Matching Efficiency and Business Cycle Fluctuations*

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Abstract

We use a simple New Keynesian model with labor-market search to study the macroeconomic implications of exogenous changes in the effectiveness of the process through which unemployed workers are matched with vacant jobs. The importance of these matching efficiency shocks for unemployment fluctuations hinges critically on the presence of pre-match hiring costs and nominal rigidities. Pre-match hiring costs govern the magnitude of the unemployment response. Nominal rigidities affect the sign of the vacancies' response. For empirically plausible parametrizations of these two key features, matching efficiency shocks generate a positive correlation between vacancies and unemployment and are thus an unlikely major source of business cycle fluctuations. These disturbances may, however, help account for specific episodes such as the recent period. A decline in matching efficiency increases inflation and raises the natural rate of unemployment above the actual rate, thus calling unambiguously for a tightening of monetary policy.

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1 Introduction

In the aftermath of the Great Recession a number of policymakers have attributed unemployment's slow recovery to a decline in the effectiveness of the process that matches unemployed workers and vacant jobs in the labor market (e.g. Kocherlakota 2010; Lacker 2012; and Plosser 2012). Recent studies provide some empirical evidence to support this view.[1] In this paper, we use a simple New Keynesian model with equilibrium search unemployment to investigate the macroeconomic implications of changes in the effectiveness of the labor market matching process.[2] Like in the seminal paper by Andolfatto (1996), we introduce a shock to the efficiency of the matching function.

Unemployed workers, job vacancies, and matching efficiency are related through the aggregate matching function (cf. Blanchard and Diamond 1989; Petrongolo and Pissarides 2001). When matching efficiency is low, for a given number of unemployed workers and vacancies, fewer new jobs will be created. Therefore, matching efficiency has an interpretation that is similar to the Solow residual of the aggregate production function.[3] However, while the literature has devoted a substantial effort to studying the production function's Solow residual and the properties of technology shocks, little is known about

[1] See for example Barlevy (2011), Barnichon and Figura (2011), Elsby, Hobijn, and Sahin (2010), Furlanetto and Groshenny (2013), Sahin, Song, Topa, and Violante (2012), Sala, Söderström, and Trigari (2012) and Veracierto (2011). Broadly, these studies suggest that matching efficiency may have deteriorated by roughly 20 percent. These studies reach different conclusions regarding the persistence of this decline. Several factors could explain a lower degree of matching efficiency: skill mismatch (Sahin, Song, Topa and Violante, 2012, and Herz and van Rens, 2012), geographical mismatch, possibly exacerbated by house-locking effects (Nenov, 2011), a reduction in search intensity by workers because of extended unemployment benefits (Kuang and Valletta 2010; Fujita 2011), a reduction in firm recruiting intensity (Davis, Faberman, and Haltiwanger, 2010), a compositional change in unemployment due to a rise in permanent layoffs and a larger share of long-term unemployment (Barnichon and Figura 2011).

[2] The use of search and matching frictions in business cycle models was pioneered by Merz (1995) and Andolfatto (1996) in the real business cycle (RBC) literature. More recently, these frictions have been studied in the New Keynesian model by Blanchard and Galí (2010), Christiano, Trabandt, and Walentin (2011), Christoffel, Kuester, and Linzert (2009), Gertler, Sala and Trigari (2008), Groshenny (2009 and 2012), Krause and Lubik (2007), Krause, Lubik, and López Salido (2008), Ravenna and Walsh (2008 and 2011), Sveen and Weinke (2008 and 2009), Trigari (2009), and Walsh (2005), among many others.

[3] Changes in matching efficiency have an endogenous component, as is the case with the Solow residual of a production function (Basu, Fernald and Kimball, 2006). How to purify the residual of the matching function is an interesting area for future research that is outside the scope of the current paper. First attempts in that direction are proposed by Borowczyk-Martins, Jolivet, and Postel-Vinay (2012), Chang (2012) and Sedlácek (2012).

the effects of shocks to the matching efficiency. This paper aims to fill this gap.

Three main contributions emerge from our analysis. First, the propagation of shocks to the matching efficiency depends crucially on the form of hiring costs. When we consider post-match hiring costs, in the form of training costs as in Gertler and Trigari (2009), we show analytically that the shock does not affect unemployment and that the conditional correlation between unemployment and vacancies is nil. When we consider pre-match hiring costs in the form of the linear costs of posting a vacancy, as in Pissarides (2000), the shock then affects unemployment and generates a positive correlation between unemployment and vacancies. In the data, however, it is well known that this correlation is strongly negative. Therefore, under both hiring cost specifications, shocks to the matching efficiency are unlikely to emerge as a main source of business cycle fluctuations. Nevertheless, these shocks can be seen as shifters of the Beveridge curve and may play a role in specific episodes as long as pre-match hiring costs are not negligible.

Our second contribution is to show that when matching efficiency shocks propagate, i.e. under pre-match hiring costs, the presence of nominal rigidities is crucial for the transmission mechanism. In fact, the response of vacancies can be positive or negative depending on the degree of nominal rigidities present in the model. The sign of the vacancy response is important because it determines the conditional correlation between unemployment and vacancies. When nominal rigidities are present, as in our baseline model, a negative shock leads to an increase in vacancies and creates a positive correlation. As we reduce the degree of nominal rigidities, the response of vacancies to a negative disturbance becomes less and less positive and eventually turns negative when prices are highly flexible. Hence, the conditional correlation between unemployment and vacancies declines substantially and can even become negative when the shock has limited persistence. Interestingly, this finding is reminiscent of Galí's (1999) result on the role of nominal rigidities for determining the sign of the employment response to a technology shock.

Our third contribution concerns the role of monetary policy. Shocks to the matching efficiency, unlike the other shocks usually considered in the literature, propagate more in models with flexible prices and wages than in models with nominal rigidities. Therefore, the natural rate of unemployment reacts more than unemployment itself and a negative matching efficiency shock reduces the unemployment gap and increases inflation. If monetary policy is based on standard intermediate targets, like inflation and unemployment gap, a negative matching efficiency shock calls for an increase in the policy rate.

Shocks to the matching efficiency are already present in the seminal paper by Andolfatto (1996) that introduced search and matching frictions in the standard RBC model. Since then, these shocks have also been considered in Beauchemin and Tasci (2012), Krause, Lubik, and Lopez-Salido (2008), Lubik (2009), Cheremukhin and Restrepo-Echevarria (2011), Justiniano and Michelacci (2011), and Mileva (2011), among others. However, none of these papers relates the form of hiring costs and the degree of nominal rigidities to the propagation of matching efficiency shocks. Importantly, our analysis help explain why matching efficiency shocks are responsible for a share of unemployment fluctuations that are large in some estimated DSGE models (cf. Lubik 2009, and Krause, Lubik, and López-Salido 2008) and limited in others (cf. Justiniano and Michelacci 2011; Furlanetto and Groshenny 2013; and Sala, Södertröm, and Trigari 2012).

As argued by Andolfatto (1996), shocks to the matching efficiency can be interpreted as reallocation shocks as long as these capture some form of mismatch in skills, in geography, or in other dimensions. Thus, our paper is also related to the literature initiated by Lilien (1982) on the importance of reallocation shocks for business cycle fluctuations. Abraham and Katz (1986) suggest that reallocation shocks play a limited role in explaining aggregate fluctuations because these imply a positive correlation between unemployment and vacancies (unlike aggregate demand shocks). However, their argument is not based on a general equilibrium analysis. Here, we qualify the suggestion by Abraham and Katz (1986) by showing that the sign of the conditional correlation between unemployment and vacancies depends on the form of the hiring costs and the degree of nominal rigidities.

The paper proceeds as follows: Section 2 briefly describes the model, section 3 presents our results, section 4 relates our results to the literature and section 5 concludes.

2 The Model

The model economy consists of a representative household, a continuum of intermediate good-producing firms, a continuum of monopolistically competitive retail firms, and monetary and fiscal authorities which set monetary and fiscal policy, respectively. The model is purposely simple. We ignore capital accumulation, real rigidities (such as habit persistence and investment adjustment costs) and wage rigidities.[4] Rather, in this paper we concentrate only on the features that are critical for the transmission of matching efficiency shocks and leave aside the unnecessary complications. Our model's version with pre-match hiring costs is very similar to Kurozumi and Van Zandweghe (2010). The version with post-match hiring costs is a simplified version of Gertler, Sala and Trigari (2008).

The Representative Household The representative household is a large family, made up of a continuum of individuals of measure one. Family members are either working or searching for a job. The model abstracts from the labor force participation decision. Following Merz (1995), we assume that family members pool their income before allowing the head of the household to choose its optimal per capita consumption.

The representative family enters each period $t = 0, 1, 2, ...$, with B_{t-1} bonds. At the beginning of each period, bonds mature, providing B_{t-1} units of money. The representative family uses some of this money to purchase B_t new bonds at nominal cost B_t/R_t, where R_t denotes the gross nominal interest rate between period t and $t+1$.

Each period, N_t family members are employed. Each employee works a fixed amount of hours and earns the nominal wage W_t. The remaining $(1 - N_t)$ family members are unemployed and each receives nominal unemployment benefits b, financed through lump-sum nominal taxes T_t. Unemployment benefits b are proportional to the steady-state nominal wage: $b = \tau W$. The representative household owns retail firms and receives each period the accumulated profits (D_t).

[4] We include all these features in a companion paper (Furlanetto and Groshenny 2013), where we estimate a medium-scale version of our model to study the evolution of unemployment during the Great Recession and to quantify the importance of structural factors for unemployment dynamics.

The family's period t budget constraint is given by

$$P_tC_t + \frac{B_t}{R_t} \leq B_{t-1} + W_tN_t + (1 - N_t)\, b - T_t + D_t, \tag{1}$$

where C_t represents a Dixit-Stiglitz aggregator of retail goods purchased for consumption purposes and P_t is the corresponding price index.

