

# Working Capital Requirement and the Unemployment Volatility Puzzle\*

Tsu-ting Tim Lin<sup>†</sup>  
Gettysburg College

May 3, 2015

## Abstract

Shimer (2005) argues that a search and matching model of the labor market in which wage is determined by Nash bargaining cannot generate the observed volatility in unemployment and vacancy in response to reasonable labor productivity shocks. This paper examines how incorporating monopolistically competitive firms with a working capital requirement (in which firms borrow funds to pay their wage bills) improves the ability of the search models to match the empirical fluctuations in unemployment and vacancy without resorting to an alternative wage setting mechanism. The monetary authority follows an interest rate rule in the model. A positive labor productivity shock lowers the real marginal cost of production and lowers inflation. In response to the fall in price level, the monetary authority reduces the nominal interest rate. A lower interest rate reduces the cost of financing and partially offsets the increase in labor cost from a higher productivity. A reduced labor cost implies the firms retain a greater portion of the gain from a productivity shock, which gives them a greater incentive to create vacancies. Simulations show that a working capital requirement does indeed improve the ability of the search models to generate fluctuations in key labor market variables to better match the U.S. data.

---

\*I am grateful to Dale Mortensen, Giorgio Primiceri, Ija Trapeznikova, Thijs van Rens, Charles Weise, and participants of the Liberal Arts Macroeconomics Workshop and Canadian Economic Association Annual Conference 2014 for their invaluable comments and suggestions.

<sup>†</sup>Email: [tlin@gettysburg.edu](mailto:tlin@gettysburg.edu); Address: Department of Economics, 300 N Washington Street, Box 391, Gettysburg, PA 17325.

# 1 Introduction

The influential work of [Shimer \(2005\)](#) has motivated many researchers to explore the cyclical properties of the search-and-matching model. Shimer argues that Nash bargaining, the wage determination mechanism in the textbook search models, generates wage changes that largely absorb the gains and losses accrued to firms from labor productivity shocks. The consequence is that the firms are left with little incentive to adjust employment in response to these shocks, which in turn leads to muted responses of key labor market variables.

Following Shimer’s commentary, many researchers have begun to examine the wage setting mechanism in greater detail. [Hall \(2005\)](#) argues that any wage in the bargaining set should be considered as a solution to the bargaining problem and offers a number of wage rules that vary in their degrees of rigidity. [Hall and Milgrom \(2008\)](#) do not consider walking away from a negotiation to be a credible threat in the bargaining problem. They argue the threat point of the bargaining process is the value of delay, not the outside options; this makes labor market conditions, including labor productivity, less influential on the wage bargaining process. [Gertler and Trigari \(2009\)](#) propose a staggered wage contracting model—employers and employees use Nash bargaining to determine wages, but only periodically. The rigid wage features of these models weaken the dependence of wages on labor productivity and allow the search models to generate more fluctuations in unemployment and vacancy.

However, other researchers, including [Pissarides \(2009\)](#), [Haefke, Sonntag, and van Rens \(2013\)](#), and [Kudlyak \(2014\)](#), have pointed out that job creation in the search models is influenced by the expected net present value of wages of new matches. They further show that the wages of new hires are much more procyclical than the average wage. Based on this evidence, they conclude that wage rigidity is unlikely to be the answer to the unemployment volatility puzzle.

In this paper, I retain a flexible wage setting mechanism while incorporating monopolistic competition and a working capital requirement in an otherwise standard search-and-matching model. My treatment of monopolistic competition is largely modeled after [Krause and Lubik \(2007\)](#)—the monopolistic competitive intermediate good producers employ workers from a frictional labor market and are subject to a price adjustment cost. The working capital requirement introduces the nominal interest rate as a component of the labor cost.<sup>1</sup> In this environment, a positive labor productivity shock lowers the real marginal cost of production and lowers inflation. The monetary authority, which follows an interest rate rule, lowers the interest rate in response to changes in the price level. A lower nominal interest

---

<sup>1</sup>[Cooley and Quadrini \(1999\)](#) and [Cooley and Quadrini \(2004\)](#) also include a working capital requirement in their treatment of the frictional labor market. However, the main differences with this paper are that they adopt a money growth rule and that their focus is the model’s response to monetary shocks.

rate partially offsets the increase in wage from higher labor productivity. This reduces the labor cost and implies that the firms retain a greater portion of the gain from productivity shock as profits, thus giving the firms a greater incentive to create more vacancies.

To evaluate the quantitative properties of the model, I calibrate and simulate the model. I find that a working capital requirement does indeed improve the ability of the model to address the unemployment volatility puzzle. Relative to the textbook search-and-matching model, a working capital requirement delivers a 78 percent increase in unemployment volatility, a 63 percent increase in vacancy volatility, and a 74 percent increase in market tightness volatility. The unemployment volatility now reaches 81 percent of the OLS regression coefficient where unemployment is the dependent variable and labor productivity is the independent variable.<sup>2</sup> The relative standard deviation of vacancy overshoots the OLS target at 147 percent. The market tightness volatility is at 106 percent of the OLS regression coefficient. Moreover, the model either maintains or improves the autocorrelations and the correlations among the labor market variables relative to the textbook search-and-matching model; these statistics are in line with their empirical counterparts. Given that the interest rate rule and monopolistic competition are not common features of the search model, I conduct a series of sensitivity analyses. I find the quantitative results of the model are robust to a wide range of specifications.

In addition to the literature mentioned above, this paper is related to a long line of research exploring the unemployment volatility puzzle. Among others, [Mortensen and Nagypál \(2007b\)](#) provide a detailed survey of the literature on the puzzle and point out that a more realistically calibrated version of the model which incorporates a simplified version of the [Hall and Milgrom \(2008\)](#) strategic bargaining setup can account for two-thirds of the observed volatility in vacancy-unemployment ratio. [Krause and Lubik \(2006\)](#) examine an environment in which workers are allowed to move from “bad” to “good” jobs. [Nagypál \(2007\)](#) studies an on-the-job search model with a hiring cost where jobs differ in their levels of amenities; she finds the interaction of on-the-job search and a hiring cost allows the model to replicate all of the observed volatility in unemployment and vacancy rates. [Mortensen and Nagypál \(2007a\)](#) show that allowing endogenous separation can improve the performance of the model but comes at the cost of countercyclical vacancy dynamics. [Hagedorn and Manovskii \(2008\)](#) advocate calibrating the model to include a high opportunity cost of employment and a low employee bargaining weight. This paper serves as a complement to the literature by offering an alternative explanation for the unemployment volatility puzzle.

---

<sup>2</sup>[Mortensen and Nagypál \(2007b\)](#) point out that the appropriate measure of the elasticities of the labor market variables with respect to labor productivity is the OLS regression coefficient since labor productivity is but one of the driving forces in the real world.

The remainder of the paper is structured as follows. Section 2 lays out the model. Section 3 presents the calibration strategy and the quantitative results of the model. Section 4 explores the robustness of the results under different interest rate and monopolist competition specifications. Section 5 concludes.

## 2 Model

### 2.1 Labor Market

There is a unit mass of workers in the economy. At the beginning of each period,  $\rho_0$  fraction of the employed workers from the previous period are separated from their jobs. Let  $n_{t-1}$  be the number of workers who were employed in the economy in period  $t-1$ . The total number of job seekers in period  $t$  is then:

$$u_t = 1 - (1 - \rho_0)n_{t-1}.$$

Let  $v_t$  be the aggregate number of vacancies posted by firms in the economy and  $m_t$  the number of matches formed. I follow the literature in assuming a Cobb-Douglas matching function:

$$m_t = m_0 u_t^\mu v_t^{1-\mu},$$

where  $m_0$  is the scale parameter and  $\mu \in (0, 1)$  is the match elasticity with respect to job seekers.

With all the ingredients in place, the law of motion for aggregate employment can be written as:

$$n_t = (1 - \rho_0)n_{t-1} + m_t.$$

Note that given the quarterly timing, I allow a worker who is exogenously separated at the beginning of a period to—(1) join the pool of job seekers; (2) form a match with an employer; and (3) produce output—all within the same quarter. This implies the relevant unemployment statistics of the model that is comparable to data is

$$u_t^m = 1 - n_t,$$

where  $u_t^m$  denotes measured unemployment. Measured unemployment corresponds to the number of workers who are not producing output at time  $t$ .

Lastly, the job finding rate for a job seeker can be defined as:

$$f_t = \frac{m_t}{u_t};$$

and likewise the vacancy fill rate:

$$q_t = \frac{m_t}{v_t}.$$

## 2.2 Final Good Firm

There is a perfectly competitive final good producer that produces composite good  $y_t$  by combining a continuum of intermediate goods indexed by  $i \in (0, 1)$  using the technology:

$$y_t = \left( \int_0^1 y_{i,t}^{\frac{\varepsilon_p - 1}{\varepsilon_p}} di \right)^{\frac{\varepsilon_p}{\varepsilon_p - 1}}, \quad (1)$$

where  $\varepsilon_p > 1$ . Let  $p_{i,t}$  be the price for intermediate good  $i$  and  $P_t$  be the price of the composite good. Profit maximization by the final good firm implies the demand for variety  $i$  is:

$$y_{i,t} = \left( \frac{P_t}{p_{i,t}} \right)^{\varepsilon_p} y_t. \quad (2)$$

Applying equation (1) and integrating over equation (2) give us the composite good price index:

$$P_t = \left( \int_0^1 p_{i,t}^{1 - \varepsilon_p} di \right)^{\frac{1}{1 - \varepsilon_p}}.$$

## 2.3 Intermediate Good Firms

Each differentiated intermediate good is produced by a monopolistically competitive firm using labor as the only input. The production technology is:

$$y_{i,t} = A_t n_{i,t},$$

where  $A_t$  is the aggregate labor productivity which follows an autoregressive process:

$$\ln A_t = \rho_A \ln A_{t-1} + \sigma^A \zeta_t^A;$$

$\zeta_t^A$  is assumed to be i.i.d.  $\mathcal{N}(0, 1)$ ;  $\sigma^A$  is the standard deviation of the innovations.

Firms acquire labor input by posting vacancies. For firm  $i$  that begins period  $t$  with  $n_{i,t-1}$  units of labor and posts  $v_{i,t}$  vacancies, its employment law of motion is

$$n_{i,t} = (1 - \rho_0)n_{i,t-1} + q_t v_{i,t},$$

where firms take the economy-wide vacancy fill rate  $q_t$  as given. The cost of vacancy creation is  $\kappa_v v_{i,t}$ .

