On-the-Job Search, Endogenous Job Separation, and the Labor Market Dynamics: A Quantitative Assessment

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Abstract

This paper re-visits the negative co-movement of unemployment and job vacancies over the business cycle by using a search and matching model. We develop an endogenous job separation model with on-the-job search and cyclical macroeconomic shocks. Incorporation of on-the-job search substantially improves the ability of the standard search and matching model with endogenous job separation to explain the cyclicality of labor market variables. Our model generates the pro-cyclicality of job vacancies and thus the negative co-movement of unemployment and job vacancies, which the standard endogenous separation model often fails to generate. Moreover, our model generates enough cyclical amplitude in the unemployment rate and the job finding rate to match what we observed in the data.

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1 Introduction

Over the business cycle, unemployment is counter-cyclical and job vacancies are pro-cyclical. The negative co-movement of unemployment and job vacancies is a key stylized fact in the labor market over the business cycle. Such a negative relationship is depicted by the Beveridge curve, which reflects the underlying matching process between employers and job seekers. The search and matching models have been used for explaining this stylized fact. However, recently the models face a difficulty in generating the negative relationship between unemployment and job vacancies. A number of studies demonstrate that models with endogenous job separation often cannot generate the observed pro-cyclicality of job vacancies, and thus cannot generate the observed negative relationship between unemployment and job vacancies (Shimer, 2005; Ramey, 2008; Mortensen and Nagypál, 2008).

This paper re-visits the negative co-movement of unemployment and job vacancies by focusing on worker flows. Recent empirical studies of the U.S. labor market reveal the following facts. First, the transition rate from unemployment to employment is pro-cyclical, while the transition rate from employment to unemployment is counter-cyclical. They contribute substantially to unemployment fluctuations over business cycle (Elsby, Michaels and Solon, 2009). Second, a large fraction of workers leaving jobs move to new jobs without intervening unemployment. This employer-to-employer flow is pro-cyclical and contributes to the cyclical movement of job vacancies (Fallick and Fleishman, 2004; Nagypál, 2005). These facts suggest that in order to study the cyclical behavior of labor market variables, especially unemployment and job vacancies, it is necessary to use a model in which workers' transition between employment, unemployment, and across jobs are endogenously determined.

In this paper, we develop a search and matching model in which workers' transition between employment, unemployment, and across jobs are endogenously determined. Our model builds on the endogenous separation model with on-the-job search developed by Miyamoto and Takahashi (2011), where key labor market variables and the distribution of employed workers in the steady state are endogenously determined. To study cyclical behavior of the labor market, we extend the model in a way that the economy moves between booms and recessions in a stochastic way. To explicitly characterize the dynamics of the model, we incorporate macroeconomic productivity shocks that follow a Poisson process and agents' rational expectations on the transition of the shocks. Thus, all labor market variables and the distribution of employed workers are computed in and out of steady-states. This allows us to analyze the dynamic behavior of worker flows over business cycles.

Our model can replicate both observed pro-cyclicality of the job finding rate and the employer-to-employer transition rate, as well as the counter-cyclicality of the employment to unemployment transition rate in the U.S. labor market. The main reason why the standard matching model with endogenous separation fails to generate the Beveridge curve is that a positive productivity shock can substantially reduce the number of job seekers (unemployed workers) by lowering job separation, which in turn makes vacancy posting less attractive. In our model, on the other hand, on-the job search adds another pool of workers for any new firm to recruit from. Since a positive productivity shock increases search activity by employed workers and thus expands the total number of job seekers, firms can have higher incentive to create vacancies.

Furthermore, our model substantially improve the ability of the search and matching model to generate enough cyclical amplitude in the job finding rate, which matches what we observed in the data. It is well known that the standard search and matching models cannot generate the observed fluctuation in the job finding rate in response to reasonable shocks (Costain and Reiter, 2008; Hall, 2005; Shimer, 2005). The incorporation of on-the-job search also helps to create amplification by generating the pro-cyclicality of job vacancies.

A number of studies use an on-the-job search model to study the cyclical behavior of the labor market. Pissarides (1994) and Krause and Lubik (2006, 2010) develop a search and matching model with two types of jobs (good and bad) to study the search activity of employed workers in bad jobs. In this paper, we allow for a continuum of job quality instead of just two discrete types. Nagypál (2007) develops an on-the-job search model with a continuum of job quality and studies the cyclical behavior of labor market variables. While job separation is exogenously determined in her model, it is endogenous in our model. Menzio and Shi (2011) develop a directed search model in which workers' transition between employment, unemployment, and across jobs are endogenously determined. By assuming that search process is directed, they characterize the equilibrium in the tractable way. In our model, we characterize the dynamics of the model by incorporating cyclical macroeconomic shocks and agents' rational expectations on the transition of shocks in the setting of random matching process.

The remainder of the paper is organized as follows. Section 2 presents salient features of the U.S. aggregate labor market over the business-cycle. Section 3 describes the theoretical model. We develop an endogenous job separation model with on-the-job search. In order to study the cyclical properties of the model, we incorporate agents' rational expectation on cyclical macroeconomic shocks into the model. In Section 4, we calibrate the model parameters and present the solutions of the model. Section 5 discusses the cyclical properties of the model. Section 6 concludes.

2 The U.S. labor market facts

This section presents some of the salient features of the U.S. labor market over the business cycle. We document the cyclical behavior of key variables in the labor market: unemployment, vacancies, and transition rates between employment and unemployment, and across employers. The cyclicality of labor market variables are studied by computing their elasticiies with respect to labor productivity.[1]

We measure labor productivity (p) as real output per person in the non-farm business sectors constructed by the Bureau of Labor Statistics (BLS). The unemployment rate (u) is the seasonally adjusted monthly data constructed by the BLS from the Current Population Survey (CPS). The data on vacancies (v) is the seasonally adjusted Help-Wanted Advertising Index constructed by the Conference Board. In this paper, we define the job finding rate (f) as the transition rate from unemployment to employment, and the separation rate (s) as the transition rate from employment to unemployment. These transition rates are constructed from the CPS short-term unemployment rate and the CPS unemployment data by using the method of Shimer (2007). Following Fallick and Fleischman (2004), we measure the rate at which workers move from employer to employer (ee). Fallick and Fleischman (2004) construct the employer-to-employer (EE) transition rate by exploiting the dependent interviewing techniques used in the CPS since 1994. In this paper, we simply update their measure of EE transition rate.

All data are transformed from monthly frequency into quarterly frequency by taking the average value for a quarter. We then construct the cyclical component of these variables as the difference between the log of the raw data and a Hodrick and Prescott (1997)'s (henceforth HP) trend with the smoothing parameter 1600. The series for u, v, f, s, and p cover the period 1951Q1-2006Q2, while the series for ee cover the period 1994Q1-2006Q2. Table 1 presents a statistical summary of the cyclical behavior of the U.S. labor market over the sample period.

The usual cyclical properties of the U.S. labor market are observed. While the unemployment rate is counter-cyclical, vacancies are pro-cyclical. These two variables exhibit a Beveridge curve with a contemporaneous correlation of -0.92. The job finding rate is procyclical and the separation rate is countercyclical. The pro-cyclicality of the job finding rate implies that in booms, it is relatively easy for unemployed workers to find jobs. The counter-cyclicality of the separation rate implies that in recessions, more employed workers lose their jobs. The EE transition rate is pro-cyclical. Thus, workers change jobs at a higher rate during booms. This is consistent with evidence that it is easier for workers to find new jobs due to a high job finding rate during booms.

In order to see the volatility of labor market variables, we compute the elasticities of variables of interest with respect to labor productivity. The unemployment rate, the job finding rate, and the separation rate are volatile. The elasticities of the unemployment rate, the job finding rate, and the separation rate are -2.50, 2.155, and -2.27, respectively. Job vacancies fluctuate more than these variables, and the elasticity is 4.41.