The family's lifetime utility is described by

$$E_t \sum_{s=0}^{\infty} \beta^s \ln C_{t+s}, \tag{2}$$

where $0 < \beta < 1$.

Intermediate Good-Producing Firms Each intermediate good-producing firm $i \in [0, 1]$ enters in period t with a stock of $N_{t-1}(i)$ employees. New matches become productive in the period. Before production starts, $\rho N_{t-1}(i)$ old jobs are destroyed. The job destruction rate ρ is constant. The workers who have lost their jobs start searching immediately and can possibly still be hired in period t with a probability given by the job finding rate. Alternatively, they will enter the unemployment pool before searching for a job in the next period. This timing convention, proposed by Ravenna and Walsh (2008) and used also by Sveen and Weinke (2009) and Christiano, Eichenbaum, and Trabandt (2013), implies that our model features a kind of job-to-job transition mechanism that is highly cyclical, given that it depends on the job-finding rate. Therefore, the flow from employment to unemployment is not constant, as it increases during recessions, even if we have a model with exogenous separation. Employment at firm i evolves according to $N_t(i) = (1 - \rho) N_{t-1}(i) + M_t(i)$ where the flow of new hires $M_t(i)$ is given by $M_t(i) = Q_tV_t(i)$. The term $V_t(i)$ denotes vacancies posted by firm i in period t and Q_t is the aggregate probability of filling a vacancy, defined as $Q_t = \frac{M_t}{V_t}$.

The expressions $M_t = \int_0^1 M_t(i)\, di$ and $V_t = \int_0^1 V_t(i)\, di$ denote aggregate matches and vacancies respectively. Aggregate employment, $N_t = \int_0^1 N_t(i)\, di$, evolves according to

$$N_t = (1 - \rho) N_{t-1} + M_t. \tag{3}$$

The matching process is described by an aggregate constant-returns-to-scale Cobb Douglas matching function,

$$M_t = L_t S_t^{\sigma} V_t^{1-\sigma}, \tag{4}$$

where S_t denotes the pool of job seekers in period t

$$S_t = 1 - (1-\rho) N_{t-1}, \tag{5}$$

and L_t is a time-varying scale parameter that captures the efficiency of the matching technology. It evolves exogenously following the autoregressive process,

$$\ln L_t = (1-\rho_L) \ln L + \rho_L \ln L_{t-1} + \varepsilon_{Lt}, \tag{6}$$

where L denotes the steady-state value of the matching efficiency, while ρ_L measures the persistence of the shock, and ε_{Lt} is $i.i.d.N\left(0, \sigma_L^2\right)$.

The job-finding rate (F_t) is defined as $F_t = \frac{M_t}{S_t}$ and aggregate unemployment is $U_t \equiv 1 - N_t$. Newly hired workers are immediately productive. Hence, the firm can adjust its output instantaneously through variations in the workforce. However, firms face hiring costs measured in terms of the finished good $\left(H_t^k(i)\right)$, where k is an index to distinguish the two types of hiring costs that we consider.

The first specification is a post-match hiring cost $\left(H_t^{post}(i)\right)$ in which total hiring costs are given by

$$H_t^{post}(i) = \frac{\phi_N}{2} \left[X_t(i)\right]^2 N_t, \tag{7}$$

where $X_t(i) = \frac{Q_t V_t(i)}{N_t(i)}$ represents the hiring rate.[5] The parameter ϕ_N governs the magnitude of the post-match hiring cost. This kind of adjustment cost was first used by Gertler and Trigari (2008) because it enables the derivation of the wage equation with staggered contracts and helps the model fit the persistence and the volatility of unemployment and

[5] Post-match hiring costs are indexed to aggregate employment. All results are confirmed if they are indexed to employment at the firm level.

vacancies that we observe in the data (Pissarides 2009). This feature has become standard in the empirical literature (cf. Christiano, Trabandt, and Walentin 2011; Gertler, Sala, and Trigari 2008; Groshenny 2012; and Sala, Söderström, and Trigari 2008). The post-match hiring cost can be interpreted as a training cost: it reflects the cost of integrating new employees into the firm's workforce.

The second specification that we consider is the hiring cost that is commonly used in the literature on search and matching frictions (Pissarides, 2000). Following the classification in Pissarides (2009), it is a pre-match hiring cost ($H_t^{pre}(i)$) that represents the cost of posting a vacancy. We use the following standard linear specification,

$$H_t^{pre}(i) = \phi_N V_t(i) . \tag{8}$$

The parameter ϕ_N governs the magnitude of the pre-match hiring cost.

Each period, firm i uses $N_t(i)$ homogeneous employees to produce $Y_t(i)$ units of intermediate good i according to the constant-returns-to-scale technology described by

$$Y_t(i) = N_t(i) . \tag{9}$$

Each intermediate good-producing firm $i \in [0,1]$ chooses employment and vacancies to maximize profits and sells its output $Y_t(i)$ in a perfectly competitive market at a price $Z_t(i)$ that represents the relative price of the intermediate good in terms of the final good. The firm maximizes

$$E_t \sum_{s=0}^{\infty} \beta^s \frac{\Lambda_{t+s+1}}{\Lambda_{t+s}} \left(Z_{t+s}(i) Y_{t+s}(i) - \frac{W_{t+s}(i)}{P_{t+s}} N_{t+s}(i) - H_{t+s}^k(i) \right), \tag{10}$$

where Λ_t represents the marginal utility of consumption. Since the firm is owned by the representative household, profits are discounted using the household's discount factor $\left(\beta^s \frac{\Lambda_{t+s+1}}{\Lambda_{t+s}}\right)$. Notice that all firms choose the same price and produce the same quantity.

Wage Setting The nominal wage $W_t(i)$ is determined through bilateral Nash bargaining,

$$W_t(i) = \arg\max \left[\Delta_t(i)^{\eta} J_t(i)^{1-\eta}\right], \tag{11}$$

where $0 < \eta < 1$ represents the worker's bargaining power. The worker's surplus, expressed in terms of final consumption goods, is given by

$$\Delta_t(i) = \frac{W_t(i)}{P_t} - \frac{b}{P_t} + \beta E_t\left[(1-\rho)(1-F_{t+1})\right]\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\Delta_{t+1}(i). \tag{12}$$

The firm's surplus in real terms is given by

$$J_t(i) = Z_t(i) - \frac{W_t(i)}{P_t} - \frac{\partial H_t^k(i)}{\partial N_t(i)} + \beta(1-\rho) E_t\left[\frac{\Lambda_{t+1}}{\Lambda_t} J_{t+1}(i)\right]. \tag{13}$$

Retail Firms There is a continuum of retail goods-producing firms indexed by $j \in [0,1]$ that transform the intermediate good into a final good $Y_t^f(j)$ that is sold in a monopolistically competitive market at price $P_t(j)$. Cost minimization implies that the real marginal cost is equal to the real price of the intermediate good (Z_t) that is common across firms. Demand for good j is given by $Y_t^f(j) = C_t(j) = (P_t(j)/P_t)^{-\theta} C_t$, where θ represents the elasticity of substitution across final goods. Firms choose their price subject to a Calvo (1983) scheme in which every period a fraction α is not allowed to re-optimize, whereas the remaining fraction $1-\alpha$ chooses optimally its price $(P_t^*(j))$ by maximizing the following discounted sum:

$$E_t \sum_{s=0}^{\infty} (\alpha\beta)^s \frac{\Lambda_{t+s}}{\Lambda_t}\left(\frac{P_t^*(j)}{P_{t+s}} - Z_{t+s}\right) Y_{t+s}^f(j). \tag{14}$$

All firms resetting prices in any given period choose the same price. The aggregate price dynamics is then given by

$$P_t = \left[\alpha P_{t-1}^{\theta} + (1-\alpha) P_t^{*1-\theta}\right]^{\frac{1}{1-\theta}}. \tag{15}$$

Monetary and Fiscal Authorities The central bank adjusts the short-term nominal gross interest rate R_t by following a Taylor-type rule,

$$\ln\left(\frac{R_t}{R}\right) = \rho_r \ln\left(\frac{R_{t-1}}{R}\right) + (1-\rho_r)\left[\rho_\pi \ln\left(\frac{P_t}{P_{t-4}}\right)^{1/4} + \rho_y \ln\left(\frac{Y_t}{Y_{t-4}}\right)^{1/4}\right]. \quad (16)$$

The degree of interest-rate smoothing ρ_r and the reaction coefficients to inflation and output growth (ρ_π and ρ_y) are all positive.

The government budget constraint takes the form

$$(1-N_t)\, b = \left(\frac{B_t}{R_t} - B_{t-1}\right) + T_t. \quad (17)$$

Aggregate Resource Constraint The aggregate resource constraint reads as follows

$$Y_t = Y_t^f + H_t^k, \quad (18)$$

where $Y_t^f = \int_0^1 Y_t^f(j)\, dj$. Notice that market clearing for each retail good implies that $Y_t^f(j) = C_t(j)$. Aggregating across firms, we obtain $Y_t^f = \Gamma_t C_t$. Price dispersion across firms $\left(\Gamma_t \equiv \int_0^1 (P_t(j)/P_t)^{-\theta} dj\right)$ drives a wedge between final output and consumption.

Parametrization Our parametrization is based on the US economy.[6] A first set of parameters is taken from the literature on monetary business cycle models. The discount factor is set at $\beta = 0.99$, the elasticity of substitution across final goods at $\theta = 11$ implies a steady-state markup of 10 percent. The parameters in the monetary policy rule are $\rho_r = 0.8$, $\rho_\pi = 1.5$, $\rho_y = 0.5$. The average degree of price duration is four quarters, corresponding to $\alpha = 0.75$.