Given that the representative household owns the firms, intermediate good firms discount future profits using household's stochastic discount factor. Firm  $i$  chooses  $v_{i,t}$  and price  $p_{i,t}$  to maximize its present discounted profits subject to its employment law of motion and the demand for good  $i$ . I assume firms and their workers jointly determine the wage through a bargaining process that will be described in detail shortly. I require the firms to finance  $\gamma \in [0, 1]$  fraction of their real wage payment  $w_{i,t}n_{i,t}$  through the financial intermediary at gross interest rate  $R_t$ ; this implies the relevant per-worker wage cost for firm  $i$  is  $(1 - \gamma + \gamma R_t)w_{i,t}$ . Firms can adjust prices by incurring a real price adjustment cost of  $\frac{\kappa_p}{2} \left( \frac{p_{i,t+s}}{p_{i,t-1+s}} - \pi \right)^2 y_{t+s}$ . Firm  $i$ 's problem can be written as:

$$\begin{aligned} \max_{\{v_{i,t+s}, p_{i,t+s}\}_{s=0}^{\infty}} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \frac{\lambda_{t+s}}{\lambda_t} \left\{ \left( \frac{p_{i,t+s}}{P_{t+s}} \right) y_{i,t+s} - (1 - \gamma + \gamma R_{t+s}) w_{i,t+s} n_{i,t+s} \right. \\ \left. - \kappa_v v_{i,t+s} - \frac{\kappa_p}{2} \left( \frac{p_{i,t+s}}{p_{i,t-1+s}} - \pi \right)^2 y_{t+s} \right\}, \end{aligned}$$

subject to

$$n_{i,t} = (1 - \rho_0)n_{i,t-1} + q_t v_{i,t},$$

and

$$y_{i,t} = \left( \frac{P_t}{p_{i,t}} \right)^{\varepsilon_p} y_t.$$

The first order conditions are:

$$v_{i,t} : \frac{\kappa_v}{q_t} = J_t, \tag{3}$$

$$p_{i,t} : 1 - \kappa_p (\pi_t - \pi) \pi_t + \beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \kappa_p (\pi_{t+1} - \pi) \pi_{t+1} \frac{y_{t+1}}{y_t} = \varepsilon_p (1 - \phi_t), \tag{4}$$

where  $\pi_t \equiv \frac{P_t}{P_{t-1}}$ . All firms are identical so I apply symmetry and drop firm subscripts.  $J_t$  is the Lagrange multiplier for employment law of motion and  $(1 - \phi_t)$  is the Lagrange multiplier

for demand.  $J_t$  can be interpreted as the value of the marginal worker to a firm and can be derived by taking the derivative of firm's objective function with respect to  $n_t$  subject to the two constraints. It is:

$$J_t = \phi_t A_t - (1 - \gamma + \gamma R_t) w_t + (1 - \rho_0) \beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} J_{t+1}. \quad (5)$$

This expression tells us the value of the marginal worker to a firm is her marginal revenue product less the wage payment plus the continuation value. Similarly,  $1 - \phi_t$  is the incremental profit from selling one additional unit of intermediate good; this leaves us with  $\phi_t$  being the real marginal cost of production. We will examine  $\phi_t$  more closely in section 2.9.

## 2.4 Financial Intermediary

There is a perfectly competitive financial intermediary that receives nominal deposits  $D_t$  from the household and a nominal lump-sum transfer  $X_t$  from the monetary authority. These funds are supplied to the loan market at gross interest rate  $R_t$ . The demand for loans comes from firms that seek to finance their wage payments  $\gamma w_t n_t$ . The loan market clearing condition is:

$$P_t \gamma w_t n_t = D_t + X_t.$$

At the end of period  $t$ , the financial intermediary returns  $R_t D_t$  to the household for the use of its deposits; the household also receives  $R_t X_t$  as profits.

## 2.5 Household

The economy consists of a representative household with a continuum of identical members. I abstract from labor force participation choice—every member of the household is either employed or is actively searching for work. Those who are employed receive wage income  $w_t$ ; those who are unemployed receive unemployment insurance  $b$  from the government. Each household member's utility is additively separable in consumption, and there is perfect risk-sharing among members of the household, yielding the same consumption for everyone in the household.

Let  $c_t$  be the household's consumption of the composite good. The household's objective function can be written as:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left( \frac{c_{t+s}^{1-\sigma} - 1}{1-\sigma} \right), \quad (6)$$

where  $\beta$  is the discount factor; and  $\sigma$  is the coefficient of relative risk aversion.

In addition to choosing consumption, the household can deposit  $D_t$  in the financial intermediary earning gross interest  $R_t$ , which can then be used to finance next period's consumption. Conditional on  $n_t$ , the number of employed household members, the household maximizes its objective function (6) subject to a sequence of budget constraints:

$$c_{t+s} + \frac{D_{t+s}}{P_{t+s}} \leq w_{t+s}n_{t+s} + R_{t-1+s} \frac{(D_{t-1+s} + X_{t-1+s})}{P_{t+s}} + (1 - n_{t+s})b + \Pi_{t+s} + T_{t+s},$$

where  $\Pi_t$  is the lump-sum dividend profit from the firms; and  $T_t$  is the sum of a lump-sum transfer from the government and the monetary authority.

The household's first order conditions are:

$$\begin{aligned} c_t : \quad c_t^{-\sigma} &= \lambda_t \\ D_t : \quad \lambda_t &= \beta R_t \mathbb{E}_t \lambda_{t+1} \frac{P_t}{P_{t+1}} \end{aligned}$$

For the purpose of wage setting that will be discussed shortly, it is useful to write down the value of an employed worker to the household. Let  $U_t$  and  $W_t$  denote the value of an unemployed worker and an employed worker respectively. The value of an unemployed worker is:

$$U_t = b + \beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} [f_{t+1}W_{t+1} + (1 - f_{t+1})U_{t+1}]; \quad (7)$$

and the value of an employed worker is:

$$W_t = w_t + \beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} [(1 - \rho_0 + \rho_0 f_{t+1})W_{t+1} + \rho_0(1 - f_{t+1})U_{t+1}]. \quad (8)$$

Equation (7) says that the value of an unemployed worker is the unemployment insurance she receives plus the continuation value weighted by the probability of finding a job in the next period. Equation (8) says that the value of an employed worker is the wage payment she receives plus the continuation value weighted by the probability that she continues to have a job in the next period. The surplus of an employed worker,  $M_t = W_t - U_t$ , is then:

$$M_t = w_t - b + \beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} (1 - \rho_0)(1 - f_{t+1})M_{t+1}. \quad (9)$$



## 2.6 Wage Setting

Labor market friction creates a positive surplus to be shared between the employers and their employees. In this model, the firms and their workers jointly determine wage  $w_t$ . As in [Shimer \(2005\)](#), Nash bargaining is used—wage is set to solve the following problem:

$$\max_{w_t} M_t^\eta J_t^{1-\eta},$$

where  $\eta \in [0, 1]$ . The first order condition is:

$$(1 - \gamma + \gamma R_t)(1 - \eta)M_t = \eta J_t. \quad (10)$$

Substituting equations (5) and (9) into condition (10) yields the wage:

$$\begin{aligned} (1 - \gamma + \gamma R_t)w_t &= \eta \phi_t A_t + (1 - \gamma + \gamma R_t)(1 - \eta)b + \eta(1 - \rho_0)\beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \frac{\kappa_v}{q_{t+1}} \\ &\quad - \eta(1 - \gamma + \gamma R_t)\beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \frac{(1 - \rho_0)(1 - f_{t+1})}{1 - \gamma + \gamma R_{t+1}} \frac{\kappa_v}{q_{t+1}}. \end{aligned}$$

It is easy to see that if firms are not required to finance any portion of their wages ( $\gamma = 0$ ) and when intermediate goods become more and more like perfect substitutes ( $\phi_t \rightarrow 1$ ), the wage becomes the standard textbook search model wage.

## 2.7 Government and Monetary Authority

Let variables without a time subscript denote their non-stochastic steady-state values. I set the unemployment insurance to be a constant fraction of the steady-state marginal product of labor  $b = \bar{b}A$ . The government imposes a lump-sum transfer  $T_t$  to finance the unemployment insurance and a monetary injection  $X_t$  that is required to clear the loan market.

I further assume the monetary authority follows the interest rate rule:

$$\left(\frac{R_t}{R}\right) = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi}\right)^{\rho_\pi} \left(\frac{y_t}{y}\right)^{\rho_y}\right]^{1-\rho_R} e^{\sigma^R \zeta_t^R}, \quad (11)$$

where  $\zeta_t^R$  is i.i.d.  $\mathcal{N}(0, 1)$  and  $\sigma^R$  is the standard deviation of the innovations.

## 2.8 Resource Constraint

Lastly, I close the model with the resource constraint:

$$y_t = c_t.$$

## 2.9 Working Capital Requirement and Job Creation

Let's take a moment and examine how the working capital requirement along with monopolistic competition is expected to allow the model to generate more employment volatility. We start with the expression for marginal cost  $\phi_t$ . Rearrange equation (5), we get:

$$\phi_t = \frac{(1 - \gamma + \gamma R_t)w_t}{A_t} + \frac{J_t - (1 - \rho_0)\beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} J_{t+1}}{A_t}.$$

A positive labor productivity shock drives down marginal cost  $\phi_t$ . Next, the price setting condition (4) yields the log-linearized form:

$$\hat{\pi}_t = \frac{\varepsilon_p - 1}{\kappa_p} \hat{\phi}_t + \beta \mathbb{E}_t \hat{\pi}_{t+1}, \quad (12)$$

where the “hat” variables are log-deviation from their non-stochastic steady-state values. Equation (12) indicates that lower real marginal cost in turn lowers inflation.

Given the monetary authority follows the interest rate rule (11), the monetary authority would lower the nominal interest rate  $R_t$  in response to a decrease in inflation. Moreover, the persistence term in the interest rate rule would keep the nominal interest rate low for several quarters.

For convenience, the Nash rent sharing wage for this model is rewritten here:

$$(1 - \gamma + \gamma R_t)w_t = \eta \phi_t A_t + (1 - \gamma + \gamma R_t)(1 - \eta)b + \eta(1 - \rho_0)\beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \frac{\kappa_v}{q_{t+1}} - \eta(1 - \gamma + \gamma R_t)\beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \frac{(1 - \rho_0)(1 - s_{t+1})}{1 - \gamma + \gamma R_{t+1}} \frac{\kappa_v}{q_{t+1}}.$$

In the presence of a working capital requirement,  $(1 - \gamma + \gamma R_t)w_t$  is the relevant per-worker labor cost to the firms. The nominal interest rate enters and affects the labor cost equation in three ways:

- (i) Lower  $R_t$  lowers the contribution of unemployment insurance to the labor cost;
  - (ii) Lower  $R_t$  raises the contribution of worker's continuation value to the labor cost;
- and

(iii) Lower  $\mathbb{E}_t R_{t+1}$  lowers the worker’s continuation value which lowers the labor cost.

Given that we expect both the contemporaneous nominal interest rate and the expected future rate to fall, effects (i) and (iii) would moderate the increase in labor cost whereas effect (ii) would increase the labor cost. While the net effect is not immediately clear, the typical calibration strategy of—(1) setting unemployment insurance  $b$  to be at least 40 percent of labor productivity; and (2) requiring vacancy creation cost  $\kappa_v$  to be a small percentage of output—suggests effect (i) would be the dominant effect and a fall in the nominal interest rate would moderate the increase in labor cost. Lastly, a smaller increase in wage cost implies firms retain a greater portion of a rise in labor productivity as profits which would in turn encourage firms to create more vacancies. The interaction of these effects is how the working capital requirement is expected to allow the model to generate more employment volatility.

### 3 Calibration and Simulation Results

This section details the calibration strategy as well as the approach this paper takes to examine the quantitative properties of the model.

