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Matching efficiency and business cycle fluctuations*

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Abstract

A large decline in the efficiency of the US labor market in matching unemployed workers and vacant jobs has been documented during the Great Recession. We use a simple New Keynesian model with search and matching frictions in the labor market to study the macroeconomic implications of matching efficiency shocks. We show that the propagation of these disturbances and their importance for business cycle fluctuations depend crucially on the form of hiring costs and on the presence of nominal rigidities.

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1 Introduction

Policy-makers have related the slow recovery of unemployment in the aftermath of the Great Recession to a less efficient matching process in the labor market (e.g. Kocherlakota, 2010). This view has received some support from empirical work by Barnichon and Figura (2011b) who find that a large decline in matching efficiency added 1.5 percentage points to the unemployment rate during the Great Recession. In this paper we take a general equilibrium perspective and we investigate the macroeconomic consequences of a decline in matching efficiency through the lens of a simple New Keynesian model with search and matching frictions in the labor market.[1]

Unemployed workers, vacancies and matching efficiency are related through the aggregate matching function (cf. Blanchard and Diamond, 1989 and Petrongolo and Pissarides, 2001). Fluctuations in matching efficiency can be interpreted as variations in the degree of search and matching frictions in the labor market. When matching efficiency is low, for a given number of unemployed workers and vacancies, few new jobs will be created. Barnichon and Figura (2011a) estimate the aggregate matching function for the US over the period 1976-2010 by using data on the job finding rate and labor market tightness. The regression residual, that represents fluctuations in matching efficiency, is relatively stable over time except during the Great Recession, when it reaches historically low levels.[2]

Several factors could explain a lower degree of matching efficiency: skill mismatch (cf. Sahin, Song, Topa and Violante, 2011 and Herz and van Rens, 2011), geographical mismatch, possibly exacerbated by house-locking effects (cf. Nenov, 2011), reduction

[1] The use of search and matching frictions in business cycle models was pionereed by Merz (1995) and Andolfatto (1996) in the Real Business Cycle (RBC) literature. More recently, the same labor market 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.

[2] A substantial decline in matching efficiency during the Great Recession is documented also by Borowczyk-Martins, Jolivet and Postel-Vinay (2011), Elsby, Hobijn and Sahin (2010) and Sedlácek (2011). Notice that the large decline in matching effciency is a feature specific to the Great Recession. According to Barnichon and Figura (2011a), in fact, matching efficiency has increased in previous post-war recessions.

in search intensity by workers because of extended unemployment benefits (cf. Kuang and Valletta, 2010), reduction in firm recruiting intensity (cf. Davis, Faberman and Haltiwanger, 2010), shifts in the composition of the unemployment pool due, for example, to a larger share of long-term unemployment or to a larger share of permanent layoffs (cf. Barnichon and Figura, 2011a).

In the framework of the aggregate matching function, matching efficiency has an interpretation similar to the one of the Solow residual in the context of the production function. Therefore, shocks to the matching efficiency play the same role as technology shocks in the production function and can be interpreted as structural shocks in modern business cycle models.[3] However, while the literature has devoted a substantial effort to studying the properties of technology shocks, little is known of the effects of shocks to the matching efficiency. This paper aims at filling this gap.

Two 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 (2008), we show analytically that the shock does not affect unemployment. When we consider pre-match hiring costs, in the form of linear costs of posting a vacancy as in Pissarides (2000), the shock now 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, in keeping with Abraham and Katz (1986), shocks to the matching efficiency are unlikely to emerge as a main source of business cycle fluctuations. Nevertheless, they can be seen as shifters of the Beveridge curve and they can play an important role in specific episodes.

