the first row in Fig. 3). In this scenario, firms anticipate the effect of the bargaining power shock on profits associated with new matches in  $t = 1$ . Hiring incentives therefore worsen in  $t = 0$ , so that employment falls in  $t = 1$ , and unemployment rises. As a result the costs for the labor good rise.



**Fig. 4.** Impulse responses to a monetary policy shock—the effect of fixed costs. *Notes:* The figure shows percentage responses (1 in the plots corresponds to a 1% increase over the respective steady state value) of endogenous variables to a 1% monetary policy shock. All variables are measured at a monthly frequency. A time period in the graphs is 1 month. The black solid line marks the calibrated benchmark model (fixed costs  $\phi = 0.0092$ ). The calibration implies a factor of proportionality  $A = 19.72$ . The red dashed line shows the case of no fixed costs, so  $A = 1$ . The green dashed-dotted line which lies inbetween these two, corresponds to the intermediate case with fixed costs  $\phi = 0.0087$  implying a factor of proportionality of  $A = 10$ .

This increase in the cost of the labor good implies that the bargaining shock is affecting inflation also under the EB regime. It is important to note that this effect is only present if the bargaining shock affects the hiring decision of firms.

These differences are in stark contrast to RTM, cp. the second row in Fig. 3. A black solid line marks responses under RTM when the bargaining power shock, which still is persistent, only affects existing matches. Blue crosses mark the response when all matches (including “new” matches) are affected. As these lines illustrate, under RTM, responses do not qualitatively depend on the distinction whether only existing matches or also new matches are affected by a wage shock. In both cases, wages rise and also inflation rises.

In sum, the impulse responses show that the RTM model features a direct channel from wages to inflation. Under EB, in contrast, there is no direct wage channel. If under EB wages affect inflation, they do so only indirectly *via* their potential effect on employment. Under EB wages thus affect inflation only to the extent that they affect employment in the first place.<sup>20</sup>

<sup>20</sup> Even though the direct effect of wages on inflation is quite different in the two bargaining schemes, the two schemes may still imply similar equilibrium behavior of endogenous variables for some types of shocks as some of the impulse responses in Fig. 3 suggest.

**Table 4**

Second moments of the model—no fix costs

Variable	Meaning	Std.	Std. to std(y)	Corr. with y	AR(1)
$\hat{y}_t$	Output	1.89 (1.92)	1.00 (1.00)	1.00 (1.00)	0.92 (0.86)
$\hat{u}_t$	Unemployment	3.48 (11.01)	1.84 (5.74)	−0.97 (−0.87)	0.90 (0.92)
$\hat{v}_t$	Vacancies	4.43 (13.15)	2.35 (6.85)	0.84 (0.90)	0.74 (0.91)

Notes: Same as Table 3 except that the model does not feature period-by-period fixed costs ( $\Phi = 0$ , so  $A = 1$ ). The table reports summary statistics of the model and compares those to the data (values in brackets). Refer to Table 3 for details.

#### 4.3. The role of fixed costs—simulations

Fig. 4 shows impulse responses to a monetary policy shock for various values of the job-related fixed cost,  $\Phi$  (with wage rigidity “switched on” again). The calibrated model is shown as a black solid line. The red dashed line shows the case without fixed costs.

While the responses of output, interest rates and inflation are hardly affected by the size of  $\Phi$ , the response of the unemployment rate is dampened by a factor of two and a half when no fixed costs are present.<sup>21</sup> Much of the response of employment instead shifts towards a reduction at the intensive margin (hours worked per employee fall by more). As an intermediate case, Fig. 4 also shows impulse responses when the factor of proportionality is halfway between the two cases just shown. This case sets  $\Phi = 0.0087$ , implying  $A = 10$  (green dashed-dotted line).<sup>22</sup> In line with the intuition underlying Eq. (34), unemployment reacts by more than in the complete absence of fixed costs but still a long way less than in our model calibrated to the US data.