Note: The seasonally adjusted unemployment rate, u, is constructed by the Bureau of Labor Statistics (BLS) from the Current Population Survey (CPS). The job vacancies, v, are the seasonally adjusted Help-Wanted Advertising Index constructed by the Conference Board. The job finding rate, f, and the separation rate, s, are constructed from the CPS. The employer-to-employer transition rate, ee, is constructed from

[1] In this paper, we treat labor productivity as an exogenous variable.

Table 1: Summary statistics

		u	v	f	s	ee	p
Average		0.057	63.92	0.611	0.035	*0.025*	62.17
Elasticity w.r.t. p		-2.50	4.408	2.155	-2.27	-	1
	u	1	-0.918	-0.925	0.517	*-0.352*	-0.265
	v	-	1	0.906	-0.549	*0.270*	0.482
	f	-	-	1	-0.366	*0.305*	0.266
	s	-	-	-	1	*-0.05*	-0.544
	ee	-	-	-	-	1	
	p	-	-	-	-	-	1

the CPS by following Fallick and Fleischman (2004). Labor productivity, p, is real output per person in the non-farm business sectors constructed by the BLS. All variables are quarterly average of monthly series. The series for u, v, f, s, and p cover the period 1951Q1-2006Q2. The series ee covers the period 1994Q1-2006Q2. All variables are reported in logs as deviations from a Hodrick-Prescott (HP) trend with smoothing parameter 1600.

3 The model

We consider a continuous time search and matching model with endogenous job separation and on-the-job search. The basic structure of the model follows Miyamoto and Takahashi (2011).[2] The point of departure in this study is that we incorporate cyclical macroeconomic shocks to study the business cycle properties of the labor market.

We assume that each agent in the economy has rational expectations on macroeconomic shocks that affect an aggregate productivity of the economy.[3] The aggregate productivity takes two values p_h and p_l. p_h is the aggregate productivity parameter in a boom state h, and p_l is the aggregate productivity parameter in a recession state l. We assume that $p_h > p_l$. Macroeconomic shocks switch aggregate productivity between them and they are generated by a Poisson process with an arrival rate η. The Poisson process captures an important feature of cyclical shocks, boom or recession will end within a finite period of time with a positive probability less than one.

Output is produced by firm-worker pairs. Let the output of each firm in the state $i \in \{h, l\}$ be given by $p_i x$ where p_i is an aggregate productivity parameter common to all producing jobs,

[2] Miyamoto and Takahashi (2011) develop a search and matching model with disembodied technological progress to study the impact of productivity growth on unemployment. Since our focus is on cyclical behavior of the labor market, we consider a version of Miyamoto and Takahashi (2011)'s model in which aggregate productivity does not grow over time.

[3] Miyamoto and Shirai (2010) develop a search and matching model in which agents have rational expectations not only on microeconomic shocks, creasing and destroying jobs, but also on macroeconomic shocks.

and x is an idiosyncratic productivity specific to each job. The initial value of idiosyncratic productivity is drawn from a distribution $F : [\underline{x}, \bar{x}] \to [0, 1]$. When an idiosyncratic shock arrives at Poisson rate λ, the value of idiosyncratic productivity changes and a new value of x is drawn from the distribution $G : [\underline{x}, \bar{x}] \to [0, 1]$.

There is a large measure of ex-ante identical firms and a unit measure of ex-ante identical workers. All agents are infinitely lived and maximize the present discounted value of their income stream with discount rate r.

A firm has only one job that can either be filled or vacant. One job is filled by one worker. A firm produces output if its job is filled. If a firm does not employ a worker, it posts a vacant job at flow cost γ and searches for a worker. Firms are free to enter the market. A worker can be either employed or unemployed. Regardless of employment state, a worker can search for a new job. If a worker is employed, she produces output and earns an endogenous wage w. If she is not employed, she gets a flow utility z and searches for a job.

Match separation occurs as the results of one of three distinct events. First, a job can be terminated by an exogenous shock that occurs at Poisson rate δ. Second, when an idiosyncratic shock arrives and a job becomes no longer profitable, the firm chooses to close down. In these two cases, the firm can either reopen a job as a new vacancy or withdraw from the labor market, while the worker becomes unemployed. Third, a worker quits when she meets an outside firm with greater productivity than the current firm. This induces a job-to-job transition. Again, the firm can either reopen a vacant job or exit from the market.

There is a single matching function that determines the number of meetings between workers and firms, as a function of the total amount of search effort of workers, $\bar{e}$, and the number of vacancies posted, v. The matching function $m_t = m(v_t, \bar{e}_t)$ is continuous, twice differentiable, increasing in its arguments, and exhibits constant returns to scale. The meeting rate per unit of vacant jobs is $m(1, \bar{e}/v) \equiv q(\theta)$, where $\theta \equiv v/\bar{e}$ is the labor market tightness. Then, the meeting rate per unit of search effort for workers is $m(v/\bar{e}, 1) = \theta q(\theta)$. Both unemployed and employed workers can search for a new job at a flow cost $c(e)$, where e is the search effort and $c(e)$ is a strictly increasing, strictly convex, twice continuously differentiable function with $c(0) = c'(0) = 0$. Workers exerting search effort e encounter new job opportunities at the Poisson rate $\theta q(\theta)e$.

3.1 Value functions

The value of an employed worker in a job with productivity x in the state i, $W_i(x)$, satisfies the following Bellman equation:

$$\begin{aligned} rW_i(x) \quad = \quad & \max_{e_i \geq 0} \left\{ w_i(x) - c(e_i) + \lambda \int \left(\max \left[W_i(x'), U_i \right] - W_i(x) \right) dG(x') + \delta \left[U_i - W_i(x) \right] \right. \\ & \left. + e_i \theta_i q(\theta_i) \int_{\underline{x}}^{\bar{x}} \mathbb{I}_{\{W_i(x') > W_i(x)\}} \left[W_i(x') - W_i(x) \right] dF(x') + \eta \left[W_j(x) - W_i(x) \right] \right\}, \quad (1) \end{aligned}$$

where U_i is the value of an unemployed worker in the state i and $\mathbb{I}_{\{\cdot\}}$ is an indicator function that equals one if its expression is true and equals zero otherwise. The flow payoff from working is $w_i(x)$. The match draws a new value of idiosyncratic productivity, x', at rate λ, in which case the worker loses the current asset value $W(x)$ and gain the asset value associate with working at x' or being unemployed, whichever is greater. Moreover, the worker loses the asset value due to exogenous separation with rate δ. The worker optimally chooses her search effort at cost $p_i c(e_i)$. If she encounters a new firm, she accepts any job that has a higher asset value $W_i(x')$ than the current asset value $W_i(x)$. The asset value of a match is expected to change due to a change in the macroeconomic state from i to $j \in \{h, l\} \backslash \{i\}$ with rate η.

The value of an unemployed worker in the state i is

$$rU_i = \max_{e} \left\{ z - c(e_i) + e_i \theta_i q(\theta_i) \int \left(\max\left[W_i(x), U_i\right] - U_i \right) dF(x) + \eta \left[U_j - U_i\right] \right\} \tag{2}$$

An unemployed worker also chooses her search effort at cost $c(e_i)$.