#### 3.1 Calibration

I begin with the labor market parameters. I set  $\bar{u}$ , the non-stochastic steady-state pool of job seekers to 0.1525—this yields 5.83 percent measured unemployment rate which is the average U.S. unemployment rate between 1951Q1 and 2012Q1. I calibrate the non-stochastic steady-state firm’s vacancy fill rate  $\bar{q}$  to 0.7, the same value used by [den Haan, Ramey, and Watson \(2000\)](#), [Cooley and Quadrini \(1999\)](#), and [Krause and Lubik \(2007\)](#). The exogenous quarterly separation rate  $\rho_0$  is set to 0.1. This is consistent with 0.034 monthly separation rate computed by [Shimer \(2005\)](#) and is within the range of values used in the literature, ranging from 0.07 in [Merz \(1995\)](#) to 0.15 in [Andolfatto \(1996\)](#). I set both the elasticity of matches to unemployment  $\mu$  and the worker’s bargaining power  $\eta$  to 0.5; they are both within the range of value in the literature.<sup>3</sup> I choose the “replacement ratio”  $\bar{b}$  to be 0.73 as is advocated in [Mortensen and Nagypál \(2007b\)](#); it is 0.4 in [Shimer \(2005\)](#) and 0.955 in [Hagedorn and Manovskii \(2008\)](#). Note that my choice of  $\mu$  and  $\bar{b}$  allows the model to

---

<sup>3</sup>The values of  $\mu$  range from 0.4 in [Merz \(1995\)](#) to 0.72 in [Shimer \(2005\)](#).  $\eta$ , worker share of match surplus, is less well-established in the literature; while my model is not directly comparable to that of [Gertler, Sala, and Trigari \(2008\)](#), it is worth noting that they estimate a medium-sized monetary DSGE model and find  $\eta$  to be 0.907 under staggered wage contracting and 0.616 under flexible wage, highlighting a wide range of plausible values for  $\eta$ .

generate greater volatility in employment variables relative to [Shimer \(2005\)](#). I will show that this alone is not sufficient to match the observed volatilities.

Next up is the set of parameters that are common in the macroeconomics literature. The discount rate  $\beta$  is set to 0.99; combined with steady-state inflation  $\pi$  of 1, the steady-state quarterly nominal interest rate is 1.01 percent. The coefficient of relative risk aversion  $\sigma$  is 2. The elasticity parameter in the consumption good aggregation technology  $\varepsilon_p$  is set to 11; this implies a steady-state markup of 10 percent, which is standard in the literature.<sup>4</sup> As for  $\kappa_p$ , the price adjustment cost parameter, note the slope of the log-linearized Phillips curve is  $\frac{\varepsilon_p - 1}{\kappa_p}$ . The empirical estimates of the slope varies widely—from 0.03 in [Galí and Gertler \(1999\)](#) to 1.25 in [Ireland \(1997\)](#). [Lubik and Schorfheide \(2004\)](#) considers a New Keynesian model similar to the one presented in this paper, and they find the value of the slope coefficient around 0.5. Given  $\varepsilon_p = 11$ , this implies  $\kappa_p = 20$ .<sup>5</sup> Neither  $\varepsilon_p$  or  $\kappa_p$  are common features of search-and-matching models; I will explore different specifications in [Section 4](#).

I calibrate the interest rate rule using the mean estimates from [Lubik and Schorfheide \(2004\)](#) since their specification of the interest rate rule most closely resembles what is modeled in this paper. The persistence parameter  $\rho_R$  is set to 0.8. The inflation and output coefficients  $\rho_\pi$  and  $\rho_y$  are 2.0 and 0.3, respectively.<sup>6</sup> I will explore different parameter values for robustness checks. Given that this paper focuses on the volatility of vacancy and unemployment following a labor productivity shock, I turn off the interest rule innovations in simulations by setting  $\sigma^R$  to 0.

The last set of parameters governs the labor productivity process.  $\rho_a$  is set to 0.8976 to match the quarterly autocorrelation of non-farm business sector output per person between 1951Q1 and 2012Q1.  $\sigma^A$  is chosen such that the simulated labor productivity volatility matches that of the data; it is calibrated to 0.00934.

The calibrated parameters are summarized in [table 1](#).

---

<sup>4</sup>See, for instance, [Lubik and Schorfheide \(2004\)](#), [Boivin and Giannoni \(2006\)](#), [Smets and Wouters \(2007\)](#), and [Cogley et al. \(2010\)](#).

<sup>5</sup>Furthermore, note that the Phillips curve slope coefficient is observationally equivalent to the one under Calvo-pricing. More specifically, a slope of 0.5 implies a median duration of prices of 6 months, which is in line with findings from [Nakamura and Steinsson \(2008\)](#) who find the median duration of 4.5 months of all goods and services and 11 months excluding sales. [Bils and Klenow \(2004\)](#) have a similar finding of 4.3 months for all goods and services and find a shorter median duration of 5.5 months excluding sales items.

<sup>6</sup>These values are within the range of what is typically found in the literature. For example, [Justiniano and Primiceri \(2008\)](#) specify a similar interest rate rule and find the interest rate persistence, inflation response, and output response coefficients to be 0.81, 1.92, and 0.10, respectively. [Cogley et al. \(2010\)](#) measures inflation gap using a time-varying inflation target and find the interest rate persistence to be 0.63; the inflation and output coefficients to be 1.78 and 0.66 respectively. [Clarida et al. \(2000\)](#) use expected inflation and output gap in their interest rate rule and find the interest rate persistence parameter, inflation response, and output response to be 0.79, 2.15, and 0.93, respectively.

| Parameter       | Value   | Description                                      |
|-----------------|---------|--|
| $\bar{u}$       | 0.1525  | 5.83 percent measured unemployment, U.S average  |
| $\bar{q}$       | 0.7     | Non-stochastic steady-state vacancy fill rate    |
| $\rho_0$        | 0.10    | 0.035 monthly separation rate                    |
| $\mu$           | 0.5     | Elasticity of matches to unemployment            |
| $\eta$          | 0.5     | Worker share of match surplus                    |
| $\bar{b}$       | 0.73    | Replacement ratio                                |
| $\beta$         | 0.99    | Discount rate                                    |
| $\pi$           | 1       | Non-stochastic steady-state inflation            |
| $\sigma$        | 2       | Constant relative risk aversion                  |
| $\varepsilon_p$ | 11      | Non-stochastic steady-state markup of 10 percent |
| $\kappa_p$      | 20      | Price adjustment cost                            |
| $\rho_R$        | 0.8     | Interest rate rule inertia                       |
| $\rho_\pi$      | 2.0     | Interest rate rule inflation                     |
| $\rho_y$        | 0.3     | Interest rate rule output                        |
| $\rho_a$        | 0.8976  | Productivity process persistence                 |
| $\sigma^A$      | 0.00934 | Standard deviation of productivity innovations   |

TABLE 1: Calibrated parameters. See Section 3.1 for details.

### 3.2 Impulse Response Functions

The model is solved using first-order perturbation methods. Figure 1 examines the effects of a one percent increase in labor productivity; this is an increase of  $A_t$  from 1 to 1.01. The magenta line (with  $\times$ s) represents the textbook search model—the version of the model without monopolistic competition and without a working capital requirement. The blue solid line is from the version of the model with monopolistic competition and no working capital requirement ( $\gamma = 0$ ). The red line (with filled circles) represent the version of the model with both monopolistic competition and a full working capital requirement ( $\gamma = 1$ ).

We begin with the marginal cost panel. Higher labor productivity lowers marginal cost which in turn lowers inflation. Due to a drop in inflation, the monetary authority lowers the nominal interest rate according to the interest rate rule.<sup>7</sup> Two observations can be made with regard to the labor cost. One, the rise in the labor cost for monopolistic competition is less than the labor cost increase for the textbook search model. This is because the firms now face a downward-sloping demand curve. Therefore the drop in marginal revenue (which equals marginal cost) neutralizes the increase in labor productivity; this in fact results in a slightly negative marginal revenue product growth ( $\hat{\phi}_t + \hat{A}_t$ ) in the quarter the shock arrives. Unlike the textbook model where the rise in wage is due directly to a contemporaneous increase in labor productivity, the initial increase in wage for the monopolistic competition model is

<sup>7</sup> $\phi_t$ ,  $\pi_t$ , and  $R_t$  are represented as flat lines under the textbook model because they are not part of the model.

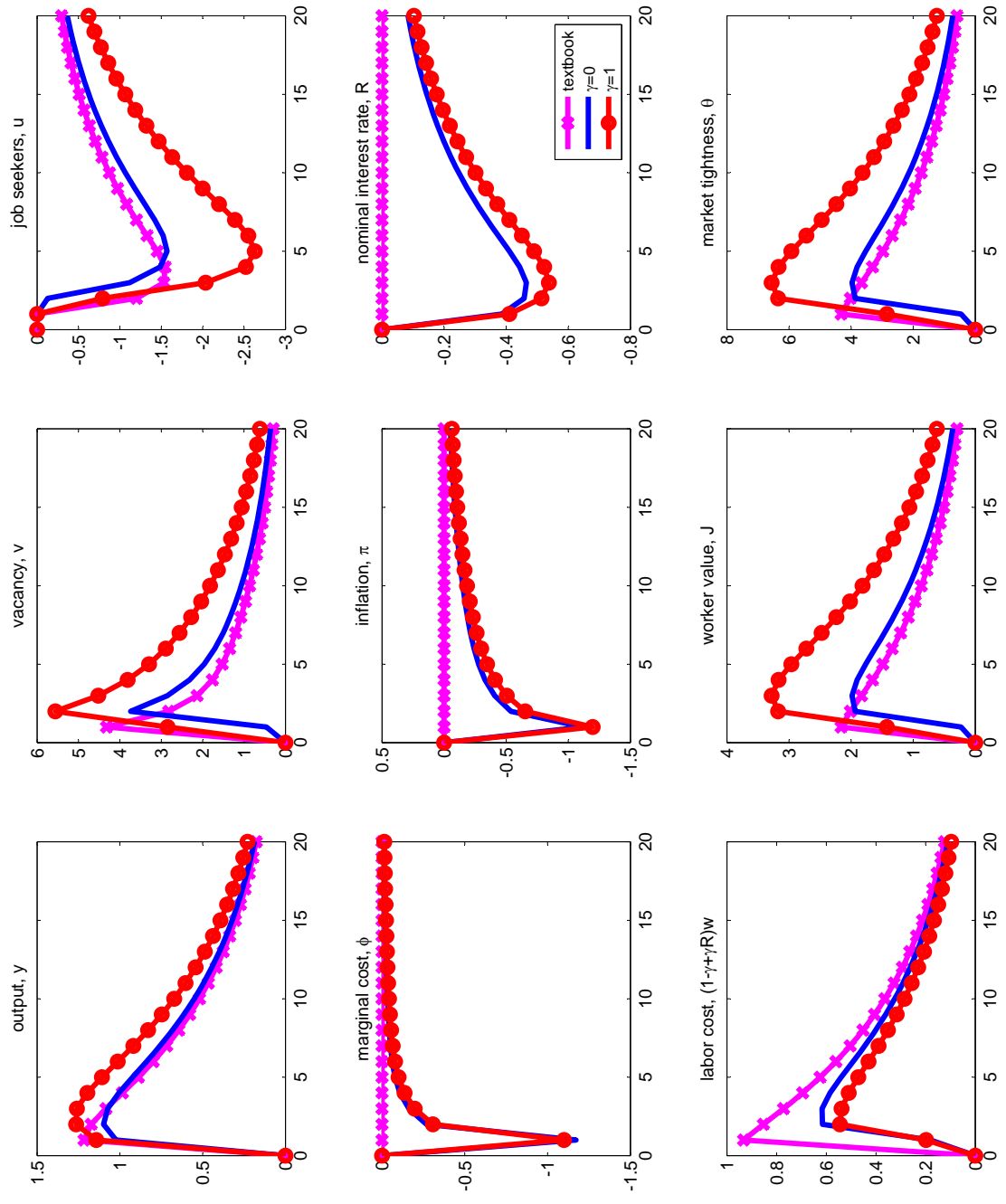


FIGURE 1: Impulse response functions for the textbook (benchmark),  $\gamma = 0$ , and  $\gamma = 1$ .

due to the rise in the continuation value of a filled position. The second observation is that the working capital requirement does indeed moderate wage increases when we compare the labor cost responses for  $\gamma = 0$  and  $\gamma = 1$ .