Table 4 corroborates this result. The model underlying this table relies on RTM and the same calibration as used so far but does not account for job-related fixed costs, so  $\Phi = 0$ . Similar to Table 3 it compares the second moments in the model under this calibration to their counterparts in the data. The standard deviation of output, the contemporaneous correlation of unemployment and vacancies with output as well as the serial correlation properties of output, unemployment rates and vacancies are hardly affected when removing job-related fixed costs. However, in the absence of fixed costs the RTM model fails to reproduce the *amplitude* of fluctuations of both unemployment and vacancies over the business cycle by a wide margin (cp. column “Std.”). We conclude that the fixed costs are instrumental for amplifying the effect of shocks on unemployment in the model.

#### 4.4. The elasticity of unemployment with respect to benefits

When calibrating the textbook search and matching model with EB in a way that ensures low steady state profits associated with jobs, the resulting model generates reasonably strong variations of unemployment over the business cycle, e.g. Hagedorn and Manovskii (2007). Under EB, such a calibration additionally implies that workers are close to indifferent between taking up work and entering unemployment. Small changes in benefits can then have a large effect on the incentives to work for a given wage. As a consequence, these calibrations tend to imply a large drop of the unemployment rate when benefits are reduced. The latter observations have lead some authors, notably Costain and Reiter (2008) and Mortensen and Nagypal (2007), to question the underlying mechanism which leads to the amplification of unemployment fluctuations over the cycle. The current subsection shows that the RTM model with fixed costs as calibrated in Section 3 is not subject to the same criticism.

Under both RTM and EB, the first-order condition for the bargained wage can be expressed as a suitably modified surplus sharing rule:

$$\eta u_t^* \delta_t^W = (1 - \eta_t) A_t^* \delta_t^F.$$

Here  $\delta_t^W$  gives the *rise* in worker surplus when hourly wages rise, while  $\delta_t^F$  gives the *fall* in the firm's profits when the wage rises. Under EB,  $\delta_t^W = \delta_t^F$  in every period and especially in steady state. As argued above, since  $\eta J = (1 - \eta)A$ , EB implies that whenever the value of labor firms is small (as it needs to be to achieve sufficient fluctuations of unemployment) the worker's surplus needs to be small, too.

This is not the case under RTM, where typically the worker's gain and the firm's loss from a wage increase are not of the same size. For the RTM bargaining scheme one can show that in steady state

$$\eta J \left[ \frac{\alpha}{\alpha - 1} - \frac{1}{\alpha - 1} \frac{mrs}{w} \right] = (1 - \eta)A.$$

<sup>21</sup> As in the previous figures, the response of the unemployment rate,  $\hat{u}_t$ , corresponds to the percent increase of the unemployment rate above its steady state ( $\equiv (u_t - u)/u \cdot 100$ ).

<sup>22</sup> The reason for the non-linear increase of  $A$  in fixed costs lies in the strong non-linearity of factor  $A = ((1 - \alpha)/\alpha) \cdot wh / [(1 - \alpha)/\alpha) \cdot wh - \Phi] \geq 1$  as fixed costs  $\Phi$  rise towards their upper bound.

If in steady state the worker's marginal rate of substitution between leisure and consumption exceeds the wage rate, the term in square brackets exceeds unity. As a result, a higher value obtains for the worker's surplus,  $\Delta$ , than under EB—for any value of a labor firm,  $J$ , and for any parametrization for the bargaining power of workers.<sup>23</sup> In particular, for the calibration of the RTM model to US data discussed in Section 3 the model yields the following values in the modified surplus sharing rule:

$$0.5 J \underbrace{\left[ \frac{0.99}{0.99 - 1} - \frac{1}{0.99 - 1} \frac{3.5123}{2.8687} \right]}_{=23.43} = 0.5 \Delta.$$

In that calibration, labor firms' profits in steady state,  $\Psi^L$ , are just a small 0.05% of the value of their revenue. This implies that the value of a job to a labor firm in steady state is as low as  $J = 0.015$ , or 1.5% of a month's output. The job, however, is valued much more by the worker. The worker's surplus is an order of magnitude larger than the value of the labor firm, with  $\Delta = 0.36$  corresponding to roughly 38% of a worker's wage per month.