Turning to the firm's side, the value of a firm with a filled job with idiosyncratic productivity x in the state i, $\Pi_i(x)$, satisfies

$$\begin{aligned} r\Pi_i(x) \quad = \quad & p_i x - w_i(x) + \lambda \int \left(\max\left[\Pi_i(x'), V_i\right] - \Pi_i(x) \right) dG(x') + \delta \left[V_i - \Pi_i(x)\right] \\ & + e_i(x) \theta_i q(\theta_i) \int_{\underline{x}}^{\bar{x}} \mathbb{I}_{\{W_i(x') > W_i(x)\}} \left[V_i - \Pi_i(x)\right] dF(x') + \eta \left[\Pi_j(x) - \Pi_i(x)\right], \end{aligned} \tag{3}$$

where V_i is the value of posting a vacancy in the state i and $e_i(x)$ is the optimal search effort of an employed worker in a job with productivity x. The flow payoff of the match to the firm is $p_i x - w_i(x)$. The match draws a new value of idiosyncratic productivity at rate λ. Facing the changed productivity, the firm continues producing if $\Pi_i(x')$ is larger than V_i. The match is destroyed exogenously at rate δ. The worker quits at rate $e_i(x)\theta_i q(\theta_i) \int_{\underline{x}}^{\bar{x}} \mathbb{I}_{\{W_i(x') > W_i(x)\}} dF(x')$, in which case the job is destroyed and the firm loses its asset value. The asset value of a match is expected to change due to a change in the macroeconomic state from i to j with rate η.

3.2 Wage determination and endogenous job separation

We assume that wages are determined by sharing the match surplus, where the worker and the firm receive shares β and $1 - \beta$, respectively.[4] We assume that the wage contract is renegotiated whenever new information arrives.[5] The total match surplus function in the state i is given by

$$S_i(x) = \Pi_i(x) + W_i(x) - U_i - V_i. \tag{4}$$

[4] In Miyamoto and Takahashi (2011), we discuss other possible wage determination mechanisms.

[5] Note that the same sharing rule holds out of steady state, consistent with the assumption that a firm and a worker can renegotiate any time new information arrives.

Surplus sharing implies that $\Pi_i(x) - V_i = (1-\beta)S_i(x)$ and $W_i(x) - U_i = \beta S_i(x)$. It is assumed that wages are determined by taking the search effort of workers as given, while search effort is chosen by workers in anticipation of the wage outcome. We assume that wages can be revised continuously at no cost, so there are no long-run contracts. Furthermore, we assume that matches cannot be recalled. This implies that the outside option of the worker is unemployment.[6]

Using equations (1), (3), and (4), we obtain

$$\begin{aligned}(r+\lambda+\delta+\eta)\, S_i(x) \quad &= \quad p_i x - c(e_i(x)) - r(U_i + V_i) + \eta\,[U_j - U_i] + \lambda \int \max\,[S_i(x), 0]\, dG(x') \\ &\quad + e_i(x)\theta_i q(\theta_i) \int_{\underline{x}}^{\bar{x}} \mathbb{I}_{\{W_i(x') > W_i(x)\}} \left[\beta S_i(x') - S_i(x)\right] dF(x') + \eta S_j(x).\end{aligned}$$

Note that $S_i(x)$ is strictly increasing in x, and thus $W_i(x)$ is strictly increasing in x. This implies that the acceptance decisions of an unemployed worker has the reservation property. Thus, an unemployed worker accepts any job with productivity $x \geq R_i$, where R_i is defined by $W_i(R_i) = U_i$. This yields $S_i(R_i) = 0$.

Since the surplus function $S_i(\cdot)$ is strictly increasing in x, the firm and the worker choose a reservation policy, i.e., they will continue their match if $S_i(x) \geq 0$ but stop if $S_i(x) < 0$. Thus, separation takes place at $x \leq R_i$.[7] Note that the reservation productivity at the time the match is formed is the same as the one at match dissolution, even though the initial distributions of productivity differ.

3.3 The optimal search choice

The optimal search effort of an employed worker and an unemployed worker is found by use of (1) and (2). Together with the surplus sharing rule, they yield

$$c'(e_i(x)) = \theta_i q(\theta_i) \int_x^{\bar{x}} \left[W_i(x') - W_i(x)\right] dF(x') = \theta_i q(\theta_i)\beta \int_x^{\bar{x}} \left[S_i(x') - S_i(x)\right] dF(x'), \qquad (5)$$

and

$$c'(e_i^u) = \theta_i q(\theta_i) \int_{R_i}^{\bar{x}} [W_i(x) - U_i]\, dF(x) = \beta\theta_i q(\theta_i) \int_{R_i}^{\bar{x}} S_i(x) dF(x), \qquad (6)$$

where the optimal search effort of an unemployed worker in the state i is denote by e_i^u. Because the search cost function is strictly convex and $S(x)$ is strictly increasing, the optimal search effort by employed workers is strictly decreasing in x for $x < \bar{x}$. Furthermore, by the convexity of $c(\cdot)$ and $c'(0) = 0$, $e(x) = 0$ for $x \geq \bar{x}$.

[6] It is important to note that the non-convexity of the Pareto frontier discussed in Shimer (2006) does not arise in our model because of the timing assumption and the nature of bargaining. See Miyamoto and Takahashi (2011) for the details.

[7] We assume that a firm can shut down unprofitable jobs without delay. Thus, the zero-profit condition holds in and out of steady-state.

Under the assumption that the cost of search effort is the same whether employed or not, a comparison of equations (5) and (6) implies that the optimal search effort when unemployed equals the search effort when employed at $x = R_i$, i.e., $e_i^u = e(R_i)$.

3.4 Vacancy creation

The value of posting a vacancy is

$$rV_i = -\gamma + q(\theta_i) \int_{\underline{x}}^{\bar{x}} \left[\Pi_i(x) - V_i\right] \Theta_i(x) dF(x) + \eta \left[V_j - V_i\right], \tag{7}$$

where $\Theta_i(x)$ is the probability that a searching worker accepts a job with productivity x in the state i. This is the ratio of search effort by workers who are willing to accept a match with initial productivity x to the total amount of search effort $\bar{e}$ exerted by all workers.

The measure of employed workers in jobs with an idiosyncratic productivity less then or equal to x is denoted by $H_i(x)$. Thus, $H_i(x)$ is the distribution of employed workers.

The total amount of search effort $\bar{e}$ exerted by all workers is

$$\bar{e}_i = ue_i^u + (1-u) \int_{R_i}^{\bar{x}} e_i(x') dH_i(x').$$

Then, the acceptance probability will be

$$\Theta_i(x) = \begin{cases} \bar{e}_i^{-1} \left[ue_i^u + (1-u) \int_{R_i}^{x} e_i(x') dH_i(x')\right] & \text{if } x \geq R_i \\ 0 & \text{if } x < R_i \end{cases}.$$

Free entry implies that the value of a vacancy is zero in equilibrium.[8] Thus,

$$V_i = 0.$$

3.5 Labor market dynamics

The evolution of unemployment in each aggregate state is given by

$$\dot{u} = \left[\lambda G(R_i) + \delta\right](1-u) - \theta_i q(\theta_i) e_i^u \left[1 - F(R_i)\right] u.$$

Thus, the steady-state unemployment rate in the state i is

$$u_i = \frac{\lambda G(R_i) + \delta}{\lambda G(R_i) + \delta + \theta_i q(\theta_i) e_u^i \left[1 - F(R_i)\right]}.$$

To close the model, we need to derive the evolution of the distribution of employed workers across idiosyncratic productivity levels, $H(x)$. Recall that $H(x)$ is the measure of employed

[8]We assume that firms can open and close vacancies without delay. This implies that regardless of whether they are in the steady-state or out of it, the free entry condition holds. Thus, $V = \dot{V} = 0$.

