ISSN 1936-5330

The Federal Reserve Bank of Kansas City
Economic Research Department

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January 2009; Revised October 2009
RWP 09-03

Research Working Papers

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First version: January 2009
This version: October 2009

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Abstract

Models of the monetary transmission mechanism often generate empirically implausible business fluctuations. This paper analyzes the role of on-the-job search in the propagation of monetary shocks in a sticky price model with labor market search frictions. Such frictions induce long-term employment relationships, such that the real marginal cost is determined by real wages and the cost of an employment relationship. On-the-job search opens up an extra channel of employment growth that dampens the response of these two components. Because real marginal cost rigidity induces small price adjustments, on-the-job search gives rise to a strong propagation of monetary shocks that increases output persistence.

Keywords: On-the-job search, cost of an employment relationship, sticky prices, business fluctuations

JEL Classification: E24, E31, E32

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* I am especially grateful to Daniele Coen-Pirani, Marvin Goodfriend, Bennett McCallum, associate editor Thomas Lubik, and an anonymous referee for comments that greatly improved this paper. I also thank Michelle Alexopoulos, Hafedh Bouakez, Michael Krause, Christopher Sleet, Tack Yun, and seminar participants at Carnegie Mellon University, Federal Reserve Bank of Kansas City, HEC Montreal, the 2009 Missouri Economics Conference, the 2009 and 2006 Midwest Macroeconomics Meeting, and the 2008 North American Summer Meeting of the Econometric Society, for helpful comments. Financial support from a William Larimer Mellon fellowship is gratefully acknowledged. The views expressed herein are solely those of the author and do not necessarily reflect the views of the Federal Reserve Bank of Kansas City or the Federal Reserve System.
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1 Introduction

There is a widespread view in the monetary business cycle literature that optimizing sticky price models need to be augmented with a source of real marginal cost rigidity in order to generate empirically plausible dynamics.[1] The marginal cost of production connects the labor market and inflation. If the structure of the labor market renders firms' marginal cost unresponsive to a change in production, the ensuing inflation adjustment can be sluggish. In that case, monetary shocks can be propagated to yield persistent effects on real economic activity.

A recent literature has studied the dynamics of real marginal cost, inflation and output in sticky price models with labor market search and matching frictions along the lines of Mortensen and Pissarides (1994).[2] The labor market frictions make employment adjustment costly, thus increasing the sensitivity of marginal cost to a demand-induced increase in real activity. In particular, such frictions give rise to a surplus from a match between a worker and a firm, which induces a long-term employment relationship. Consequently, the marginal cost is determined by the cost of an employment relationship, i.e. the cost of hiring a worker net of the expected saving of future hiring costs, in addition to the real wage. To expand production, firms must increase their hiring by posting vacancies, and as vacancies rise and unemployment declines the labor market tightens. If real wages are set so as to split the surplus of the match, then the tighter labor market leads to higher wages. But it also raises the cost of an employment relationship, since hiring is relatively expensive when the labor market is tight. Therefore, both components contribute to a rise in marginal cost.

This paper revisits the question of whether search frictions are a source of real marginal cost rigidity by studying the role of on-the-job search for marginal cost dynamics. Employer-to-employer transitions are an important part of U.S. labor market flows. Fallick and Fleischman (2004) use the Current Population Survey to construct a measure of employer-to-employer flows. They find that 2.6 percent of employed workers change employers in an average month. That is about as large as the flow of workers leaving employment out of the labor force and twice

[1] Empirical responses to monetary shocks are documented in an extensive vector autoregression literature; see e.g. Christiano et al. (1999). There is a large literature that studies the so-called persistence problem of models with staggered price setting; see e.g. Chari et al. (2000).

[2] Examples include Christoffel and Linzert (2005) and Krause and Lubik (2007), who study the role of real wage rigidity. The latter authors find that search frictions per se do not improve the ability of a sticky price model to explain the persistent effects of monetary shocks. Walsh (2005) shows that search frictions affect the dynamics of real marginal cost to the effect of augmenting the persistence in output and inflation in a model with habit persistence in consumption preferences and price indexing to past inflation. Krause et al. (2008) and Ravenna and Walsh (2008) focus on estimation of a New Keynesian Phillips curve, whereas Sveen and Weinke (2007) and Trigari (2009) analyze the role of the intensive and extensive margin. An early exploration is conducted by Walsh (2003).

as large as the flow of workers moving from employment to unemployment, so that employer-to-employer transitions make up 39 percent of separations. Nagypál (2008) studies employer-to-employer transitions in the Survey of Income and Program Participation and calculates that they account for 49 percent of separations. Moreover, these transitions are highly procyclical, as also emphasized by Shimer (2005b).

The magnitude and procyclicality of this job-to-job flow of workers suggests that accounting for it may substantially diminish the sensitivity of the components of marginal cost to monetary shocks. The reason is that if workers can search on-the-job for more productive and valuable jobs, they become a source of employment growth in addition to unemployed workers. If this pool of employed searchers expands during periods of booming economic activity, it moderates the tightening of the labor market that occurs as firms post vacancies aiming to expand employment. By dampening the labor market tightening, such positive comovement between vacancy creation and on-the-job search can induce sluggishness in the rise of wages and the cost of an employment relationship. As a result, a monetary expansion leads to a mitigated increase in marginal cost and hence in inflation. That amplifies the effect of the shock on aggregate demand and thus strengthens firms' incentive to post vacancies. The increased vacancy posting fuels the boom and thus further stimulates on-the-job search. This complementarity turns on-the-job search into a propagation mechanism that can generate large fluctuations in the vacancy-unemployment ratio, which translates into strong employment and output growth.

This reasoning is borne out by the quantitative analysis of a sticky price model with search frictions. The analysis shows that when workers can search on-the-job, a monetary shock induces a dampened response of the components of marginal cost, and thus of marginal cost and inflation. Under a baseline calibration, the impact response of inflation is reduced by about half. The resulting effect on aggregate demand almost doubles the impact response of output and the output response displays a hump-shaped pattern. Model simulations correspondingly show a substantial reduction of fluctuations in inflation, marginal cost and its components relative to output. Thus, on-the-job search constitutes a powerful propagation mechanism of monetary shocks. This finding is in stark contrast with the result of Krause and Lubik (2007) that introducing an exogenous source of real wage rigidity into a labor market with search frictions has only minor effects on the dynamics of marginal cost. If wage rigidity is imposed, the change in surplus of a match generated by a monetary shock accrues largely to the firm and increases the incentive to adjust vacancies. That amplifies the tightening of the labor market and hence amplifies the fluctuations in the cost of an employment relationship.

Allowing workers to search on-the-job also leads the model to more accurately reproduce cyclical properties of the U.S. labor market. Simulation of the model economy with on-the-job search shows that the size of fluctuations in unemployment, vacancies and the vacancy-unemployment ratio comes close to the large fluctuations observed in the U.S. data. In addition, the complementarity of on-the-job search and vacancy creation produces a more persistent response of the labor market variables and generates a negative correlation between vacancies and unemployment (i.e. the Beveridge curve).

New matches become productive instantaneously in the model, but the above conclusions based on model simulations are robust to the more conventional timing where such matches become productive in the subsequent period.[3] In contrast, when workers cannot search on-the-job the timing assumption affects the labor market dynamics substantially. With instantaneous productivity of new matches, a shock provokes a large but short-lived adjustment in vacancy creation on impact. This response produces a large volatility of vacancies and labor market tightness, even when generated by productivity shocks, but it also yields a negative autocorrelation of vacancies and fails to produce a Beveridge curve.[4] If instead new matches become productive with a lag, productivity shocks generate larger autocorrelation in labor market variables and a Beveridge curve, but fail to amplify fluctuations in the labor market, reflecting the lack of propagation that is emphasized by Shimer (2005a). Thus, each timing assumption introduces a distinct deficiency in the standard labor market with search frictions, which is overcome when workers can search on-the-job. With on-the-job search the timing assumption is crucial for determining the effect of price stickiness on the transmission of productivity shocks to the labor market. An increase in price stickiness amplifies the volatility of the vacancy-unemployment ratio due to productivity shocks if new matches produce instantaneously, but reduces it if the new matches start producing with a lag.

A few recent models of labor market search and matching frictions show that on-the-job search can amplify the fluctuations in vacancies, unemployment, and the vacancy-unemployment ratio due to productivity shocks. In Tasci's (2007) model, imperfect information about the match quality provides a motive for on-the-job search. Employed and unemployed workers search for jobs without incurring a search cost, and posting more vacancies makes firms more likely to contact either employed or unemployed workers. When productivity is high, more low-quality matches survive, which gives rise to procyclical transitions from low quality to high quality jobs. According to Nagypál (2007), an idiosyncratic job-satisfaction value provides an

[3]If new matches become productive with a lag, and without another margin of instantaneous production adjustment, a shift in aggregate demand produces an implausibly large impact on marginal cost, its components, and inflation.

[4]The strong impact response of vacancies in the absence of on-the-job search arises because firms adjust employment in the face of a predetermined stock of unemployed workers, so an initial change in matches results from a change in vacancies only. The timing assumption is also adopted in models with wage bargaining by e.g. Blanchard and Galí (2010), Krause et al. (2008), Ravenna and Walsh (2008), Sveen and Weinke (2007), and Kurozumi and Van Zandweghe (2008), but none of these papers evaluates the model in terms of labor market fluctuations. Rotemberg (2008) studies a model with wage posting.

incentive for workers to search on-the-job. Firms are more likely to retain employed workers than workers hired from the unemployment pool, because the former have a higher job satisfaction. Then, firms prefer to hire employed workers because they incur a hiring cost after a match is made. Krause and Lubik (2006) propose a labor market model with both good and bad jobs, which pay different wages due to differences in the cost of vacancy creation. Workers in bad jobs search for good jobs, because the latter have a higher productivity and pay a higher wage. In the latter two models, the job-to-job transition rate is procyclical because searching workers increase their search effort in response to a rise in the job finding rate. A positive productivity shock induces firms to post vacancies, which raises the job finding rate, and the ensuing increase in on-the-job search mitigates the tightening of the labor market and thus encourages firms to post more vacancies. The present paper introduces Krause and Lubik's specification of the labor market into an otherwise standard New Keynesian model. This labor market specification allows reproducing the large and procyclical job-to-job flows that are a salient fact of the U.S. labor market, while retaining the tractability of the New Keynesian model because heterogeneity is limited to two types of jobs.

The paper proceeds as follows. A sticky price model with on-the-job search is presented in Section 2. In Section 3 the model is analyzed quantitatively to assess the role of on-the-job search. Section 4 contains a robustness analysis with respect to the timing of matching and production and key parameter values. Section 5 adds some concluding remarks.