As a result, an increase in benefits does not cause a dramatic rise in steady state unemployment rates: increasing the replacement rate,  $b/wh$ , from 40% to 41% in the calibrated economy with RTM raises the unemployment rate in the long-run by 1.11% (from 5.88pp to 5.95pp). This is an order of magnitude lower than the values reported for EB by Costain and Reiter (2008) and well in line with the empirical literature. For purposes of comparison, for example, Nickell and Layard (1999) find that this semi-elasticity of the unemployment rate with respect to the replacement rate is 1.3, while Costain and Reiter (2008) favor a value of 2.<sup>24</sup> We view this property of the model as a further argument in favor of using RTM instead of EB in models with unemployment fluctuations.<sup>25</sup>

## 5. Conclusions and outlook

The current paper has presented a New Keynesian model with search and matching frictions which (a) in many elements is similar in structure to policy-models without equilibrium unemployment. Most importantly, the model implies a wage channel to inflation, which is one of the central features of policy-models used at central banks. The model (b) is empirically successful in reproducing the pronounced fluctuations of unemployment over the business cycle. Towards this aim, the model accounts for fixed costs associated with maintaining an existing job. Job-related fixed costs amplify the effect of wages (smooth) on profits (need to be volatile) in the model. While our calibration relies on low profits associated with jobs in steady state, it does not at the same time demand a small gap between the value of working and the value of unemployment for the worker. The model presented in this paper therefore (c) implies reasonable comparative statics in the labor market: steady state unemployment does not change tremendously when unemployment benefits rise meaning that the change is in line with empirical evidence.

The model is based on Trigari's (2006) right-to-manage (RTM) formulation and shares some properties with the recent literature using search and matching frictions but efficient bargaining, cp. Hagedorn and Manovskii (2007). Namely, in order to reproduce the size of unemployment fluctuations over the business cycle, steady state profits of labor firms need to be small and wages must not move one-to-one with profits. Yet, this is just how far the similarities go. Most notably, the unemployment fluctuation mechanism does not rely on smooth wages or on a high outside option of the worker. It does, especially, not require that entry-wages do respond little to the business cycle. This is important since sticky wages of new hires have received only limited empirical blessing recently, see Pissarides (2007) and Haefke et al. (2007).

The combination of RTM bargaining and fixed costs thus brings back to life the wage channel in a model with a realistic degree of unemployment fluctuations and a realistic response of unemployment to changes in the benefit level as our calibration to US data illustrates. With the wage channel alive and well, we believe, it is time to explore the inclusion of this mechanism in a larger-scale policy model—and to check the robustness of policy advice derived under the alternative bargaining schemes.

## Appendix A. Steady state and linearized economy

The appendix presents the steady state of our model economy with RTM bargaining, and the equilibrium conditions linearized around steady state. For completeness, we also present the steady state equations and linearized equilibrium conditions for the efficient bargaining model used for Figs. 2 and 3.

<sup>23</sup> The condition  $mrs > w$  is not special to RTM but also holds for the calibration with EB used in Fig. 2, cf. Table 5 in the Appendix. In fact, under EB, as  $\alpha \rightarrow 1$ ,  $mrs > w$  becomes a necessary condition for positive ex post profits of labor firms and thus for the existence of an equilibrium with positive hiring costs.

<sup>24</sup> We are not the first to highlight the qualitative differences of the RTM and the efficient bargaining approaches when it comes to the effect of structural reforms, see for example Blanchard and Giavazzi (2003).

<sup>25</sup> Not least due to the absence of the wage channel under EB, inflation behaves differently than under RTM. In general equilibrium, this in turn translates into the size of fluctuations of unemployment which would be the target for identifying the size of fixed costs,  $\phi$ . In order to abstract from these complications which arise only in a New Keynesian model environment, in a companion note to the current paper (Christoffel and Kuester, 2007), we use an RBC setup to compare the implied elasticity of unemployment benefits to changes in replacement rates under RTM and efficient bargaining, and confirm above results.

