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A new Keynesian model with unemployment: The effect of on-the-job search

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Abstract

Although new Keynesian models with labor market frictions report an increase in unemployment and a decrease in labor market tightness in response to a positive technology shock, which appears to be in line with recent empirical findings, the volatilities of these variables are not as high as their empirical counterparts. This calls for the introduction of new modeling tools to amplify the volatilities of the unemployment rate and labor market tightness. Along this line, this paper contributes to the *theoretical* literature by studying the effect of employment-to-employment flow in a new Keynesian model with labor market frictions. We consider two types of firms that offer different wage levels, which incentivize low-paid agents to search on the job. Differently from the existing literature, the main source of wage dispersion is the difference between firms' bargaining powers. The proposed model generates a higher volatility of unemployment and labor market tightness in response to a positive technology shock compared to the model without on-the-job search, without causing a significant change in the responses of other variables.

KEYWORDS

employment-to-employment flow, new Keynesian model, search and matching, the Shimer puzzle, unemployment fluctuations

JEL CLASSIFICATION

E12, E24, E32, J63, J65

1 | MOTIVATION

Search and matching (SM) models, pioneered by Mortensen and Pissarides (1994), provide a convenient environment for macroeconomic analysis of labor markets. In addition to that, SM models attempt to explain business cycles in the presence of labor market frictions. However, as argued by Shimer (2005), the standard SM model is incapable of generating the observed fluctuations in the *unemployment rate* and *labor market tightness* in response to a positive technology shock. Along with this *volatility* puzzle, some scholars also questioned the sign of the correlation between productivity and unemployment in these models. As a matter of fact, starting with Galí (1999), there has been a debate on the sign of that correlation when he showed that positive technology shock leads to an increase in unemployment, which is in stark contrast with the negative correlation found in SM-based real business cycle models.

Barnichon (2010, 2014) argued that the Mortensen–Pissarides model is confronted with not one but two challenges: it needs to match both the sign and the magnitude of the responses in unemployment and labor market tightness to a technology shock. Following these two critiques on SM-based business cycle models, in this paper we start with a new Keynesian (NK) model in the intersection of the models proposed by Galí (2010) and Blanchard and Galí (2010) (henceforth, referred to as GBG). Building on these highly tractable models, which allow for a relatively simpler and more transparent analysis compared to the related models in the literature, our baseline model generates the positive correlation between productivity and unemployment because of nominal rigidities.[1] Our main contribution is to extend the baseline model by introducing *on-the-job search* into the framework, which amplifies the volatilities of unemployment and labor market tightness.

Employer-to-employer flow is an important transition mechanism in the labor market. Fallick and Fleischman (2001), Nagypal (2008), and Bjelland, Fallick, Haltiwanger, and McEntarfer (2011) empirically showed that a significant part of the transitions in the labor market is employer-to-employer flow.[2] Fujita (2010) reported some basic statistics of on-the-job search activity in the United Kingdom, using the Labour Force Survey and providing a valuable source to get stylized facts about on-the-job search. Comparing the unemployment rate with the ratio of on-the-job searchers to the employed agents, the paper shows that on average 5.5% of the employed workers search on-the-job in the United Kingdom during the period 2002Q1–2009Q2, which is higher than the 5% unemployment rate for the aforementioned period.

There is also a bulk of theoretical studies focusing on the effect of job-to-job transitions on the real economy. To our understanding, the two studies closest in spirit to our paper are Krause and Lubik (2007) and Van Zandweghe (2010). These authors integrated on-the-job search into business cycle models and found negative correlations between productivity and unemployment, contradicting with the aforementioned results reported by Barnichon (2010) and Galí (2010).

We argue that incorporating on-the-job search into the model not only provides a realistic labor market environment but also stands as a good candidate to amplify the

[1] The interested reader is referred to Section 6 of Blanchard and Galí (2010) for a detailed literature review on studies that combine certain key elements of NK and SM models.

[2] Fallick and Fleischman (2001) found that on average 2.6% of the employed agents change their jobs each month in the United States. This number corresponds to the double of employment-to-unemployment flow. Nagypal (2008) reported that almost half of the separations are job-to-job transitions. In a more recent paper, two ratios are explicitly calculated by Bjelland et al. (2011): in the United States , the ratio of the number of people experiencing an employer-to-employer transition to the total number of employees is 4.1% and the ratio of the same to the total number of people separating from their jobs is 27.3%.

volatilities of unemployment and labor market tightness. An important difference from the existing on-the-job search models is our way of model construction. In the majority of earlier studies, the source of wage dispersion is the different cost and productivity levels for different types of firms. Although we preserve the cost-difference assumption in our model, the main source of wage dispersion lies in the difference between firms' bargaining powers. We assume that there are two types of firms, *aggressive* firm and *passive* firm, such that the former type has a relatively higher bargaining power than the latter type during wage bargaining, which in turn implies that an aggressive firm offers lower wage levels.[3]

The *theoretical* model we propose in this paper can be thought of as a step forward in addressing the aforementioned shortcoming since the responses of unemployment and labor market tightness are amplified. The interpretation is as follows. In the standard NK model, firms are demand constrained so that an increase in productivity leads to a sluggish adjustment in aggregate demand to the new productivity level due to nominal rigidities. Accordingly, firms employ less labor during this process. Hence, a positive change in technology leads to an increase in unemployment. When on-the-job search is introduced, a positive technology shock leads not only to a decrease in the flow of unemployment to employment but also to an increase in the flow of employment to employment. The job finding rate of on-the-job searchers is procyclical, and the posted vacancies are mostly filled by on-the-job searchers rather than unemployed. And as a result, on-the-job search fundamentally amplifies the responses of the unemployment rate and labor market tightness. The proposed model achieves this outcome without leading to any significant differences between the responses of other model variables.