workers in jobs with an idiosyncratic productivity less than or equal to x. The change in the mass $H(x)$ over time is derived by computing the inflows less the outflows from that mass. In each aggregate state i, it is given by

$$\begin{aligned} \dot{H}(x) &= \theta_i q(\theta_i) e_i^u \left[F(x) - F(R_i)\right] u + \lambda \left[G(x) - G(R_i)\right] \left[H(\bar{x}) - H(x)\right] \\ &\quad - \left(\lambda G(R_i) + \delta\right) H(x) - \lambda H(x) \left[1 - G(x)\right] - \theta_i q(\theta_i) \left[1 - F(x)\right] \int_{R_i}^{x} e_i(x') dH(x'). \quad (8) \end{aligned}$$

The first and second terms in the right-hand side of (8) are the inflows to the mass H. The inflows consists of unemployed and employed workers. The flow of unemployed workers who obtain a job with productivity x or less is given by the first term. Due to the idiosyncratic productivity shocks, employed workers who originally work in jobs with productivity higher than x may move to this mass, which is captured by the second term. The outflows from this subset consists of three components, which are represented by the second line of (8). The first component is the flow of those who lose their jobs after an idiosyncratic productivity shock or an exogenous separation shock, which is equal to $\left(\lambda G(R_i) + \delta\right) H(x)$. The second one is is the flow of those whose jobs' productivity becomes higher than x after the arrival of an idiosyncratic productivity shock and this equals $\lambda H(x) \left[1 - G(x)\right]$. The third one is the flow of those who find jobs that have a higher productivity than their current jobs, which is captured by the last term.

The measure of employer-to-employer (EE) transition is given by

$$EE_i = (1 - u_i) \int_{R_i}^{\bar{x}} \theta_i q(\theta_i) e_i(x) \left[1 - F(x)\right] dH_i(x),$$

so that the EE transition rate is

$$\lambda^{ee} = \int_{R_i}^{\bar{x}} \theta_i q(\theta_i) e_i(x) \left[1 - F(x)\right] dH_i(x).$$

Since the flow of employment-to-unemployment transition is $\left[\lambda G(R_i) + \delta\right](1 - u_i)$, the separation rate, defined as the flow rate from employment to unemployment is $\lambda G(R_i) + \delta$.

4 Quantitative analysis

In this section, we calculate the equilibrium of the above model using numerical methods, since it is not possible to solve analytically. We first calibrate the model to match several dimensions of the data. Then, we solve the model numerically under the calibrated parameter values.

4.1 Calibration

We calibrate the model to match certain U.S. labor market facts. We choose one quarter as the length of a model period. We set the discount rate $r = 0.012$ to match the annual real interest rate of approximately 5%.

We assume the matching function is Cobb-Douglas, given by $m(v, \bar{e}) = m_0 v^{1-\alpha} \bar{e}^{\alpha}$, where m_0 is the matching constant and α is the matching elasticity with respect to the total search effort of workers. Following Mortensen and Nagypál (2007), the elasticity parameter α is set to 0.5.

The search cost function is specified by $c(e) = c_0 e^{1+\kappa}$, where c_0 is a scale parameter and $\kappa > 0$.[9] Following Miyamoto and Takahashi (2011), we assume that the idiosyncratic productivity distribution F is a truncated exponential in the range $[0, 1]$, so that $F(x) = \frac{1-\exp(-\nu x)}{1-\exp(-\nu)}$. This distribution is useful because a single parameter controls the extent to which new draws are concentrated towards the lower end of the distribution. We assume $G = F$. The aggregate productivity in the state l, p_l, is normalized to one.

Silva and Toledo (2009) use evidence provided by Davis, Faberman, and Haltiwanger (2006) and Nagypál (2004) to determine the exogenous and endogenous components of the separation rate. They assume that endogenous job separation accounts for, on average, 35% of total separations. Since we target a total separation rate of 0.036, we set the monthly exogenous separation rate at $\delta = 0.0234$. Following Miyamoto and Takahashi (2011), we set the unemployment flow utility z to 0.202.[10]

Given this, we target mean levels of the unemployment rate (0.057), the vacancy rate (0.043), the job finding rate (0.061), the separation rate (0.035), and the job-to-job transition rate (0.025). We also target the elasticities of these variables with respect to labor productivity reported in Table 1.

Following Elsby and Michaels (2008), we target the elasticity of average wages of newly hired workers with respect to aggregate productivity to be equal to approximately 0.8, based on the results of Haefke, Sonntag and van Rens (2009).[11] Following Miyamoto and Takahashi (2011), we target the mean-min wage ratio to be equal to 1.70.[12] We target the mean-min wage ratio because the spread of the distribution of idiosyncratic productivity affects the distribution of wages. In order to calibrate an aggregate productivity process, we target the frequency of switching from

[9] The calibrated $\kappa = 0.193$ suggests that the search cost function is approximately linear and search is highly elastic. Merz (1995) and Krause and Lubik (2006) also find a similar value of κ to ours. Krause and Lubik (2006) argue that a value of κ close to zero appears the most plausible for a variety of reasons. First, there may be increasing returns to search. Second, the model tries to explain data generated by search at both the intensive and extensive margins.

[10] As suggested by Hall and Milgrom (2008), Miyamoto and Takahashi (2011) target the unemployment flow utility z to be 71% of the average wage of employed workers in the economy. They assume that the unemployment flow utility includes both unemployment insurance and the value of leisure.

[11] Haefke, Sonntag and van Rens (2009) document that wages of newly hired workers strongly respond to aggregate labor market conditions while the wages of workers in ongoing jobs does not fluctuate much. The main reason why we target the elasticity of newly hired workers' wages is that the flexibility of new hires' wages is relevant to the cyclicality of the job finding rate in a labor market with search frictions, since it affect firms' decisions to create jobs. Furthermore, rigid wages of workers in ongoing job relationships are at odds with the assumption of Nash wage setting that we employ in this paper.

[12] Using a variety of data sources, Hornstein, Krusell and Violante (2007) estimate the mean-min wage ratio to be between 1.5 and 2. Thus, our target value lies in the middle of their result.

one state to another. We use the result of the NBER's Business Cycle Dating Committee to pin down the frequency of switches. In addition, to capture the adjustment speed of labor market variables, we use the elasticity of the unemployment rate in two-period ahead with respect to labor productivity as our target. By using these moments, we choose the parameter values of c_0, m_0, p^h, γ, η, κ, λ, and ν. The parameter values are summarized in Table 2.

Table 2: Parameter values

Parameter	Description	Value	Source/Target
r	Discount rate	0.012	Data
p_l	Aggregate productivity	1	Normalization
z	Flow value of unemployment	0.202	Miyamoto and Takahashi (2011)
α	Elasticity of matching function	0.5	Mortensen-Nagypál (2007)
δ	Exogenous job separation rate	0.023	65% of total separation
c_0	Scale parameter of search cost function	0.935	Match target moments:
m_0	Scale parameter of matching function	28.74	Mean and elasticity of the unemployment rate,
p_h	Aggregate productivity	1.042	the vacancy rate, the job-finding rate,
γ	Cost of posting a vacancy	2.621	the separation rate, and
β	Worker's bargaining power	0.545	job-to-job transition rate
η	Arrival rate of cyclical shocks	0.165	mean-min wage ratio
κ	Parameter in search cost function	0.193	elasticity of average wages of newly hired
λ	Arrival rate of idiosyncratic shock	0.314	the number of switches
ν	Parameter in productivity distribution	3.459	the elasticity of u_{t+2} w.r.t p_t

4.2 Model solutions

Table 3 reports the selected endogenous variables of interest under the calibrated parameter values. The results are encouraging. The mean levels of the relevant labor market variables are close to their data moments. The model generates the correct signs for the elasticities. The model-implied elasticities in the unemployment rate and the job finding rate are larger than their data moments. This implies that our model can generate enough cyclical amplitude in these two variables, which the standard search and matching models often fail to generate. Regarding job vacancies and the job finding rate, the model-implied elasticities fall short of what observed in the data.