### A.1. Steady state

We turn to present the steady state of the model economy with RTM bargaining. Variables indexed by superscript \* have the same steady state as non-indexed variables, so e.g.  $J^* = J$ . Nominal rate:

$$R = \frac{\Pi}{\beta}.$$

Inflation (quarter-on-quarter):

$$\Pi = 1.$$

Inflation (year-on-year):

$$\Pi^a = 4\Pi.$$

Marginal utility of consumption:

$$\lambda = (c - \varrho c)^{-\sigma}.$$

Marginal cost and price of labor good:

$$mc = x^L = \frac{\varepsilon - 1}{\varepsilon}.$$

Matches:

$$m = \sigma_m u^\xi v^{1-\xi}.$$

Employment:

$$\vartheta n = m.$$

Unemployment:

$$u = 1 - n.$$

Probability of finding a worker:

$$q = \frac{m}{v}.$$

Probability of finding a job:

$$s = \frac{m}{u}.$$

Wage bargaining first-order condition:

$$\eta J \delta^W = (1 - \eta) \Delta \delta^F, \quad (35)$$

$$\delta^F = \frac{1}{1 - \beta(1 - \vartheta)^\gamma} w h, \quad (36)$$

$$\delta^W = \frac{1}{1 - \beta(1 - \vartheta)^\gamma} h \left[ \frac{-\alpha}{1 - \alpha} w - \frac{-1}{1 - \alpha} mrs \right]. \quad (37)$$

Hours first-order condition:

$$w = x^L z \alpha h^{\alpha-1}. \quad (38)$$

Definition marginal rate of substitution:

$$mrs = \frac{\kappa^L h^\varphi}{\lambda}.$$

Value of labor firm:

$$J = \frac{1}{1 - \beta(1 - \vartheta)} \left[ \frac{1 - \alpha}{\alpha} w h - \Phi \right]. \quad (39)$$

Surplus of representative family:

$$\Delta = \frac{1}{1 - \beta(1 - \vartheta - s)} \left[ w h - b - mrs \cdot h \frac{1}{1 + \varphi} \right].$$

Vacancy posting—zero profit condition:

$$\kappa = q \beta J.$$

Resource constraint:

$$y = c + g + \kappa v + \phi n.$$

Production:

$$y = nzh^\alpha.$$

Period profit of a labor firm:

$$\psi^L = x^L zh^\alpha - wh - \phi.$$

Period profit of a goods differentiation firm:

$$\psi^C = (1 - mc)y.$$

## A.2. Linearized model economy

This subsection presents the linearized model economy.

Consumption Euler equation:

$$\hat{\lambda}_t = E_t\{\hat{\lambda}_{t+1} + \hat{R}_t + \hat{\varepsilon}_t^p - \hat{\Pi}_{t+1}\},$$

where  $\hat{\lambda}_t = -(\sigma/(1-\varrho))(\hat{C}_t - \varrho\hat{C}_{t-1})$ .

New Keynesian Phillips curve:

$$\hat{\Pi}_t = \beta E_t\{\hat{\Pi}_{t+1}\} + \frac{(1-\omega)(1-\omega\beta)}{\omega} \hat{m}\hat{C}_t,$$

where  $\hat{m}\hat{C}_t = \hat{x}_t^L$ .

Matching:

$$\hat{m}_t = \xi \hat{u}_t + (1 - \xi) \hat{v}_t.$$

Employment stock:

$$\hat{n}_t = (1 - \vartheta) \hat{n}_{t-1} + \frac{m}{n} \hat{m}_{t-1}.$$

Link employment to unemployment:

$$\hat{n}_t = -\frac{u}{1-u} \hat{u}_t.$$

Probability of finding a worker:

$$\hat{q}_t = \hat{m}_t - \hat{v}_t.$$

Probability of finding a job:

$$\hat{s}_t = \hat{m}_t - \hat{u}_t.$$

Bargaining first-order condition for the wage rate:

$$\hat{J}_t^* + \hat{\delta}_t^W = \hat{A}_t^* + \hat{\delta}_t^F - \frac{1}{1-\eta} \hat{\eta}_t. \quad (40)$$