The structure of the paper is as follows. In Section 2, we formulate our model specifying the differences from the GBG model. Section 3 presents the calibration values, and Section 4 reports impulse responses to a positive technology shock. We conclude in Section 5.

2 | A NEW KEYNESIAN MODEL WITH UNEMPLOYMENT AND ON-THE-JOB SEARCH

In this section, we start with a model in the intersection of the models proposed by GBG and we extend this baseline model by introducing on-the-job search for a particular group of workers. In that regard, we assume two types of firms that offer different wage levels: *aggressive* firm (A) and *passive* firm (P). The bargaining power of aggressive firms over workers is assumed to be greater than that of passive firms, such that passive firms offer a higher wage compared to aggressive firms. Accordingly, workers who earn relatively less (i.e., who work at an aggressive firm) would be willing to search for better paid jobs.

The sequence of events is as follows: At the beginning of a period, firms announce vacancies. Unemployed agents and workers at an aggressive firm search for new jobs. Both types of job search take place at the same time. The matched individuals start working immediately. All agents work until the end of the period at which they may get separated by an exogenous rate of $\delta \in [0, 1)$. The separated workers are unemployed at the beginning of the next period. If an individual does not

[3] For this assumption, *labor unions* constitute a good support. It is well known that individuals and firms are not the only actors in the labor market but there are also labor unions with an aim to attain a lower unemployment rate and higher wages for their members. Assuming that there are two types of unions, *weak* union and *strong* union, it can be argued that a firm operating in a sector associated with the weak union (i.e., aggressive firm) would have a relatively higher bargaining power in comparison to that operating in a sector associated with the strong union (i.e., passive firm).

get separated, she works at the same firm in the next period; unless she searches on the job and is matched with a new firm.

2.1 | Households

We assume that the economy is populated by a continuum of households of measure one and that the representative household is a member of a large family (Merz, 1995). The large family assumption enables us to assume full risk sharing within the family and helps us avoid distributional issues which may arise due to heterogeneity of firms. The representative family maximizes the objective function

$$E_0\left\{\sum_{t=0}^{\infty}\beta^t\left(\log(C_t)-\chi\frac{N_t^{1+\phi}}{1+\phi}\right)\right\},$$

where $\beta \in (0,1)$ is the discount factor and ϕ indicates the inverse of the Frisch labor supply elasticity. The standard utility function shows that agents get utility from consumption and disutility from supplying labor, and that there is no burden of unemployed agents in terms of utility. The aggregate consumption level for different types of consumption goods is denoted by

$$C_t = \left(\int_0^1 C_t(i)^{\frac{\epsilon-1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}},$$

and the fraction of employed agents is shown by N_t. In this model, we assume full participation of households meaning that all agents are either employed or unemployed. This implies that the fraction of unemployed agents is $u_t = 1 - N_t$.

The budget constraint of the family is given by

$$Q_tB_t + \int_0^1 P_t(i)C_t(i)di \leq B_{t-1} + \int_0^1 W_t^A(j)N_t^A(j)dj + \int_0^1 W_t^P(j)N_t^P(j)dj + \Pi_t,$$

where $P_t(i)$ is the price of good i and B_t denotes one-period riskless nominal bond holdings at the price of Q_t. The nominal wage level paid by aggressive and passive firms is denoted by W_t^A and W_t^P, respectively. N_t^A and N_t^P are the fraction of employed agents working at aggressive and passive firms, respectively. The transfers and profit of final goods firms are embedded in Π_t.

The optimal demand condition for good i is given by

$$C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} C_t, \tag{1}$$

where

$$P_t = \left(\int_0^1 P_t(i)^{1-\epsilon} di\right)^{\frac{1}{1-\epsilon}}$$

is the price index for consumption goods. Consequently, the Euler equation is given by

$$Q_t = \beta E_t \left\{ \frac{C_t}{C_{t+1}} \frac{P_t}{P_{t+1}} \right\}.$$

It is worth noting that, in this model, differently from the standard business cycle models, wages are not adjusted according to the labor supply decision of the household. As an attribute of the SM model, wages are demand-determined and set according to a bilateral bargaining between workers and firms.

2.2 | Firms

There are intermediate goods and final goods sectors. Unlike conventional NK models, price stickiness is introduced at the final goods production stage.[4] The intermediate goods sector is perfectly competitive, and the sole factor of production is labor.

2.2.1 | Final goods producers

The final goods sector is monopolistically competitive. The firms, indexed by $i \in [0, 1]$, produce differentiated goods by utilizing an identical technology and using intermediate goods produced by aggressive and passive firms as their inputs. The production function of a final goods producer is

$$Y_t(i) = (Z_t^A(i))^{\gamma}(Z_t^P(i))^{1-\gamma}$$

where $Z_t^A(i)$ and $Z_t^P(i)$ denote the quantity of intermediate goods produced by aggressive and passive firms, respectively. The weight parameter $\gamma \in (0, 1)$ is the share of intermediate goods produced by aggressive firms.