A second set of parameter values is taken from the literature on search and matching

[6] Our objective is not to calibrate parameters to match moments in the model and in the data. Such an exercise would require the unrealistic assumption that the business cycle is driven only by shocks to the matching efficiency. Less ambitiously, our objective is to illustrate some simple economic mechanisms under a plausible parametrization that is standard in the literature. Importantly, only two parameters (the degree of nominal rigidity and the autocorrelation in the shock process) can overturn the theoretical mechanims described in the paper. We provide extensive sensitivity analysis to these parameters in section 4.

in the labor market. The degree of exogenous separation is set at $\rho = 0.08$, while the steady-state value of the unemployment rate is $U = 0.06$. The elasticity in the matching function is $\sigma = 0.5$, in the range of plausible values proposed by Petrongolo and Pissarides (2001). In the absence of convincing empirical evidence on the value for the bargaining power parameter η, we set it equal to 0.5 to satisfy the Hosios condition. The vacancy filling rate Q is set equal to 0.70. We follow Blanchard and Galí (2010) by setting ϕ_N such that total hiring costs in the steady state are equal to one percent of steady state output in both models. The value of unemployment benefits τ is derived from the steady-state conditions. These choices are common in the literature and avoid the indeterminacy issues that are widespread in this kind of model, as shown by Kurozumi and Van Zandweghe (2010) among others. Finally, the degree of persistence for the shock process is set at 0.6. Table 1 summarizes our parametrization.

The log-linear first-order conditions that do not depend on the form of the hiring cost function are listed in table 2. Lower scale variables stand for the capital variables expressed in log-deviation from the steady state. In tables 3 and 4 we report the three loglinearized first-order conditions that depend on the form of the hiring cost function (the job creation condition, the wage equation, and the market-clearing condition). The non linear equilibrium conditions are listed in appendix 3 together with the description of the steady-state.

3 The Effects of Matching Efficiency Shocks

In this section we present our three main results. In particular, we show how the effects of matching efficiency shocks on vacancies and unemployment depend crucially on the nature of hiring costs and on the degree of nominal rigidities. Moreover, we discuss how these results pose some implications for monetary policy.

3.1 Hiring Costs

In figure 1 we plot the impulse responses from a negative shock to the matching efficiency in the model with post-match hiring costs, as in Gertler and Trigari (2009) (dashed lines) and in the model with pre-match hiring costs, as in Pissarides (2000) (solid lines).

The paper's first result is that unemployment is invariant to the shock in the model with post-match hiring costs, unlike what occurs in the model with pre-match hiring costs. With post-match hiring costs, only vacancies and the probability of filling a vacancy react to the shock. A negative shock to the matching efficiency makes it more difficult to fill a vacancy because the job market is less efficient (q_t decreases), but firms react by posting more vacancies (v_t increases) so as to keep the hiring rate (x_t) constant. When expressed in deviation from the steady state, the responses of the two variables in absolute values are exactly of the same magnitude. This finding implies that employment does not react to the shock and, in turn, that unemployment and output are also invariant to the shock. All variables unrelated to the matching process remain unaffected by the matching efficiency shock. Put simply, the shock does not propagate.

With pre-match hiring costs it is still true that the probability of filling a vacancy decreases and that firms react by posting more vacancies. However, in this case the two effects do have not the same magnitude; a negative shock delivers a decrease in hiring and an increase in unemployment. The shock behaves like a negative technology shock: a less efficient matching process in the labor market increases the firm's marginal cost and moves output and inflation in different directions. Overall, the shock has a contractionary effect on the economy.

Why are hiring costs so important for propagating the shock? In a model with only post-match hiring costs, it is costly for firms to integrate new employees whereas it is costs nothing to post vacancies. A negative matching efficiency shock directly reduces the probability of filling a vacancy. In response to such shock, firms can avoid costly fluctuations in hiring by posting more vacancies. Firms perfectly control the hiring rate by varying vacancies. A shock to the matching efficiency affects the magnitude of the search frictions but this has no real consequences in the model because search is cost-free. In the end, even if search frictions are present, these are inactive and the model behaves like a model with employment adjustment costs.[7] By contrast, in a model with pre-match

[7]This point can be seen analytically by combining the list of equilibrium conditions in tables 2 and 3. In appendix 1 we show that unemployment dynamics do not depend on the matching function that is needed only to study the behavior of vacancies.

hiring costs, search is costly and therefore fluctuations in the magnitude of the search frictions have real consequences. In this case firms do not suffer costs from fluctuations in hiring and find it optimal to decrease the hiring rate. In figure 2 we see that matching efficiency shocks generate a correlation between unemployment and vacancies which is positive in the model with pre-match hiring costs and zero in a model with post-match hiring costs.

A second perspective on the role of the hiring cost functions is given by comparing the job creation conditions across the two models:

$$\phi_N X_t (1 - X_t) + \frac{W_t}{P_t} = Z_t + \beta (1 - \rho) E_t \frac{\Lambda_{t+1}}{\Lambda_t} \phi_N X_{t+1}, \tag{19}$$

$$\frac{\phi_V}{Q_t} + \frac{W_t}{P_t} = Z_t + \beta (1 - \rho) E_t \frac{\Lambda_{t+1}}{\Lambda_t} \frac{\phi_V}{Q_{t+1}}, \tag{20}$$

where equation (19) refers to the model with post-match hiring costs while equation (20) relates to the model with pre-match costs. On the left hand side we have the average cost of hiring a worker; this consists of a wage component and a hiring cost component. The hiring cost component is given by $\phi_N X_t (1 - X_t)$ in the model with post-match hiring costs and by $\frac{\phi_V}{Q_t}$ in the model with pre-match hiring costs. In the first case the firm is able to minimize the hiring cost component by moving vacancies in such a way that the hiring rate is constant. In the second case the hiring cost component is always positive (which results in an output loss from the market clearing condition) and depends directly on aggregate labor market conditions (Q_t). In other words, the congestion externality implied by the search frictions has real consequences. A negative shock raises the hiring cost component of the marginal cost of hiring, so the firm reacts by reducing hiring.

Thus far we have investigated two polar cases: a model that only has post-match hiring costs and a model with only pre-match hiring costs. Yashiv (2000) has proposed a generalized hiring cost function that combines the two components in the following way,

$$H_t^{gen}(i) = \frac{\gamma}{2}\left[\frac{\phi_V V_t(i) + (1-\phi_V) M_t(i)}{N_t(i)}\right]^2 N_t, \tag{21}$$

where γ relates to the size of total hiring costs[8] and $0 \leq \phi_V \leq 1$ governs the importance of the pre-match component. When ϕ_V is equal to 0 we revert to the model that only has the post-match hiring costs described above. When ϕ_V is equal to 1 we obtain a model with quadratic pre-match hiring costs.[9] In figure 3 we consider this more general, and arguably more realistic case, and plot the response of selected variables to a negative matching efficiency shock for different values of ϕ_V. We see that the choice of ϕ_V matters greatly for determining the magnitude of the unemployment response. Importantly, unemployment already reacts substantially for values of ϕ_V as low as 0.25. Silva and Toledo (2009) and Yashiv (2000) estimate the relative shares of pre-match and post-match costs in total hiring costs. Both studies find that post-match hiring costs account for at least 70 percent of total hiring costs, suggesting that a realistic value for ϕ_V is around 0.3. The same result is confirmed in an estimated New Keynesian model for Sweden by Christiano, Trabandt, and Walentin (2011).

Overall, our analysis shows that empirical models of the business cycle that incorporate unemployment should consider pre-match and post-match hiring costs in an integrated framework. We do this in a companion paper (cf. Furlanetto and Groshenny 2013) in which we estimate a medium-scale version of this model to study the evolution of unemployment during the Great Recession and to quantify the importance of structural factors for unemployment dynamics.

3.2 Nominal Rigidities

Having used the previous subsection to show how the nature of hiring costs affects the propagation of matching shocks, we now restrict our attention to the simple model with standard linear costs for posting vacancies and turn to the role of nominal rigidities. In

[8] γ is set such that total hiring costs in the steady state are equal to one percent of steady state output.
[9] The derivations for the model with a generalized hiring cost function are provided in appendix 3.

figure 4 we plot impulse responses in the baseline model with sticky prices (solid lines) and with flexible prices (dashed lines). The presence of sticky prices affects the sign of the vacancy response. Under sticky prices firms do not increase prices as much as they would prefer in response to a less efficient matching process in the labor market. Therefore, the decrease in output is limited. Given the reduced matching efficiency, firms need to post more vacancies to achieve their hiring target. When prices are flexible, firms can increase prices optimally, so as to keep markups constant. The fall in aggregate demand is more pronounced and firms need a larger contraction in hiring. To achieve this goal, firms cut posted vacancies.

The importance of nominal rigidities for the sign of the vacancy response reminds us of the debate regarding how employment responds to a technology shock in the standard New Keynesian model. The analogy is justified by the fact that a matching efficiency shock can also be seen as a technology shock in the production of new hires. Galí (1999) has linked the sign of the employment response to the presence of nominal rigidities and inertia in monetary policy. When prices are rigid and monetary policy is not overly too aggressive, a positive technology shock lowers employment. Alternatively, when prices are flexible the labor market expands. Figure 4 shows that the same is true for the response of vacancies to a matching efficiency shock. The relationship between the sign of the vacancy response and the degree of nominal rigidity can also be shown analytically in the extreme (but still instructive) case where monetary policy is exogenous (instead of having an interest rate rule) and prices are fixed (not sticky), closely following Galí (1999). The derivation is provided in appendix 2.

Although a quantitative evaluation of the importance of matching efficiency shocks is not this paper's objective, impulse responses in figure 4, particularly the sign of the vacancy response, can provide some insights on the relevance of this shock. In fact, unemployment and vacancies move in the same direction and they are almost perfectly positively correlated (also see figure 2). It is well recognized that in the data unemployment and vacancies are strongly negatively correlated. This simple observation suggests that shocks to the matching efficiency are unlikely to emerge as a main source of business cycle fluctuations in a model where prices are sticky. Nevertheless, these shocks can be seen as shifters of the Beveridge curve with potentially important effects in specific episodes. Recent analysis of the Beveridge curve dynamics through the lenses of DSGE models and time-varying vector autoregressions (VARs) models are provided in Benati and Lubik (2012) and Lubik (2011).