Aggregate hours index (from hours first-order conditions):

$$\hat{x}_t^L + \hat{z}_t + (\alpha - 1) \hat{h}_t = \hat{w}_t. \quad (41)$$

Evolution of aggregate real wage:

$$\hat{w}_t = \gamma[\hat{w}_{t-1} - \hat{\Pi}_t] + (1 - \gamma) \hat{w}_t^*. \quad (42)$$

Law of motion of  $\hat{\delta}_t^F$ :

$$\begin{aligned} \hat{\delta}_t^F = & [1 - \beta(1 - \vartheta)\gamma] \left[ \frac{-\alpha}{1-\alpha} \hat{w}_t^* + \frac{1}{1-\alpha} (\hat{x}_t^L + \hat{z}_t) \right] \\ & + \beta(1 - \vartheta)\gamma E_t \left\{ \frac{-\alpha}{1-\alpha} [\hat{w}_t^* - \hat{w}_{t+1}^* - \hat{\Pi}_{t+1}] + \hat{\delta}_{t+1}^F + \hat{\lambda}_{t+1} - \hat{\lambda}_t \right\}. \end{aligned} \quad (43)$$

Law of motion of  $\widehat{\delta}_t^W$ :

$$\begin{aligned}\delta^W \widehat{\delta}_t^W &= \frac{-\alpha}{1-\alpha} wh \left[ \frac{-\alpha}{1-\alpha} \widehat{w}_t^* + \frac{1}{1-\alpha} (\widehat{x}_t^L + \widehat{z}_t) \right] \\ &\quad - \frac{-1}{1-\alpha} mrs \cdot h \left[ \frac{(-1)(1+\varphi)}{1-\alpha} \widehat{w}_t^* - \widehat{\lambda}_t + \frac{1+\varphi}{1-\alpha} (\widehat{x}_t^L + \widehat{z}_t) \right] \\ &\quad + \frac{\beta(1-\vartheta)\gamma}{1-\beta(1-\vartheta)\gamma} \left[ \left( \frac{\alpha}{1-\alpha} \right)^2 wh - \frac{(1+\varphi)}{(1-\alpha)^2} mrs \cdot h \right] E_t \{ \widehat{w}_t^* - \widehat{w}_{t+1}^* - \widehat{\pi}_{t+1} \} \\ &\quad + \beta(1-\vartheta)\gamma \delta^W E_t \{ \widehat{\lambda}_{t+1} - \widehat{\lambda}_t + \widehat{\delta}_{t+1}^W \}.\end{aligned}\quad (44)$$

Evolution of  $\widehat{J}_t^*$ :

$$\begin{aligned}J \widehat{J}_t^* &= \frac{wh}{\alpha} [-\alpha \widehat{w}_t^* + \widehat{x}_t^L + \widehat{z}_t] + \frac{\beta(1-\vartheta)\gamma}{1-\beta(1-\vartheta)\gamma} wh E_t \{ \widehat{w}_{t+1}^* + \widehat{\pi}_{t+1} - \widehat{w}_t^* \} \\ &\quad + \beta(1-\vartheta) J E_t \{ \widehat{\lambda}_{t+1} - \widehat{\lambda}_t + \widehat{J}_{t+1}^* \}.\end{aligned}\quad (45)$$

Evolution of  $\widehat{\Delta}_t^*$ :

$$\begin{aligned}\Delta \widehat{\Delta}_t^* &= wh \frac{1}{1-\alpha} [-\alpha \widehat{w}_t^* + \widehat{x}_t^L + \widehat{z}_t] - \frac{1}{1+\varphi} mrs \cdot h \left[ \frac{1+\varphi}{1-\alpha} (-\widehat{w}_t^* + \widehat{x}_t^L + \widehat{z}_t) - \widehat{\lambda}_t \right] \\ &\quad + \frac{\beta(1-\vartheta)\gamma}{1-\beta(1-\vartheta)\gamma} \left[ \frac{\alpha}{1-\alpha} wh - \frac{1}{1-\alpha} mrs \cdot h \right] E_t \{ \widehat{w}_{t+1}^* + \widehat{\pi}_{t+1} - \widehat{w}_t^* \} \\ &\quad - \frac{\beta\gamma s}{1-\beta(1-\vartheta)\gamma} \left[ \frac{\alpha}{1-\alpha} wh - \frac{1}{1-\alpha} mrs \cdot h \right] E_t \{ \widehat{w}_{t+1}^* + \widehat{\pi}_{t+1} - \widehat{w}_t \} \\ &\quad + (1-\vartheta-s)\beta \Delta E_t \{ \widehat{\lambda}_{t+1} - \widehat{\lambda}_t + \widehat{\Delta}_{t+1}^* \} - \beta \Delta s \widehat{S}_t.\end{aligned}\quad (46)$$