2 A sticky price model with on-the-job search

This section describes the labor market, the household and firm optimization problems, and the wage determination. There are final good producing firms that set nominal prices subject to price rigidity, and intermediate good producing firms that hire in the frictional labor market.[5]

2.1 The labor market

There are two types of jobs: a high wage ("good") job and a low wage ("bad") job. The cost of creating a job by any firm is represented by the flow cost of posting a vacancy: $P_t\gamma_g$ for good jobs and $P_t\gamma_b$ for bad jobs, where $\gamma_g > \gamma_b$ and P_t is the aggregate price index at time t. In the presence of search frictions these costs give rise to different surpluses of a match in each type of job.

At the beginning of a period, a proportion $\rho \in (0,1)$ of existing matches $n_{g,t-1}, n_{b,t-1}$ is exogenously destroyed before matching starts. Unemployed workers decide ex ante toward

[5]The separation of pricing and hiring decisions is a common simplifying assumption in this literature. Kuester (2007), Sveen and Weinke (2007), and Thomas (2009) study real rigidities that arise from joint pricing and hiring decisions.

which type of job they direct their search effort, and subsequently meet vacant jobs randomly in the matching market for that type of job. Workers employed in a bad job also search for good jobs and transition immediately if matched. All newly matched workers become productive instantaneously, so the evolution of period t employment in each type of job is described by the laws of motion

$$n_{gt} = (1-\rho)n_{g,t-1} + m_{gt}, \tag{1}$$

$$n_{bt} = (1-s_t p_{gt})[(1-\rho)n_{b,t-1} + m_{bt}], \tag{2}$$

where m_{gt}, m_{bt} denote, respectively, the number of newly filled good and bad jobs, p_{gt} is the probability to find a good job, and s_t is the search intensity of workers in bad jobs (the unemployed search intensity is constant and normalized to one).[6] The product $s_t p_{gt}$ gives the probability of a quit. The matching frictions of workers and firms are represented by a constant returns to scale matching function that determines the number of new matches between job searchers and vacancies for each type of job as

$$m_{gt} = \psi_g (u_{gt} + e_t)^{\xi} v_{gt}^{1-\xi}, \tag{3}$$

$$m_{bt} = \psi_b u_{bt}^{\xi} v_{bt}^{1-\xi}. \tag{4}$$

Here u_{it}, $i = g, b$, are the measures of unemployed workers searching for good and bad jobs, v_{it} are the measures of vacancies, the scale parameters ψ_i reflect the efficiency of the matching process, and $\xi \in (0,1)$ is the unemployment elasticity of new matches. In the presence of on-the-job search, $u_{gt} + e_t$ workers search for good jobs in period t, where

$$e_t = s_t[(1-\rho)n_{b,t-1} + m_{bt}] \tag{5}$$

is the measure of effective search by employed workers. With the size of the labor force normalized to one, the total number of jobless searchers is given by

$$u_t = 1 - (1-\rho)n_{t-1}, \tag{6}$$

where $u_t = u_{bt} + u_{gt}$ and $n_t = n_{bt} + n_{gt}$.

The ratio of vacancies to searchers is a measure of the labor market tightness. For good jobs, this tightness is given by $\theta_{gt} = v_{gt}/(u_{gt} + e_t)$, while for bad jobs it is simply $\theta_{bt} = v_{bt}/u_{bt}$. Thus, the aggregate labor market tightness, $\theta_t = v_t/(u_t + e_t)$, is distinct from the vacancy-unemployment $(v-u)$ ratio, v_t/u_t, where $v_t = v_{gt} + v_{bt}$. The job finding probability (the worker

[6] The job heterogeneity and endogenous on-the-job search intensity are the key ingredients of Krause and Lubik's (2006) model. However, in their model newly matched workers, whether having left an unemployment spell or quit a job, become productive in the subsequent period. This timing assumption is adopted in Section 4.1.

matching rate) for each type of job is then

$$p_{gt} \equiv \frac{m_{gt}}{u_{gt}+e_t} = \psi_g \theta_{gt}^{1-\xi}, \tag{7}$$

$$p_{bt} \equiv \frac{m_{bt}}{u_{bt}} = \psi_b \theta_{bt}^{1-\xi}, \tag{8}$$

so that a worker is more likely to find a job when the labor market is tight. Similarly, the firm matching rate is given by

$$q_{it} \equiv \frac{m_{it}}{v_{it}} = \psi_i \theta_{it}^{-\xi}, \qquad i = g, b, \tag{9}$$

and rises when the labor market becomes slack.

2.2 Households

The representative household consists of a continuum of measure one of infinitely lived family members who pool their consumption risk, following Merz (1995). Each period the household chooses consumption C_t, bond holdings B_t, real money balances M_t/P_t, and on-the-job search effort that maximize its expected lifetime utility

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} + \chi \ln\left(\frac{M_t}{P_t}\right) - (n_{bt} + p_{gt} e_t)\kappa s_t^{1+\tau}\right]$$

subject to the period budget constraint

$$P_t[w_{gt}n_{gt} + w_{bt}n_{bt} + A(1-n_{gt}-n_{bt})] + D_t + B_t + M_t = P_tC_t + B_{t-1}R_{t-1} + M_{t-1} + T_t \tag{10}$$

and the structure of the labor market as described by Eqs. (1)–(8). Here, $\beta \in (0,1)$ is the intertemporal discount factor, $\sigma > 0$ is the coefficient of relative risk aversion, R_t is the nominal interest rate, and T_t is a lump-sum transfer from the monetary authority. Family income consists of wage income $P_t w_{it} n_{it}$ from employment in a type i job, for $i = g, b$, unemployment income $P_t A(1-n_{gt}-n_{bt})$ and other income D_t. The latter consists of monopoly profits from the final good firms, rents related to labor market frictions from intermediate good firms, minus a lump-sum transfer to finance unemployment income. The disutility associated with work effort is normalized to zero. However, search effort by workers matched with a bad job entails a utility cost, with an elasticity parameter $\tau > 0$. Consumption consists of a composite of differentiated goods $f \in [0,1]$ defined as $C_t = \left[\int_0^1 C_t(f)^{(\epsilon-1)/\epsilon} df\right]^{\epsilon/(\epsilon-1)}$, where $\epsilon > 1$ is the elasticity of substitution between these goods. Cost minimization of the household's consumption across goods implies that the demand for each good is given by $C_t(f) = [P_t(f)/P_t]^{-\epsilon} C_t$, while the aggregate price index is $P_t = \left[\int_0^1 P_t(f)^{\epsilon-1} df\right]^{1/(\epsilon-1)}$. The household's consumption and asset choices yield the consumption Euler equation and money demand equation

$$\frac{C_t^{-\sigma}}{P_t} = R_t \beta E_t \frac{C_{t+1}^{-\sigma}}{P_{t+1}}, \tag{11}$$

$$\frac{M_t}{P_t} = \chi \frac{R_t}{R_t - 1} C_t^{\sigma}, \tag{12}$$

where $C_t^{-\sigma}$ is the marginal utility of consumption. Taking account of the labor market flows gives rise to an asset value of employment in each type of job. Specifically,

$$\begin{aligned} W_{gt} &= w_{gt} - A + E_t\beta_{t,t+1}(1-\rho)(1-p_{g,t+1})W_{g,t+1}, \\ W_{bt} &= w_{bt} - A - \kappa s_t^{1+\tau} C_t^{\sigma} \\ &+ E_t\beta_{t,t+1}(1-\rho)(1-p_{b,t+1})\left[(1-s_{t+1}p_{g,t+1})W_{b,t+1} + s_{t+1}p_{g,t+1}\left(W_{g,t+1} - \kappa s_{t+1}^{1+\tau}C_{t+1}^{\sigma}\right)\right], \end{aligned}$$

describe the household's marginal value of a family member matched with a good respectively a bad job. This condition is standard for workers matched with a good job: the value is the premium of the wage over the unemployment benefit plus the expected present value in the next period. The latter is discounted by the time-varying discount factor that values future consumption in present terms, $\beta_{t,t+j} = \beta(C_{t+j}/C_t)^{-\sigma}$, for $j = 1, 2, \ldots$, and by the probability that the job is destroyed and no new good job is found. Accepting a good job generates a surplus W_{gt} regardless of previous employment status, because the opportunity is always unemployment. For a match with a bad job, the current return is diminished by the search cost expressed in consumption units. The continuation value states that contingent on still or again being matched with a bad job in the next period, the worker's value will be that of a bad job, with probability $1 - s_{t+1}p_{g,t+1}$, or that of a good job net of the future search cost (since W_g does not incorporate this cost), with probability $s_{t+1}p_{g,t+1}$. The assumption of directed search, which leads to distinction between u_{gt} and u_{bt} in the pool of jobless searchers, implies that the ex ante asset value of a worker is equal whether this worker be matched with a good job or a bad job, so

$$p_{gt}W_{gt} = p_{bt}\left[(1-s_tp_{gt})W_{bt} + s_tp_{gt}\left(W_{gt} - \kappa s_t^{1+\tau}C_t^{\sigma}\right)\right]$$

is the directed search arbitrage condition. Workers in bad jobs determine their optimal search intensity to satisfy the on-the-job search condition,

$$(1+\tau)\kappa s_t^{\tau} C_t^{\sigma} = p_{gt}\left[W_{gt} - W_{bt} - \kappa s_t^{1+\tau}C_t^{\sigma}\right].$$

The marginal search cost is increasing in the worker's on-the-job search intensity and the marginal benefit is decreasing in this argument. Also, the marginal benefit curve is shifted up by an increase in the good job finding probability or by an increase in the differential between the asset values of employment in good and bad jobs, which consequently generate an increase in search intensity.