Under the assumption of flexible prices, final goods producers would optimally set the price of their good subject to the demand equation (1) at each period. Therefore, the profit maximization condition suggests that $P_t(i) = \mathcal{M} \cdot MC_t$, where MC_t denotes the real marginal cost and $\mathcal{M} = \frac{\epsilon - 1}{\epsilon}$ is the desired markup. The quantity demanded for intermediate goods, Z_t^A and Z_t^P, is given by

$$Z_t^A(i) = \gamma \frac{P_t(i)}{P_t^A} Y_t(i) \qquad Z_t^P(i) = (1-\gamma) \frac{P_t(i)}{P_t^P} Y_t(i),$$

where P_t^A and P_t^P are the prices of intermediate goods produced by aggressive and passive firms, respectively. Accordingly, the real marginal cost of production is the weighted average of input

[4] The assumption is first proposed by Walsh (2005) and later used by GBG and other papers with labor market frictions in Dynamic Stochastic General Equilibrium (DSGE) models.

prices:

$$MC_t = \left(\frac{P_t^A}{\gamma P_t}\right)^{\gamma} \left(\frac{P_t^P}{(1-\gamma)P_t}\right)^{1-\gamma}. \tag{2}$$

Final goods producers set the price of their goods to maximize the expected discounted profits due to Calvo-type price setting (Calvo, 1983). At each period, a firm is able to reset its price with probability $1-\theta$. This implies that the price levels for the θ fraction of final goods producers remain constant at any given period. The reoptimizing firms' price level is

$$P_t^* = \frac{\epsilon}{\epsilon - 1} \frac{\sum_0^{\infty} \theta^k \Lambda_{t,t+k} P_{t+k}^{\epsilon} Y_{t+k} MC_{t+k}}{\sum_0^{\infty} \theta^k \Lambda_{t,t+k} P_{t+k}^{\epsilon-1} Y_{t+k}}, \tag{3}$$

where $\Lambda_{t,t+k} = \beta^k (C_t / C_{t+k})$ denotes the stochastic discount factor.

2.2.2 | Intermediate goods producers

There are two types of intermediate goods firms in a perfectly competitive environment: aggressive firm (A) and passive firm (P). Their production functions are, respectively, given by

$$Z_t^A = A_t N_t^A \qquad Z_t^P = A_t N_t^P,$$

where A_t denotes the common technology level for both types of firms. We assume that $a_t = \log A_t$ follows an $AR(1)$ process

$$a_t = \rho_a a_{t-1} + \epsilon_t^a,$$

where ϵ_t^a denotes the technology shock and ρ_a is the autoregressive coefficient of the technological process.

The employment levels in aggressive and passive firms evolve according to

$$N_t^A = (1-\delta) N_{t-1}^A + H_t^A \qquad N_t^P = (1-\delta) N_{t-1}^P + H_t^P,$$

where H_t^A and H_t^P are the newly hired agents in aggressive and passive firms at time t, respectively. As in GBG, we assume that new hires start working immediately.

2.3 | Labor market

The main difference between the two types of intermediate goods producers is their relative bargaining powers over workers. The bargaining power of aggressive firms (ξ^A) is greater than that of passive firms (ξ^P). Given the above-defined production functions, the wage level in aggressive firms turns out to be less than the wage level in passive firms.

There are five assumptions about job search:

1 Search is *indirect*: Jobseekers do not know the type of firms during job search.
2 The outside option of agents is unemployment regardless of their prior-to-search state in the labor market. Put differently, if an on-the-job searcher is matched with a new firm, the bargaining process does not start unless the worker resigns from her job.[5]
3 Wages are *flexible*: A worker's wage is updated every period as if she is newly matched. Hence, a worker at a passive firm has no incentive to do on-the-job search. It then follows as a fact that an on-the-job searcher was a worker at an aggressive firm at the end of the previous period.
4 It is obvious that if an on-the-job searcher matches with a passive firm, then she prefers to resign from her existing job. If the new match is an aggressive firm, however, she would be indifferent. Here we assume that a matched on-the-job searcher resigns for sure to negotiate with the new match. This assumption does not cause a qualitative difference in our results.
5 The job finding rates are different for on-the-job searchers (denoted by p_t) and for the unemployed (denoted by q_t).

We assume that only a fraction $\varphi \in [0, 1]$ of workers can search on the job. Notice that, left to themselves, all agents working at an aggressive firm would prefer searching on the job for the prospect of a wage increase. However, in real life, on-the-job search has additional costs and frictions compared to job search by an unemployed. Such additional frictions are not explicitly modeled in this paper. Instead we utilize this on-the-job search intensity parameter to capture those frictions. A low value of φ implies that workers face too many frictions, so that only a small portion of them can search on the job even if all of them would want to.

At the beginning of period t, there is a pool of on-the-job searchers and unemployed agents denoted by OJS_t and U_t^0, respectively. Thus, we have

$$OJS_t = \varphi(1-\delta)N_{t-1}^A \qquad\qquad U_t^0 = 1-(1-\delta)N_{t-1}.$$

Accordingly, we can define job searchers at period t as

$$Pool_t = U_t^0 + OJS_t.$$

Total hiring at period t is denoted by H_t. Differently from GBG, the number of posted vacancies is not equal to the number of newly hired workers in aggressive firms. The reason is that there is a reallocation of workers in aggressive firms. In particular, we can define the posted vacancies in aggressive firms as

$$V_t^A = H_t^A + H_t^o,$$

where H_t^A indicates the change in the number of workers in aggressive firms and H_t^o is defined as $q_t OJS_t$. On the passive firm side, however, the number of posted vacancies is equal to the number of newly hired workers since there is no reallocation of workers. Therefore, we have $V_t^P = H_t^P$.