3.3 Policy Implications

Our previous results on the importance of the hiring costs specification and the degree of nominal rigidities have implications for monetary policy that we model as a simple Taylor-type rule. In the model with post-match hiring costs, inflation and output (together with unemployment) are invariant to shocks to the matching efficiency. Therefore, the monetary policy authority does not change the policy rate, even in presence of large fluctuations in the matching efficiency. Instead, when the pre-match hiring cost component is not negligible, the monetary policy authority reacts to the shock by increasing the policy rate to dampen inflationary pressures (despite the decrease in output). This reasoning shows how important it is for central banks to understand the relative role of different disturbances over the business cycle. When negative demand shocks (i.e. shocks that move output and inflation in the same direction) are prevalent, the Taylor-type rule prescribes an expansionary monetary policy. When negative matching efficiency shocks are present, monetary policy is contractionary in our model.

While studying the optimal policy response to matching efficiency shocks is outside the scope of the paper, it is interesting to discuss the implications for the unemployment gap, which is a concept often present in the policy debate. Speeches by Kocherlakota (2010), Bullard (2012), Lacker (2012), and Plosser (2011) allude to the possibility that structural factors in the labor market have been responsible for a large decline in matching efficiency, which in turn has lead to an increase in the natural rate of unemployment. According to these views, the unemployment gap, defined as the difference between actual unemployment and the natural rate, may be low in the aftermath of the Great Recession and expansionary monetary policies may not be appropriate. Our model can be used to evaluate this hypothesis. Following the literature, we define the natural rate as the rate of unemployment that emerges in a model with flexible prices and wages (cf. the dashed lines in figure 4).[10] In keeping with the framework used in the previous section, we see that the natural rate of unemployment reacts more than the actual unemployment rate in response to a negative disturbance.[11] Therefore, a negative matching efficiency shock moves the inflation rate and the unemployment gap in opposite directions, while a contractionary monetary policy simultaneously contributes to lower inflation and to closing the unemployment gap.

In the policy discussion it is often said that monetary policy cannot do much to deal with structural features of the labor market: *"You can't change the carpenter into a nurse easily...monetary policy can't retrain people. Monetary policy can't fix these problems"* (Plosser 2011) or *"I would go back to a single mandate. I think there is an overemphasis on what the Fed can really do about unemployment"* (Bullard 2012) or *"There are many possible sources of mismatch –geography, skills, demography...it is hard to see how the Fed can do much to cure this problem"* (Kocherlakota 2010). On the contrary, according to our model, monetary policy has a role to play in response to a matching efficiency shock because its intermediate targets (inflation and the unemployment gap) are affected by this kind of shock: the model prescribes a contractionary monetary policy response, at least as long as the pre-match component in total hiring costs is not irrelevant.

Note, however, that our results should be interpreted very cautiously. Our prescription is valid only conditional on the presence of matching efficiency shocks while the available empirical evidence seems to agree that these factors have played only a minor role in recent years (cf. Barnichon and Figura 2012; Furlanetto and Groshenny 2013; and Sala, Söderström, and Trigari 2012). If other shocks were responsible for the large increase in unemployment during the Great Recession and for its slow decline in the recovery period (for example negative financial shocks), an expansionary monetary policy may be appropriate. Nevertheless, we believe that our paper elucidates some new theoretical mechanisms that make the policy debate more transparent.

[10] This definition has been advocated also by Kocherlakota (2010).

[11] Interestingly, the matching efficiency shock is the only shock that can generate this pattern (cf. Furlanetto and Groshenny 2013).

4 Our Results in Perspective

Our results presented in the previous section can be related to the debate on the importance of reallocation shocks initiated by Lilien (1982),[12] according to whom these shocks could explain up to 50 percent of unemployment fluctuations in the postwar period. The empirical regularity underlying this result is a positive correlation between the dispersion of employment growth rates across sectors and the unemployment rate. However, Abraham and Katz (1986) show that this positive correlation is consistent not only with reallocation shocks but also with aggregate demand shocks under general conditions. According to Abraham and Katz (1986), data on unemployment and vacancies are more useful to disentangling the importance of reallocation shocks. In fact, they argue that reallocation shocks, unlike aggregate demand shocks, deliver a positive correlation between unemployment and vacancies as reallocation shocks can be seen as shifters of the Beveridge curve along a positively sloped job creation line.[13] Therefore, data on unemployment and vacancies suggest the primacy of aggregate shocks, rather than reallocation shocks. This argument has been used as an identifying assumption in VARs to reevaluate the importance of reallocation shocks. Blanchard and Diamond (1989) conclude that reallocation shocks play a minor role in unemployment fluctuations, at least at business cycle frequencies (for a review of this literature, cf. Gallipoli and Pelloni, 2008).

Our paper contributes to the literature on the relationship between reallocation shocks and the conditional correlation between unemployment and vacancies by highlighting the different role of pre-match and post-match hiring costs and by using a fully specified general equilibrium model, instead of a partial equilibrium model as used in the previous literature. The distinction between pre-match and post-match hiring costs is crucial: while both models imply an outward shift of the Beveridge curve, post-match hiring costs generate a nil conditional correlation between unemployment and vacancies (given

[12] In this paper we follow the seminal contribution by Andolfatto (1996) and interpret the shock to the matching efficiency as a reallocation shock. This seems to be a natural choice in the context of a one-sector model. The same interpretation is given in Justiniano and Michelacci (2011), Furlanetto and Groshenny (2013), and Sala, Söderström, and Trigari (2012). An alternative and promising approach is the use of multisector models that have, however, a less tractable structure (cf. Garin, Pries, and Sims 2011).

[13] The statement makes reference to a partial equilibrium model of the labor market with search and matching frictions (cf. Jackman, Layard, and Pissarides 1989).

that unemployment is invariant to the shock) whereas pre-match hiring costs imply that unemployment and vacancies move in the same direction (see figure 2). In that sense our model qualifies the statement by Abraham and Katz (1986) by showing that the sign of the conditional correlation between unemployment and vacancies depends on the form of the hiring costs. Importantly, the use of a general equilibrium model is essential for our conclusion. In fact, in a model with post-match hiring costs, the shift in the Beveridge curve is accompanied by a general equilibrium effect on job creation that leaves unemployment unaffected by the shock, whereas in the model with pre-match hiring costs the two effects have different magnitudes and unemployment reacts to the shock.

Furthermore, we provide a second contribution (specific to the model with pre-match hiring cost) to the literature on reallocation shocks. As already anticipated, our baseline model with sticky prices and pre-match hiring costs generates a positive conditional correlation between unemployment and vacancies in response to a reallocation shock. In figure 5 we appreciate that the sign of the correlation does not depend on the degree of autocorrelation in the shock process. However, this result is not as general as the previous literature has taken for granted. In fact, it relies on the presence of nominal rigidities. From figure 5, we see that in a flexible price version of our model ($\alpha = 0$), the correlation between unemployment and vacancies depends on the degree of autocorrelation in the shock process. When the shock process is very persistent, we confirm the finding in Abraham and Katz (1986): the matching shock generates a positive conditional correlation between unemployment and vacancies. But for lower degrees of persistence, the correlation between unemployment and vacancies declines and becomes negative for values of ρ_L lower than 0.6. When the shock is i.i.d, the conditional correlation between unemployment and vacancies is -0.52, meaning that the sign of the conditional correlation is in line with the one for the unconditional correlation. In figure 6 we see that the shock generates a negative conditional correlation (blue areas) when persistence is limited and when the degree of nominal rigidity is low.

Other papers have found that reallocation shocks do not necessarily imply a positive correlation between unemployment and vacancies. Hosios (1994) and Justiniano and Michelacci (2011) have shown that in models with endogenous separation unemployment and vacancies can move in opposite directions in response to a reallocation shock.[14] Therefore, data on unemployment and vacancies are inconclusive for identifying reallocation shocks. Our paper shows that reallocation shocks can move unemployment and vacancies in opposite directions even in a model with exogenous separation. However, our distinctive contribution is on how the presence of nominal rigidities whose presence generalizes the validity of the argument in Abraham and Katz (1986).

Finally, our paper contributes to the literature on estimated DSGE models with unemployment for the United States in which different studies reach very different conclusions on the importance of matching efficiency shocks for unemployment fluctuations. Furlanetto and Groshenny (2013) and Sala, Söderström and Trigari (2012) find that they are almost irrelevant. In Lubik (2009), matching efficiency shocks explain 92 percent of unemployment and 38 percent of vacancy fluctuations in a RBC model very similar to our baseline model. Justiniano and Michelacci (2011) also estimate a RBC model for the United States and for several other countries. However, in contrast to Lubik (2009), they find that matching efficiency shocks explain only 11 percent of unemployment fluctuations in the United States.[15] Our model can, at least in part,[16] reconcile all these different results: in Lubik (2009) hiring costs are only pre-match whereas in Justiniano and Michelacci (2011) there is also a post-match component. According to our analysis, the larger the weight of the post-match component is, the lower the importance of matching efficiency shocks should be, in keeping with the results in Lubik (2009) and Justiniano and Michelacci (2011). Krause, Lubik, and López-Salido (2008) estimate a sticky price version of the model in Lubik (2009) where prices are flexible. They find that match-

[14] Hosios (1994) uses a partial equilibrium model with temporary layoffs where the reallocation shock is modeled as a shock to the relative price dispersion across firms. Justiniano and Michelacci (2011) propose a dynamic general equilibrium model with endogenous separation where the source of reallocation is a shock to the matching efficiency, as in our model. Both papers include a shock to the separation rate as a second reallocation shock. Moreover, the two studies emphasize that reallocation shocks, unlike other shocks, move job finding rates and job separation rates in the same direction. Davis and Haltiwanger (1999) and Balakrishan and Michelacci (2011) use this comovement as an identifying assumption in a VAR. In our paper we concentrate on the role of hiring costs and nominal rigidities and we do not model endogenous separation. In a model with endogenous separation the effect of a negative matching efficiency shock on unemployment is likely to be even smaller given that a lower job finding rate is accompanied by a lower separation.