2.3 Intermediate good producers and wage determination

Intermediate goods are sold in two perfectly competitive markets. The representative intermediate good i producing firm uses a linear production technology given by

$$y_{it} = a_t n_{it}, \qquad i = g, b, \tag{13}$$

where aggregate productivity evolves stochastically according to

$$\log a_t = \rho_a \log a_{t-1} + \varepsilon_{at}, \qquad \varepsilon_{at} \sim N(0, \sigma_a^2). \tag{14}$$

The firm chooses n_{it} and v_{it} to maximize profits by selling at a relative price z_{it}. All firms value future profits with the household's time-varying discount factor because they are ultimately owned by households. Thus, the firm solves

$$\max E_0 \sum_{t=0}^{\infty} \beta_{t,t+1} \left[(z_{it} a_t - w_{it}) n_{it} - \gamma_i v_{it} \right]$$

subject to (1) and (9) if the firm produces good g, or (2) and (9) if it produces good b. The conditions for profit maximization include

$$\begin{aligned} \frac{\gamma_g}{q_{gt}} &= J_{gt}, \\ J_{gt} &= z_{gt} a_t - w_{gt} + E_t \beta_{t,t+1} (1 - \rho) J_{g,t+1}, \end{aligned}$$

for good g producers and

$$\begin{aligned} \frac{\gamma_b}{(1 - s_t p_{gt}) q_{bt}} &= J_{bt}, \\ J_{bt} &= z_{bt} a_t - w_{bt} + E_t \beta_{t,t+1} (1 - \rho)(1 - s_{t+1} p_{g,t+1}) J_{b,t+1}, \end{aligned}$$

for good b producers. The Lagrange multiplier J_{it} is the good i producer's asset value of a filled job. Profit maximization requires this value to be equal to the average cost of filling a type i job opening. The average cost is the flow cost of posting a vacancy times the number of vacancies posted in order to fill one job, which is the inverse of the vacancy filling probability. For bad jobs, the vacancy filling probability is the product of the firm matching rate and the probability of no separation due to a quit. Combining the optimality conditions yields the job creation conditions, which equate the cost of filling a vacancy to its expected value:

$$\frac{\gamma_g}{q_{gt}} = z_{gt} a_t - w_{gt} + E_t \beta_{t,t+1} (1 - \rho) \frac{\gamma_g}{q_{g,t+1}}, \tag{15}$$

$$\frac{\gamma_b}{(1 - s_t p_{gt}) q_{bt}} = z_{bt} a_t - w_{bt} + E_t \beta_{t,t+1} (1 - \rho) \frac{\gamma_b}{q_{b,t+1}}. \tag{16}$$

Wages are determined so as to split the surplus of a match between a worker and a firm according to a surplus maximizing rule.[7] That is, $w_{it} = \arg\max W_{it}^{\eta} J_{it}^{1-\eta}$, where $\eta \in (0, 1)$ is

[7] A good b producing firm may reduce worker turnover and thereby increase the value of a match by offering its workers a higher wage. In this case, the Nash bargaining solution is not applicable as a motivation for wage determination through surplus splitting. Following Pissarides' (1994) theoretical analysis of on-the-job search, I maintain the assumption of surplus splitting on the grounds that it is more appealing than other non-bargaining approaches taken in this literature. Shimer (2006) analyzes a model of on-the-job search where wages are the outcome of a strategic bargaining game. In the robustness analysis in Section 4.1, the timing of matching and production implies that current wages do not affect the incentive for on-the-job search, so splitting the surplus is equivalent to the Nash bargaining solution.

interpreted as a relative measure of the worker's bargaining power. The first order conditions provide the surplus splitting rules, $\eta J_{it} = (1-\eta) W_{it}$, which result in the wage equations

$$w_{gt} = \eta \left[z_{gt} a_t + E_t \beta_{t,t+1} (1-\rho) p_{g,t+1} \frac{\gamma_g}{q_{g,t+1}} \right] + (1-\eta) A \quad (17)$$

$$\begin{aligned} w_{bt} &= \eta \left[z_{bt} a_t + E_t \beta_{t,t+1} (1-\rho) p_{b,t+1} \frac{\gamma_b}{q_{b,t+1}} \right] + (1-\eta) \left[A + \kappa s_t^{1+\tau} C_t^{\sigma} \right] \\ &- \eta E_t \beta_{t,t+1} (1-\rho)(1-p_{b,t+1}) s_{t+1} p_{g,t+1} \left[\frac{\gamma_g}{q_{g,t+1}} - \frac{1-\eta}{\eta} \kappa s_{t+1}^{1+\tau} C_{t+1}^{\sigma} \right] \end{aligned} \quad (18)$$

A good job entails compensation for a fraction η of firm revenue and the saving of hiring costs that the firm expects to enjoy thanks to the match, in addition to a fraction $1-\eta$ of the forgone unemployment income. For workers in a bad job, in addition, more intensive search tends to raise the wage as compensation for the larger search cost, but tends to reduce it to compensate the firm for the increased probability of a quit.

Further use of the surplus splitting rules allows writing the directed search arbitrage condition as

$$p_{gt} \frac{\gamma_g}{q_{gt}} = p_{bt} \left[\frac{\gamma_b}{q_{bt}} + s_t p_{gt} \left(\frac{\gamma_g}{q_{gt}} - \frac{1-\eta}{\eta} \kappa s_t^{1+\tau} C_t^{\sigma} \right) \right], \quad (19)$$

whereas the on-the-job search intensity condition becomes

$$\frac{1-\eta}{\eta} (1+\tau) \kappa s_t^{\tau} C_t^{\sigma} = p_{gt} \left[\frac{\gamma_g}{q_{gt}} - \frac{\gamma_b}{(1 - s_t p_{gt}) q_{bt}} - \frac{1-\eta}{\eta} \kappa s_t^{1+\tau} C_t^{\sigma} \right]. \quad (20)$$

2.4 Final good producers

The final good market is characterized by monopolistic competition. Each of a continuum of final good producers, indexed by $f \in [0,1]$, combines intermediate goods b and g into a differentiated good using a Cobb-Douglas production technology $Y_t(f) = Y_{gt}(f)^{1-\alpha} Y_{bt}(f)^{\alpha}$. The share parameter $\alpha \in [0,1]$ of input b can be interpreted as a productivity differential: let $\alpha < 1/2$ so that productivity of input g exceeds that of b. A firm f chooses the cost-minimizing bundle of inputs that leads to the demand functions for inputs g and b,

$$Y_{gt}(f) = (1-\alpha) \left(\frac{z_t}{z_{gt}} \right) Y_t(f), \quad (21)$$

$$Y_{bt}(f) = \alpha \left(\frac{z_t}{z_{bt}} \right) Y_t(f). \quad (22)$$

Here, z_t is the real marginal cost of each final good firm, which is given by the weighted average of factor prices

$$z_t = \left(\frac{z_{gt}}{1-\alpha} \right)^{1-\alpha} \left(\frac{z_{bt}}{\alpha} \right)^{\alpha}. \quad (23)$$

Final good producers set the price of their product in order to maximize discounted expected real profits subject to demand from households and subject to Calvo (1983) and Yun (1996) style price stickiness. Specifically, a fixed fraction $\nu \in (0,1)$ of randomly chosen firms does not reoptimize price but indexes to the steady state inflation rate, π, while each remaining firm faces the problem

$$\max_{P_t^*} \; E_t \sum_{k=0}^{\infty} \nu^k \beta_{t,t+k} \left(\frac{P_t^* \pi^k}{P_{t+k}} - z_{t+k} \right) \left(\frac{P_t^* \pi^k}{P_{t+k}} \right)^{-\epsilon} C_{t+k}.$$

The optimal price satisfies the first order condition for profit maximization

$$P_t^* = \frac{\epsilon}{\epsilon - 1} \frac{\sum_{k=0}^{\infty} (\nu \pi^{-\epsilon})^k E_t \beta_{t,t+k} P_{t+k}^{\epsilon} C_{t+k} z_{t+k}}{\sum_{k=0}^{\infty} (\nu \pi^{1-\epsilon})^k E_t \beta_{t,t+k} P_{t+k}^{\epsilon-1} C_{t+k}}, \tag{24}$$

and is related to the aggregate price index by

$$P_t = [(1-\nu)(P_t^*)^{\epsilon-1} + \nu(\pi P_{t-1})^{\epsilon-1}]^{\frac{1}{\epsilon-1}}. \tag{25}$$

2.5 Equilibrium

To close the model, the monetary authority is assumed to follow the money growth rule

$$\log \mu_t = (1-\rho_\mu) \log \mu + \rho_\mu \log \mu_{t-1} + \varepsilon_{\mu t}, \qquad \varepsilon_{\mu t} \sim N(0, \sigma_\mu^2), \tag{26}$$

where $\mu_t = M_t / M_{t-1}$ denotes the growth rate of the nominal money supply and μ is its steady state value. This formulation of monetary policy follows most of the literature that deals with the persistence of responses to monetary shocks, such as Chari et al. (2000), Dotsey and King (2006), and Krause and Lubik (2007). The government has access to lump-sum taxes and conducts a Ricardian fiscal policy, so that the government budget constraint need not be specified.

In equilibrium, market clearing implies that $B_t = B_{t-1} = 0$ and $M_t = M_{t-1} + T_t$ in each period. Intermediate good market clearing requires that

$$Y_{it} = y_{it} - \gamma_i v_{it}, \quad i = g, b, \tag{27}$$

where $Y_{it} \equiv \int Y_{it}(f) df$, and final good market clearing requires that $Y_t(f) = C_t(f)$, for all $f \in [0,1]$, which implies that

$$Y_t \equiv \int_0^1 Y_t(f) df = C_t \Delta_t, \tag{28}$$

where $\Delta_t = \int [P_t(f)/P_t]^{-\epsilon} df$ measures the relative price dispersion among final good producing firms. A rational expectations equilibrium consists of initial values for the productivity level, the growth rate of the nominal money supply, and the number of matched workers in both types of jobs, as well as sequences for the endogenous variables satisfying equations (1)$-$(28).

2.6 Calibration and steady state implications

The ensuing analysis uses a realistic calibration of model parameters to evaluate the model quantitatively. The baseline calibration is summarized in Table 1. The discount factor β is equal to 0.99, the relative risk aversion is $\sigma = 1$, $\epsilon = 11$ is chosen to yield a steady state gross markup of 1.1, the interest rate semielasticity of money demand is one, which is the intermediate value considered by Dotsey and King (2006), and $\nu = 0.67$ is set to correspond to an average frequency of price adjustment equal to three quarters, which is in line with recent microeconomic evidence on the frequency of price changes. In the labor market, the bargaining parameter is $\eta = 0.5$, following most of the literature on search frictions. The elasticity of the matching functions, $\xi = 0.5$, is the midpoint between the values chosen by Krause and Lubik (2006) and Nagypál (2007). The rate of job destruction is $\rho = 0.1$, and the steady state unemployment rate $1 - n = 0.05$, which imply a steady state pool of unemployed searchers of size $u = 0.145$.