[5] This assumption is quite standard in the literature. A technical reason behind this assumption is that if the outside option of an on-the-job searcher is her current job, then there would be a continuum of wage levels which harms the simplicity of the model.

In our model, the labor market tightness is defined as

$$x_t = \frac{H_t}{Pool_t} = \frac{H_t^o + H_t^u}{U_t^0 + OJS_t},$$

where $H_t^u = q_t U_t^0$ is the fraction of newly hired workers from the unemployment pool. Moreover, we define the end-of-period unemployment rate as $u_t = 1 - N_t$.

Following GBG, the cost for posting a vacancy is defined in terms of the constant elasticity of substitution (CES) bundle of final goods.[6] The cost per vacancy is an increasing function of the technology level and the corresponding ratio of the posted vacancies to the pool of job searchers. In particular, we assume

$$G_t^A = A_t B\left(\frac{V_t^A}{Pool_t}\right)^{\alpha} \qquad G_t^P = A_t B\left(\frac{H_t^P}{Pool_t}\right)^{\alpha},$$

where α and B are positive constants.[7]

2.4 | Price setting

Let P_t^A and P_t^P denote the price levels of the intermediate goods produced by aggressive and passive firms, respectively. These prices are taken as given. Moreover, let W_t^A and W_t^P represent the nominal wage levels of aggressive and passive firms, respectively. Profit maximization requires the following conditions to be satisfied for all t:

$$\left(\frac{P_t^A}{P_t}\right)A_t = \frac{W_t^A}{P_t} + G_t^A - \beta(1-\delta)E_t\left\{\frac{C_t}{C_{t+1}}(1-\varphi p_{t+1})G_{t+1}^A\right\} \tag{4}$$

$$\left(\frac{P_t^P}{P_t}\right)A_t = \frac{W_t^P}{P_t} + G_t^P - \beta(1-\delta)E_t\left\{\frac{C_t}{C_{t+1}}G_{t+1}^P\right\}. \tag{5}$$

Note that the left-hand side of Equations (4) and (5) represents the real marginal product of labor, and their right-hand side denotes the real marginal cost including vacancy posting costs. It is worth noting that Equation (5) resembles the findings of Galí (2010). However, our introduction of on-the-job search leads to an additional term that to appear in Equation (4). We can define the net vacancy posting costs of aggressive and passive firms as

$$B_t^A = G_t^A - (1-\delta)E_t\{\Lambda_{t,t+1}(1-\varphi p_{t+1})G_{t+1}^A\}$$

[6] GBG assumed that the number of vacancies is equal to the number of newly hired workers. However, in our model, those numbers are different due to the reallocation of newly hired on-the-job searchers. Therefore, we use "cost for posting a vacancy" rather than the concept of cost for hiring.

[7] As discussed by GBG, assuming a matching function of the form $H = ZU^{\eta}V^{1-\eta}$ would give an expected cost function in the same form of our cost functions above.

$$B_t^P = G_t^P - (1-\delta)E_t\{\Lambda_{t,t+1}G_{t+1}^P\}.$$

As a result, *ceteris paribus*, an increase in φ leads to an increase in the net vacancy posting cost of aggressive firms. We then rewrite Equations (4) and (5) as follows:

$$\left(\frac{P_t^A}{P_t}\right)A_t = \frac{W_t^A}{P_t} + B_t^A \tag{6}$$

$$\left(\frac{P_t^P}{P_t}\right)A_t = \frac{W_t^P}{P_t} + B_t^P. \tag{7}$$

Finally, we describe the price dynamics. Plugging the log-linearized version of Equation (3) into the (log-linearized) law of motion for the aggregate price level,[8] we have

$$\mathfrak{p}_t = \theta\mathfrak{p}_{t-1} + (1-\theta)\mathfrak{p}_t^*,$$

where $\mathfrak{p}_t$ denotes the log-linearized aggregate price level.[9] The dynamic Phillips equation is derived as

$$\pi_t = \beta E_t\{\pi_{t+1}\} - \kappa\,\hat{\mu}_t$$

where $\kappa = (1-\theta)(1-\theta\beta)/\theta$ and $\hat{\mu}_t$ denotes the deviation of the average price markup from its steady-state value. We write the marginal cost by log-linearizing Equation (2) and plugging it into $\hat{\mu}_t = \mathfrak{p}_t - mc_t - \mu$, which is derived from the log-linearization of $P_t(i) = \mathcal{M}\cdot MC_t$. It then follows that

$$\hat{\mu}_t = \mu_t - \mu = \gamma\mu_t^A + (1-\gamma)\mu_t^P - \mu.$$

2.5 | Wage determination

When on-the-job search is introduced, the set of feasible payoffs is typically nonconvex. Hence, the axiomatic Nash bargaining solution and the standard strategic bargaining solutions may be inapplicable (see Shimer, 2006, p. 815). Keeping this in mind, here we impose a surplus splitting rule.

For a representative agent, the expected value resulting from being a worker at an aggressive firm is given by

$$V_t^{NA} = \frac{W_t^A}{P_t} - \chi C_t N_t^{\phi} + E_t\left\{\Lambda_{t,t+1}\left[\delta(1-q_{t+1})V_{t+1}^U\right.\right.$$

[8] See Chapter 3 of Galí (2008) for log-linearization and detailed derivations.