The model also predicts the correct signs for all correlation coefficients. The correlation between the unemployment rate and the vacancy rate is -0.74. Although this is lower than the empirical counterpart, the model succeeds to generate the negative co-movement of unemployment and vacancies. While the correlation between the job finding rate and the unemployment rate matches the data moment well, the correlation coefficients of the separation rate and the EE transition rate are much greater than their empirical counterparts.

The mean-min wage ratio is 2.53, which is higher than the target value. However, several previous studies on wage dispersion, especially those with labor market friction, find similar values. The elasticity of average wages of newly hired workers with respect to aggregate productivity is 0.62, which is slightly lower than the target value of 0.77. The rate of switching from one state to another one is 0.048 and the elasticity of the unemployment rate in two-period ahead with respect to aggregate productivity is -2.97. They are close to their empirical moments, 0.049 and -5.32, respectively.

The steady-state equilibrium values of interest in states h and l are also reported in Table 3. It shows that, under plausible parameter values, when an aggregate productivity is high, labor market tightness and search effort are high, while the reservation productivity is low. A higher aggregate productivity increases the value of a match and encourages firms to open more vacancies. It also makes job separation more costly and lowers the reservation productivity. Since a higher productivity increases the benefits of searching for a job, the optimal search effort increases. Labor market tightness and search effort increases and the reservation productivity decreases with a high aggregate productivity. As a result, the unemployment rate falls and vacancies increases.

In Figure 1, we plot the density of the distribution of initial idiosyncratic productivity draws F and the endogenous equilibrium distribution of employed workers across productivity H in states h and l. Since employed workers move from low to high productivity jobs through on-the-job search, H first-order stochastically dominates F.

The equilibrium distribution of employed workers is skewed right, which is well approximated by the lognormal distribution. Several counteracting effects generate this right skewed distribution. First, since employed workers in low productivity job have a high search effort, they are more likely to move to high productivity jobs. Second, since it is hard for high-paid workers to find a better job, the mass in the upper portion of the support of match productivity increases less rapidly. Third, due to a shape of the initial distribution, an idiosyncratic productivity shock reduces the number of employed workers in the upper portion of the support. While the first effect tends to reduce the number of employed workers in lower productivity jobs, the second and third effects tend to reduce the number of workers in higher productivity jobs.

The comparison of the equilibrium distribution in a boom with that in a recession shows that a level of aggregate productivity affects the characteristic of the distribution in two ways. First, an increase in aggregate productivity reduces the reservation productivity value, and then the support of the endogenous distribution of employed workers becomes larger. Second, an increase in aggregate productivity increases the composition of employed workers in jobs with high productivity. Specifically, for relatively low idiosyncratic productivity x, the number of employed workers in a recession is larger than that in a boom, while for relatively high x, the number of employed workers in a recession is smaller than that in a boom.

The equilibrium search effort as a function of idiosyncratic productivity is plotted in Figure 2. The optimal search effort of workers is decreasing with idiosyncratic productivity. Thus, the search effort of unemployed workers is higher than that of employed workers. Figure 2 shows that the optimal search effort is higher when an aggregate productivity is high. This is because a higher aggregate productivity increases the benefits of searching for a job.

Table 3: Model Solutions

Variable	Description	Mean		Elasticity		Solution	
		Data	Model	Model	Data	at p_h	at p_l
θ	Labor market tightness					.338	.332
R	Reservation productivity					.158	.165
u	Unemployment rate	.057	.050	-2.50	-3.406	.047	.055
v	Job vacancies	.043	.036	4.408	1.554	.036	.034
-	Job finding rate	.611	.651	2.155	3.509	.690	.598
$\lambda G(R) + \delta$	Separation rate	.035	.034	-2.27	-.263	.0341	.0345
$\bar{e}$	Total amount of search effort					.108	.104
e^u	Search effort of an unemployed					.876	.786
λ^{ee}	EE transition rate	.025	.031	2.20	2.519	.032	.029

	$Corr(u,v)$	$Corr(u,f)$	$Corr(u,s)$	$Corr(u,\lambda^{ee})$
Data	-0.74	-0.96	0.96	-0.87
Model	-0.92	-0.93	0.52	-0.35

5 Business Cycle Analysis

This section studies the cyclical properties of our model. We first study the dynamics of the model by examining the responses of labor market variables to macroeconomic shocks. Second, we study whether our model can generate enough cyclical amplitude in key labor market variables. Lastly, we consider a model without on-the-job search and study the cyclical properties of the model. By comparing our model with the model without the on-the-job search, we can assess the contribution of the on-the-job search on our results.

5.1 Dynamics

We now study the dynamics of the model by examining the response of the economy to shocks to aggregate productivity. Before examining the responses of labor market variables to a shock to aggregate productivity, it is useful to study the effect of the shock on endogenous variables, v,