Moving on to the worker value panel. We see that even though the labor cost rises much less for  $\gamma = 0$  relative to the textbook model, it does not translate into a significantly different worker value. Again, this is because the fallen marginal revenue offsets the increase in labor productivity, resulting in similar surpluses. Next, comparing the IRFs of  $\gamma = 0$  and  $\gamma = 1$  allows us to see that even a modest amount of difference in the labor cost translates into a noticeable difference in worker value. This is in part due to the fact that wages are typically several times larger than the surplus value of a worker to a firm in search models; so a small change in wage can have a large impact on worker value. Moreover, employer-employee relationships last an extended period of time, and small differences add up over the lifetime of a relationship.

Lastly, market tightness. The log-linearized version of the job creation condition (3) is:

$$\mu\hat{\theta}_t = \hat{J}_t.$$

With what we have just seen in the IRFs for worker value  $J_t$ , it should be no surprise that  $\gamma = 1$  version of the model generates the largest response in market tightness while  $\gamma = 0$  performs comparably to the textbook model.

The IRFs confirm the intuition of the model: a working capital requirement can help the search-and-matching models generate more fluctuations in employment variables. In the following section I present the numerical simulation results.<sup>8</sup>

### 3.3 Simulation Results

I have reproduced table 1 in [Shimer \(2005\)](#) using U.S. data from 1951Q1 to 2012Q1. Unemployment is the quarterly average of monthly seasonally adjusted level of unemployment from the Bureau of Labor Statistics (BLS). From January 1951 to November 2000, vacancy is from the Conference Board's help-wanted index; from December 2000 onward, vacancy is BLS's total non-farm job openings.<sup>9</sup> The quarterly vacancy figures are averaged over monthly numbers. Labor productivity is BLS's output per person in the non-farm business

---

<sup>8</sup>It is worth noting that, as pointed out by [Fujita and Ramey \(2007\)](#), the textbook search model does not have a propagation mechanism. Based on what we have observed here, the interaction between marginal revenue and labor productivity yields hump-shaped responses in output, vacancy, and market tightness; it provides a level of propagation that is not seen in the textbook model.

<sup>9</sup>As is commonly done in the literature, I combine the two vacancy series by finding the ratio of job openings to help-wanted index in December 2000 and applying the ratio to all job openings figures to convert them to help-wanted index-like numbers.

|                            | $u$    | $v$   | $v/u$  | $A$    |
|----------------------------|--------|-------|--------|--------|
| Standard deviation         | 0.192  | 0.190 | 0.370  | 0.020  |
| Quarterly autocorrelation  | 0.943  | 0.944 | 0.945  | 0.898  |
| OLS regression coefficient | -4.011 | 3.383 | 7.394  | -      |
| Correlation matrix         | $u$    | 1     | -0.876 | -0.969 |
|                            | $v$    | -     | 1      | 0.968  |
|                            | $v/u$  | -     | -      | 1      |
|                            | $A$    | -     | -      | 1      |

TABLE 2: Summary statistics, quarterly U.S. data, 1951–2012Q1. This table is a replication of table 1 in [Shimer \(2005\)](#) with the time horizon extended to 2012Q1. The OLS regression coefficients are  $\rho_{x,A} \frac{\sigma_x}{\sigma_A}$  for variable  $x$ .

|                            | $u$    | $v$   | $v/u$  | $A$    |
|----------------------------|--------|-------|--------|--------|
| Standard deviation         | 0.190  | 0.202 | 0.382  | 0.020  |
| Quarterly autocorrelation  | 0.936  | 0.940 | 0.941  | 0.878  |
| OLS regression coefficient | -3.876 | 3.676 | 7.564  | -      |
| Correlation matrix         | $u$    | 1     | -0.894 | -0.971 |
|                            | $v$    | -     | 1      | 0.975  |
|                            | $v/u$  | -     | -      | 1      |
|                            | $A$    | -     | -      | 1      |

TABLE 3: Summary statistics, quarterly U.S. data, 1951–2003. This table is a reproduction of table 1 in [Shimer \(2005\)](#). The OLS regression coefficients are not in the original table. The coefficient is  $\rho_{x,A} \frac{\sigma_x}{\sigma_A}$  for variable  $x$ .

sector. All data is logged and detrended using Hodrick-Prescott filter with a smoothing parameter of  $10^5$ . One set of statistics that is not in the original Shimer table is the OLS regression coefficients. [Mortensen and Nagypál \(2007b\)](#) point out that since labor productivity is one of the many driving forces in the real world, one cannot expect labor productivity shocks to explain all the fluctuations in labor market variables. Therefore, the elasticity of market tightness with respect to labor productivity should be the OLS regression coefficient where market tightness is the dependent variable and labor productivity is the independent variable. It can be computed as  $\rho_{\theta,A} \left( \frac{\sigma_\theta}{\sigma_A} \right)$ , where  $\rho_{\theta,A}$  is the correlation coefficient between market tightness and labor productivity and  $\sigma_\theta$  and  $\sigma_A$  are the standard deviations. The summary statistics are reproduced in table 2 below. For comparison purpose, table 3 is a reproduction of table 1 in [Shimer \(2005\)](#). The statistics between two different sample periods are comparable. I will use the statistics of the more comprehensive sample as the yardstick.

Each round of simulation is done by drawing 1,245 i.i.d.  $\mathcal{N}(0, \sigma^A)$  labor productivity shocks; simulating the economy with those shocks; discarding the first 1,000 periods; and computing the relevant statistics for the remaining 245 periods corresponding to the number of quarters from 1951Q1 to 2012Q1. The statistics reported in table 4 are their means across



|                             | $u$              |                  | $v$               |                   | $v/u$             |                   | $A$               |                   |
|-----------------------------|------------------|------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Standard deviation          | 0.037<br>(0.006) | 0.039<br>(0.006) | 0.061<br>(0.007)  | 0.061<br>(0.008)  | 0.092<br>(0.013)  | 0.095<br>(0.014)  | 0.160<br>(0.024)  | 0.020<br>(0.003)  |
| Quarterly autocorrelation   | 0.944<br>(0.016) | 0.962<br>(0.011) | 0.739<br>(0.057)  | 0.847<br>(0.038)  | 0.919<br>(0.021)  | 0.935<br>(0.019)  | 0.959<br>(0.012)  | 0.882<br>(0.032)  |
| Relative standard deviation | 1.833<br>(0.028) | 1.915<br>(0.046) | 3.033<br>(0.097)  | 3.005<br>(0.045)  | 4.958<br>(0.027)  | 4.655<br>(0.063)  | 7.874<br>(0.151)  | 1<br>-            |
| $u$                         | 1<br>-           | 1<br>-           | -0.703<br>(0.065) | -0.780<br>(0.053) | -0.827<br>(0.044) | -0.914<br>(0.024) | -0.935<br>(0.019) | -0.865<br>(0.036) |
| $v$                         | -                | -                | 1<br>-            | 1<br>-            | 1<br>-            | 0.967<br>(0.007)  | 0.973<br>(0.006)  | 0.965<br>(0.006)  |
| $v/u$                       | -                | -                | -                 | -                 | -                 | 1<br>-            | 1<br>-            | 0.999<br>(0.000)  |
| $A$                         | -                | -                | -                 | -                 | -                 | -                 | -                 | 1<br>-            |

TABLE 4: Summary statistics from simulations. The first column under each variable is the summary statistics for the textbook search model; the second column is the model with monopolistic competition, price adjustment cost, and firms are not required to finance their wage bill  $\gamma = 0$ ; and the third column is when firms are required to finance their wage bill in full  $\gamma = 1$ . Each reported statistic is the mean from 10,000 simulations. The standard deviation across simulations are reported in parentheses.

10,000 simulations. The figures in parentheses are the standard deviations of the statistics.

There are three columns under each variable. The first column is from the textbook search model (no monopolistic competition and no working capital requirement); the second column contains statistics for the  $\gamma = 0$  model (monopolistic competition and no working capital requirement); and the third column is for  $\gamma = 1$  model which has a full complement of features (monopolistic competition and full working capital requirement).

Since the textbook model in this paper is slightly different from that of Shimer (2005), I will first go over the textbook model results to establish the benchmark upon which the model needs to improve.<sup>10</sup> As Mortensen and Nagypál (2007b) point out, with labor productivity as the sole driving force of the model, one should not expect the employment fluctuations to match the data, so I will compare the relative standard deviations in the simulations to the data OLS regression coefficients as opposed to data relative standard deviations.

First, with the elasticity of matches to market tightness at 0.5 and the opportunity cost of employment at 0.73, the model is more volatile relative to Shimer (2005). However, unemployment volatility is still less than half of the data ( $1.833/4.011 = 0.457$ ). The model vacancy's volatility does improve to nearly 90 percent of the OLS coefficient ( $3.033/3.383 = 0.897$ ). Largely because of the vacancy volatility, market tightness volatility performs better at 4.513 or 61 percent of the OLS coefficient rather than the 1.750 or 24 percent in Shimer (2005). However, the model still cannot reproduce observed patterns.

Aside from the volatility of unemployment and market tightness, there appear to be shortcomings in the Beveridge curve (the strong negative correlation between unemployment and vacancy) and low autocorrelation in vacancy. The model shows a correlation coefficient of  $-0.703$  between unemployment and vacancy where it is  $-0.894$  in the data. This difference is due to the quarterly discrete time setup—the pool of job seekers in period  $t$   $u_t$  depends only on period  $t - 1$ 's employment pool so it lags vacancy  $v_t$  by one quarter. If we look at  $1 - n_t$  which is the number of people without a job in period  $t$ , the correlation coefficient with  $v_t$  is  $-0.899$  which is in line with the observed Beveridge curve. In terms of autocorrelation of vacancy, the model autocorrelation is 0.739 while it is 0.944 in the data. This difference is because the textbook search model lacks a propagation mechanism so vacancy jumps the moment a shock arrives and then adjusts back to its steady-state value. Therefore, vacancy would jump back and forth in response to positive and negative productivity shocks which reduce its autocorrelation.