[15] Similar numbers are found for Germany, Norway, and Sweden, but there is evidence of a somewhat more important role for the matching efficiency shock in France and in the United Kingdom.

[16] The two models in Lubik (2009) and Justiniano and Michelacci (2011) are similar but not identical. These differences can also influence the propagation of matching efficiency shocks.

ing efficiency shocks explain 37 percent of unemployment fluctuations. According to our analysis, the model with sticky prices implies a positive conditional correlation between unemployment and vacancies, whereas this is not always the case in a model with flexible prices (it depends on the persistence of the shock that is not reported in Lubik 2009). Therefore, our results can rationalize a more important role for matching efficiency shocks in RBC models. Finally, these shocks are almost irrelevant for output and unemployment fluctuations in estimated models with a dominant post-match component in total hiring costs and some degree of nominal rigidity, like Furlanetto and Groshenny (2013) and Sala, Söderström, and Trigari (2012). These results are fully consistent with the theory discussed in the previous section.

5 Conclusion

Our analysis of the transmission mechanism for shocks to the matching efficiency emphasizes the importance of the form taken by the hiring cost function and the role of nominal rigidities. In the extreme case when hiring costs are only post-match, the shock does not propagate and matching efficiency shocks are irrelevant for business cycle fluctuations. When hiring costs include a pre-match component, the shock propagates and generates a positive conditional correlation between unemployment and vacancies. This result is in keeping with Abraham and Katz (1986), at least insofar as prices are sticky and the shock is persistent. Importantly, a negative shock creates inflationary pressure and lowers the unemployment gap, thus calling for a contractionary monetary policy response.

An interesting avenue for future research is to consider some of the determinants of matching efficiency in isolation. For example, the duration of the unemployment benefit[17] and the search effort of workers and firms can be modeled explicitly in simple extensions of the standard model. These exercises can be seen as a way to purify the matching function's Solow residual, as it has been done for the production function. In this sense, the endogenous search effort can play the same role as endogenous capital utilization does in the production function. We leave these extensions for future research.

[17] The role of extended unemployment benefits in the Great Recession is discussed in a recent paper by Zhang (2013).

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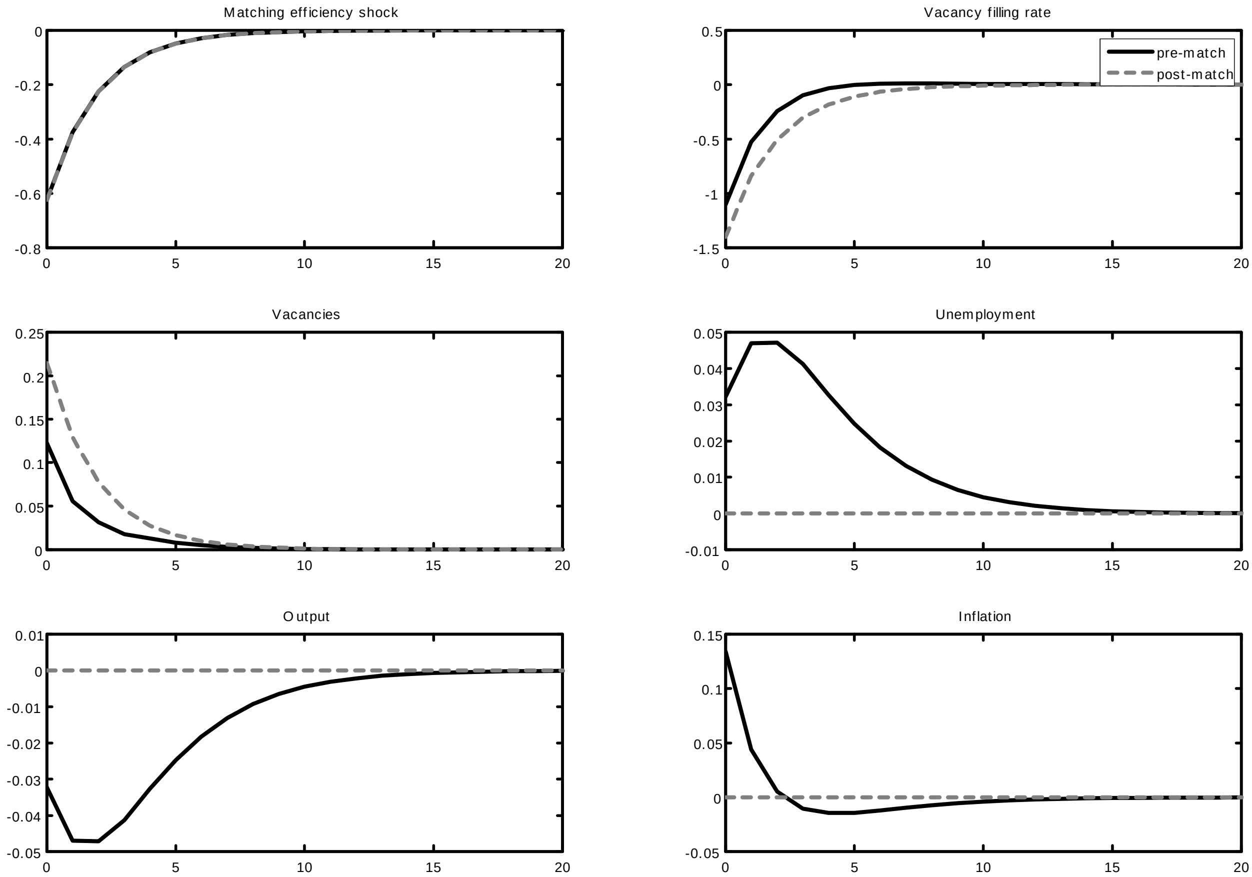

Figure 1: Impulse responses to a negative matching efficiency shock in the model with pre-match hiring costs (solid lines) and in the model with post-match hiring costs (dashed lines). The standard deviation of the shock is set equal to 1 percent. Impulse responses are expressed in percentage points.

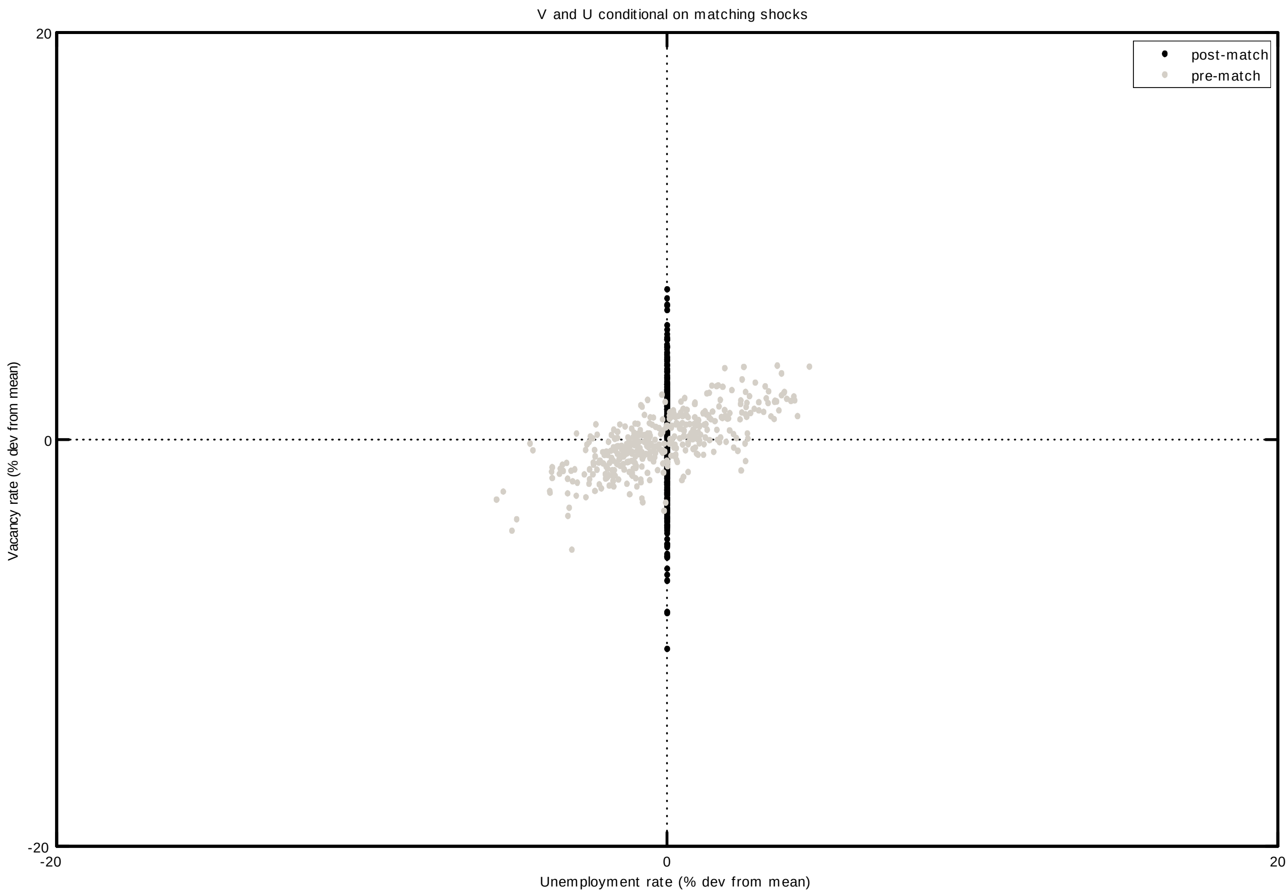

Figure 2: Simulated series for vacancies and unemployment conditional on matching efficiency shocks in the model with post-match hiring costs (black dots) and in the model with pre-match hiring costs (grey dots).