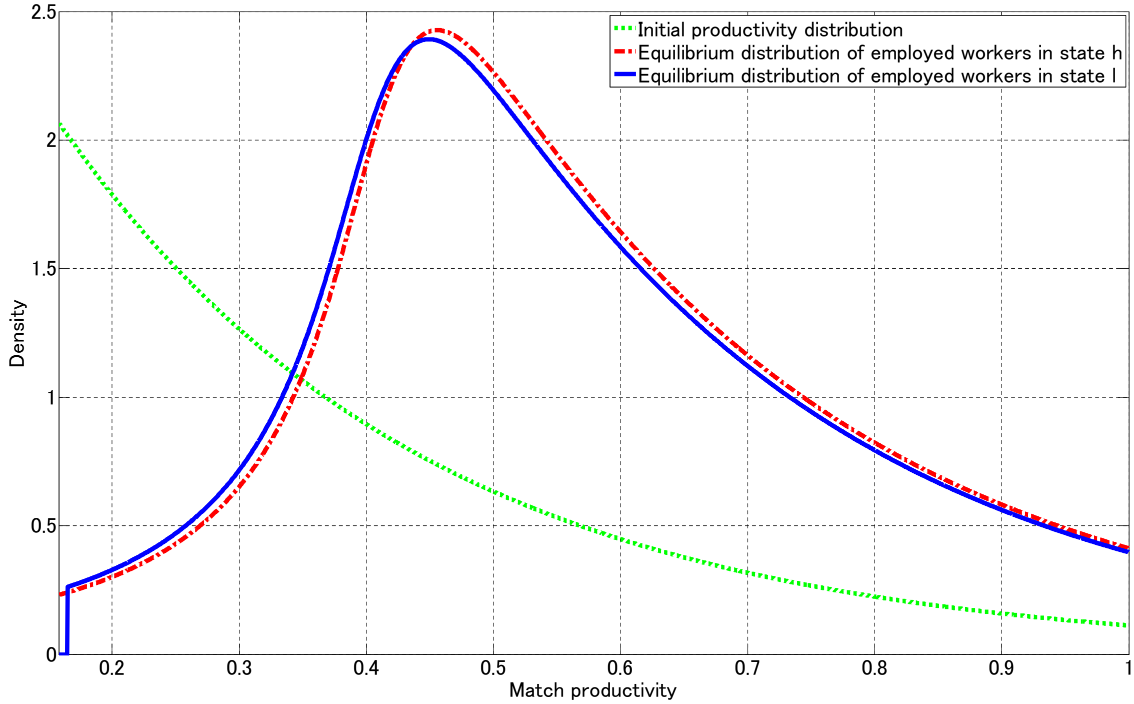

Figure 1: Distribution of employed workers

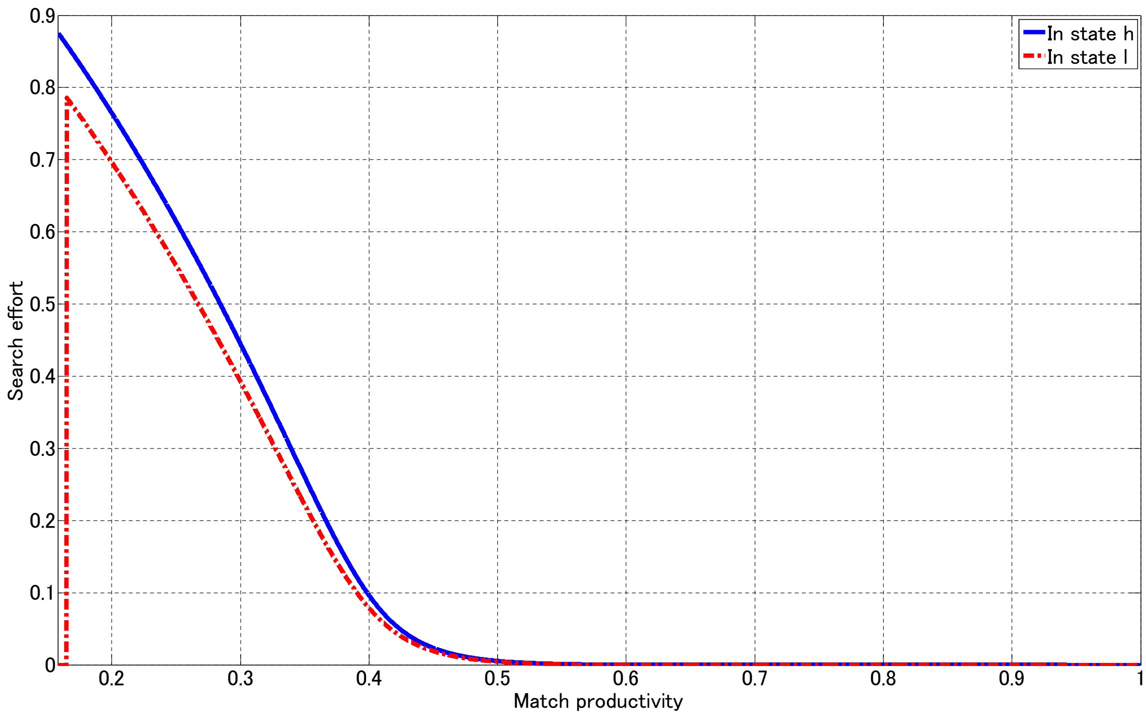

Figure 2: Optimal search effort

θ, R, $e(x)$, and e^u. In the steady-state, we obtain the equilibrium value of labor market tightness from the assumption that expected profit from creating a new vacancy is zero. We assume that this property holds out of the steady-state as well. In other words, we assume that firms can open and close vacancies without delay. To ensure that this assumption holds, job vacancies (v) and so market tightness (θ) have to be jump variables. Similar assumption is made about the reservation productivity determination. We assume that a firm can shut down unprofitable jobs without delay, and thus the zero-profit condition holds in and out of steady-state. Under this assumption, the reservation productivity R becomes a jump variable. Furthermore, since optimal search conditions do not depend on sticky variables, the optimal search effort $e(x)$ and e^u become jump variables too. A positive shock to aggregate productivity increases θ, $e(x)$, and e^u, and reduces R, while a negative shock reduces θ, $e(x)$, and e^u, and increases R.

The effect of a positive macroeconomic shock We begin by examining the effect of a positive shock to the aggregate productivity. The economy is initially assumed to be in the steady state associate with aggregate productivity p_l. Then, a macroeconomic shock hits the economy and aggregate productivity jumps up to p_h, and afterward, remains at this higher level.

Figure 3-(a) show the response of the job-finding rate and the separation rate to the positive shock to p. On the impact, the job-finding rate jumps up and the separation rate jumps down to their steady-state values associated with p^h through an upward jump in θ and a downward jump in R. An increase in θ and decrease in R raise the probability that an unemployed worker finds a job. The separation rate falls because the decrease in R lowers job destruction after an idiosyncratic shock is revealed.

The unemployment rate is a sticky variable and is driven by jumps in the three forward-looking variables, θ, R, and e^u. As seen in Figure 3-(b), following the initial changes of these variables, the unemployment rate starts declining smoothly until it converges to the steady-state value associated with p^h.

Figure 3-(b) also shows the response of the EE transition rate. On the impact, the EE transition rate jumps up due to upward jumps in θ and $e(x)$. Then, the EE transition rate has a hump-shaped response. This hump-shaped response is generated by the shift of the distribution of employed workers toward jobs with lower idiosyncratic productivity. A decrease in reservation productivity increase employed workers in low productivity jobs. Since they have high search intensity and are likely to find a better job, the EE transition rate initially increases. However, eventually the composition of employed workers in high productivity jobs increases. Since they have low search intensity and less likely to find a better job, the EE transition rates decreases toward the new steady-state value.

Figure 3-(c) shows the response of the number of job vacancies to a positive aggregate shock. On the impact, the total number of vacancies in the economy jumps up and then starts declining toward its steady-state value associate with p^h. In order to see the role of on-the-job search in

vacancy creation, we decompose the number of job vacancies into vacancies filled by unemployed workers (vu) and vacancies filled by employed workers (ve). On the impact, vu jumps up because of upward jumps in labor market tightness and search efforts. Then, it decreases over time because the number of unemployed workers decreases. The decline in unemployed workers lowers firms' incentive to open vacancies for this group of workers. Note that the number of vacancies for unemployed workers becomes lower than its initial value. On the other hand, on the impact, ve jumps up and then has a hump-shaped response. This hump-shaped response is generated by the effects that generate the hump-shaped response of the EE transition rate. Overall, the increase in vacancies for employed workers dominates the decrease in vacancies for unemployed workers, and then the total number of vacancies increases.

The effect of a negative macroeconomic shock We now turn to study the effect of a negative shock to aggregate productivity. We assume that the economy is initially in the steady state associate with p_h. Then a negative shock hits the economy and aggregate productivity jumps down to p_l, and afterward, remains at this lower level.

Table 4-(a) shows the response to the aggregate shock of the job finding rate and the separation rate. On the impact, the job finding rate jumps down and the separation rate jumps up to their steady state values associated with p_l and they remain in the values.

The dynamics of the unemployment rate is asymmetric, in the sense that it jumps up at the moment of a shock on aggregate productivity. Since the reservation productivity R jumps up at the moment of the negative shock, the jobs with idiosyncratic productivity x in the range $R_h \leq x < R_l$ become unprofitable and close down. The number of workers who lose their jobs is $H_h(R_l) - H_h(R_h)$ and unemployment increases instantaneously by this amount. Following this jump, the unemployment rate increases over time toward the steady-state value associated to p_l. Figure 4-(b) shows the response of the unemployment rate to the negative shock.

When the negative shock hits the economy, the EE transition rate falls instantaneously. This drop is due to downward jumps in θ and $e(x)$ and upward jump in R. It is important to note that the magnitude of this drop is larger than that of the rise in the EE transition rate when a positive shock is revealed. This is because some employed workers whose search efforts are high lose their jobs immediately when the negative shock hits the economy. Following this initial change, the EE transition rate decreases for a while and then increases toward a new steady-state value. Figure 4-(b) shows the response of the EE transition rate to the negative aggregate productivity shock.