Next we move onto the  $\gamma = 0$  version of the model which incorporates monopolistic com-

---

<sup>10</sup>The key differences are the choice of labor market parameters—the “replacement ratio,” workers’ bargaining power, and the elasticity of market tightness with respect to new matches—as well as the quarterly discrete time setup.

petition but no working capital requirement. The volatilities of the labor market variables are comparable to that of the textbook model. Unemployment volatility shows a 4 percent increase; vacancy volatility decreases by less than 1 percent; market tightness volatility increases by 3 percent. These results are not surprising from what we have seen in the impulse response functions. Note the interaction of marginal revenue  $\phi_t$  and labor productivity  $A_t$  generates a hump-shaped response to marginal revenue product of labor which in turn generates hump-shaped responses to vacancy, unemployment, and market tightness. The interaction of marginal revenue and labor productivity therefore increases the autocorrelations of these variables. The interaction also improves the Beveridge curve and the correlation between market tightness and unemployment.

Lastly we examine the  $\gamma = 1$  version of the model. Notice that when firms are required to finance their wage bills and incorporate the nominal interest rate as a component of the labor cost, volatilities of employment variables increase significantly. Unemployment volatility now reaches 81 percent of the OLS coefficient, up from 46 percent. The relative standard deviation of vacancy overshoots at 147 percent of the OLS coefficient; and market tightness becomes slightly more volatile than the data at 106 percent, up from 61 percent achieved by the textbook model. Overall, requiring firms to finance their wage bills in full increases vacancy volatility by 63 percent over the textbook search model and 65 percent over the  $\gamma = 0$  version of the model; unemployment volatility shows a 78 percent increase over the textbook model and 70 percent over  $\gamma = 0$ ; market tightness volatility goes up by 74 percent and 69 percent relative to the textbook and  $\gamma = 0$  versions of the model, respectively. It also produces stronger autocorrelations and correlations among labor market variables; these statistics are in line with their empirical counterparts.

|                                    | Data  | Textbook         | $\gamma = 0$     | $\gamma = 1$     |                  |
|------------------------------------|-------|------------------|------------------|------------------|------------------|
| Labor cost-productivity elasticity | 0.606 | 0.954<br>(0.001) | 0.719<br>(0.011) | 0.632<br>(0.010) | 1.294<br>(0.024) |

TABLE 5: Data and simulated model labor cost statistics. The data labor cost is constructed following [Hagedorn and Manovskii \(2008\)](#) by taking the product of labor share and labor productivity. The data labor cost series is then logged and HP detrended using  $10^5$  as the smoothing parameter. The data labor cost-productivity elasticity is the OLS coefficient from regressing log labor cost on log productivity. The elasticity from the simulated model is the relative standard deviation—the standard deviation of labor cost divided by the standard deviation of labor productivity. The first column under the full working capital requirement is the labor cost  $(1 - \gamma + \gamma R_t)w_t$ , and the second column is the wage component of the labor cost  $w_t$ .

Table 5 examines the cyclical properties of labor cost. I follow [Hagedorn and Manovskii \(2008\)](#) and construct the labor cost by multiplying the BLS labor share and labor productivity. The data is then logged and detrended with an HP filter using  $10^5$  as the smoothing

parameter. I find that OLS coefficient from regressing log labor cost on log labor productivity is 0.606 in the data. Unsurprisingly, the relative standard deviation for the textbook model is nearly 1 at 0.954, echoing the findings of many other researchers.

Due to the interaction of marginal revenue and labor productivity, the incorporation of monopolistic competition into the textbook model reduces labor cost elasticity to 0.719. Furthermore, with both monopolistic competition and a full working capital requirement, the elasticity of labor cost drops to 0.632, which is comparable to the data.

Next we examine the cyclical properties of the wage component of labor cost. As [Pissarides \(2009\)](#) argues, the dynamics of job creation in a search and matching model like the one examined here is driven by the share of firm's surplus in a new match. Therefore, when considering the cyclicity of wages in the context of a search and matching model, the relevant comparison is the results of panel studies of job changers rather than aggregate studies. [Haefke et al. \(2013\)](#) and [Kudlyak \(2014\)](#) have made the similar point in more recent studies. More importantly, these studies establish that the individual wages, especially those in newly-formed matches, are more procyclical than average wage. [Pissarides \(2009\)](#) surveys the literature and finds the consensus wage-productivity elasticity between 1948–2006 to be 1.02. Using Panel Study of Income Dynamics data, [Pissarides \(2009\)](#) finds elasticity to be 1.70.

It is interesting to note that while a working capital requirement generates a more rigid labor cost than the textbook search and matching model, the model does not require rigid wages to address the unemployment volatility puzzle. In fact, under a full working capital requirement, the relative standard deviation of the wage component in labor cost to labor productivity is 1.294, which is in line with the findings in [Pissarides \(2009\)](#).

## 4 Robustness

Given that the interest rate rule and monopolistic competition are not standard features of the search model, I explore alternative calibrations in this section and examine their effects on the quantitative results of the model.

### 4.1 Interest Rate Rule

There are three parameters— $\rho_R$ ,  $\rho_\pi$ , and  $\rho_y$ —in the interest rate rule. As a quick refresher,  $\rho_R$  is the interest rate persistence parameter,  $\rho_\pi$  and  $\rho_y$  are the weights the monetary authority assigns to the inflation target and the steady-state output, respectively. I will examine the parameters one by one.

Intuitively, the smaller the  $\rho_R$ , the less weight the monetary authority places on previous period's interest rate and the more weight on keeping inflation and output close to their steady-state values. The role  $\rho_R$  plays is shown in figure 2. As we can see, smaller  $\rho_R$  serves to prevent inflation from falling too much. Working through the Phillips curve, equation (12), marginal revenue also stays closer to its steady-state value. Combining this with lower  $R_t$ , worker value is kept high when  $\rho_R$  is smaller.<sup>11</sup> The mean relative standard deviation of market tightness (the standard deviation across simulations is in parentheses) for  $\rho_R = 0.7$  is 8.648 (0.139); it is 6.842 (0.081) for  $\rho_R = 0.9$ .

Figure 3 examines  $\rho_\pi$ , the weight on inflation. The greater the  $\rho_\pi$ , the more the monetary authority would like to keep inflation close to its steady-state value; this leads to smaller initial drop in inflation and marginal revenue. However, the discrepancy in marginal revenue product is largely offset by the labor cost—after the initial shock, there is little difference in worker value and market tightness under different values of  $\rho_\pi$ . The relative standard deviations for  $\rho_\pi = 1.5$  and  $\rho_\pi = 3$  are 8.254 (0.106) and 7.796 (0.120), respectively.

Figure 4 examines  $\rho_y$ . Relatively speaking, a smaller  $\rho_y$  indicates that the monetary authority places a greater emphasis on keeping interest rate and inflation close to their steady-state values. It keeps inflation and marginal revenue from falling too much immediately following the shock and keeps worker value high. However, marginal revenue recovers quickly even with a high  $\rho_y$ . While the specification with a higher  $\rho_y$  has a similar marginal revenue as the specification with a lower  $\rho_y$  by the second quarter after the shock, it also has a relatively low nominal interest rate, and interest rate inertia keeps  $R_t$  low, which leads to lower labor cost. This allows the worker value for higher  $\rho_y$  to overtake the worker value of lower  $\rho_y$  in quarter 2, resulting in a slightly greater response to market tightness. The mean standard deviation and standard deviation of the statistics across simulations are:  $\rho_y = 0.1$ —7.430 (0.135); and  $\rho_y = 0.5$ —8.443 (0.152).

It should be noted that the main quantitative result—the working capital requirement allows search-and-matching model to generate substantially more volatility—holds for a wide range of parameter values in the interest rate rule. Table 6 summarizes the simulations. Next I will examine the parameters in the Phillips curve.

## 4.2 Phillips Curve

There are two parameters in the Phillips curve— $\kappa_p$  price adjustment cost and  $\varepsilon_p$  the degree of substitutability among intermediate goods.

---

<sup>11</sup>In the case of  $\rho_R = 0.9$ , inflation is allowed to fall to the extent that the marginal revenue product falls significantly and temporarily reduces worker value despite a positive productivity shock.

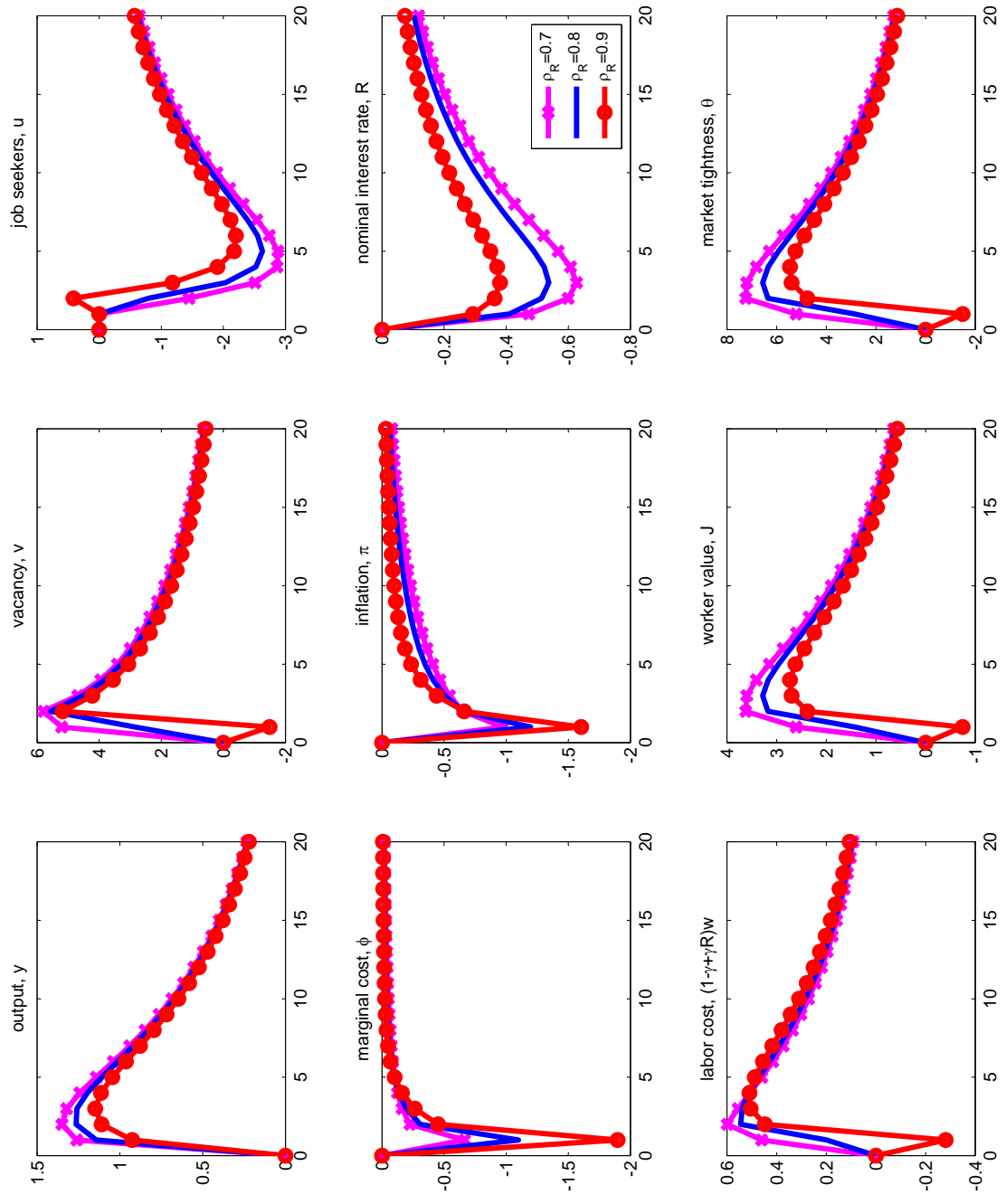


FIGURE 2: Impulse response functions for the different interest rate inertia  $\rho_R$  under  $\gamma = 1$ .