[9] In this paper, we use lower case letters for the log transformations of the corresponding variables. However, given that p_t denotes the job-finding rate of on-the-job searchers, we make an exception for the log-linearized aggregate price level.

$$+\Big(\delta q_{t+1}\tau_{t+1} + (1-\delta)(\varphi(p_{t+1}\tau_{t+1} + (1-p_{t+1})) + (1-\varphi))\Big)V_{t+1}^{NA}$$
$$+\Big(\delta q_{t+1}(1-\tau_{t+1}) + (1-\delta)\varphi p_{t+1}(1-\tau_{t+1})\Big)V_{t+1}^{NP}\Big]\Big\},$$

where τ_t is the probability of a job searcher matching with an aggressive firm. Here, the first term is the real wage level for an aggressive firm, the second term is the marginal rate of substitution between consumption and labor market effort, and the third term is the expected value of future earnings. For a representative agent, the expected value resulting from being a worker at a passive firm is given by

$$V_t^{NP} = \frac{W_t^P}{P_t} - \chi C_t N_t^{\phi} + E_t\Big\{\Lambda_{t,t+1}\Big[\delta(1-q_{t+1})V_{t+1}^U$$
$$+\Big(\delta q_{t+1}\tau_{t+1}\Big)V_{t+1}^{NA} + \Big(\delta q_{t+1}(1-\tau_{t+1}) + (1-\delta)\Big)V_{t+1}^{NP}\Big]\Big\}.$$

Moreover, the expected value of an unemployed agent is

$$V_t^U = E_t\Big\{\Lambda_{t,t+1}\Big[(1-q_{t+1})V_{t+1}^U + q_{t+1}(\tau_{t+1}V_{t+1}^{NA} + (1-\tau_{t+1})V_{t+1}^{NP})\Big]\Big\}.$$

Accordingly, we define the surplus of a representative agent resulting from an employment relationship with an aggressive firm as $S_t^{HA} = V_t^{NA} - V_t^U$ and that with a passive firm as $S_t^{HP} = V_t^{NP} - V_t^U$, which in turn implies the following equations:

$$S_t^{HA} = \frac{W_t^A}{P_t} - \chi C_t N_t^{\phi} + (1-\delta)E_t\Big\{\Lambda_{t,t+1}\Big[\Big(\varphi p_{t+1}(\tau_{t+1}-1) + 1 - q_{t+1}\tau_{t+1}\Big)S_{t+1}^{HA}$$
$$+\Big(\varphi p_{t+1}(1-\tau_{t+1}) - q_{t+1}(1-\tau_{t+1})\Big)S_{t+1}^{HP}\Big]\Big\}.$$

$$S_t^{HP} = \frac{W_t^P}{P_t} - \chi C_t N_t^{\phi} + (1-\delta)E_t\Big\{\Lambda_{t,t+1}\Big[\Big(1 - q_{t+1}(1-\tau_{t+1})\Big)S_{t+1}^{HP} - \Big(q_{t+1}\tau_{t+1}\Big)S_{t+1}^{HA}\Big]\Big\}.$$

The surpluses of aggressive and passive firms from the profit maximization conditions, which are, respectively, denoted by S_t^{FA} and S_t^{FP}, are given by

$$S_t^{FA} = MRPN_t^A - \frac{W_t^A}{P_t} + (1-\delta)E_t\Big\{\Lambda_{t,t+1}(1-\varphi p_{t+1})S_{t+1}^{FA}\Big\} \tag{8}$$

$$S_t^{FP} = MRPN_t^P - \frac{W_t^P}{P_t} + (1-\delta)E_t\Big\{\Lambda_{t,t+1}S_{t+1}^{FP}\Big\}, \tag{9}$$

where $MRPN_t^A = (P_t^A/P_t)A_t$ and $MRPN_t^P = (P_t^P/P_t)A_t$ stand for the marginal productivity of labor in aggressive and passive firms, respectively. It follows from Equations (4) and (8) that $S_t^{FA} = G_t^A$ and from Equations (5) and (9) that $S_t^{FP} = G_t^P$.

Recalling that ξ^A and ξ^P, respectively, denote the bargaining powers of aggressive and passive firms, the surplus splitting rule stipulates that firms and workers determine the wage levels according to the following maximization problems:

$$\max_{W_t^A} \ (S_t^{HA}(j))^{1-\xi^A}(S_t^F(j))^{\xi^A} \qquad \max_{W_t^P} \ (S_t^{HP}(j))^{1-\xi^P}(S_t^F(j))^{\xi^P}$$

subject to the corresponding value functions. The solutions to these maximization problems are as follows:

$$(1-\xi^A)S_t^{FA}(j) = \xi^A S_t^{HA}(j) \qquad (1-\xi^P)S_t^{FP}(j) = \xi^P S_t^{HP}(j).$$

The real wage levels in aggressive and passive firms are

$$\begin{aligned}\frac{W_t^A}{P_t} &= MRS_t + \eta^A\left(G_t^A - \beta(1-\delta)E_t\left\{\frac{C_t}{C_{t+1}}(\varphi p_{t+1}(\tau_{t+1}-1) + 1 - q_{t+1}\tau_{t+1})G_{t+1}^A\right\}\right)\\ &\quad -\eta^P\left(\beta(1-\delta)E_t\left\{\frac{C_t}{C_{t+1}}(\varphi p_{t+1}(1-\tau_{t+1}) - q_{t+1}(1-\tau_{t+1}))G_{t+1}^P\right\}\right)\end{aligned} \tag{10}$$

and

$$\begin{aligned}\frac{W_t^P}{P_t} &= MRS_t + \eta^P\left(G_t^P - \beta(1-\delta)E_t\left\{\frac{C_t}{C_{t+1}}(1 - q_{t+1}(1-\tau_{t+1}))G_{t+1}^P\right\}\right)\\ &\quad +\eta^A\left(\beta(1-\delta)E_t\left\{\frac{C_t}{C_{t+1}}(q_{t+1}\tau_{t+1})G_{t+1}^A\right\}\right),\end{aligned} \tag{11}$$

where $\eta^A = (1-\xi^A)/\xi^A$ and $\eta^P = (1-\xi^P)/\xi^P$.