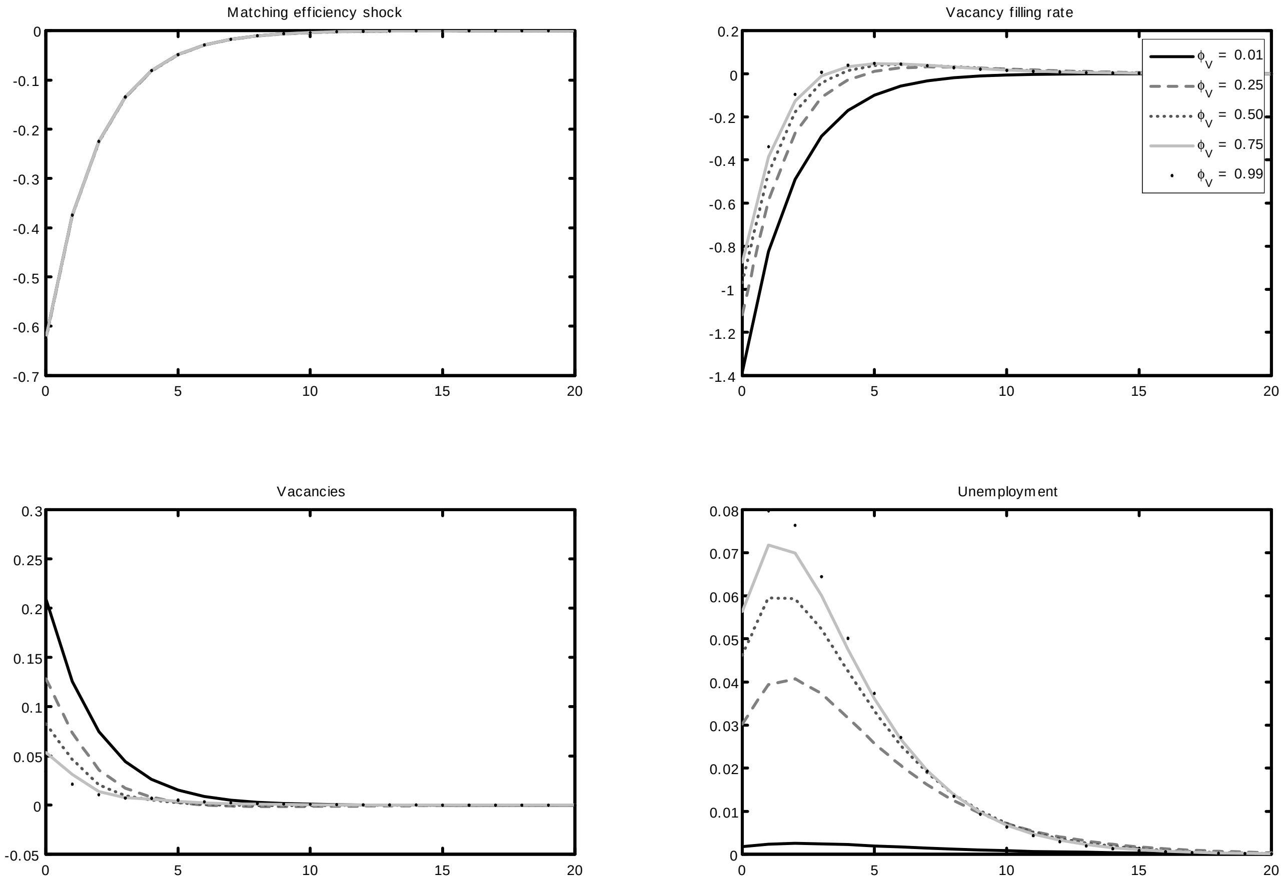

Figure 3: Impulse responses to a negative matching efficiency shock in the baseline model with a generalized hiring cost function. The standard deviation of the shock is set equal to 1 percent. Impulse responses are expressed in percentage points.

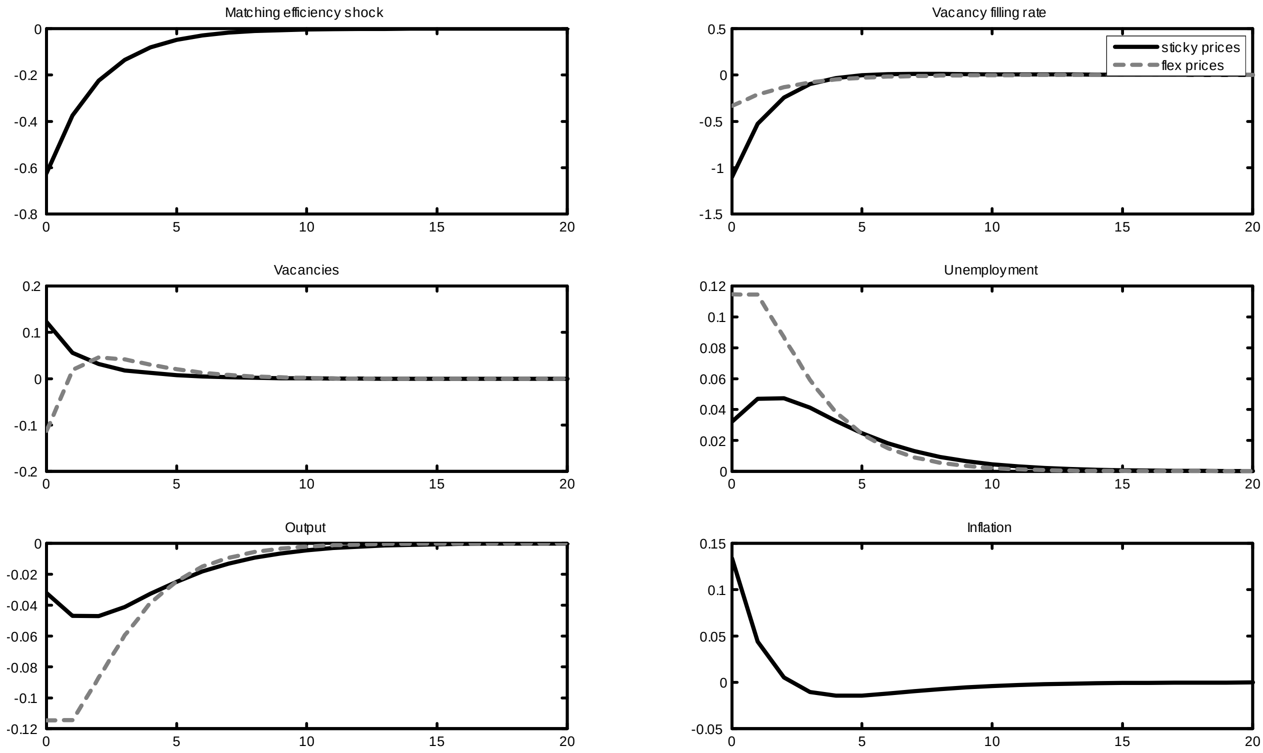

Figure 4: Impulse responses to a negative matching efficiency shock in the model with pre-match hiring costs with sticky prices (bold lines) and with flexible prices (dashed lines). The standard deviation of the shock is set equal to 1 percent. Impulse responses are expressed in percentage points.

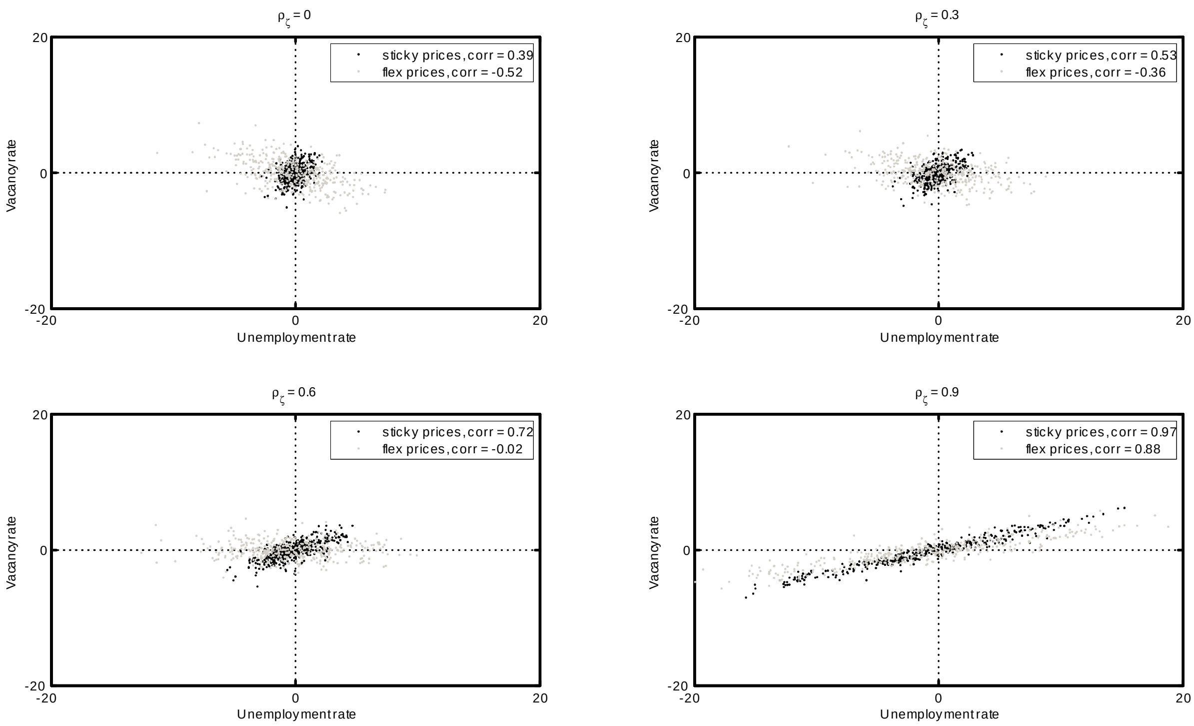

Figure 5: Simulated series for vacancies and unemployment conditional on matching efficiency shocks in the model with pre-match hiring costs with sticky prices (black dots) and with flexible prices (grey dots) for different values of persistence in the shock process.