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 va-

[3] The residual of the matching function can have an endogenous component, as it is the case for the Solow residual in the production function (cf. Basu, Fernald and Kimball, 2006, among others). How to purify the Solow residual of the matching function is an interesting area for future research that is outside the scope of the current paper. Here we concentrate on the transmission mechanism for the exogenous component.

cancy 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 the sign of the employment response to a technology shock.[4]

Shocks to the matching efficiency are already present in the seminal paper by Andolfatto (1996) that introduces search and matching frictions in the standard RBC model. Since then, these shocks have also been considered in Beauchemin and Tasci (2008), Krause, Lubik and Lopez-Salido (2008), Lubik (2009), Cheremukhin and Restrepo-Echevarria (2011), Justiniano and Michelacci (2011) and Mileva (2011). 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 can help reconcile the different results on the importance of matching efficiency shocks found in estimated DSGE models: those disturbances explain 92% of unemployment fluctuations in Lubik (2009), 37% in Krause, Lubik and López-Salido (2008) and only 11% in Justiniano and Michelacci (2011).

As argued in the seminal paper by Andolfatto (1996), shocks to the matching efficiency can be interpreted as reallocation shocks as long as they 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 they 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 statement

[4] In the appendix we show analytically how nominal rigidities can induce a negative response of employment to a positive technology shock and a negative response of vacancies to a positive matching efficiency shock.

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 wholesale goods-producing firms, a continuum of monopolistically competitive retail firms, and monetary and fiscal authorities, which set monetary and fiscal policy respectively. The model is deliberately simple. We ignore features such as capital accumulation, real rigidities (such as habit persistence and investment adjustment costs) and wage rigidities. We include all these features in a companion paper (Furlanetto and Groshenny, 2012), 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. Based on the results from our companion paper, we can safely concentrate only on the features that are critical for the transmission of matching efficiency shocks and ignore the unnecessary complications. Our model is very similar to Kurozumi and Van Zandweghe (2010) in the version with pre-match hiring costs and is a simplified version of Gertler, Sala and Trigari (2008) in the version with post-match hiring costs.

The representative household There is a continuum of identical households of mass one. Each 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.[5] Following Merz (1995), we assume that family members pool their income before allowing the head of the family to choose optimal per capita consumption.

The representative family enters each period $t = 0, 1, 2, ...,$ with B_{t-1} bonds. At the

[5] The model abstracts from the labor force participation decision.

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: $b = \tau W$. During period t, the representative household receives total nominal factor payments $W_t N_t + (1-N_t)\, b$ as well as profits D_t. The family purchases retail goods for consumption purposes.

The family's period t budget constraint is given by

$$P_t C_t + \frac{B_t}{R_t} \leq B_{t-1} + W_t N_t + (1-N_t)\, b - T_t + D_t. \tag{1}$$

where C_t represents a Dixit-Stiglitz aggregator of retail goods 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 $0 < \beta < 1$.

The representative intermediate goods-producing firm Each intermediate goods-producing firm $i \in [0,1]$ enters in period t with a stock of $N_{t-1}(i)$ employees. 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 (cf. Ravenna and Walsh, 2008). 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 $M_t(i) = Q_t V_t(i)$. $V_t(i)$ denotes vacancies posted by firm i in period t and Q_t is the aggregate probability of filling a vacancy defined as $Q_t = \frac{M_t}{V_t}$.

$M_t = \int_0^1 M_t(i)\, di$ 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 $i.i.d.N(0, \sigma_L^2)$.

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 become 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 kinds 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

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

where $X_t(i) = \frac{Q_t V_t(i)}{N_t(i)}$ and represents the hiring rate. The parameter ϕ_N governs the magnitude of the post-match hiring cost. This kind of adjustment cost was used by Gertler and Trigari (2008) because it makes possible the derivation of the wage equation with staggered contracts and helps the model fit the persistence and the volatility of unemployment and vacancies that we observe in the data (Pissarides, 2009). Since then, this feature has become standard in the empirical literature (cf. Christiano, Trabandt and Walentin, 2011, Gertler, Sala and Trigari, 2007, Groshenny, 2011, 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 employment pool.