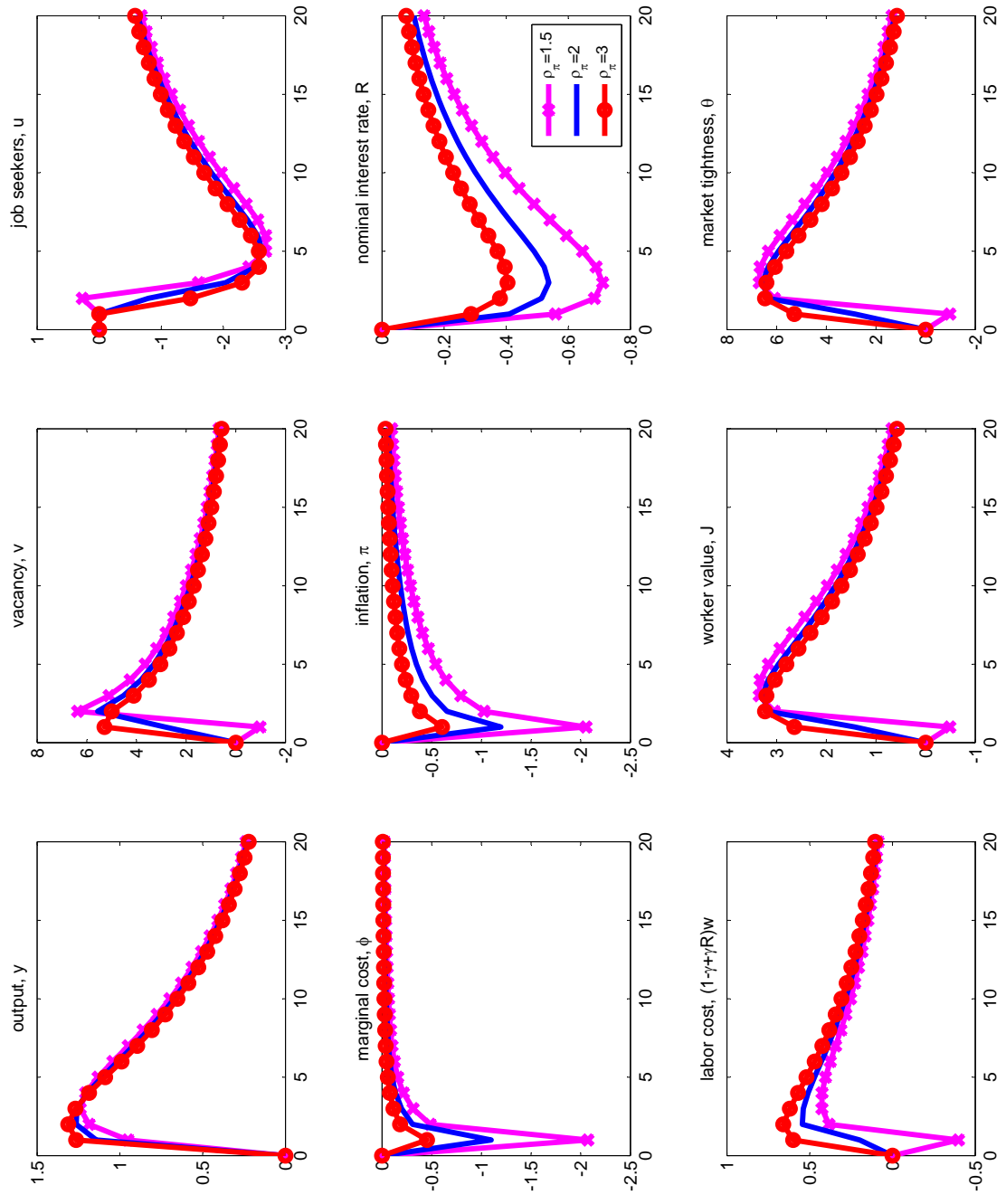


FIGURE 3: Impulse response functions for the different weight on inflation  $\rho_\pi$  under  $\gamma = 1$ .

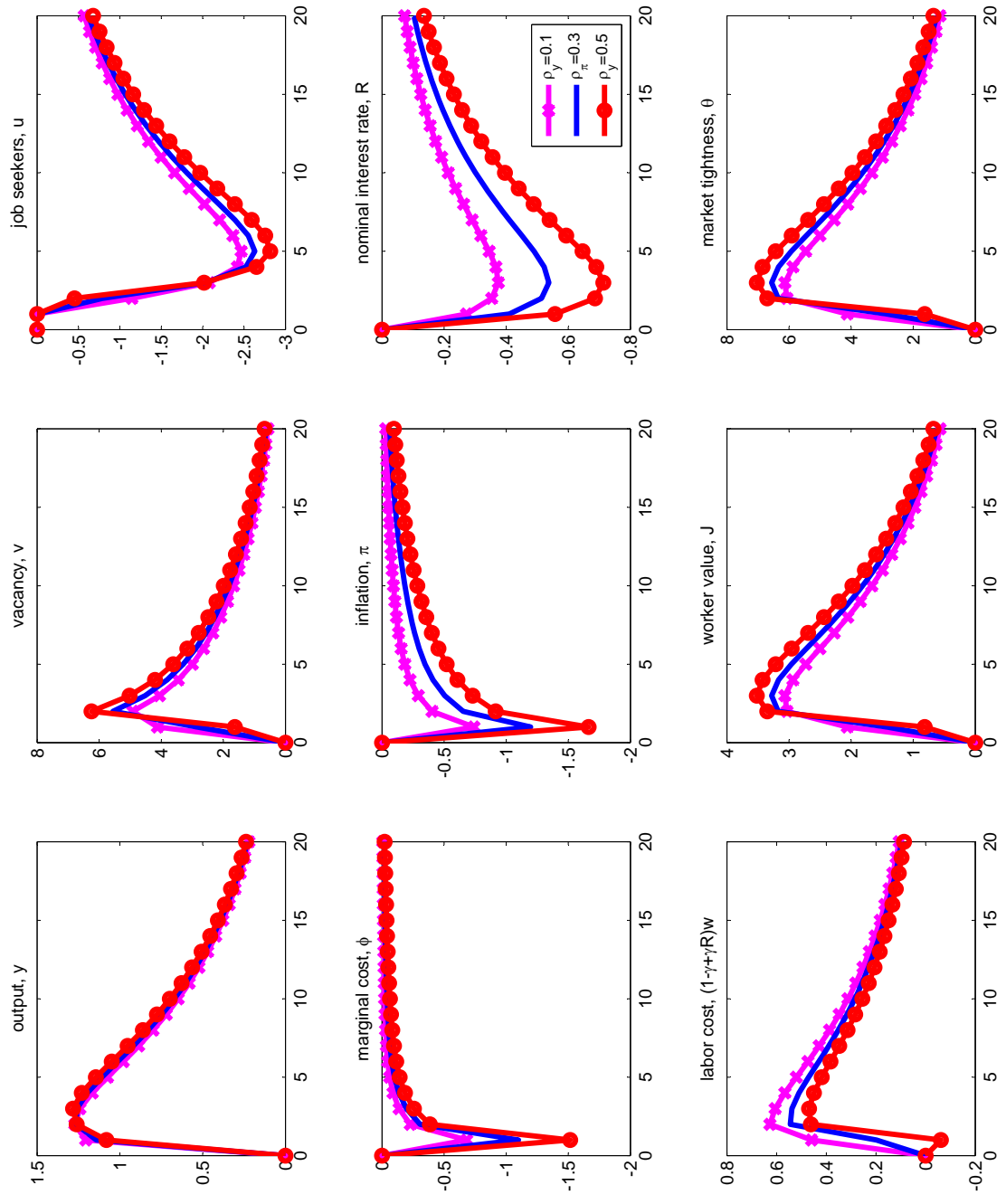


FIGURE 4: Impulse response functions for the different weight on output  $\rho_y$  under  $\gamma = 1$ .



|                             | Data     | $\rho_R = 0.7$    | $\rho_R = 0.9$    | $\rho_\pi = 1.5$  | $\rho_\pi = 3$    | $\rho_y = 0.1$    | $\rho_y = 0.5$    |
|-----------------------------|----------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Relative standard deviation | $u$      | 4.011<br>(0.089)  | 3.573<br>(0.067)  | 2.788<br>(0.082)  | 3.377<br>(0.079)  | 3.215<br>(0.081)  | 3.491<br>(0.093)  |
|                             | $v$      | 3.383<br>(0.051)  | 5.504<br>(0.115)  | 4.551<br>(0.112)  | 5.422<br>(0.054)  | 4.990<br>(0.030)  | 5.357<br>(0.041)  |
|                             | $v/u$    | 7.394<br>(0.139)  | 8.648<br>(0.081)  | 6.842<br>(0.106)  | 8.254<br>(0.120)  | 7.796<br>(0.135)  | 8.443<br>(0.152)  |
| Autocorrelation             | $u$      | 0.943<br>(0.010)  | 0.967<br>(0.015)  | 0.949<br>(0.014)  | 0.954<br>(0.010)  | 0.965<br>(0.009)  | 0.968<br>(0.009)  |
|                             | $v$      | 0.944<br>(0.028)  | 0.889<br>(0.060)  | 0.739<br>(0.052)  | 0.779<br>(0.034)  | 0.866<br>(0.025)  | 0.894<br>(0.027)  |
|                             | $v/u$    | 0.945<br>(0.015)  | 0.949<br>(0.030)  | 0.897<br>(0.025)  | 0.912<br>(0.017)  | 0.942<br>(0.013)  | 0.952<br>(0.014)  |
| Correlation coefficient     | $u, v$   | -0.876<br>(0.048) | -0.807<br>(0.064) | -0.722<br>(0.06)  | -0.746<br>(0.05)  | -0.796<br>(0.046) | -0.813<br>(0.047) |
|                             | $u, v/u$ | -0.969<br>(0.021) | -0.926<br>(0.032) | -0.887<br>(0.029) | -0.898<br>(0.022) | -0.921<br>(0.020) | -0.929<br>(0.020) |
|                             | $v, v/u$ | 0.968<br>(0.006)  | 0.970<br>(0.007)  | 0.960<br>(0.007)  | 0.963<br>(0.006)  | 0.969<br>(0.006)  | 0.971<br>(0.006)  |

TABLE 6: Robustness checks for interest rate rule parameters. Each reported statistic is the mean from 10,000 simulations. The standard deviation across simulations are reported in parentheses.