Figure 4-(c) shows the response of the total numbers of job vacancies, vacancies filled by unemployed workers (vu), and vacancies filled by employed workers (ve). On the impact, both vu and ve jump down due to downward jumps in labor market tightness and search effort of workers. Following the initial changes, vu increases over time toward the steady-state value associated with p^l. Since the number of unemployed workers increases and they have high search effort, firms have incentive to open vacancies for them. It is of interest that vacancies for unemployed workers in a

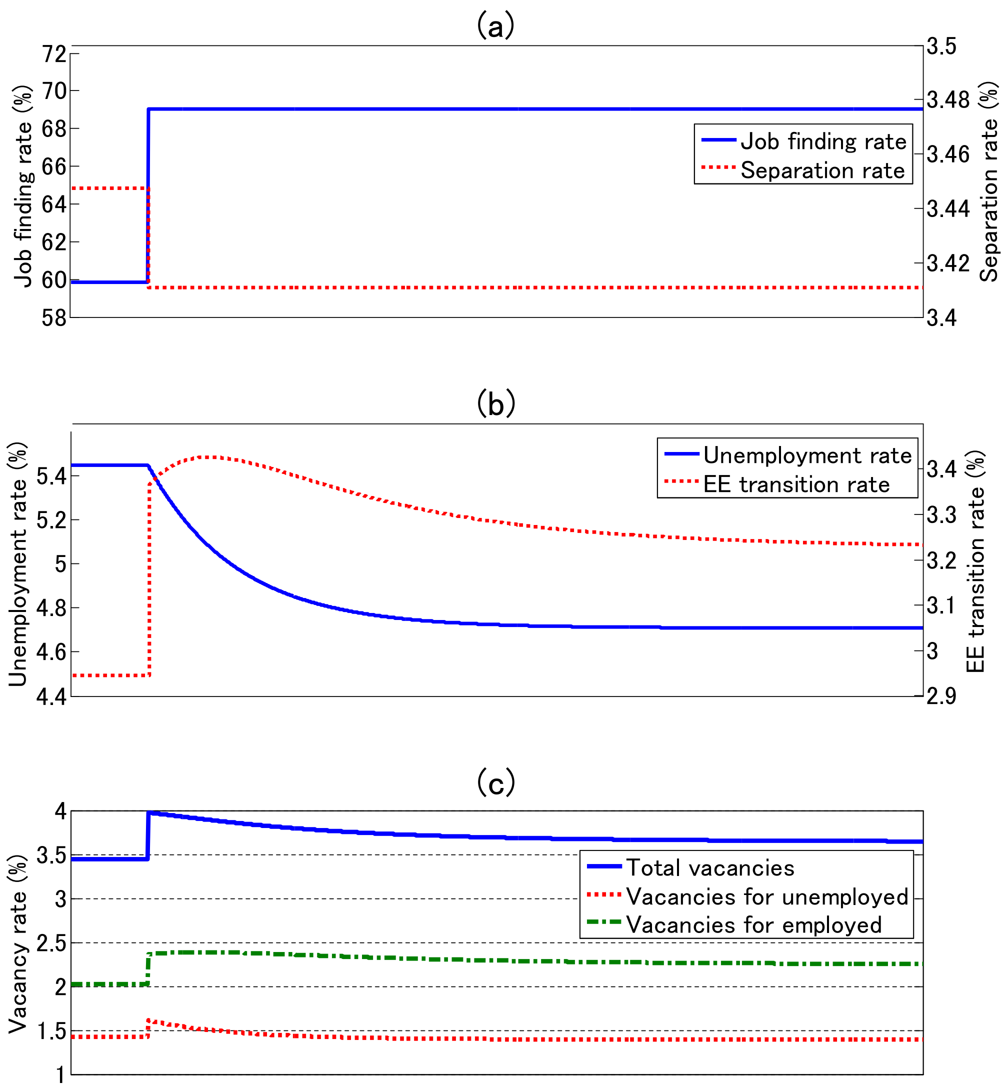

Figure 3: Responses to a positive shock (From recession to boom)

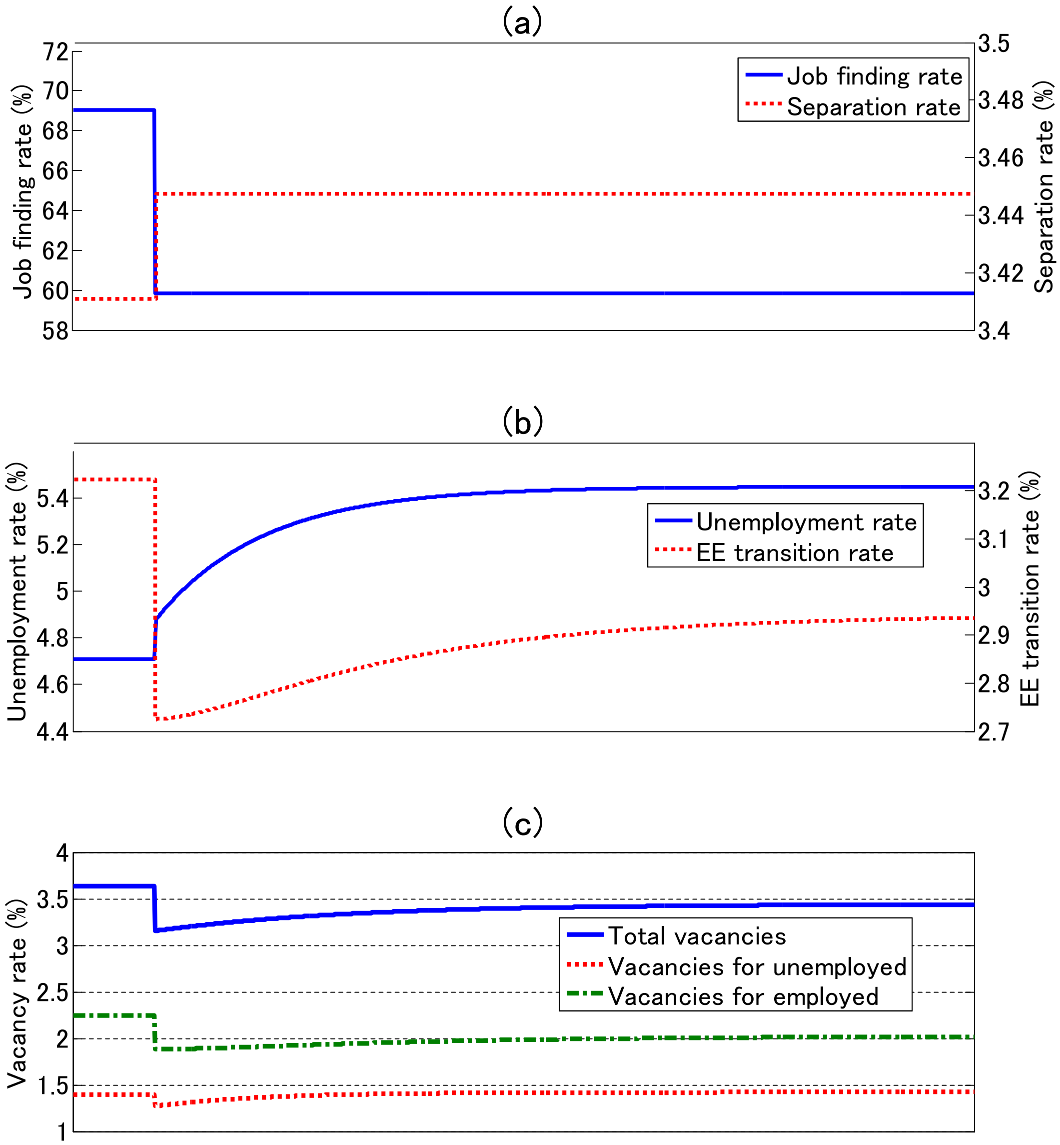

Figure 4: Responses to a negative shock (from boom to recession)

recession are greater than those in a boom. On the other hand, following the initial change, ve first declines and then increases toward the new steady state value. Since the number of employed workers decreases, firms first reduce job vacancies for employed workers. However, the shift of the distribution of employed workers toward matches with lower idiosyncratic productivity increases the number of actively searching employed workers. Thus, firms start to open job vacancies for these workers. Since the decrease in ve is larger than the increase in vu, overall, the number of total job vacancies decreases.