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 ($H_t^{pre}(i)$) and it represents the cost of posting a vacancy. We use a standard linear specification that reads as follows

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

The parameter ϕ_V 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

$$Y_t(i) = N_t(i) . \tag{8}$$

Each wholesale goods-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 relative price $Z_t(i)$. The firm maximizes

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

Wage setting $W_t(i)$ is determined through bilateral Nash bargaining,

$$W_t(i) = \arg\max \left[\Delta_t(i)^{\eta} J_t(i)^{1-\eta} \right], \tag{9}$$

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

$$\Delta_t(i) = \frac{W_t(i)}{P_t} - \frac{b}{P_t} + \beta E_t \left[(1-\rho)(1-F_{t+1}) \right] \left(\frac{\Lambda_{t+1}}{\Lambda_t} \right) \Delta_{t+1}(i). \tag{10}$$

The firm's surplus in real terms is given by

$$J_t(i) = Z_t(i) - \frac{W_t(i)}{P_t} + \frac{\partial H_t^k(i)}{\partial N_t(i)} + \beta(1-\rho) E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} J_{t+1}(i) \right]. \tag{11}$$

Retail firms There is a continuum of retail goods-producing firms indexed by $j \in [0,1]$ that transform the wholesale good (bought at price Z_t, which is common across wholesale goods-producing firms) into a final good $Y_t^f(j)$ that is sold in a monopolistically competitive market at price $P_t(j)$. 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 its price by maximizing the following discounted sum

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

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

$$\ln\left(\frac{R_t}{R}\right) = \rho_r \ln\left(\frac{R_{t-1}}{R}\right) + (1-\rho_r)\left[\rho_\pi \ln\left(\frac{P_t}{P_{t-4}}\right)^{1/4} + \rho_y \ln\left(\frac{Y_t}{Y_{t-4}}\right)^{1/4}\right], \tag{12}$$

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 is of the form

$$(1-N_t) b = \left(\frac{B_t}{R_t} - B_{t-1} \right) + T_t. \tag{13}$$

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 final goods at $\theta = 11$ implying 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 4 quarters, corresponding to $\alpha = 0.75$.

A second set of parameter values is taken from the literature on search and matching in the labor market. The degree of exogenous separation is set at $\rho = 0.08$, 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) and we set ϕ_V and ϕ_N such that total hiring costs in steady state are equal to one percent of steady state output in both models. The value of unemployment benefits is derived from the steady-state conditions. These choices are common in the literature and avoid 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).

[6] Our objective is not to calibrate parameters to match moments in the model and in the data. That 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.

3 The effects of matching efficiency shocks

In this section 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.

3.1 Hiring costs

In figure 1 we plot impulse responses to a negative shock to the matching efficiency in the model with post-match hiring costs as in Gertler and Trigari (2008) (dashed lines) and in the model with pre-match hiring costs as in Pissarides (2000) (solid lines).

The first result of the paper is that unemployment is invariant to the shock in the model with post-match hiring costs, unlike 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 implies that employment does not react and, in turn, 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 have not the same magnitude and 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 marginal cost and moves output and inflation in different directions. Overall, the shock has a contractionary effect on the economy.

Why hiring costs are so important for the propagation of the shock? In a model with only post-match hiring cost, it is costly for firms to integrate new employees whereas it is costless 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 costless. In the end, even if search frictions are present, they are inactive and the model behaves like a model with employment adjustment costs. In a model with pre-match hiring costs, instead, 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 neutrality result is given by comparing the job creation conditions across the two models:

$$\phi_N X_t \left(1 - X_t\right) + \frac{W_t}{P_t} = Z_t + \beta \left(1 - \rho\right) E_t \frac{\Lambda_{t+1}}{\Lambda_t} \phi_N X_{t+1} \tag{14}$$

$$\frac{\phi_V}{Q_t} + \frac{W_t}{P_t} = Z_t + \beta \left(1 - \rho\right) E_t \frac{\Lambda_{t+1}}{\Lambda_t} \frac{\phi_V}{Q_{t+1}} \tag{15}$$

where (14) refers to the model with post-match hiring costs while (15) relates to the model with pre-match costs. On the left hand side we have the average cost of hiring a worker which has a wage component and a hiring cost component. The hiring cost component is given by $\phi_N X_t \left(1 - X_t\right)$ 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 in the marginal cost of hiring and the firm reacts by reducing hiring.