Figure 5 plots the IRFs for different values of  $\kappa_p$ . Intuitively, the smaller the  $\kappa_p$ , the greater degree of price flexibility. This means prices would change more to avoid large swings in marginal revenues. This keeps worker value high and allows firms to create more vacancies than when it is more costly to adjust prices. [Lubik and Schorfheide \(2004\)](#) use a log-likelihood approach to estimate a New Keynesian Phillips curve similar to the one presented in this paper. They find the 90-percent interval of the slope coefficient  $\frac{\varepsilon_p - 1}{\kappa_p}$  to be  $[0.27, 0.89]$ . Assuming a 10-percent steady-state markup as is typically done in the literature, it implies  $\kappa_p \in [11.24, 37.04]$ . Here I provide a robustness check for  $\kappa_p = 10$  and  $\kappa_p = 40$ . The statistics for relative standard deviation of market tightness are: for  $\kappa_p = 10$ —8.682 (0.134); and for  $\kappa_p = 40$ —6.762 (0.129).

In terms of  $\varepsilon_p$ , the degree of substitutability among intermediate goods, the smaller the  $\varepsilon_p$ , the larger the steady-state markup; the larger the markup, the greater portion of sales proceeds is retained as profits and the greater the incentive to create vacancies. This effect is what we observe in figure 6. Estimates of the steady-state markup in the literature vary depending on the types of frictions considered and the specification of the model.<sup>12</sup> In this section I consider  $\varepsilon_p = 6.67$  and 20, which correspond to a 15 percent and a 5 percent steady-state markup, respectively. Note that the Phillips curve coefficient is  $\frac{\varepsilon_p - 1}{\kappa_p}$ . When

<sup>12</sup>For example, [Christiano et al. \(2005\)](#) find the steady-state markup ranges from 6 percent to 20 percent; [Rotemberg and Woodford \(1997\)](#) finds the steady-state markup to be approximately 13 percent.

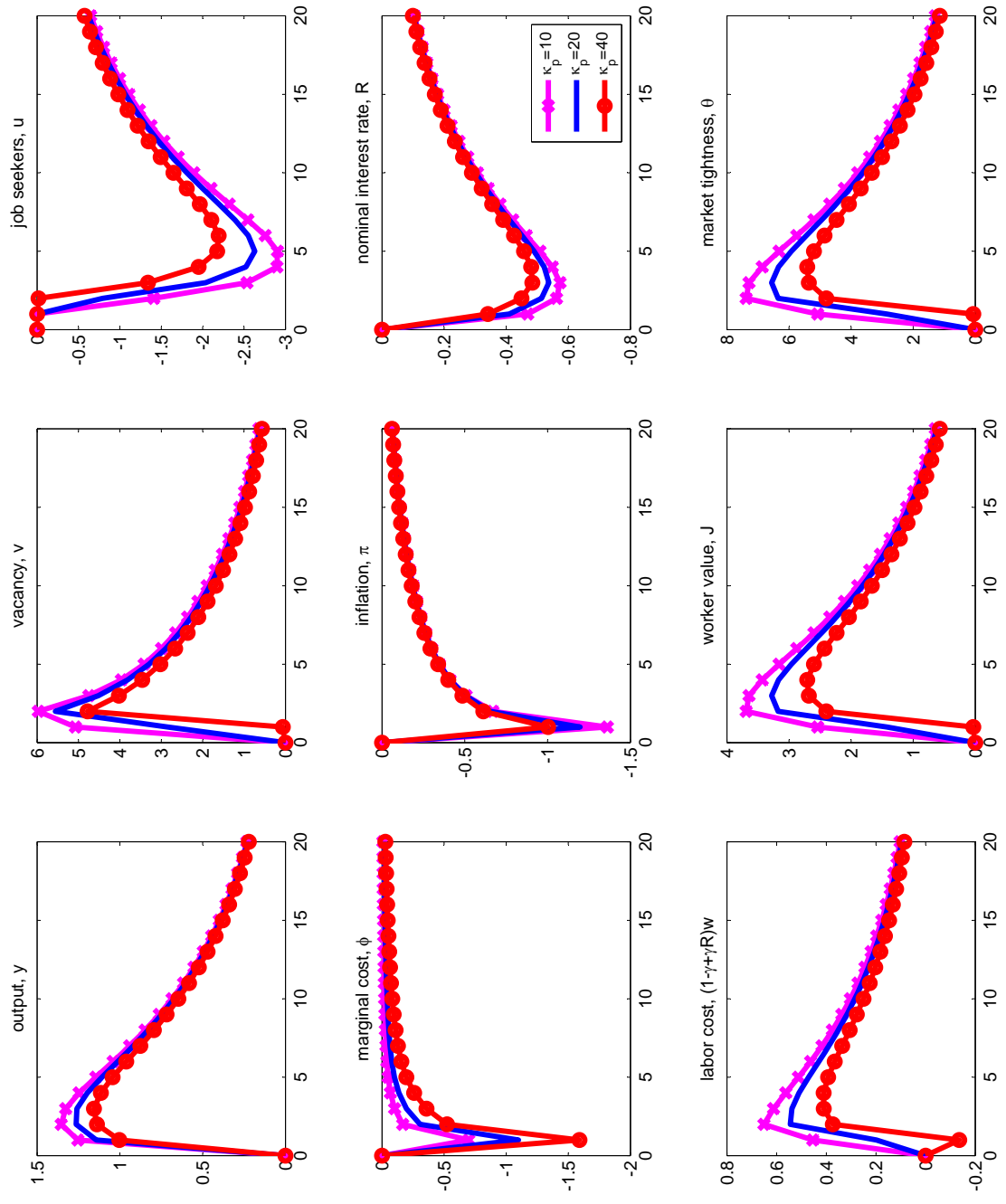


FIGURE 5: Impulse response functions for the different  $\kappa_p$  under  $\gamma = 1$ .

|                             | Data     | $\kappa_p = 10$ | $\kappa_p = 40$   | $\varepsilon_p = 6.67$ | $\varepsilon_p = 20$ |                   |
|-----------------------------|----------|-----------------|-------------------|------------------------|----------------------|-------------------|
| Relative standard deviation | $u$      | 4.011           | 3.586<br>(0.087)  | 2.790<br>(0.080)       | 4.410<br>(0.144)     | 2.911<br>(0.069)  |
|                             | $v$      | 3.383           | 5.527<br>(0.055)  | 4.321<br>(0.038)       | 6.607<br>(0.039)     | 4.488<br>(0.048)  |
|                             | $v/u$    | 7.394           | 8.682<br>(0.134)  | 6.762<br>(0.129)       | 10.609<br>(0.269)    | 7.048<br>(0.105)  |
| Autocorrelation             | $u$      | 0.943           | 0.967<br>(0.010)  | 0.965<br>(0.010)       | 0.975<br>(0.008)     | 0.967<br>(0.010)  |
|                             | $v$      | 0.944           | 0.892<br>(0.027)  | 0.857<br>(0.037)       | 0.931<br>(0.019)     | 0.895<br>(0.026)  |
|                             | $v/u$    | 0.945           | 0.950<br>(0.014)  | 0.941<br>(0.018)       | 0.966<br>(0.010)     | 0.951<br>(0.014)  |
| Correlation coefficient     | $u, v$   | -0.876          | -0.806<br>(0.048) | -0.799<br>(0.050)      | -0.848<br>(0.040)    | -0.806<br>(0.048) |
|                             | $u, v/u$ | -0.969          | -0.926<br>(0.021) | -0.922<br>(0.022)      | -0.944<br>(0.017)    | -0.926<br>(0.021) |
|                             | $v, v/u$ | 0.968           | 0.970<br>(0.006)  | 0.969<br>(0.006)       | 0.976<br>(0.006)     | 0.970<br>(0.006)  |

TABLE 7: Robustness checks for monopolistic competition parameters.  $\varepsilon_p = 6.67$  corresponds to 15 percent steady-state markup;  $\varepsilon_p = 20$  corresponds to 5 percent steady-state markup. Each reported statistic is the mean from 10,000 simulations. The standard deviation across simulations are reported in parentheses.

$\varepsilon_p$  is small, the ratio of log-deviation in inflation to log-deviation in marginal cost is small. This is especially prevalent in the quarter the shock hits the economy. The magnitudes of the falls in marginal revenue and inflation are about 1-to-1 for the 15 percent markup case, whereas marginal costs fall by much less in the other two cases for similar changes in inflation. Note this initial fall in marginal cost contributes to a lower marginal revenue product and lower worker value in quarter 1 for the 15 percent markup specification. However, once marginal revenue recovers, worker value picks back up due to lower labor cost. 15 percent markup calibration generates a relative standard deviation of 10.609 (0.269); 5 percent markup generates 7.048 (0.105).

Similar to our examination of the interest rate rule, the main result of the paper continues to hold for a wide range of Phillips curve parameters. Table 7 summarizes the simulations.

### 4.3 Partial Working Capital Requirement

Section 3.3 focuses on zero working capital requirement ( $\gamma = 0$ ) and a full working capital requirement ( $\gamma = 1$ ). Table 8 presents simulation results under various partial working capital requirements.

From what we have seen between  $\gamma = 0$  and  $\gamma = 1$ , it should not be surprising to find that