With respect to on-the-job search, Krause and Lubik (2006) are followed in setting the steady state quit rate equal to $qr = p_g e/n = 0.06$ and the search cost elasticity parameter to $\tau = 0.1$. The sensitivity of the results to the choice of τ is examined in Section 4.2. To introduce job heterogeneity, the cost of posting a vacancy for a good job must exceed that of posting a vacancy for a bad one. The former is set to $\gamma_g = 0.16$, as in Krause and Lubik, while the latter is assumed to be eight times smaller: $\gamma_b = 0.02$. The share of input b in final output is set to $\alpha = 0.36$, which is slightly below the value in Krause and Lubik. The efficiency level of the matching functions is $\psi_g = \psi_b = 0.61$ and is chosen to obtain an aggregate firm matching rate of $q = 0.7$, following den Haan et al. (2000).

Finally, the monetary growth process is characterized by an autoregressive parameter $\rho_\mu = 0.50$ and a standard deviation $\sigma_\mu = 0.006$, which are typical estimates. The autoregressive coefficient of the productivity shock is set to 0.95 and its standard error is set to $\sigma_a = 0.0055$. The latter value is chosen to generate a standard deviation of output in the baseline model in line with that observed in the U.S. data. The cyclical properties of the model are then assessed by the ratios of the standard deviation of variables of interest to that of output.

With this calibration the system of steady state equations, collected in Appendix A, can be solved numerically for the job type-specific parameters. The resulting parameter values are $q_g = 1.28$, $q_b = 0.54$, $p_g = 0.29$, $p_b = 0.69$, $v_g = 0.05$, $v_b = 0.17$, $u_g = 0.011$, $u_b = 0.134$, $n_g = 0.60$, $n_b = 0.35$, $m_g = 0.06$, $m_b = 0.09$. The relative prices are $z_g = 0.48$ and $z_b = 0.47$ and the real wages are $w_g = 0.46$ and $w_b = 0.45$.[8] The steady state search intensity is $s = 0.48$,

[8] The steady state wage differential is only two percent and it is difficult to generate much larger wage differentials with reasonable calibrations. However, the importance of on-the-job search in the model depends on the differential between the asset values of employment in the two types of jobs. Calibrations that yield a

such that $e = 0.20$, the scale parameter of the search cost is equal to $\kappa = 0.04$, and the unemployment income is $A = 0.42$. The model equations are log-linearized around their steady state and summarized in Appendix B.

2.7 The dynamics of real marginal cost

This subsection addresses three questions. What is the wedge between real marginal cost and real wages that arises in the presence of search frictions? How does this wedge affect the cyclical dynamics of marginal cost? And what is the role of on-the-job search in this dynamics?

The job creation conditions (15) and (16) show the wedge between wages and marginal cost in the presence of search frictions. Rewriting these conditions with the intermediate good prices on the left hand side yields

$$\begin{aligned} z_{gt} &= \frac{1}{a_t}\left[w_{gt} + \frac{\gamma_g}{q_{gt}} - E_t\beta_{t,t+1}(1-\rho)\frac{\gamma_g}{q_{g,t+1}}\right], \\ z_{bt} &= \frac{1}{a_t}\left[w_{bt} + \frac{\gamma_b}{(1-s_t p_{gt})q_{bt}} - E_t\beta_{t,t+1}(1-\rho)\frac{\gamma_b}{q_{b,t+1}}\right]. \end{aligned}$$

If the labor market is frictionless, which is equivalent to $\gamma_g = \gamma_b = 0$, the relative price of each intermediate good is equal to the ratio of the wage to the marginal product of labor, i.e. a_t, such that the real marginal cost of final good production is given by the weighted average of real wages over the marginal product. With search frictions in the labor market, the relative price of each intermediate good depends also on the current average cost of hiring a worker, adjusted for the expected, discounted saving of future hiring costs that a match entails. Thus, hiring a worker generates a match that can be productive for multiple periods, but the current relative price of an intermediate good only reflects the cost of having a job filled in the current period. This is the *cost of an employment relationship* that the firm incurs in addition to the wage payment.[9]

The cyclical dynamics of the cost of an employment relationship may amplify the changes in marginal cost that arise from fluctuations in wages. Consider the example of an expansionary monetary shock. Because intermediate good firms increase their vacancy posting in response to the resulting increase in demand, new matches are formed, the labor market tightens, and expectations about future labor market tightness rise as the new matches reduce the future unemployment pool. Real wages increase as a result. The cost of an employment relationship

larger steady state differential in asset values do not necessarily imply a larger steady state wage differential. For instance, shutting down on-the-job search by setting $s = 0$ raises the steady state wage differential but reduces that between the asset values of employment.

[9] Goodfriend and King (2001) describe most labor transactions in advanced economies as governed by long-term employment relationships between workers and firms and also emphasize that the "effective" real marginal cost may be more volatile than the real wage because of such employment relationships.

also rises as long as the increase in current hiring cost that is brought about by the tighter labor market is not exceeded by expected savings in discounted future hiring cost due to expectations of even tighter future labor market conditions.

On-the-job search can diminish the increase in wages and in the cost of an employment relationship. That is because searching workers provide firms with an additional channel of hiring, which is not available when all new workers have to come from the unemployment pool. The additional vacancy posting prompted by the shock raises the good job finding probability, which induces workers in bad jobs to increase their search intensity for a good job. The resulting expansion of the effective pool of search for good jobs dampens the tightening of the labor market for such jobs. This in turn promotes the posting of more vacancies for good jobs, as it slows down the decrease in the firm matching rate. Thus, the complementarity between search effort by workers and vacancy posting by firms enables fast and persistent growth of vacancies and employment without a rapidly tightening labor market. Employment and vacancies for bad jobs can similarly grow without a rapid tightening in that labor market, as unemployed searchers redirect their search toward bad jobs.[10] The attenuation of the current and expected future labor market tightening can mute the response of wages, the current and expected future hiring cost, and hence of the cost of an employment relationship. As a result, with on-the-job search in the labor market the marginal cost in the final good sector may display sluggishness. The direction and quantitative importance of these effects are evaluated in the next section.

3 Implications of on-the-job search for business fluctuations

The model is analyzed via impulse-responses and simulations, and the analysis shows that on-the-job search dampens the cyclical fluctuations in the components of marginal cost. The reduced sensitivity of marginal cost to monetary or productivity shocks is key to explaining the dampened inflation response and the propagation toward real activity of such shocks.

The role of on-the-job search is evaluated by way of comparison with the associated model without on-the-job search, which is obtained by setting the on-the-job search intensity $s_t = s = 0$ in all periods.[11] It is also evaluated relative to an alternative source of real wage rigidity given by a variant of the wage norm proposed by Hall (2005), to underline the drastically different implications of on-the-job search. Following the analysis of Krause and Lubik (2007), let wages

[10] The implications of on-the-job search for the labor market dynamics correspond to those described by Krause and Lubik (2006).

[11] In this case the steady state equations under the baseline calibration imply the following job type-specific parameter values: $q_g = 0.75, q_b = 0.26, p_g = 0.50, p_b = 1.41, v_g = 0.08, v_b = 0.13, u_g = 0.12, u_b = 0.025, n_g = 0.60, n_b = 0.35, m_g = 0.06, m_b = 0.04, z_g = 0.48, z_b = 0.45, w_g = 0.46$, and $w_b = 0.45$. The absence of on-the-job search reduces the steady state number of vacancies and new matches for bad jobs because such firms do not need to take into account that workers may quit.

for each type of job $i = g, b$ be determined according to

$$w_{it} = \delta \bar{w}_{it} + (1 - \delta) w_{it}^N,$$

where w_{it}^N is a notional wage, $\bar{w}_{it}$ is a wage norm and $\delta \in [0, 1]$. Assume that the notional wage is computed as the Nash bargaining outcome in the model without wage rigidity, and that the steady state wage determines the wage norm for each type of job. Thus, two variants of the model without on-the-job search are considered, characterized by $\delta = 0$ (henceforth, standard search model) or $\delta = 0.78$ (henceforth, wage norm model). The latter value is chosen to match the relative volatility of real wages in the baseline model with on-the-job search or in the U.S. data, whichever is smaller.

3.1 Impulse responses

Figure 1 displays the dynamic responses of the model economy with on-the-job search (the solid line), and the two model variants with only unemployed search, to a one percent increase in the money growth rate. Looking over the plots in the first column, it is clear that on-the-job search substantially dampens the response of inflation; the response on impact is reduced by more than half in comparison with the standard search model (the dashed line). This reflects the attenuated response of the real marginal cost, which in turn stems from a dampened response of the real wage and of the cost of an employment relationship. In contrast, when the wage norm is the source of real rigidity, the attenuation of the inflation and real marginal cost responses is less substantial, which is consistent with the irrelevance result of Krause and Lubik (2007). Indeed, in this case the real wage response is dampened but the cost of an employment relationship becomes more sensitive to the shock. Because the additional surplus of a match generated by the monetary shock accrues largely to the firm, and firms post vacancies until the hiring cost is equal to its match value, the wage rigidity provides firms with an incentive to post more vacancies. This amplifies the response of the current and expected future labor market tightness and thereby the cost of an employment relationship. On-the-job search, on the other hand, dampens changes in hiring costs. This mitigates fluctuations in the cost of an employment relationship, despite a strengthened vacancy creation that is required to bring hiring cost in line with the match value.

The second column of the figure shows that the dampened marginal cost gives rise to a strong propagation when workers search on-the-job. Output rises persistently and displays a hump-shaped pattern. This reflects developments in the labor market, where the response of unemployment, vacancies, and the $v - u$ ratio is amplified and shows a gradual return to steady state. Vacancy posting surges on impact because the rise in consumption demand necessitates a commensurate increase in matches, while the number of unemployed workers is predetermined. Without on-the-job search there is much less persistence in the labor market variables. Vacancies surge on impact but barely rise thereafter, so that the resulting decline in unemployment is small and rapidly vanishing despite the unemployed being the only source of employment growth. The wage norm amplifies the output and labor market responses, but to a lesser extent than on-the-job search.

Figure 2 shows the dynamic responses of the cost of an employment relationship and its components, the hiring cost and the expected, discounted future hiring cost, to the monetary shock. The cost of an employment relationship rises because the former component increases more than the latter in all three model variants. On-the-job search dampens the rise in both components, whereas the wage norm amplifies the response in both components. Also, on-the-job search attenuates the response of the expected, discounted future hiring cost more than that of the current hiring cost, which is consistent with the anticipation that the pool of searchers will not be exhausted as quickly when both employed and unemployed workers search for jobs. For bad jobs in particular, the rise in the current hiring cost is mainly due to additional vacancy posting necessitated by the worker quits that arise from increased search intensity, whereas the redirection of search by unemployed workers toward bad jobs induces a substantial dampening of the current and future labor market tightening.[12]

3.2 Model simulation

Simulation results can quantify the effects of on-the-job search on the model dynamics that are illustrated by the impulse-responses. Table 2 reports standard deviations and correlations computed from simulation results generated by the three models, both unconditional and conditional on monetary shocks or productivity shocks. Statistics for the model economies are computed as the average of 1,000 simulated histories of 178 quarters. All variables are reported in logs and are HP filtered with smoothing parameter equal to 1,600. These numbers can be compared to similar statistics computed from quarterly U.S. data covering the period 1964:1−2008:2, which are displayed in the first column of the table.[13]

The results corroborate the account of the role of on-the-job search that is highlighted by the impulse-responses. That is, the volatility of inflation, marginal cost, wages, and the cost of

[12]Note that in the absence of on-the-job search, the responses of the cost of an employment relationship and its components are identical for good jobs and for bad jobs, because the dynamics of labor market tightness is identical for both types of jobs.