Vacancy posting equation:

$$-\frac{\kappa}{q} \widehat{q}_t = \frac{\beta\gamma}{1-\beta(1-\vartheta)\gamma} wh E_t \{ \widehat{w}_{t+1}^* + \widehat{\pi}_{t+1} - \widehat{w}_t \} + \beta J E_t \{ \widehat{\lambda}_{t+1} - \widehat{\lambda}_t + \widehat{J}_{t+1}^* \}.\quad (47)$$

Market clearing:

$$y \widehat{y}_t = c \widehat{c}_t + g \widehat{g}_t + \kappa v \widehat{v}_t + \Phi n \widehat{n}_t.$$

Aggregate production:

$$\widehat{y}_t = \widehat{z}_t + \alpha \widehat{h}_t + \widehat{n}_t.$$

Average period profits in labor good sector:

$$\widehat{\psi}_t^L = \frac{1-\alpha}{\alpha} \frac{wh}{1-\alpha wh - \phi} [\widehat{w}_t + \widehat{h}_t].\quad (48)$$

Taylor rule:

$$\widehat{R}_t = \gamma_R \widehat{R}_{t-1} + (1-\gamma_R) \left[ \frac{\gamma_\pi}{12} \widehat{\pi}_{t-1}^a + \frac{\gamma_y}{12} \widehat{y}_t \right] + \widehat{\varepsilon}_t^{\text{money}}.$$

Law of motion of the shocks:

$$\widehat{e}_t^b = \rho_b \widehat{e}_{t-1}^b + \zeta_t^b, \quad \zeta_t^b \stackrel{\text{iid}}{\sim} N(0, \sigma_b^2),$$

$$\widehat{z}_t = \rho_z \widehat{z}_{t-1} + \zeta_t^z, \quad \zeta_t^z \stackrel{\text{iid}}{\sim} N(0, \sigma_z^2),$$

$$\widehat{g}_t = \rho_g \widehat{g}_{t-1} + \zeta_t^g, \quad \zeta_t^g \stackrel{\text{iid}}{\sim} N(0, \sigma_g^2),$$

$$\widehat{e}_t^{\text{money}} = \zeta_t^{\text{money}}, \quad \zeta_t^{\text{money}} \stackrel{\text{iid}}{\sim} N(0, \sigma_{\text{money}}^2).$$

#### A.2.1. Model underlying Fig. 3

For Fig. 3, we distinguish  $\widehat{J}_t$ ,  $\widehat{\Delta}_t$ ,  $\widehat{\delta}_t^W$ ,  $\widehat{\delta}_t^F$ ,  $\widehat{h}_t$  and  $\widehat{w}_t^*$  by whether the match is active in  $t$  for the first time or whether it has been producing previously, marked but superscripts  $e$  (existing) and  $n$  (new). Also the bargaining power shock is indexed by the match duration.

The bargaining first-order conditions for the wage rate by match duration read as

$$\hat{j}_t^{e,n} + \hat{\delta}_t^{W,e,n} = \hat{\Delta}_t^{e,n} + \hat{\delta}_t^{F,e,n} - \frac{1}{1-\eta} \hat{\eta}_t^{e,n}. \quad (49)$$

Hours:

$$\hat{x}_t^L + \hat{z}_t + (\alpha - 1) \hat{h}_t^{e,n} = \hat{w}_t^{e,n}. \quad (50)$$