In SM models, the surplus splitting rule implies that the wage equation is a convex combination of marginal rate of substitution and marginal productivity of labor. By contrast, in our model, there emerge additional terms in the wage equations due to firm heterogeneity and the introduction of on-the-job search. The probability of a job searcher matching with an aggressive firm appears in both equations due to the indirect search assumption. In addition to that the on-the-job search intensity parameter appears in Equation (10), since only the workers at aggressive firms can search on the job. The equation indicates that an increase in the ratio of on-the-job searchers leads to a decrease in the wage level in aggressive firms. The reason is that a high ratio of on-the-job searchers causes an increase in aggressive firms' hiring cost in the future, thereby leading aggressive firms to decrease their labor costs at this period considering higher future hiring costs.

2.6 | Monetary policy

The monetary policy is assumed to follow the Taylor-type interest rule represented by

$$i_t = \rho + \phi_\pi \pi_t + \phi_y \hat{y}_t,$$

where i_t is the nominal interest rate and $\rho = -\log \beta$ is the household's discount rate.

2.7 | Market clearing conditions and solving the model

In this section, we emphasize certain characteristics of the model. First, the steady state is independent of the monetary policy rule and the degree of price stickiness. Second, we assume that the steady-state level of technology is $A = 1$. Finally, following GBG, we assume that hiring costs are paid in terms of final goods. This implies that the goods market clearing condition is

$$Y_t = C_t + G_t^A V_t^A + G_t^P V_t^P$$

at the equilibrium. To solve the model, we log-linearize the system of equations around zero inflation steady state.

3 | CALIBRATION AND THE STEADY STATE

In this section, the calibration of model parameters is illustrated. Here we use the conventional parameter values if they do not contradict with the model. All parameters are determined according to quarterly values. We set the discount factor $\beta = 0.99$ and the inverse of the Frisch labor supply elasticity $\phi = 5$. The parameter for price stickiness is set to its average duration in one year: $\theta = 0.75$. The gross markup of prices over marginal cost value is $\mathcal{M} = 1$. Following Blanchard and Galí (2010), we set the hiring cost function parameter $\alpha = 1$. And, having no evidence on the share of intermediate goods produced by aggressive firms in the production of final goods, we set $\gamma = 0.5$.[10]

To calibrate the labor market parameters, we first pin down the steady-state values of the unemployment rate and the job finding rate of unemployed agents utilizing the average values in the UK economy. Accordingly, the average value for $u = 0.05$ and the approximate value for $q \approx 0.25$. Since we assume full participation of agents, we have $N = 1 - u = 0.95$. Furthermore, since there is no hard evidence on the number of aggressive firms, we assume that $N^A = N^P = 0.475$. The separation rate is calculated using $\delta = qu/((1-q)N) \approx 0.02$. As for the coefficients in the Taylor rule, we take the calibration values from the literature. In particular, we set $\phi_\pi = 1.5$ and $\phi_y = 0.125$.

We now turn to the calibration of the parameters related to on-the-job search. To do so, we use the values reported by Fujita (2010). We set the ratio of on-the-job searchers to the employed agents to 5.5%, which implies that 11% of the workers at an aggressive firm search on the job. Thus, we

[10] When there is no evidence, we opt for symmetry. Controlling for the asymmetric values of the parameters, we can further report that our results are qualitatively robust.

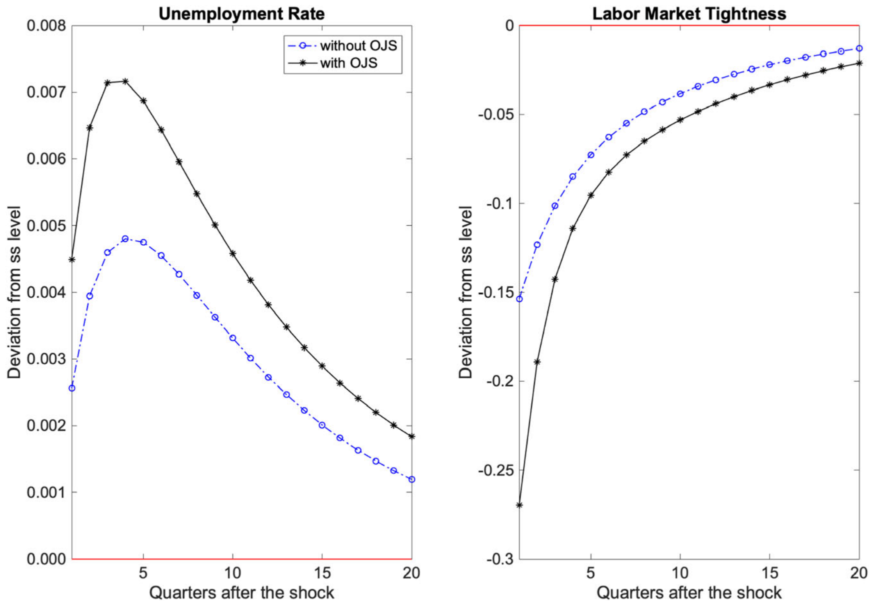

FIGURE 1 The impulse responses to a positive technology shock (with and without OJS) [Colour figure can be viewed at wileyonlinelibrary.com]

set $\varphi = 0.11$. The probability of finding a better paid job, which is denoted by $p(1-\tau)$, is reported to be approximately 0.096. Using the given information, it can be calculated that $\tau \approx 0.8$, so that the job finding rate of on-the-job searchers would be $p \approx 0.48$. This implies that the probability of filling an empty vacancy is higher for an on-the-job searcher in comparison with an unemployed agent.