[13]Output is measured as the seasonally adjusted real GDP, converted to per capita terms by dividing by the civilian non-institutional population aged 16 and older. Inflation is the growth rate of the consumer price index. The real wage is the seasonally adjusted average hourly earnings of the private sector divided by the consumer price index. Unemployment is the civilian unemployment rate of persons aged 16 and older. Vacancies are measured by the Conference Board's help-wanted advertising index.

an employment relationship drops relative to that of output. The relative standard deviation of inflation in the presence of on-the-job search closely matches that of the U.S. consumer price index. In contrast, a wage norm reduces wage volatility but exacerbates fluctuations in the cost of an employment relationship, such that the relative volatility of marginal cost and inflation is dampened to a lesser extent. These conclusions remain unchanged when the volatilities are conditional on either monetary shocks or productivity shocks.

In the labor market with on-the-job search, fluctuations in unemployment, vacancies and the $v - u$ ratio explain more than two thirds of the observed volatility in the U.S. data. At the same time, fluctuations in the labor market tightness, i.e. the ratio of vacancies to search of employed and unemployed workers, are dampened substantially by the interaction between vacancies and employed search: tightness is more than three times less volatile than the $v - u$ ratio. Having workers search on-the-job does not increase the relative volatility of vacancies and the $v - u$ ratio. Notably, even conditional on productivity shocks on-the-job search actually reduces the relative standard deviation of vacancies and raises that of the $v - u$ ratio only slightly. However, on-the-job search generates a more persistent response of these variables, as reflected in the autocorrelations reported in the table, and also generates a negative correlation between unemployment and vacancies (i.e. the Beveridge curve), although the correlation is less negative than in the U.S. data. In the standard search model, i.e. absent on-the-job search, the relative volatility of vacancies is large, especially if conditional on monetary shocks but even in response to productivity shocks. The latter finding is at odds with the amplification puzzle that is emphasized by Shimer (2005a). With a predetermined number of unemployed searchers, a shock that necessitates an instant adjustment of matches induces such a spike in vacancy creation. However, it also yields a small (even negative) autocorrelation of vacancies, and fails to generate a Beveridge curve. In the next section it is shown that this amplification of vacancies stems from the timing assumption that new matches become productive instantaneously.

At this point the conclusion can be drawn that on-the-job search substantially improves the properties of the sticky price model with search frictions in terms of marginal cost, inflation and output dynamics, as well as in terms of the labor market dynamics of unemployment, vacancies and the $v - u$ ratio.

4 Robustness analysis

In this section the foregoing analysis is verified for robustness to the timing assumption of matching and production of workers. In addition, the sensitivity of the results to two key parameters, the search cost elasticity and the degree of price stickiness, is investigated.

4.1 Timing of matching and production

Does on-the-job search continue to attenuate the fluctuations in wages and the cost of an employment relationship, the result emphasized in the previous section, when a match becomes productive in the period following the time of its creation? This timing assumption is more conventional in the labor market search literature. Moreover, it could be conjectured that the sensitivity of the cost of an employment relationship to shifts in production in the absence of on-the-job search is generated by the large fluctuations in the $v-u$ ratio in the standard search model analyzed in the previous section. Below it is shown, to the contrary, that when new matches start producing with a lag, on-the-job search amplifies the fluctuations in vacancies and the $v-u$ ratio substantially but dampens those in the cost of an employment relationship.

The following equations change. In the labor market, matches are accumulated according to the motion laws

$$\begin{aligned} n_{gt} &= (1-\rho)(n_{g,t-1}+m_{gt}), \\ n_{bt} &= (1-\rho)[(1-s_t p_{gt})n_{b,t-1}+m_{bt}], \end{aligned}$$

where n_{it}, $i=g,b$, is the employment available at the end of period t. The measure of effective on-the-job search and the number of jobless searchers is, respectively,

$$\begin{aligned} e_t &= s_t n_{b,t-1}, \\ u_t &= 1-n_{t-1}. \end{aligned}$$

For households, the timing implies that the asset value of an employed worker in a good and a bad job, respectively, becomes

$$\begin{aligned} W_{gt} &= w_{gt}-A+E_t\beta_{t,t+1}(1-\rho)(1-p_{gt})W_{g,t+1}, \\ W_{bt} &= w_{bt}-A-\kappa s_t^{1+\tau}C_t^{\sigma}+E_t\beta_{t,t+1}(1-\rho)\left[(1-p_{bt}-s_t p_{gt})W_{b,t+1}+s_t p_{gt}W_{g,t+1}\right], \end{aligned}$$

whereas the directed search arbitrage condition and the on-the-job search intensity condition are given by[14]

$$\begin{aligned} p_{gt}E_t\beta_{t,t+1}(1-\rho)W_{g,t+1} &= p_{bt}E_t\beta_{t,t+1}(1-\rho)W_{b,t+1}, \\ (1+\tau)\kappa s_t^{\tau}C_t^{\sigma} &= p_{gt}E_t\beta_{t,t+1}(1-\rho)\left(W_{g,t+1}-W_{b,t+1}\right). \end{aligned}$$

Intermediate good firms' production technology is given by

$$y_{it}=a_t n_{i,t-1}, \qquad i=g,b,$$

[14]In contrast to the baseline model of Section 2, the on-the-job search intensity depends on expected future wages. Since real wages are renegotiated every period, firms with bad jobs cannot affect the incentive for on-the-job search by offering a higher wage. Hence, splitting the surplus of a match between worker and firm corresponds to the Nash bargaining solution.

and their optimization problem generates the job creation conditions

$$\begin{aligned}
\frac{\gamma_g}{q_{gt}} &= E_t\beta_{t,t+1}(1-\rho)\left[z_{g,t+1}a_{t+1} - w_{g,t+1} + \frac{\gamma_g}{q_{g,t+1}}\right],\\
\frac{\gamma_b}{q_{bt}} &= E_t\beta_{t,t+1}(1-\rho)\left[z_{b,t+1}a_{t+1} - w_{b,t+1} + (1-s_{t+1}p_{g,t+1})\frac{\gamma_b}{q_{b,t+1}}\right].
\end{aligned}$$

The wage equations are

$$\begin{aligned}
w_{gt} &= \eta\left[z_{gt}a_t + p_{gt}\frac{\gamma_g}{q_{gt}}\right] + (1-\eta)A,\\
w_{bt} &= \eta\left[z_{bt}a_t + (1-s_t)p_{bt}\frac{\gamma_b}{q_{bt}}\right] + (1-\eta)\left[A + \kappa s_t^{1+\tau}C_t^{\sigma}\right].
\end{aligned}$$

Finally, using the surplus splitting rule, the directed search arbitrage condition and the on-the-job search intensity condition become

$$\begin{aligned}
p_{gt}\frac{\gamma_g}{q_{gt}} &= p_{bt}\frac{\gamma_b}{q_{bt}},\\
\frac{1-\eta}{\eta}(1+\tau)\kappa s_t^{\tau}C_t^{\sigma} &= p_{gt}\left(\frac{\gamma_g}{q_{gt}} - \frac{\gamma_b}{q_{bt}}\right).
\end{aligned}$$

The description of final good producers and the monetary authority remains unchanged.

The calibration is adjusted in three respects. First, the standard deviation of the productivity shock is raised slightly to $\sigma_a = 0.0056$ in order to match the standard deviation of U.S. GDP. Second, the steady state measure of unemployed searchers is set to $u = 0.145$ (implying $n = 0.855$) to match the value implied by the definition of steady state unemployed searchers in the baseline model. Third, the degree of real wage rigidity in the wage norm model is set to match the relative standard deviation of real wages in the U.S. data, which requires that $\delta = 0.73$.[15]

Table 3 displays the simulation results. The effects of on-the-job search are qualitatively similar to those presented in the previous section: on-the-job search dampens the fluctuations in wages and the cost of an employment relationship, and consequently induces a substantial reduction in the volatility of marginal cost and inflation. In contrast, the wage norm amplifies the fluctuations in the cost of an employment relationship, such that marginal cost and inflation volatility are dampened to a lesser extent. Comparing these results quantitatively to those reported in Table 2, the fluctuations in prices and costs are substantially larger with the conventional timing, in particular when generated by monetary shocks. Moreover, inflation and marginal cost display very small autocorrelation, and the correlation of inflation and output is negative, even conditional on monetary shocks. This reflects the absence of a margin of

[15] The steady state equations imply similar job type-specific parameter values as those reported in Section 2.6: $q_g = 1.37, q_b = 0.48, p_g = 0.27, p_b = 0.77, v_g = 0.04, v_b = 0.18, u_g = 0.033, u_b = 0.112, n_g = 0.54, n_b = 0.31, m_g = 0.06, m_b = 0.09, z_g = 0.48, z_b = 0.46, w_g = 0.46$, and $w_b = 0.45$.

instantaneous adjustment of production, which requires relative prices to adjust to dampen the change in consumption demand on impact of a monetary shock. In the labor market, on-the-job search increases the fluctuations in unemployment fourfold, those of vacancies twofold and those of the $v - u$ ratio threefold, whereas it makes the fluctuations in labor market tightness almost three times smaller than those of the $v - u$ ratio.[16] The labor market variables are highly autocorrelated and a Beveridge curve obtains, even in the standard search model and the wage norm model.

4.2 Key parameter values

As emphasized above, the complementarity between firms' vacancy creation and workers' on-the-job search intensity gives rise to a procyclical flow of job-to-job transitions. Thus, the endogenous movements in search intensity are central to explaining, on the one hand, the large fluctuations in the $v - u$ ratio that reflect the powerful propagation of shocks, and, on the other hand, the muted changes in labor market tightness that translate into rigidity of marginal cost and inflation. Figure 3 illustrates the importance of the search intensity for the dynamics of inflation in the baseline model of Section 2, by varying the elasticity of the search cost. As the search cost becomes less elastic, a worker's search intensity is more sensitive to economic conditions and hence the relative volatility of inflation is reduced. The effect is particularly strong for the case of money growth shocks.