A third perspective on the neutrality result for the model with post-match hiring costs is obtained analytically by using the list of equilibrium conditions in tables 2 and 3. By substituting T7 into T3, we obtain

$$n_t = n_{t-1} + \frac{\rho}{1-\rho} x_t \tag{16}$$

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

$$\begin{aligned} w_t - p_t &= \left(\frac{\eta Z P}{W}\right) z_t + \left(\frac{\eta 2 \phi_N \rho^2 P}{W}\right) x_t \\ &- \left(\frac{\eta \beta (1-\rho) \phi_N F \rho P}{W}\right) \left(r_t - E_t \pi_{t+1} - E_t n_{t+1} - \frac{(1-\rho) N}{1-(1-\rho) N} n_t\right) \end{aligned} \tag{17}$$

In the system of 9 equilibrium conditions (T1, T2, T4, T8, T9, T11, T13, 16 and 17) 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.[7]

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

$$H_t(i) = \frac{\kappa}{2} \left[\frac{\phi_V V_t(i) + (1-\phi_V) M_t(i)}{N_t(i)}\right]^2 N_t(i)$$

where κ relates to the size of total hiring costs and $0 \leq \phi_V \leq 1$ governs the importance

[7] This point was brought to our attention by Larry Christiano in a private conversation 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 understand why unemployment volatility was higher in the model by Gertler and Trigari (2008) rather than in standard search and matching models and there was no discussion on shocks to the matching efficiency.

of the pre-match component. When ϕ_V is equal to 0 we are back to the model with only post-match hiring costs described above. Instead, when ϕ_V is equal to 1 we obtain a model with quadratic pre-match hiring costs.[8] 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 a lot for the magnitude of the unemployment response. Importantly, unemployment reacts substantially already 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 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 with unemployment should consider pre-match and post-match hiring costs in an integrated framework. This is the way we follow in a companion paper (cf. Furlanetto and Groshenny, 2012) where 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 shown in the previous section 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 of posting vacancies and turn to the role of nominal rigidities. In figure 4 we plot impulse responses in the baseline model with sticky prices (solid lines) and in the same model 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 like 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

[8] The derivations for the model with a generalized hiring cost function are provided in Furlanetto and Groshenny (2012).

post more vacancies to achieve their hiring target. When prices are flexible, firms can increase prices optimally, so as to keep the mark-up constant. The decrease of aggregate demand is more pronounced and firms need a larger contraction in hiring. To achieve this goal, firms cut vacancies.

The importance of nominal rigidities for the sign of the vacancy response reminds us of the debate on the response of employment 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 too aggressive, a positive technology shock lowers employment. Instead, 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 interesting) case in which monetary policy is exogenous (instead of an interest rate rule) and prices are fixed (instead of sticky), closely following Galí (1999). The derivation is provided in the appendix.

Although a quantitative evaluation of the importance of matching efficiency shocks is not the objective of this paper, impulse responses in figure 4, and in particular the sign of the vacancy response, can give 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 (see also figure 2). Instead, it is well known 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.

4 Our results in perspective

Our results from the previous section can be related to the debate on the importance of reallocation shocks initiated by Lilien (1982),[9] according to which these shocks could explain up to 50 percent of unemployment fluctuations in the postwar period. The empirical regularity underlying that 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 disentangle 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.[10] Therefore, according to Abraham and Katz (1986), data on unemployment and vacancies suggest the primacy of aggregate shocks, rather than reallocation shocks. That argument has been used as an identifying assumption in VARs (Vector Autoregressions) 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.[11]

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, rather than a partial equilibrium model as 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

[9] In this paper we follow the seminal contribution by Andolfatto (1996) and we interpret the shock to the matching efficiency as a reallocation shock: if job creation is easier within sectors than across sectors, as seems plausible, reallocation shocks will affect aggregate matching efficiency. This seems to be a natural choice in the context of a one-sector model. An alternative approach that would allow for a more rigorous treatment of reallocation shocks would be the use of multisector models that have, however, a less tractable structure (cf. Garin, Pries and Sims, 2011).