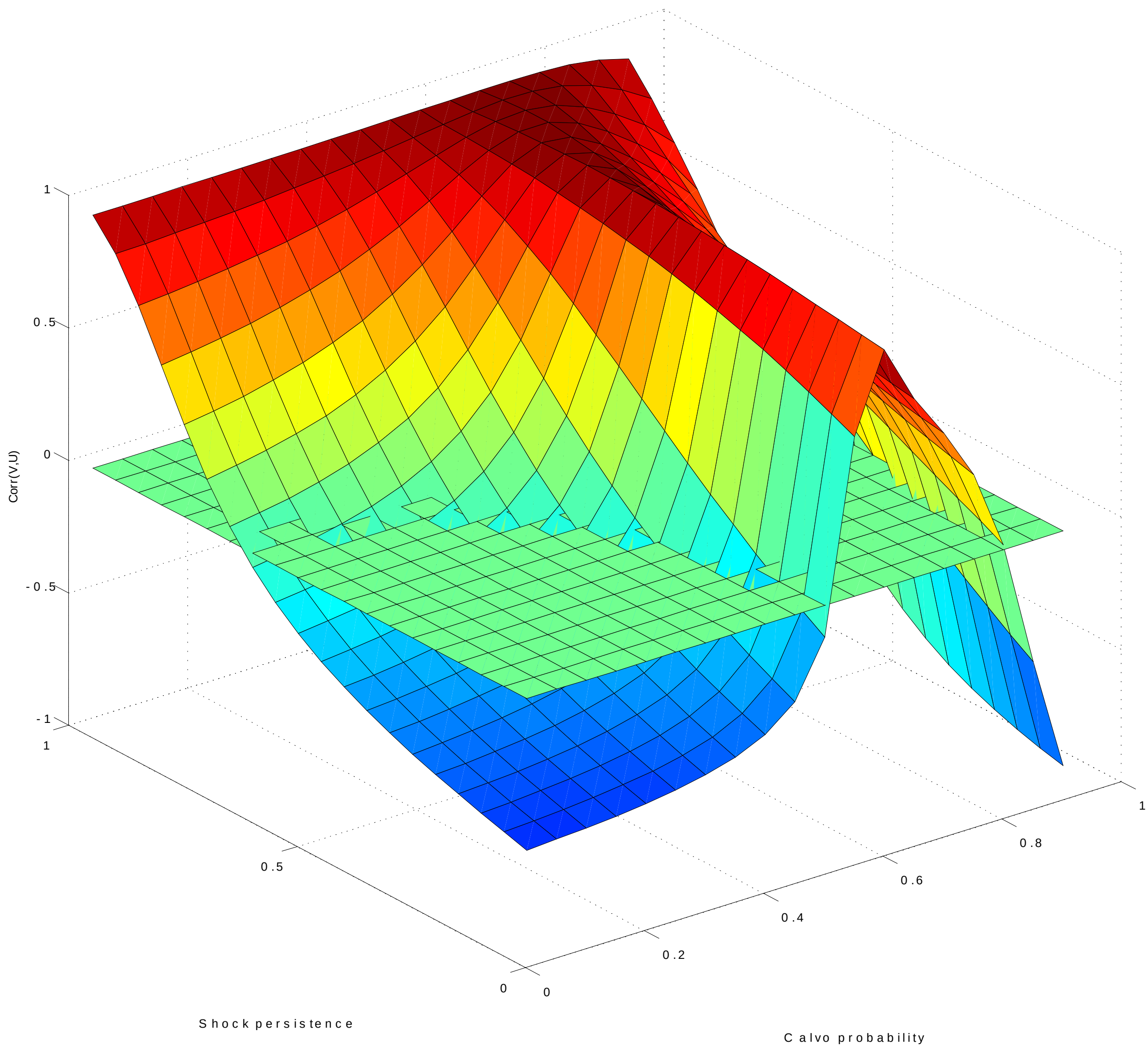

Figure 6: Conditional correlation between unemployment and vacancies (vertical axis) as a function of the degree of shock persistence (horizontal axis on the left) and of the degree of nominal rigidity (horizontal axis on the right).

Table 1: Parametrization

Discount rate	β	0.99
Elasticity of substitution between goods	θ	11
Interest rate smoothing	ρ_r	0.8
Response to inflation in the Taylor rule	ρ_π	1.5
Response to output growth in the Taylor rule	ρ_y	0.5
Calvo coefficient for price rigidity	α	0.75
Probability to fill a vacancy within a quarter	Q	0.7
Separation rate	ρ	0.08
Unemployment rate	U	0.06
Elasticity of the matching function	σ	0.5
Bargaining power	η	0.5
Hiring costs to output ratio	$\frac{H^k}{Y}$	0.01
Matching shock persistence	ρ_L	0.6

Table 2: Log-linearized first-order conditions

Euler equation	$c_t = E_t c_{t+1} - (r_t - E_t \pi_{t+1})$	(T 1)
Production function	$y_t = n_t$	(T 2)
Law of motion for employment	$n_t = (1-\rho)\, n_{t-1} + \rho(q_t + v_t)$	(T 3)
Definition of unemployment	$u_t = -\left(\frac{N}{U}\right) n_t$	(T 4)
Probability of filling a vacancy	$q_t = l_t - \sigma \left(v_t + \left(\frac{(1-\rho)N}{S} \right) n_{t-1} \right)$	(T 5)
Job finding rate	$f_t = l_t + (1-\sigma) \left(v_t + \left(\frac{(1-\rho)N}{S} \right) n_{t-1} \right)$	(T 6)
Definition of the hiring rate	$x_t = q_t + v_t - n_t$	(T 7)
New Keynesian Phillips curve	$\pi_t = \beta E_t \pi_{t+1} + \kappa z_t$	(T 8)
Monetary policy rule	$r_t = \rho_r r_{t-1} + (1-\rho_r) \left(\rho_\pi \frac{1}{4}(p_t - p_{t-4}) + \rho_y \frac{1}{4} (y_t - y_{t-4}) \right)$	(T 9)
Matching efficiency shock	$l_t = \rho_L l_{t-1} + \epsilon_{L,t}$	(T 10)

Table 3: Additional equations for the model with post-match hiring costs

$$x_t = -\left(\frac{W}{\phi_N \rho (1-2\rho) P} \right) (w_t - p_t) + \left(\frac{Z}{\phi_N \rho (1-2\rho)} \right) z_t - \frac{\beta(1-\rho)}{(1-2\rho)} (r_t - E_t \pi_{t+1} - E_t x_{t+1}) \quad \text{(T 11)}$$

$$w_t - p_t = \left(\frac{\eta Z P}{W} \right) z_t + \left(\frac{\eta 2 \phi_N \rho^2 P}{W} \right) x_t - \left(\frac{\eta \beta (1-\rho) \phi_N F \rho P}{W} \right) (r_t - E_t \pi_{t+1} - E_t x_{t+1} - E_t f_{t+1}) \quad \text{(T 12)}$$

$$y_t = \left(1 - \frac{\phi_N \rho^2}{2} \right) c_t + \phi_N \rho^2 x_t + \frac{\phi_N \rho^2}{2} n_t \quad \text{(T 13)}$$

Table 4: Additional equations for the model with pre-match hiring costs

$$q_t = \left(\frac{WQ}{P \phi_V} \right) (w_t - p_t) - \left(\frac{ZQ}{\phi_V} \right) z_t + \beta (1-\rho) (r_t - E_t \pi_{t+1} + E_t q_{t+1}) \quad \text{(T 14)}$$

$$w_t - p_t = \left(\frac{\eta Z P}{W} \right) z_t - \left(\frac{\eta \beta (1-\rho) \phi_V F P}{WQ} \right) (r_t - E_t \pi_{t+1} + E_t q_{t+1} - E_t f_{t+1}) \quad \text{(T 15)}$$

$$y_t = \left(1 - \frac{\phi_V V}{N} \right) c_t + \frac{\phi_V V}{N} v_t \quad \text{(T 16)}$$

Table 5: Additional equations for the model with generalized hiring cost function

$$\left(2\left(\frac{1}{\rho}-1\right)\left(\frac{\phi_V V}{N\Psi}v_t+\frac{(1-\phi_V)M}{N\Psi}m_t-n_t\right)-\frac{1}{\rho}x_t\right)=-\left(\frac{W}{\gamma\Psi^2P}\right)(w_t-p_t)+\left(\frac{Z}{\gamma\Psi^2}\right)z_t$$

$$-\frac{\beta(1-\rho)}{\rho}\left(r_t-E_t\pi_{t+1}+E_tx_{t+1}-2\left(\frac{\phi_V V}{N\Psi}E_tv_{t+1}+\frac{(1-\phi_V)M}{N\Psi}E_tm_{t+1}-E_tn_{t+1}\right)\right) \quad \text{(T 17)}$$

$$w_t-p_t=\left(\frac{\eta ZP}{W}\right)z_t+\left(\frac{\eta 2\gamma P\Psi}{W}\right)\left(\frac{\phi_V V}{N}v_t+\frac{(1-\phi_V)M}{N}m_t-\Psi n_t\right)-\left(\frac{\eta\beta(1-\rho)\gamma FP\Psi}{W\rho}\right)$$

$$\left[\Psi\left(r_t-E_t\pi_{t+1}+E_tn_{t+1}-E_tf_{t+1}\right)-\frac{2\phi_V V}{N}E_tv_{t+1}-\left((1-\phi_V)\rho-\frac{\phi_V V}{N}\right)E_tm_{t+1}\right] \quad \text{(T 18)}$$

$$y_t=\left(1-\frac{\gamma\Psi^2}{2}\right)c_t+\frac{\gamma\Psi}{N}\left(\phi_V Vv_t+(1-\phi_V)Mm_t\right)-\frac{\gamma\Psi^2}{2}n_t \quad \text{(T 19)}$$

where $\Psi=\frac{\phi_V V+(1-\phi_V)M}{N}$.