Following Blanchard and Galí (2010), and setting the ratio of total hiring cost to the output level to 0.01, we calculate the value of B in hiring cost functions. Both for an economy with and without on-the-job search, we use the same value $B = 2.28$.[11] For the case without on-the-job search, we assume that $\xi^A = \xi^P = 0.5$; while for the case with on-the-job search, after setting $\xi^A = 1$, we calculate the corresponding values for ξ^P and χ. Accordingly, we set the relative bargaining power of passive firms $\xi^P \approx 0.12$ and the disutility of labor $\chi = 1.15$.

The calibration values are summarized in Table 1 (see Web Appendix A).

4 | IMPULSE RESPONSES

As discussed earlier, the aim of this paper is to examine the effect of on-the-job search on labor market dynamics, especially on the unemployment rate and labor market tightness. In this regard, we compare the responses of these variables to a one percentage point increase in technology in the models with and without on-the-job search. This positive technology shock dies out gradually according to $AR(1)$ process with an autoregressive coefficient $\rho_a = 0.9$.

Figure 1 shows the dynamic responses of unemployment and labor market tightness. The solid line with star signs and the dashed line with dots demonstrate the responses of the cor-

[11] This is calculated using the parameters and calibration values for the model without on-the-job search.

responding variable in the models with and without on-the-job search, respectively. In particular, when we set the level of on-the-job search intensity to 0%, the *level* deviation of the unemployment rate is 0.0026 in the first period, and when we set its level to 11% (based on the aforementioned calibration), then the same response increases to 0.0045. These correspond to 5.2% and 9% increases in the unemployment rate, respectively. Furthermore, when we set the level of on-the-job search intensity to 0%, the *percentage* deviation of labor market tightness is −0.1535 in the first period, and when we set its level to 11%, then the same response decreases to −0.2697.

In the standard NK model, after a positive technology shock, we observe an increase in the unemployment rate. The mechanism behind this is as follows: After a positive technology shock, aggregate demand cannot adjust immediately due to nominal rigidities in the short run. Since firms become more productive, they decrease their demand for labor and post less vacancies. Consequently, the unemployment rate increases. Since employment-to-employment transitions are another channel affecting the flow of employment, the introduction of on-the-job search amplifies the increase in unemployment. More precisely, not only there is a decrease in vacancies posted by firms, but also a significant fraction of vacancies are filled by on-the-job searchers. Some of on-the-job searchers rematch with aggressive firms, and some of them fill the positions posted by passive firms. The remaining vacancies are filled by unemployed agents. However, the number of vacancies filled by unemployed agents is less than the number of filled vacancies in the model without on-the-job search, which is even less than the number of separated agents. Moreover, in addition to the exogenous separation, the jobs left by the matched on-the-job searchers are destructed. Therefore, the unemployment pool expands, so that we observe a higher increase in the unemployment rate. Because of the same reason we also observe a higher decrease in labor market tightness compared to the model without on-the-job search.

Since we concentrate on the directions and volatilities of unemployment and labor market tightness, we only report the responses of these variables. The impulse response graphs for the other variables are reported in Web Appendix B. For those variables, there is no significant difference between the responses in the models with and without on-the-job search. This outcome fulfills our aim of increasing the volatilities of unemployment and labor market tightness without creating another change in the model dynamics.

Next, we conduct some sensitivity analyses in order to investigate the robustness of our results regarding the amplification effect of the introduction of on-the-job search. To do so, arguably, the most relevant model parameter is for on-the-job search intensity, denoted by φ. However, notice that the calibration value of this parameter is endogenously determined within the model, depending on the ratio of aggressive firms, N^A, and the ratio of on-the-job searchers to the employed agents, $OJS/((1-\delta)N)$. This prevents us from conducting a sensitivity analysis by changing φ directly, so that we concentrate on the effects of changing two other calibration values: (i) N^A and (ii) $OJS/((1-\delta)N)$.

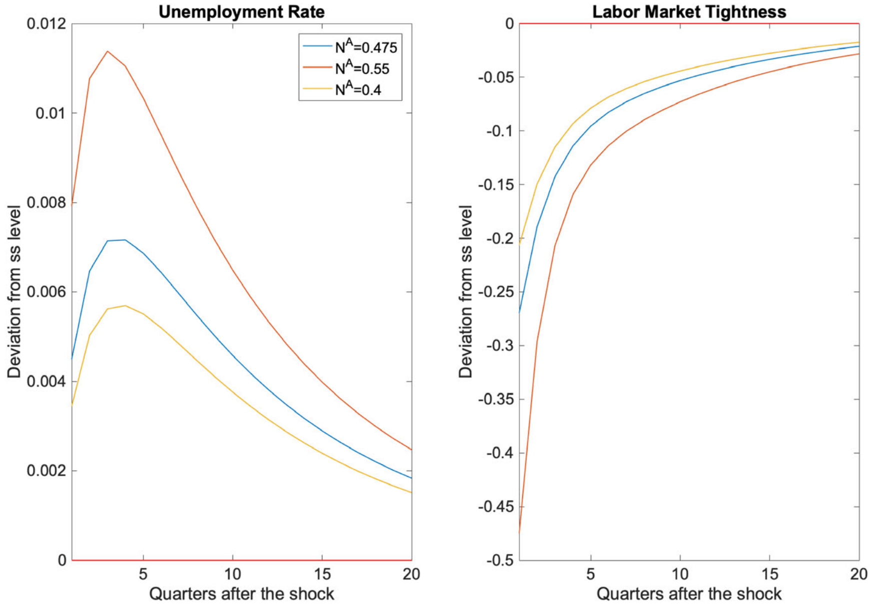

FIGURE 2 The impulse responses under different levels of N^A (for 0.4, 0.475, 0.55) [Colour figure can be viewed at wileyonlinelibrary.com]