Another key parameter is the degree of price stickiness. Krause and Lubik (2006) analyze the role of on-the-job search for the labor market variables in a real business cycle model, where nominal prices have no real effects and productivity shocks are the only source of fluctuations. The left panel of Figure 4 depicts the effects on the $v - u$ ratio of relaxing each of these restrictions in the baseline model of Section 2. As firms face more nominal rigidity, productivity shocks generate an exceedingly large relative standard deviation of the $v - u$ ratio. If conditional on monetary shocks, the size of this relative volatility does not depend much on the degree of price stickiness, even for very small degrees of price stickiness. The right panel shows a comparable figure generated by simulations of the model with no margin of instantaneous production adjustment. Interestingly, an increase in price stickiness now dampens the fluctuations in the $v - u$ ratio induced by productivity shocks. The relative volatility arising from monetary shocks is again not sensitive to the degree of price stickiness.

The opposite relationship between price stickiness and labor market fluctuations under the two timing assumptions is a consequence of the different impact of a productivity shock. That

[16] The fluctuations conditional on productivity shocks in unemployment, and hence those in the $v - u$ ratio, are somewhat smaller than the statistics reported by Krause and Lubik (2006). The gap can be accounted for by the simultaneous effects of a positive degree of price stickiness, the specification of the cost of on-the-job search effort in terms of utility, and a larger steady state pool of unemployed searchers.

impact is particularly large for vacancies under the timing of the baseline model and particularly large for relative prices with the conventional timing. Hence, in the baseline model, a positive productivity shock induces a downward adjustment of employment in the short run, as demand for goods with previously set prices is fixed and can be met with fewer workers. That is followed by an expansion of employment and production as firms gradually adjust their prices. These dynamics are highlighted by Galí (1999) in a sticky price model with a competitive labor market. Stickier prices then induce larger fluctuations in the labor market by requiring a larger initial downward adjustment of vacancies and employment. With the conventional timing, on the contrary, employment is predetermined so there is no downward employment adjustment in the short run. Relative prices of intermediate goods must therefore fall to bring aggregate consumption in line with increased production. But that price decline dampens the increase in these firms' incentive for new vacancy creation and thus the increase in the $v-u$ ratio. Stickier prices require a larger downward adjustment of relative prices, such that the fluctuations in the $v-u$ ratio due to productivity shocks are diminished.

5 Concluding remarks

This paper demonstrates that introducing on-the-job search in an otherwise standard New Keynesian model with search frictions substantially improves the model from two perspectives. First, it reduces the sensitivity of marginal cost to monetary or productivity shocks, which dampens the resulting inflation response and increases the propagation toward output. Second, it also improves the cyclical labor market properties of the model by generating sizable fluctuations in and large autocorrelation of the key labor market variables, and a Beveridge curve.

The analysis also produces insight in the dynamics of the model with a standard labor market, where workers cannot search on-the-job. If new matches become productive instantaneously, vacancies and the $v-u$ ratio display large volatility, even if this is generated by productivity shocks, but small autocorrelation and the model fails to produce a Beveridge curve. This contrasts with the case where new matches become productive with a lag, in which the labor market variables display a lack of amplification but are highly autocorrelated and in which a Beveridge curve obtains. On-the-job search brings about substantial improvement of the deficiencies associated with each timing assumption.

A Steady state

The following steady state equations are used to obtain values of the job type specific parameters based on the baseline calibration.

$$
\begin{aligned}
m_g &= \psi_g (u_g + e)^{\xi} v_g^{1-\xi} \\
m_b &= \psi_b u_b^{\xi} v_b^{1-\xi} \\
p_g &= \frac{m_g}{u_g + e} \\
p_b &= \frac{m_b}{u_b} \\
q_i &= \frac{m_i}{v_i}, \qquad i = g, b \\
q &= \frac{m_g + m_b}{v_g + v_b} \\
p_g \frac{\gamma_g}{q_g} &= p_b \left[\frac{\gamma_b}{q_b} + s p_g \left(\frac{\gamma_g}{q_g} - \frac{1-\eta}{\eta} \kappa s^{1+\tau} C^{\sigma} \right) \right] \\
z_g - w_g &= \frac{\gamma_g}{q_g} [1 - \beta(1-\rho)] \\
(z_b - w_b)(1 - s p_g) &= \frac{\gamma_b}{q_b} [1 - \beta(1-\rho)(1 - s p_g)] \\
w_g &= \eta \left[z_g + \beta(1-\rho) p_g \frac{\gamma_g}{q_g} \right] + (1-\eta) A \\
w_b &= \eta \left[z_b + \beta(1-\rho) \frac{\gamma_b}{q_b} \right] + (1-\eta) \left[A + \kappa s^{1+\tau} C^{\sigma} \right] - \eta \beta (1-\rho) \left(\frac{1-p_b}{p_b} \right) p_g \frac{\gamma_g}{q_g} \\
\frac{1-\eta}{\eta} (1+\tau) \kappa s^{\tau} C^{\sigma} &= p_g \left[\frac{\gamma_g}{q_g} - \frac{\gamma_b}{(1 - s p_g) q_b} - \frac{1-\eta}{\eta} \kappa s^{1+\tau} C^{\sigma} \right] \\
m_g &= \rho n_g \\
m_b (1 - s p_g) &= n_b [1 - (1-\rho)(1 - s p_g)] \\
u &= u_g + u_b \\
u &= 1 - (1-\rho)(n_g + n_b) \\
\frac{z_g}{z_b} &= \frac{1-\alpha}{\alpha} \left(\frac{n_b - \gamma_b v_b}{n_g - \gamma_g v_g} \right) \\
\frac{\varepsilon - 1}{\varepsilon} &= \left(\frac{z_g}{1-\alpha} \right)^{1-\alpha} \left(\frac{z_b}{\alpha} \right)^{\alpha} \\
C &= \frac{\varepsilon}{\varepsilon - 1} \frac{z_g (n_g - \gamma_g v_g)}{1-\alpha} \\
e &= s[(1-\rho) n_b + m_b] \\
qr &= \frac{p_g e}{n_g + n_b}
\end{aligned}
$$

B Log-linearized model

This appendix describes the log-linearized approximation of the model. Firm and worker matching rates are written in terms of labor market tightness using the log-linear approximation to Eqs. (7)−(9): $\hat{p}_{it} = (1-\xi)\hat{\theta}_{it}$ and $\hat{q}_{it} = -\xi\hat{\theta}_{it}$, for $i = g, b$. In addition, the approximation of the stochastic discount factor $\hat{\beta}_{t,t+1} = -(\hat{R}_t - \hat{\pi}_{t+1})$ is used.

1. Consumption Euler equation, (11):

$$\sigma \hat{C}_t = \sigma E_t \hat{C}_{t+1} - (\hat{R}_t - E_t \hat{\pi}_{t+1})$$

2. New Keynesian Phillips curve, (24) and (25):

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \frac{(1-\nu)(1-\beta\nu)}{\nu}\hat{z}_t$$

3. Money growth, (26):

$$\hat{\mu}_t = \rho_\mu \hat{\mu}_{t-1} + \varepsilon_{\mu t}$$

4. Evolution real money balances, $md_t \equiv M_t/P_t$:

$$\hat{md}_t = \hat{md}_{t-1} + \hat{\mu}_t - \hat{\pi}_t$$

5. Money demand, (12):

$$\hat{md}_t = \sigma \hat{C}_t - \frac{1}{R-1}\hat{R}_t$$

6. Intermediate good production, (13):

$$\hat{y}_{it} = \hat{a}_t + \hat{n}_{it}, \qquad i = g, b$$

7. Productivity, (14):

$$\hat{a}_t = \rho_a \hat{a}_{t-1} + \varepsilon_{at}$$

8. Intermediate good market clearing, (27):

$$Y_i \hat{Y}_{it} = y_i \hat{y}_{it} - \gamma_i v_i \hat{v}_{it}, \qquad i = g, b$$

9. Relative price intermediate goods, (21), (22):

$$\hat{z}_{it} = \hat{z}_t + \hat{C}_t - \hat{Y}_{it}, \qquad i = g, b$$

10. Real marginal cost, (23):

$$\hat{z}_t = (1-\alpha)\hat{z}_{gt} + \alpha \hat{z}_{bt}$$

11. Employment good jobs, (1):

$$\hat{n}_{gt} = (1-\rho)\hat{n}_{g,t-1} + \rho\left(\hat{v}_{gt} - \xi\hat{\theta}_{gt}\right)$$

12. Employment bad jobs, (2):

$$\hat{n}_{bt} = (1-\rho)(1-sp_g)\hat{n}_{b,t-1} + [1-(1-\rho)(1-sp_g)]\left(\hat{v}_{bt} - \xi\hat{\theta}_{bt}\right) - \frac{sp_g}{1-sp_g}\left[\hat{s}_t + (1-\xi)\hat{\theta}_{gt}\right]$$

13. Effective on-the-job search, (5):

$$\hat{e}_t = \hat{s}_t + (1-\rho)(1-sp_g)\hat{n}_{b,t-1} + [1-(1-\rho)(1-sp_g)]\left(\hat{v}_{bt} - \xi\hat{\theta}_{bt}\right)$$

14. Unemployed search, (6):

$$u_g\hat{u}_{gt} + u_b\hat{u}_{bt} = -(1-\rho)(n_g\hat{n}_{g,t-1} + n_b\hat{n}_{b,t-1})$$

15. Labor market tightness good jobs:

$$\hat{\theta}_{gt} = \hat{v}_{gt} - \left(\frac{u_g}{u_g+e}\right)\hat{u}_{gt} - \left(\frac{e}{u_g+e}\right)\hat{e}_t$$

16. Labor market tightness bad jobs:

$$\hat{\theta}_{bt} = \hat{v}_{bt} - \hat{u}_{bt}$$

17. Good job creation, (15):

$$\begin{aligned}\xi\hat{\theta}_{gt} &= [1-\beta(1-\rho)]\left[\left(\frac{z_g}{z_g-w_g}\right)(\hat{z}_{gt}+\hat{a}_t) - \left(\frac{w_g}{z_g-w_g}\right)\hat{w}_{gt}\right] \\ &- \beta(1-\rho)(\hat{R}_t - E_t\hat{\pi}_{t+1}) + \beta(1-\rho)\xi E_t\hat{\theta}_{g,t+1}\end{aligned}$$