Appendix 1

The invariance of unemployment to matching efficiency shocks in the model with post-match hiring costs can be obtained analytically by using the list of equilibrium conditions in tables 2 and 3. By substituting T7 into T3, we obtain

$$n_t = n_{t-1} + \frac{\rho}{1-\rho} x_t, \tag{22}$$

and by substituting T.5, T.6 and T.7 into T.12, we have

$$\begin{aligned} w_t - p_t \quad = \quad & \left(\frac{\eta Z P}{W}\right) z_t + \left(\frac{\eta 2 \phi_N \rho^2 P}{W}\right) x_t - \left(\frac{\eta \beta \left(1-\rho\right) \phi_N F \rho P}{W}\right) \\ & \left(r_t - E_t \pi_{t+1} - 2 E_t x_{t+1} - E_t n_{t+1} - \frac{\left(1-\rho\right) N}{1-\left(1-\rho\right) N} n_t\right). \end{aligned} \tag{23}$$

In the system of 9 equilibrium conditions (T1, T2, T4, T8, T9, T11, T13, 22 and 23) with 9 endogenous variables, q_t, f_t and v_t never appear. Therefore, that block of equations is not affected by how the matching function is specified. More specifically, unemployment dynamics are invariant to shocks to the matching efficiency and to different values of the elasticity in the matching function (σ). q_t, f_t and v_t are determined residually by T5, T6 and T7.[18]

[18] This point was brought to our attention by Larry Christiano in a private conversation a few years ago. The same concept is expressed in a note written by Thjis Van Rens (2008) who also refers to a conversation with Larry Christiano. At that time the point was relevant to understanding why unemployment volatility was higher in the model by Gertler and Trigari (2008) than in standard search and matching models and there was no discussion on shocks to the matching efficiency.

Appendix 2

The relationship between the sign of the vacancy response and the degree of nominal rigidity can also be shown analytically in an extreme (but still instructive) case, following Galí (1999) step-by-step. For the sake of the argument, we consider the case of exogenous monetary policy (instead of an interest rate rule) and fixed prices (instead of sticky prices) and we postulate the following equation for money demand in log-linear terms,

$$m_t - p_t = y_t.$$

The assumptions of exogenous money and fixed prices imply that output is fixed in the period. Given fixed output and exogenous technology, employment is also fixed (see T.2). Then, from (T.3) there will be no job creation in response to the shock. Finally, the response of vacancies to matching efficiency shocks can be derived by using the matching function. Being new hires fixed in the period and searchers a predetermined variable, the following is true:

$$v_t = -\frac{1}{(1-\sigma)} l_t.$$

According to our calibration ($\sigma = 0.5$), a one percent decrease in the matching efficiency will be accompanied by a 2 percent increase in vacancies. Therefore, under the extreme case of exogenous money and fixed prices, the vacancy response will be always positive.[19] This is also true in our model although the increase in vacancies is of course lower, given that monetary policy is endogenous and prices are not fixed. Nevertheless, the larger the degree of price rigidity is (and the more inertial monetary policy is), the more positive the vacancy response will be (as the more negative the effect of a positive technology shock on the labor input will be).[20]

[19] Notice that in this special case the distinction between pre-match and post-match hiring costs vanishes: in both cases unemployment is invariant to shocks to the matching efficiency.

[20] Notice that the negative response of vacancies can be even larger in models with additional nominal rigidities (sticky wages), real rigidities (habit persistence) and with capital accumulation (cf. Furlanetto and Groshenny 2013). Here, we prefer to use the simplest set-up to make our point more transparent.

Appendix 3

List of common equilibrium conditions in the symmetric equilibrium:

$$\Lambda_t = (C_t)^{-1}$$
$$\frac{\Lambda_t}{R_t} = \beta E_t \left(\frac{\Lambda_{t+1}}{\Pi_{t+1}}\right)$$
$$Y_t = N_t$$
$$N_t = (1-\rho) N_{t-1} + Q_t V_t$$
$$U_t = 1 - N_t$$
$$S_t = 1 - (1-\rho) N_{t-1}$$
$$Q_t = L_t \left(\frac{V_t}{S_t}\right)^{-\sigma}$$
$$F_t = L_t \left(\frac{V_t}{S_t}\right)^{1-\sigma}$$
$$P_t^* = \frac{\theta}{\theta-1} \frac{E_t \sum_{s=0}^{\infty} (\alpha\beta)^s \Lambda_{t+s} P_{t+s}^{\theta} C_{t+s} Z_{t+s}}{E_t \sum_{s=0}^{\infty} (\alpha\beta)^s \Lambda_{t+s} P_{t+s}^{\theta-1} C_{t+s}}$$
$$P_t = \left[\alpha P_{t-1}^{\theta} + (1-\alpha) P_t^{*1-\theta}\right]^{\frac{1}{1-\theta}}.$$

Conditions specific to the model with post-match hiring costs

$$Y_t = \Gamma_t C_t + \frac{\phi_N}{2} \left[\frac{Q_t V_t}{N_t}\right]^2 N_t$$
$$\frac{W_t}{P_t} = \eta \left[Z_t + \phi_N X_t^2 + \beta (1-\rho) \phi_N E_t \frac{\Lambda_{t+1}}{\Lambda_t} F_{t+1} X_{t+1}\right] + (1-\eta) \frac{b}{P_t}$$
$$\phi_N X_t = Z_t - \frac{W_t}{P_t} + \phi_N X_t^2 + \beta (1-\rho) \phi_N E_t \frac{\Lambda_{t+1}}{\Lambda_t} X_{t+1}.$$

Conditions specific to the model with pre-match hiring costs

$$Y_t = \Gamma_t C_t + \phi_V V_t$$
$$\frac{W_t}{P_t} = \eta \left[Z_t + \beta (1-\rho) E_t \frac{\Lambda_{t+1}}{\Lambda_t} F_{t+1} \frac{\phi_V}{Q_{t+1}}\right] + (1-\eta) \frac{b}{P_t}$$
$$\frac{\phi_V}{Q_t} = Z_t - \frac{W_t}{P_t} + \beta (1-\rho) E_t \frac{\Lambda_{t+1}}{\Lambda_t} \frac{\phi_V}{Q_{t+1}}.$$

Conditions specific to the model with generalized hiring cost function

$$Y_t = \Gamma_t C_t + \frac{\gamma}{2} \left[\frac{\phi_V V_t + (1-\phi_V) M_t}{N_t}\right]^2 N_t$$
$$\frac{W_t}{P_t} = \eta \left[Z_t + \gamma \left[\frac{\phi_V V_t + (1-\phi_V) M_t}{N_t}\right]^2 + \beta (1-\rho) \gamma E_t \frac{\Lambda_{t+1}}{\Lambda_t} F_{t+1} \left[\frac{\phi_V V_{t+1} + (1-\phi_V) M_{t+1}}{N_{t+1}}\right]^2 \frac{N_{t+1}}{M_{t+1}}\right] + (1-\eta) \frac{b}{P_t}$$
$$\gamma \left[\frac{\phi_V V_t + (1-\phi_V) M_t}{N_t}\right]^2 \frac{N_t}{M_t} = Z_t - \frac{W_t}{P_t} + \gamma \left[\frac{\phi_V V_t + (1-\phi_V) M_t}{N_t}\right]^2 + \beta (1-\rho) \gamma E_t \frac{\Lambda_{t+1}}{\Lambda_t} \left[\frac{\phi_V V_{t+1} + (1-\phi_V) M_{t+1}}{N_{t+1}}\right]^2 \frac{N_{t+1}}{M_{t+1}}.$$

Steady state: common conditions

$$N = 1 - U$$
$$Y = N$$
$$S = 1 - (1 - \rho) N$$
$$V = \frac{\rho N}{Q}$$
$$Z = \frac{\theta - 1}{\theta}$$
$$R = \frac{1}{\beta}$$
$$L = Q \left(\frac{V}{S}\right)^{\sigma}$$
$$F = L \left(\frac{V}{S}\right)^{1-\sigma}.$$

Steady state: conditions specific to the model with post-match hiring costs

$$\frac{W}{P} = Z - \phi_N \rho (1 - \rho) (1 - \beta)$$
$$\tau = \frac{\frac{W}{P} - \eta \left(Z + \phi_N \rho^2 + \beta (1-\rho) F \rho \phi_N \right)}{(1-\eta) \frac{W}{P}}$$
$$C = Y - \frac{\phi_N}{2} \rho^2 N.$$

Steady state: conditions specific to the model with pre-match hiring costs

$$\frac{W}{P} = Z - \frac{\phi_V}{Q} (1 - \beta (1 - \rho))$$
$$\tau = \frac{\frac{W}{P} - \eta \left(Z + \beta (1-\rho) F \phi_V Q^{-1} \right)}{(1-\eta) \frac{W}{P}}$$
$$C = Y - \phi_V V.$$

Steady state: conditions specific to the model with generalized hiring cost function

$$\frac{W}{P} = Z - \gamma \rho \left(\frac{\phi_V}{Q} + 1 - \phi_V \right)^2 (1 - \rho) (1 - \beta)$$
$$\tau = \frac{\frac{W}{P} - \eta \left(Z + \gamma \rho^2 \left(\frac{\phi_V}{Q} + 1 - \phi_V \right)^2 + \beta (1-\rho) F \rho \gamma \left(\frac{\phi_V}{Q} + 1 - \phi_V \right)^2 \right)}{(1-\eta) \frac{W}{P}}$$
$$C = Y - \frac{\gamma}{2} \rho^2 \left(\frac{\phi_V}{Q} + 1 - \phi_V \right)^2 N.$$