Law of motion of  $\hat{\delta}_t^{F,e,n}$ :

$$\hat{\delta}_t^{F,e,n} = \left[ \frac{-\alpha}{1-\alpha} \hat{w}_t^{e,n} + \frac{1}{1-\alpha} (\hat{x}_t^L + \hat{z}_t) \right]. \quad (51)$$

Law of motion of  $\hat{\delta}_t^{W,e,n}$ :

$$\begin{aligned} \delta^W \hat{\delta}_t^{W,e,n} &= \frac{-\alpha}{1-\alpha} wh \left[ \frac{-\alpha}{1-\alpha} \hat{w}_t^{e,n} + \frac{1}{1-\alpha} (\hat{x}_t^L + \hat{z}_t) \right] \\ &\quad - \frac{1}{1-\alpha} mrsh \left[ \frac{(-1)(1+\varphi)}{1-\alpha} \hat{w}_t^{e,n} - \hat{\lambda}_t + \frac{1+\varphi}{1-\alpha} (\hat{x}_t^L + \hat{z}_t) \right]. \end{aligned} \quad (52)$$

Evolution of  $\hat{j}_t^{e,n}$ :

$$J \hat{j}_t^{e,n} = \frac{wh}{\alpha} [-\alpha \hat{w}_t^{e,n} + \hat{x}_t^L + \hat{z}_t] + \beta(1-\vartheta) J E_t \{ \hat{\lambda}_{t+1} - \hat{\lambda}_t + \hat{j}_{t+1}^e \}. \quad (53)$$

Evolution of  $\hat{\Delta}_t^{e,n}$ :

$$\begin{aligned} \Delta \hat{\Delta}_t^{e,n} &= wh \frac{1}{1-\alpha} [-\alpha \hat{w}_t^{e,n} + \hat{x}_t^L + \hat{z}_t] - \frac{1}{1+\varphi} mrsh \left[ \frac{1+\varphi}{1-\alpha} (-\hat{w}_t^{e,n} + \hat{x}_t^L + \hat{z}_t) - \hat{\lambda}_t \right] \\ &\quad + (1-\vartheta-s) \beta \Delta E_t \{ \hat{\lambda}_{t+1} - \hat{\lambda}_t + \hat{\Delta}_{t+1}^e \} - \beta \Delta s \hat{s}_t. \end{aligned} \quad (54)$$

Vacancy posting equation

$$-\frac{\kappa}{q} \hat{q}_t = \beta J E_t \{ \hat{\lambda}_{t+1} - \hat{\lambda}_t + \hat{j}_{t+1}^n \}. \quad (55)$$

As an example for subsequent aggregation, the evolution of the aggregate real wage rate

$$\hat{w}_t = (1-\vartheta) \hat{w}_t^e + \vartheta \hat{w}_t^n. \quad (56)$$

### A.3. Efficient bargaining

The steady state equations and the linearized equilibrium conditions under EB largely coincide with the ones under RTM bargaining with the exception of the following equations.

#### A.3.1. Steady state under efficient bargaining

The wage-bargaining first-order condition (35) is replaced by

$$\eta J = (1-\eta) \Delta$$

reflecting that  $\delta^F = \delta^W$  under efficient bargaining. As a consequence, we drop the steady state equations governing these terms, (36) and (37), from the steady state of the model.

The first-order condition for hours worked (38) changes to

$$mrs = x^L z \alpha h^{\alpha-1}.$$

The equation for the value of the firm (39) reads as

$$J = \frac{1}{1-\beta(1-\vartheta)} [x^L z h^\alpha - wh - \phi].$$

The remaining equations are identical with the ones under RTM. The steady state in the calibration of the EB model underlying Figs. 2 and 3 is given in Table 5.