5.2 Business-cycle volatility

Recent research has demonstrated that the standard search and matching model cannot generate enough cyclical amplitude in key labor market variables, particularly in the job finding rate to match that observed in U.S. data.[13] We now study whether our model can solve this problem. To address this, we re-calibrate our model without targeting the elasticities of unemployment, vacancies, the job-finding rate, the separation rate, and the EE transition rate with respect to labor productivity, and compute these measures by using simulated data.

Table 4: Volatility of Labor Market Variables

	Data	Model with OJS	Comparative Statics
$\partial \ln u / \partial \ln p$	-2.50	-5.037	-5.339
$\partial \ln v / \partial \ln p$	4.408	1.964	1.618
$\partial \ln f / \partial \ln p$	2.155	5.407	5.407
$\partial \ln s / \partial \ln p$	-2.27	-0.288	-0.288

Table 4 reports the results of this exercise. Similar to our original results, the model generates the counter-cyclicality of the unemployment rate and the separation rate, and the pro-cyclicality of vacancies, the job-finding rate, and the EE transition rate. Thus, the prediction of the model is consistent with basic U.S. labor market facts. In terms of magnitude, while the model-generated elasticities in the unemployment rate and the job finding rate are much greather than what we observed in the data, the elasticities in job vacancies and the separation rate are smaller than thier empirical counterparts.

Our result is in contrast with earlier studies based on the standard search and matching models. Shimer (2005) finds that aggregate productivity fluctuations account for approximately ten percent of the cyclical volatility of key labor market variables in the search and matching model with counter cyclical separation. Mortensen and Naygpál (2008) find this failure in a

[13] Shimer (2005) demonstrates that the standard search and matching model cannot generate the observed unemployment and vacancies fluctuations in response to productivity shocks of reasonable size. This failure of the model has come to be known as the "unemployment volatility puzzle" or the "Shimer puzzle". (Mortensen and Nagypál, 2007; Pissarides, 2009).

model with endogenous separation. These differences are the results of incorporating on-the-job search into the model. The incorporation of the on-the-job search generates amplifications and the pro-cyclicality of job vacancies by expanding the pool of potential hires for firms. In the model without on-the-job search, a positive aggregate productivity shock increases the value of positing a vacancy, inducing more vacancy creation. On the other hand, it lowers a number of job seekers by reducing the reservation productivity. This dampens the positive effect of aggregate productivity shock on the supply of job vacancies. Since the latter effect dominates the former effect under the plausible parameter values, the model without on-the-job search generates the counter-cyclicality of job vacancies and small magnitude of unemployment and vacancy fluctuations. In contrast, in the model with on-the-job search, a positive shock to aggregate productivity increases search activity by employed workers and thus expands the pool of workers for any new firm to recruit from. This induces more vacancy creations. As a result, the model generates the pro-cyclicality of job vacancies and generates more variations in labor market variables.

In order to study the response of the model to productivity shocks, a number of studies in the literature compare steady-state equilibria with different values of the aggregate productivity parameter. It is well known that in the standard search model, such a comparative static exercise gives results that are essentially equivalent to the true dynamic response of the model. We now assess whether or not this exercise is valid in our model.

In Table 4, we report how the variables of interest change across steady-state equilibria when the level of aggregate productivity changes. Table 4 shows that the result of comparative static exercise is different from that of the full stochastic model. This is due to the presence of on-the-job search. Without on-the-job search, the transition dynamics of the model is very fast due to the instantaneous adjustment of the vacancy-unemployment ratio and high job finding rate. Thus, steady-state response to aggregate shocks are very good approximations to the true dynamic response of the model. However, in the model with on-the-job search, due to the low job-to-job transition rate of employed workers and the slow adjustment of the distribution of employed workers across jobs, the adjustment towards the new steady-state could be much more prolonged.

5.3 The Calibration Strategy

Our calibration strategy is not standard, since we use not only mean levels of labor market variables but also elasticities of them as targets. We now evaluate our calibration strategy by removing the elasticities from target moments and re-calibrating the model (henceforth we call it the standard calibration). This experiment allows us to examine whether using measures of volatility in labor market variables as targets is important for studying cyclical property of the model.

Table 5 shows the results. Since the standard strategy targets the mean levels of labor market variables, the model-generated mean levels are much closer than those under our calibration. However, there are larger discrepancies between the model implied elasticities and empirical counterparts, compared to the results under our original calibration strategy. For other variables, there is more discrepancy between the model-generated values and the target movements under the standard calibration strategy. Thus, under our calibration strategy, the model captures the data relatively better than it under the standard calibration strategy. Furthermore, the calibrated parameter values are different between these two calibration strategies. This implies that the measure of volatility is informative for parameter values when we study the cyclical properties of the model.

Table 5: Comparison of calibration strategies

Moments	Data	Our Calibration	Standard	Parameters	Our Calibration	Standard
$E(u)$	0.057	0.050	0.062	c_0	0.935	1.479
$E(v)$	0.043	0.036	0.042	m_0	28.74	36.92
$E(f)$	0.611	0.651	0.626	p_h	1.042	1.069
$E(s)$	0.035	0.034	0.039	γ	2.621	1.775
$E(\lambda^{ee})$	0.025	0.031	0.024	β	0.545	0.542
$\partial \ln u / \partial \ln p$	-2.504	-3.409	(-5.037)	η	0.165	0.159
$\partial \ln v / \partial \ln p$	4.408	1.558	(1.964)	κ	0.193	0.109
$\partial \ln f / \partial \ln p$	2.155	3.512	(5.407)	λ	0.314	0.376
$\partial \ln s / \partial \ln p$	-2.273	-0.263	(-0.288)	υ	3.459	4.780
$\partial \ln \lambda^{ee} / \partial \ln p$	2.2	2.527	(4.260)			
$E(Mm)$	1.7	2.534	2.051			
$\partial \ln w^{new} / \partial \ln p$	0.77	0.611	0.699			
Pr(switch)	0.050	0.048	0.048			
$\partial \ln u_{t+2} / \partial \ln p_t$	-5.325	-2.976	-4.392			

6 Conclusion

This paper studies the cyclical behavior of unemployment and job vacancies by focusing on worker flows. Recent empirical studies of the U.S. labor market suggest that in order to study the cyclical behavior of unemployment and job vacancies, it is important to take into account workers' transition between employment, unemployment, and across employers. We develop a search and matching model in which they are endogenously determined. We incorporate on-the-job search into the endogenous job separation model of Mortensen and Pissarides (1994). In order to study the cyclical behavior of the labor market, we also incorporate agents' rational expectation on cyclical macroeconomic shocks into the model. The incorporation of rational expectation on cyclical macroeconomics shocks enables us to examine the dynamic properties of an equilibrium model with on-the-job search in a tractable way.

The incorporation of on-the-job search substantially improves the ability of the search and matching model to explain the cyclicality of labor market variables. We demonstrate that our model generates a negative co-movement of unemployment and job vacancies in the form of the Beveridge curve. Furthermore, it also generates enough cyclical amplitude in the unemployment rate and the job-finding rate to match that observed in the data. These are what the standard search and matching model with endogenous job separation often fails to generate. These results are due to the incorporation of on-the-job search. The incorporation of on-the-job search generates the pro-cyclicality of job vacancies, which induces the negative relationship between unemployment and job vacancies over the business-cycle and helps to create amplification.

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