18. Bad job creation, (16):

$$\begin{aligned}\xi\hat{\theta}_{bt} &= [1-\beta(1-\rho)(1-sp_g)]\left[\left(\frac{z_b}{z_b-w_b}\right)(\hat{z}_{bt}+\hat{a}_t) - \left(\frac{w_b}{z_b-w_b}\right)\hat{w}_{bt}\right] \\ &- \beta(1-\rho)(1-sp_g)(\hat{R}_t - E_t\hat{\pi}_{t+1}) + \beta(1-\rho)(1-sp_g)\xi E_t\hat{\theta}_{b,t+1} \\ &- \frac{sp_g}{1-sp_g}\left[\hat{s}_t + (1-\xi)\hat{\theta}_{gt}\right]\end{aligned}$$

19. Wage good job, (17):

$$w_g\hat{w}_{gt} = \eta z_g(\hat{z}_{gt}+\hat{a}_t) - \eta\beta(1-\rho)p_g\frac{\gamma_g}{q_g}(\hat{R}_t - \hat{\pi}_{t+1}) + \eta\beta(1-\rho)p_g\frac{\gamma_g}{q_g}E_t\hat{\theta}_{g,t+1}$$

20. Wage bad job, (18):

$$\begin{aligned} w_b\hat{w}_{bt} &= \eta z_b(\hat{z}_{bt}+\hat{a}_t)+\eta\beta(1-\rho)\left[\left(\frac{1-p_b}{p_b}\right)p_g\frac{\gamma_g}{q_g}-\frac{\gamma_b}{q_b}\right](\hat{R}_t-E_t\hat{\pi}_{t+1}) \\ &+ (1-\eta)\kappa s^{1+\tau}C^{\sigma}\left[(1+\tau)\hat{s}_t+\sigma\hat{C}_t\right]-\eta\beta(1-\rho)\left(\frac{1-p_b}{p_b}\right)p_g\frac{\gamma_g}{q_g}E_t\hat{\theta}_{g,t+1} \\ &+ \eta\beta(1-\rho)\left[\frac{p_g}{p_b}\frac{\gamma_g}{q_g}(1-\xi)+\frac{\gamma_b}{q_b}\xi\right]E_t\hat{\theta}_{b,t+1} \end{aligned}$$

21. Directed search arbitrage condition, (19):

$$\begin{aligned} &\left\{[1+(1+\tau)(1-sp_b)]p_g\frac{\gamma_g}{q_g}-(2+\tau)p_b\frac{\gamma_b}{q_b}\right\}\hat{s}_t+\left[(1-sp_b)p_g\frac{\gamma_g}{q_g}-p_b\frac{\gamma_b}{q_b}\right]\sigma\hat{C}_t \\ = &\left[(1-sp_b)p_g\frac{\gamma_g}{q_g}\xi+p_b\frac{\gamma_b}{q_b}(1-\xi)\right]\hat{\theta}_{gt}-\left[p_g\frac{\gamma_g}{q_g}(1-\xi)+p_b\frac{\gamma_b}{q_b}\xi\right]\hat{\theta}_{bt} \end{aligned}$$

22. On-the-job search intensity, (20):

$$\begin{aligned} &\left[\frac{1-\eta}{\eta}\kappa s^{\tau}C^{\sigma}(1+\tau)(sp_g+\tau)+\frac{\gamma_b}{q_b}\frac{sp_g^2}{(1-sp_g)^2}\right]\hat{s}_t+\frac{1-\eta}{\eta}\kappa s^{\tau}C^{\sigma}\sigma(1+\tau+sp_g)\hat{C}_t \\ = &\left[\frac{1-\eta}{\eta}\kappa s^{\tau}C^{\sigma}(1+\tau)(1-\xi)-\frac{\gamma_b}{q_b}\frac{sp_g^2}{(1-sp_g)^2}(1-\xi)+p_g\frac{\gamma_g}{q_g}\xi\right]\hat{\theta}_{gt}-\frac{p_g}{1-sp_g}\frac{\gamma_b}{q_b}\xi\hat{\theta}_{bt} \end{aligned}$$

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Figure 1: Responses to a positive one percent money growth shock

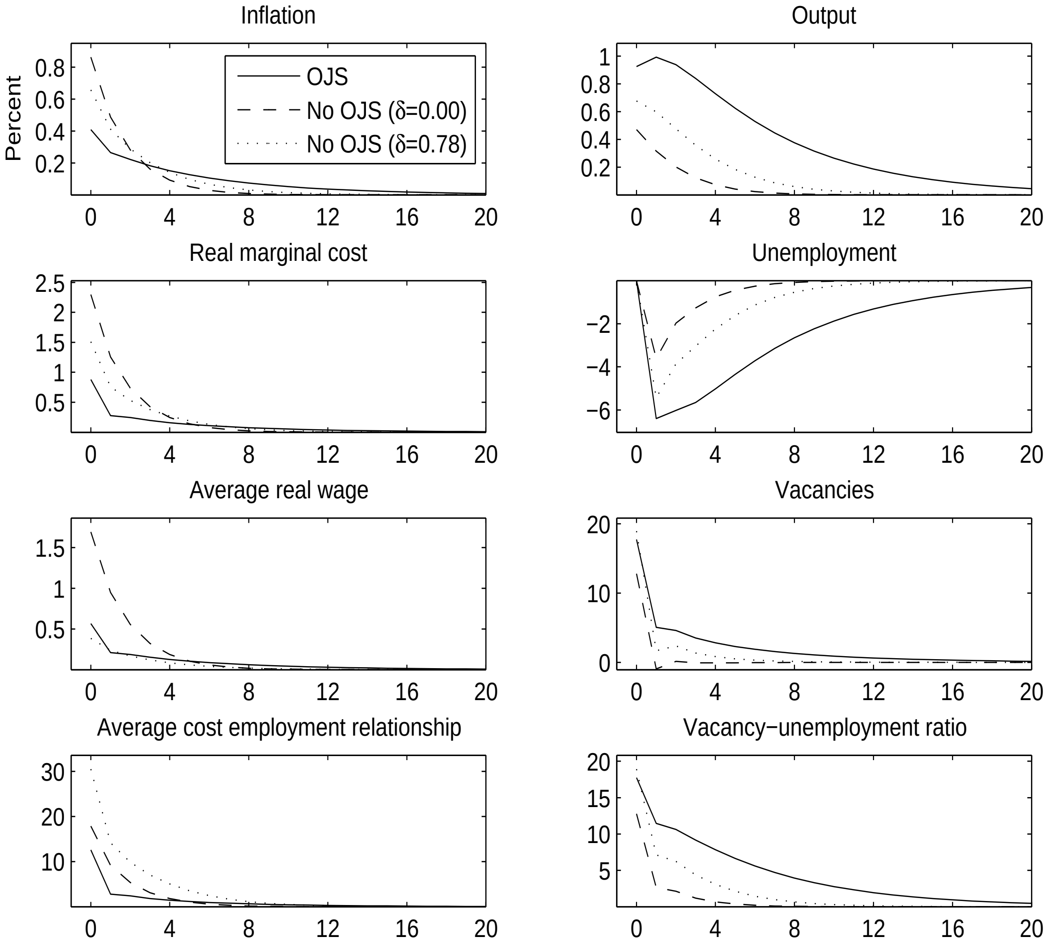

Figure 2: Responses of the cost of an employment relationship to a positive one percent money growth shock