Figure 2 reports the impulse responses under three different levels of N^A. If this parameter increases from 0.475 to 0.55, we see that the on-the-job search intensity parameter φ decreases to 0.095, and the volatilities of the unemployment rate and labor market tightness increase; while in case N^A decreases to 0.4, the intensity parameter φ would increase to 0.131, leading to a decrease in the same volatilities. Furthermore, Figure 3 reports the impulse responses under three different levels of $OJS/((1-\delta)N)$. If this ratio increases from 5.5% to 7%, we see that the on-the-job search intensity parameter φ increases to 0.14, and the volatilities of the unemployment rate and labor market tightness increase; while in case $OJS/((1-\delta)N)$ decreases to 4%, the intensity parameter φ decreases to 0.08, leading to a decrease in the same volatilities.

Finally, as it can be seen above, the source of the change in the on-the-job search intensity parameter influences the nature of changes in the volatilities of unemployment and labor market tightness. For instance, if φ increases due to a decrease in N^A, the impulse responses would be amplified, whereas conversely, if it increases as a result of an increase in $OJS/((1-\delta)N)$, then the impulse responses would be suppressed. The reason is that changing either of the values of parameters selected for our sensitivity analyses does not only influence φ but it also affects the other model parameters, such as bargaining power of passive firms, wage dispersion between aggressive and passive firms, hiring costs, and job finding rate of on-the-job searchers. Therefore, the interaction between φ and those parameters results in different dynamics.

5 | CONCLUSION

The unemployment rate and labor market tightness are two crucial macroeconomic indicators. The SM models enable us to study these labor market variables in a coherent economic environment. However, the business cycle models with the standard SM model structure are unable

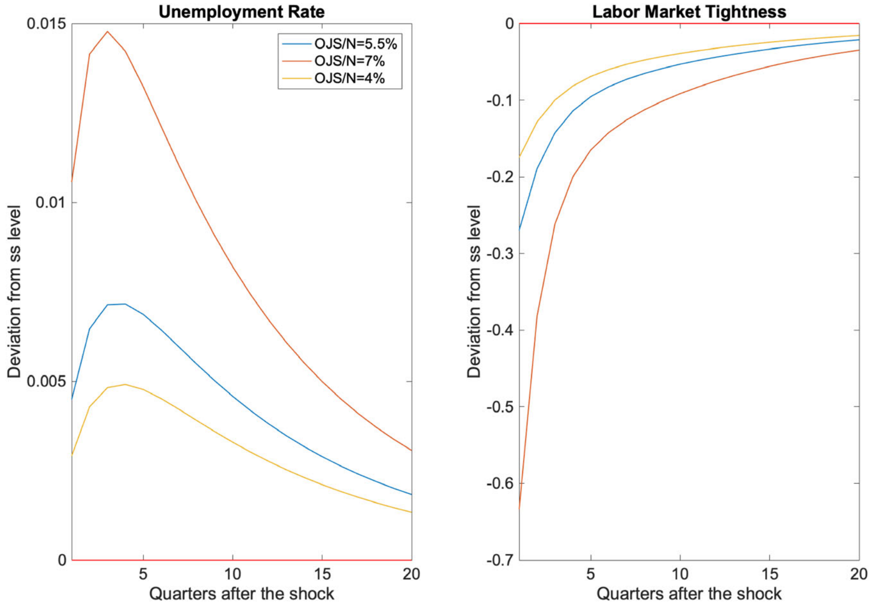

FIGURE 3 The impulse responses under different levels of the $OJS/((1-\delta)N)$ ratio (for 4%, 5.5%, 7%) [Colour figure can be viewed at wileyonlinelibrary.com]

to generate the observed fluctuations in the unemployment rate and labor market tightness in response to a positive technology shock both quantitatively and qualitatively. It is well-observed that an increase in the productivity level leads to an increase in the unemployment rate and to a decrease in labor market tightness. Galí (2010) provided a NK model with SM frictions that qualitatively replicate these empirical findings. However, for the quantitative match, his model is in need of further extensions. Along this line, Barnichon (2010, 2014) introduced variable labor effort to Galí (2010)'s model and replicated the aforementioned correlations quantitatively.

In this paper, we have introduced on-the-job search into a NK model in the intersection of the models proposed by Blanchard and Galí (2010) and Galí (2010). Our motivation is that a model with on-the-job search not only provides a realistic labor market environment but also stands as a good candidate to amplify the volatilities of unemployment and labor market tightness. To incorporate on-the-job search, we have assumed a two-tier sector including firms with different bargaining powers. Letting a fraction of workers to search on-the-job, we have shown that on-the-job search amplifies the volatilities of unemployment and labor market tightness without causing a change in the responses of other variables.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.