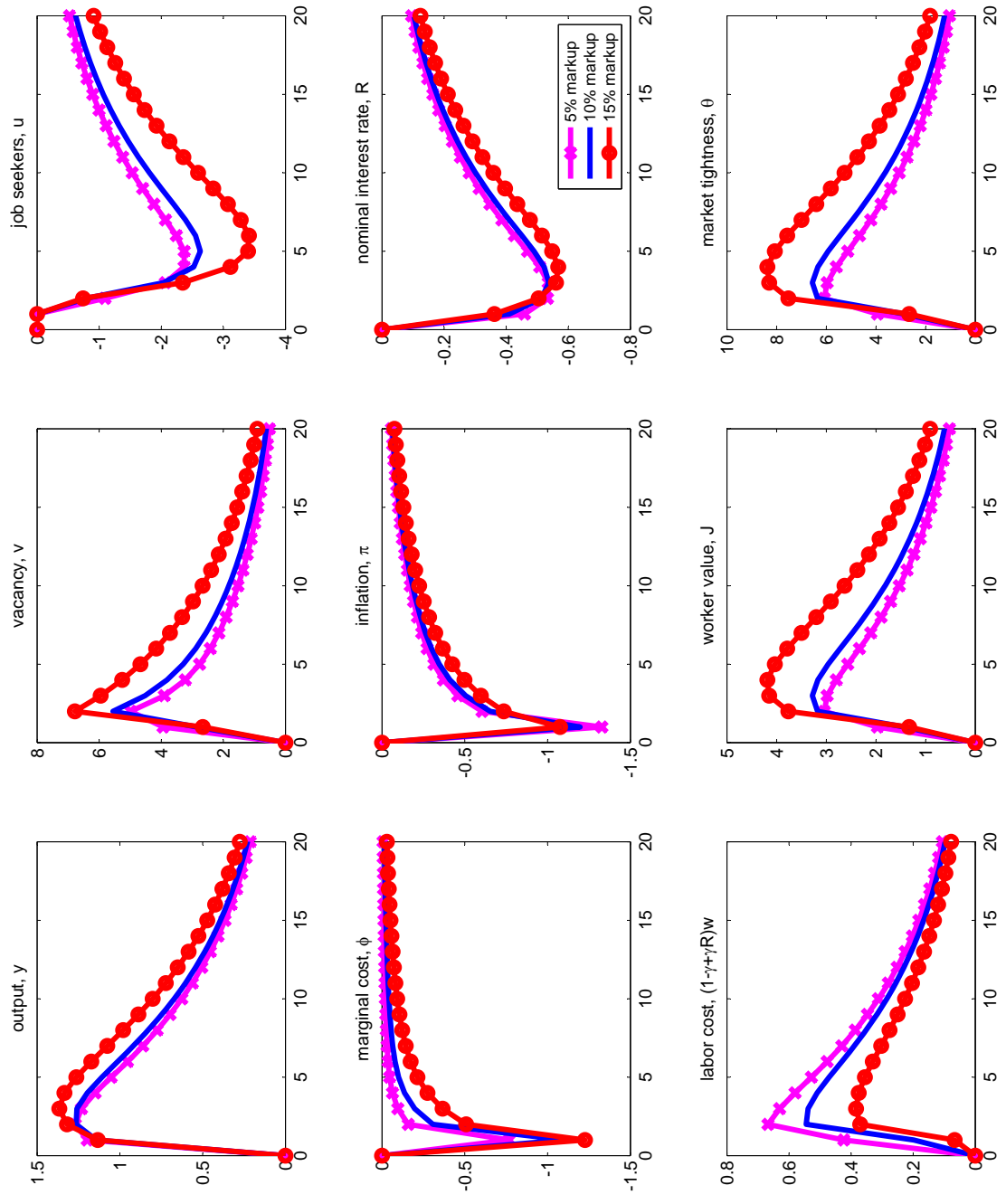


FIGURE 6: Impulse response functions for the different  $\varepsilon_p$  under  $\gamma = 1$ .

|                             |          | Data   | $\gamma = 0$      | $\gamma = 0.25$   | $\gamma = 0.5$    | $\gamma = 0.75$   | $\gamma = 1$      |
|-----------------------------|----------|--------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Relative standard deviation | $u$      | 4.011  | 1.915<br>(0.046)  | 2.201<br>(0.055)  | 2.518<br>(0.065)  | 2.870<br>(0.076)  | 3.263<br>(0.089)  |
|                             | $v$      | 3.383  | 3.005<br>(0.045)  | 3.407<br>(0.037)  | 3.863<br>(0.032)  | 4.378<br>(0.029)  | 4.958<br>(0.027)  |
|                             | $v/u$    | 7.394  | 4.655<br>(0.063)  | 5.334<br>(0.083)  | 6.090<br>(0.104)  | 6.932<br>(0.126)  | 7.874<br>(0.151)  |
| Autocorrelation             | $u$      | 0.943  | 0.962<br>(0.011)  | 0.966<br>(0.010)  | 0.968<br>(0.009)  | 0.970<br>(0.009)  | 0.971<br>(0.009)  |
|                             | $v$      | 0.944  | 0.847<br>(0.037)  | 0.880<br>(0.030)  | 0.900<br>(0.026)  | 0.912<br>(0.023)  | 0.919<br>(0.021)  |
|                             | $v/u$    | 0.945  | 0.935<br>(0.019)  | 0.946<br>(0.016)  | 0.953<br>(0.014)  | 0.957<br>(0.012)  | 0.959<br>(0.012)  |
| Correlation coefficient     | $u, v$   | -0.876 | -0.780<br>(0.053) | -0.800<br>(0.049) | -0.813<br>(0.046) | -0.822<br>(0.045) | -0.827<br>(0.044) |
|                             | $u, v/u$ | -0.969 | -0.914<br>(0.024) | -0.923<br>(0.022) | -0.929<br>(0.020) | -0.932<br>(0.019) | -0.935<br>(0.019) |
|                             | $v, v/u$ | 0.968  | 0.967<br>(0.007)  | 0.969<br>(0.006)  | 0.971<br>(0.006)  | 0.972<br>(0.006)  | 0.973<br>(0.006)  |

TABLE 8: Model statistics with different levels of working capital requirement;  $\gamma$  is the fraction of the total wage bill a firm is required to borrow. Each reported statistic is the mean from 10,000 simulations. The standard deviation across simulations are reported in parentheses.

the model generates greater amounts of labor market variable volatility the higher the  $\gamma$ . It is worth noting that the model with a full working working capital requirement produces a vacancy response that is higher than what is observed in the data. A partial working capital requirement— $\gamma$  between 0 and 1—reduces this volatility, but it reduces unemployment volatility at the same time. However, the propagation mechanism generated by monopolistic competition is preserved regardless of the value of  $\gamma$  and allows the model to show desirable autocorrelations and correlation coefficients among key labor market variables.

## 5 Conclusion

Shimer (2005) argues that search-and-matching models that utilize Nash bargaining cannot match the observed volatility in key labor market variables with plausible labor productivity shocks. This paper examines how a working capital requirement along with monopolistic competition can increase employment fluctuations without resorting to an alternative wage setting mechanism. I find that, relative to the textbook search-and-matching model, the model with monopolistic competition and a working capital requirement delivers a 78 percent increase in unemployment volatility, a 63 percent increase in vacancy volatility, and a 74 percent increase in market tightness volatility. The unemployment volatility now reaches

81 percent of the OLS regression coefficient. The relative standard deviation of vacancy overshoots the target at 147 percent. The market tightness volatility is 106 percent of the OLS regression coefficient. Moreover, the proposed modification either maintains or improves the autocorrelation and the correlation among the labor market variables. These statistics are in line with their empirical counterparts. The robustness checks show that these quantitative results continue to hold under a wide range of interest rate rule and monopolistic competition specifications.

## References

- ANDOLFATTO, D. (1996): “Business Cycles and Labor-Market Search,” *American Economic Review*, 86, 112–132.
- BILS, M. AND P. J. KLENOW (2004): “Some Evidence on the Importance of Sticky Prices,” *Journal of Political Economy*, 112, 947–985.
- BOIVIN, J. AND M. P. GIANNONI (2006): “Has Monetary Policy Become More Effective?” *The Review of Economics and Statistics*, 88, 445–462.
- CHRISTIANO, L. J., M. EICHENBAUM, AND C. L. EVANS (2005): “Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy,” *Journal of Political Economy*, 113, 1–45.
- CLARIDA, R., J. GALÍ, AND M. GERTLER (2000): “Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory,” *The Quarterly Journal of Economics*, 115, 147–180.
- COGLEY, T., G. E. PRIMICERI, AND T. J. SARGENT (2010): “Inflation-Gap Persistence in the US,” *American Economic Journal: Macroeconomics*, 2, 43–69.
- COOLEY, T. F. AND V. QUADRINI (1999): “A Neoclassical Model of the Phillips Curve Relation,” *Journal of Monetary Economics*, 44, 165–193.
- (2004): “Optimal Monetary Policy in a Phillips-curve World,” *Journal of Economic Theory*, 118, 178–208.
- DEN HAAN, W. J., G. RAMEY, AND J. WATSON (2000): “Job Destruction and Propagation of Shocks,” *American Economic Review*, 90, 482–498.
- FUJITA, S. AND G. RAMEY (2007): “Job Matching and Propagation,” *Journal of Economic Dynamics & Control*, 31, 3671–3698.
- GALÍ, J. AND M. GERTLER (1999): “Inflation dynamics: A structural econometric analysis,” *Journal of Monetary Economics*, 44, 195 – 222.
- GERTLER, M., L. SALA, AND A. TRIGARI (2008): “An Estimated Monetary DSGE Model with Unemployment and Staggered Nominal Wage Bargaining,” *Journal of Money, Credit, and Banking*, 40, 1713–1764.

- GERTLER, M. AND A. TRIGARI (2009): “Unemployment Fluctuations with Staggered Nash Wage Bargaining,” *Journal of Political Economy*, 117, 38–86.
- HAEFKE, C., M. SONNTAG, AND T. VAN RENS (2013): “Wage rigidity and job creation,” *Journal of Monetary Economics*, 60, 887–899.
- HAGEDORN, M. AND I. MANOVSKII (2008): “The Cyclical Behavior of Equilibrium Unemployment and Vacancies Revisited,” *American Economic Review*, 98, 1692–1706.
- HALL, R. E. (2005): “Employment Fluctuations with Equilibrium Wage Stickiness,” *American Economic Review*, 95, 50–65.
- HALL, R. E. AND P. R. MILGROM (2008): “The Limited Influence of Unemployment on the Wage Bargain,” *American Economic Review*, 98, 1653–1674.
- IRELAND, P. N. (1997): “A small, structural, quarterly model for monetary policy evaluation,” *Carnegie-Rochester Conference Series on Public Policy*, 47, 83–108.
- JUSTINIANO, A. AND G. E. PRIMICERI (2008): “The Time-Varying Volatility of Macroeconomic Fluctuations,” *American Economic Review*, 98, 604–641.
- KRAUSE, M. U. AND T. A. LUBIK (2006): “The Cyclical Upgrading of Labor and On-the-job Search,” *Labour Economics*, 13, 459–477.
- (2007): “The (ir)relevance of real wage rigidity in the New Keynesian model with search frictions,” *Journal of Monetary Economics*, 54, 706–727.
- KUDLYAK, M. (2014): “The cyclicity of the user cost of labor,” *Journal of Monetary Economics*, 68, 53–67.
- LUBIK, T. A. AND F. SCHORFHEIDE (2004): “Testing for Indeterminacy: An Application to U.S. Monetary Policy,” *American Economic Review*, 94, 190–217.
- MERZ, M. (1995): “Search in the Labor Market and the Real Business Cycle,” *Journal of Monetary Economics*, 36, 269–300.
- MORTENSEN, D. T. AND E. NAGYPÁL (2007a): “Labor-market Volatility in Matching Models with Endogenous Separations,” *Scandinavian Journal of Economics*, 109, 645–665.
- (2007b): “More on Unemployment and Vacancy Fluctuations,” *Review of Economic Dynamics*, 10, 327–347.



- NAGYPÁL, E. (2007): “Labor-market Fluctuations and On-the-job Search,” Northwestern University mimeo.
- NAKAMURA, E. AND J. STEINSSON (2008): “Five Facts about Prices: A Reevaluation of Menu Cost Models,” *The Quarterly Journal of Economics*, 123, 1415–1464.
- PISSARIDES, C. A. (2009): “The Unemployment Volatility Puzzle: Is Wage Stickiness the Answer?” *Econometrica*, 77, 1339–1369.
- ROTEMBERG, J. AND M. WOODFORD (1997): *An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy*, MIT Press, chap. 6, 297–361, NBER Macroeconomics Annual 1997, Volume 12.
- SHIMER, R. (2005): “The Cyclical Behavior of Equilibrium Unemployment and Vacancies,” *American Economic Review*, 95, 25–49.
- SMETS, F. AND R. WOUTERS (2007): “Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach,” *American Economic Review*, 97, 586–606.