#### A.3.2. Linearized model economy under efficient bargaining

The linearized model economy under EB largely coincides with the one under RTM bargaining with the exception of the following equations. As said, for efficient bargaining we abstract from wage rigidity by assumption. The wage-bargaining

**Table 5**

Steady state with efficient bargaining

Variable	Value	Description
$y$	1	Output
$c$	0.6354	Consumption
$g$	0.3424	Government consumption
$mrs$	2.8687	Marginal rate of substitution between leisure and cons.
$w$	2.8240	Real hourly wage rate
$wh$	0.9413	Wage per employee
$u$	0.0588	Unemployment rate
$v$	0.0854	Vacancies (as share of labor force)
$s$	0.4802	Probability of finding a job within a month
$q$	0.3306	Probability of finding a worker within a month
$b/(wh)$	0.40	Unemployment insurance replacement rate
$\kappa v/y \cdot 100$	1.3563	Percent share of output lost to vacancy posting
$\Phi/(x^L zh^2)$	0.0095	Share of a labor firm's revenue lost to fixed costs
$\Psi^C/y$	0.0909	Profit share (wholesale sector) in total output
$\Psi^L n/y$	0.0145	Profit share (labor sector) in total output
$J$	0.4813	Value of a labor firm
$\Delta$	0.4813	Surplus of the worker from working

Notes: Steady state for the efficient bargaining version of the model used in Fig. 2. The targets are the same as in Table 1 and so are most parameters. The exceptions being the following:  $\gamma = 0$ ,  $\sigma_m = 0.3984$ ,  $\kappa = 0.1588$ ,  $\kappa^L = 310.24$ .

first-order condition (40) is replaced by

$$\hat{J}_t^* = \hat{\Delta}_t^* - \frac{1}{1-\eta} \hat{\eta}_t,$$

reflecting that  $\hat{\delta}_t^F = \hat{\delta}_t^W$ . As a consequence, we drop the equations governing these terms, (43) and (44), from the model.

The first-order condition for hours worked (41) changes to

$$\hat{x}_t^L + \hat{z}_t + (\alpha - 1)\hat{h}_t = \varphi \hat{h}_t - \hat{\lambda}_t.$$

Eq. (42) which linked newly bargained wages to aggregate wages is redundant—by assumption in the EB model variant all wages are bargained every period.

The equation for the value of the firm (53) does not depend on wage stickiness anymore, in addition it does not use the first-order condition for hours worked to simplify terms anymore. It reads as

$$J \hat{J}_t^* = x^L z h^\alpha [\hat{x}_t^L + \hat{z}_t + \alpha \hat{h}_t] - wh[\hat{w}_t + \hat{h}_t] + \beta(1 - \vartheta) J E_t \{\hat{\lambda}_{t+1} - \hat{\lambda}_t + \hat{J}_{t+1}^*\}.$$

Similarly, the equation for the worker surplus (54) changes to

$$\Delta \hat{\Delta}_t^* = wh[\hat{w}_t + \hat{h}_t] - \frac{mrsh}{1+\varphi} [(1+\varphi)\hat{h}_t - \hat{\lambda}_t] + (1-\vartheta-s)\beta \Delta E_t \{\hat{\lambda}_{t+1} - \hat{\lambda}_t + \hat{\Delta}_{t+1}^*\} - \beta \Delta s \hat{s}_t.$$

The vacancy posting equation (55) has the same form as under RTM (when setting  $\gamma = 0$ ).

The equation for average period profits in the labor good sector changes from (48) to

$$\Psi^L \hat{\Psi}_t^L = x^L z h^\alpha [\hat{x}_t^L + \hat{z}_t + \alpha \hat{h}_t] - wh[\hat{w}_t + \hat{h}_t].$$

In the calibration of the EB model we assume the same size of fixed costs,  $\Phi$ , as under RTM. Unemployment benefits are small. Under EB this implies a much larger value of a job to a firm,  $J$ , than under RTM. In turn this requires considerably higher vacancy posting costs,  $\kappa$ , than under the RTM calibration to match the labor market steady state targets. Typical calibrations with EB would feature lower labor profits and vacancy posting costs. In order to prevent that the responses for output for EB in Fig. 3 are disproportionately influenced by this (through the response of vacancies), we therefore assume for the EB charts in Fig. 3 that vacancy posting costs do not require resources but are lump sum tax costs rebated to the family. For a similar assumption see Trigari (2006). Note that this only affects the scenario marked by green squares in Fig. 3.

The adjustments to the model economy in terms of the two vintages of matches in Fig. 3 are analogous to the ones described for RTM bargaining.

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