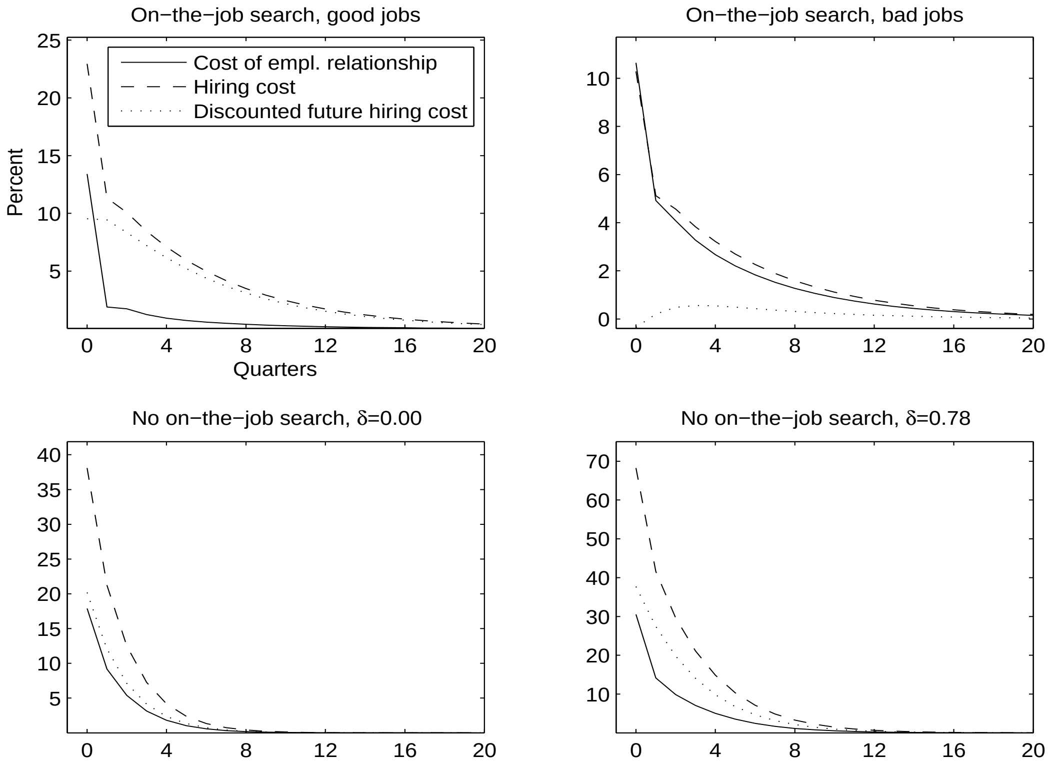

Figure 3: Inflation sensitivity to the search cost elasticity

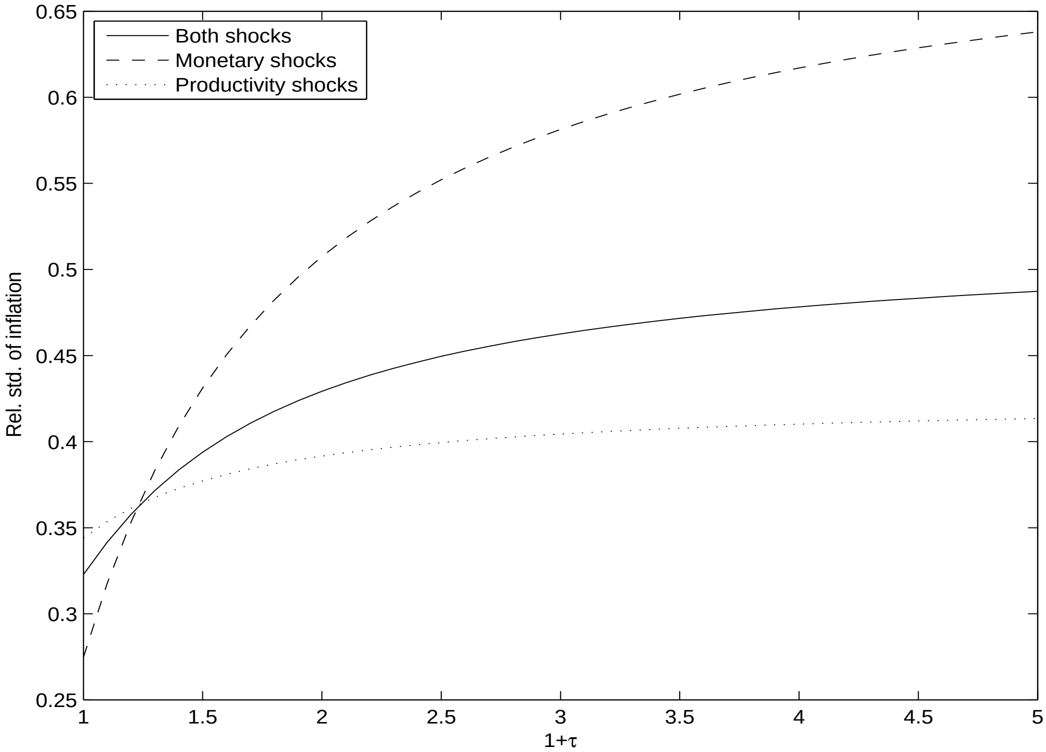

Figure 4: Labor market sensitivity to the degree of price stickiness

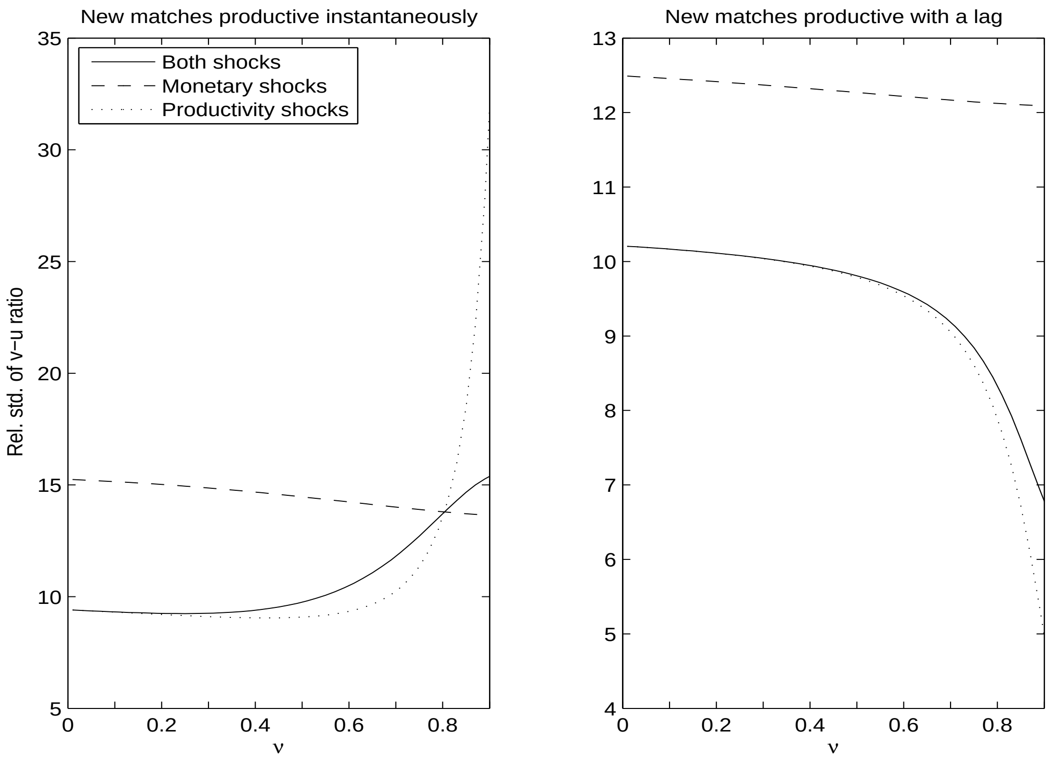

Table 1: Baseline calibration

Preferences and final good technology		
β	0.99	discount factor
σ	1	relative risk aversion
ϵ	11	demand elasticity
ν	0.67	fraction of firms not adjusting price
α	0.36	share of input b in final output
τ	0.1	search cost elasticity parameter
Labor market		
γ_g	0.16	good job creation cost
γ_b	0.02	bad job creation cost
ξ	0.5	search elasticity of matches
η	0.5	worker share of surplus
ρ	0.1	separation rate
$1-n$	0.05	unemployment rate
ψ_i	0.61	matching efficiency type $i = g, b$ jobs
qr	0.06	quit rate
Productivity and monetary shock process		
ρ_μ	0.50	autoregressive coefficient monetary shock
σ_μ	0.006	standard deviation monetary shock
ρ_a	0.95	autoregressive coefficient productivity shock
σ_a	0.0055	standard deviation productivity shock

Table 2: Business cycle properties of U.S. economy and simulated model economies

	U.S.	Model with on-the-job search			Model without on-the-job search					
					$\delta = 0.00$			$\delta = 0.78$		
Relative Std.		$\mu\&a$	μ	a	$\mu\&a$	μ	a	$\mu\&a$	μ	a
Output (Y)	1.50	1.50	0.83	1.23	0.79	0.31	0.72	1.17	0.52	1.05
Inflation (π)	0.30	0.34	0.32	0.35	0.84	1.74	0.52	0.53	0.82	0.43
Marginal cost	–	0.61	0.60	0.61	2.47	4.60	1.81	1.28	1.78	1.13
Wage	0.71	0.30	0.39	0.24	1.62	3.41	0.97	0.30	0.48	0.23
Cost emp. rel.	–	6.14	8.49	4.68	19.2	35.3	14.3	21.9	35.4	17.1
Unempl. (u)	7.25	5.28	6.27	4.77	3.73	7.25	2.58	4.68	7.20	3.82
Vacancies (v)	8.83	8.77	12.0	6.77	12.4	23.8	8.81	11.7	20.7	8.22
$v - u$ ratio	15.8	11.3	14.1	9.85	12.2	23.4	8.59	13.2	21.5	10.2
Tightness	–	3.14	3.76	2.81	12.2	23.4	8.59	13.2	21.5	10.2
Quit rate	–	12.1	16.5	9.42	–	–	–	–	–	–
Autocorrelation										
Output	0.86	0.87	0.76	0.92	0.80	0.50	0.85	0.85	0.66	0.89
Inflation	0.48	0.54	0.50	0.55	0.39	0.42	0.32	0.46	0.48	0.45
Marginal cost	–	0.28	0.18	0.32	0.37	0.41	0.31	0.39	0.38	0.40
Unempl.	0.91	0.80	0.71	0.87	0.40	0.42	0.38	0.69	0.56	0.81
Vacancies	0.91	0.29	0.15	0.49	-0.17	-0.14	-0.20	0.11	-0.02	0.32
$v - u$ ratio	0.91	0.66	0.52	0.79	0.08	0.10	0.04	0.44	0.27	0.63
Correlation										
Y, π	0.36	0.14	0.92	-0.18	0.19	0.99	-0.26	0.15	0.97	-0.22
v, u	-0.93	-0.25	-0.09	-0.43	0.22	0.21	0.24	-0.12	0.06	-0.33

Notes: Standard deviations are relative to that of output. μ and a denote results conditional on monetary and productivity shocks respectively.

Table 3: Business cycle properties of U.S. economy and simulated model economies: New matches become productive with a lag

	U.S.	Model with on-the-job search			Model without on-the-job search $\delta = 0.00$			$\delta = 0.73$		
Relative Std.		μ&a	μ	a	μ&a	μ	a	μ&a	μ	a
Output (Y)	1.50	1.50	0.26	1.46	0.80	0.07	0.80	1.01	0.13	1.00
Inflation (π)	0.30	0.64	3.04	0.37	1.17	11.0	0.67	0.92	6.10	0.50
Marginal cost	–	3.10	17.2	0.94	6.08	55.2	3.67	4.58	32.5	1.95
Wage	0.71	1.57	8.86	0.38	3.16	30.0	1.76	0.71	4.88	0.34
Cost emp. rel.	–	53.8	305	12.3	68.8	632	40.6	91.0	664	33.6
Unempl. (u)	7.25	4.73	5.90	4.69	1.21	6.11	1.09	3.09	6.13	3.02
Vacancies (v)	8.83	5.61	8.89	5.49	2.40	15.6	1.98	5.46	14.0	5.21
$v - u$ ratio	15.8	9.33	12.2	9.24	3.12	17.3	2.73	7.69	16.6	7.46
Tightness	–	3.21	3.87	3.19	3.12	17.3	2.73	7.69	16.6	7.46
Quit rate	–	8.33	12.4	8.17	–	–	–	–	–	–
Autocorrelation										
Output	0.86	0.91	0.81	0.92	0.76	0.56	0.76	0.86	0.65	0.86
Inflation	0.48	0.12	-0.03	0.43	0.05	0.06	0.01	0.08	0.01	0.25
Marginal cost	–	-0.05	-0.07	0.07	-0.03	-0.03	-0.04	-0.04	-0.06	0.07
Unempl.	0.91	0.93	0.84	0.93	0.84	0.68	0.88	0.89	0.76	0.90
Vacancies	0.91	0.79	0.51	0.81	0.55	0.26	0.69	0.72	0.39	0.76
$v - u$ ratio	0.91	0.91	0.76	0.91	0.75	0.50	0.83	0.85	0.62	0.87
Correlation										
Y, π	0.36	-0.15	-0.30	-0.19	-0.21	-0.20	-0.34	-0.17	-0.28	-0.25
v, u	-0.93	-0.62	-0.32	-0.64	-0.42	-0.10	-0.54	-0.58	-0.23	-0.61

Notes: Standard deviations are relative to that of output. μ and a denote results conditional on monetary and productivity shocks respectively.