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

[11] A useful review of empirical results in this literature is proposed in Gallipoli and Pelloni (2008).

costs generate a nil conditional correlation between unemployment and vacancies (given 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 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 degree of autocorrelation in the shock process. When the shock process is very persistent, we confirm the finding by Abraham and Katz (1986) and 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_m lower than 0.6. When the shock is iid, the conditional correlation between unemployment and vacancies is -0.52, meaning that the sign of the conditional correlation is in line with one of 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. This point was also raised by Hosios (1994) but in a partial equilibrium model where the reallocation shock was modeled as a shock to the relative price dispersion across firms.[12] In his model, as in the flexible price version of our model with pre-match hiring costs, data on unemployment and vacancies are not conclusive to disentangle aggregate shocks and reallocation shocks. As far as we know, this is the first paper that shows this point when the reallocation shock is given by a shock to the matching efficiency.

Finally, our paper contributes to the literature on DSGE models with unemployment for the US. Lubik (2009), Krause, Lubik and Lopez-Salido (2008), and Justiniano and Michelacci (2011) include shocks to the matching efficiency in their analysis, although none of these papers focuses on the transmission mechanism. Importantly, the three studies reach very different conclusions on the role of matching efficiency shocks. Lubik (2009) finds that they 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 an RBC model for the US and for several other countries. However, in contrast to Lubik (2009), they find that matching efficiency shocks explain only 11 percent of unemployment and 3 percent of vacancy fluctuations in the US.[13] Our model can, at least in part,[14] reconcile these 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 results in Lubik (2009) and Justiniano and Michelacci (2011). Finally, Krause, Lubik and López-Salido (2008) estimate a sticky price version of the model in Lubik (2009) where prices are flexible. They find that matching efficiency shocks explain 37 percent of unemployment and only 1 percent of vacancy 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

[12] Hosios (1994) also considers a second kind of reallocation shock, a shock to the job separation rate. That shock always generates a positively sloped Beveridge curve in his model. This is also the case in our model (results are available upon request).

[13] Similar numbers are found for Germany, Norway and Sweden, whereas there is evidence of a somewhat more important role for the shock in France and in the UK.

[14] The two models are similar but not identical. These differences can also influence the propagation of matching efficiency shocks.

a more important role for matching shocks in RBC models.

5 Conclusion

Our analysis of the transmission mechanism for shocks to the matching efficiency emphasizes the importance of the form of the hiring cost function and of the presence 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, in keeping with Abraham and Katz (1986), at least insofar as prices are sticky and the shock is persistent.

Although the focus of the paper is on the positive implications of shocks to the matching efficiency, our results deliver some policy implications for the natural rate of unemployment as long as we define it as the rate of unemployment that emerges in a model with flexible prices. This definition has been advocated recently by Kocherlakota (2010). Our model implies that under post-match hiring costs the natural rate of unemployment (as unemployment itself) is unaffected from fluctuations in matching efficiency. Under pre-match hiring costs instead, the natural rate of unemployment reacts more than unemployment and the shock is a potentially important driver of the natural rate. The shock behaves like a technology shock calling for an accommodative monetary policy response.

A further avenue for future research is to consider some of the determinants of matching efficiency in isolation. For example, the length of the unemployment benefit duration and the search effort of workers and firms can be modeled explicitly in simple extensions of the standard model. This exercise can be seen as a way to purify the Solow residual of the matching function, as has been done for the production function. In that sense, the role of endogenous search effort can play the same role as endogenous capital utilization in the production function. We leave these extensions for future research.

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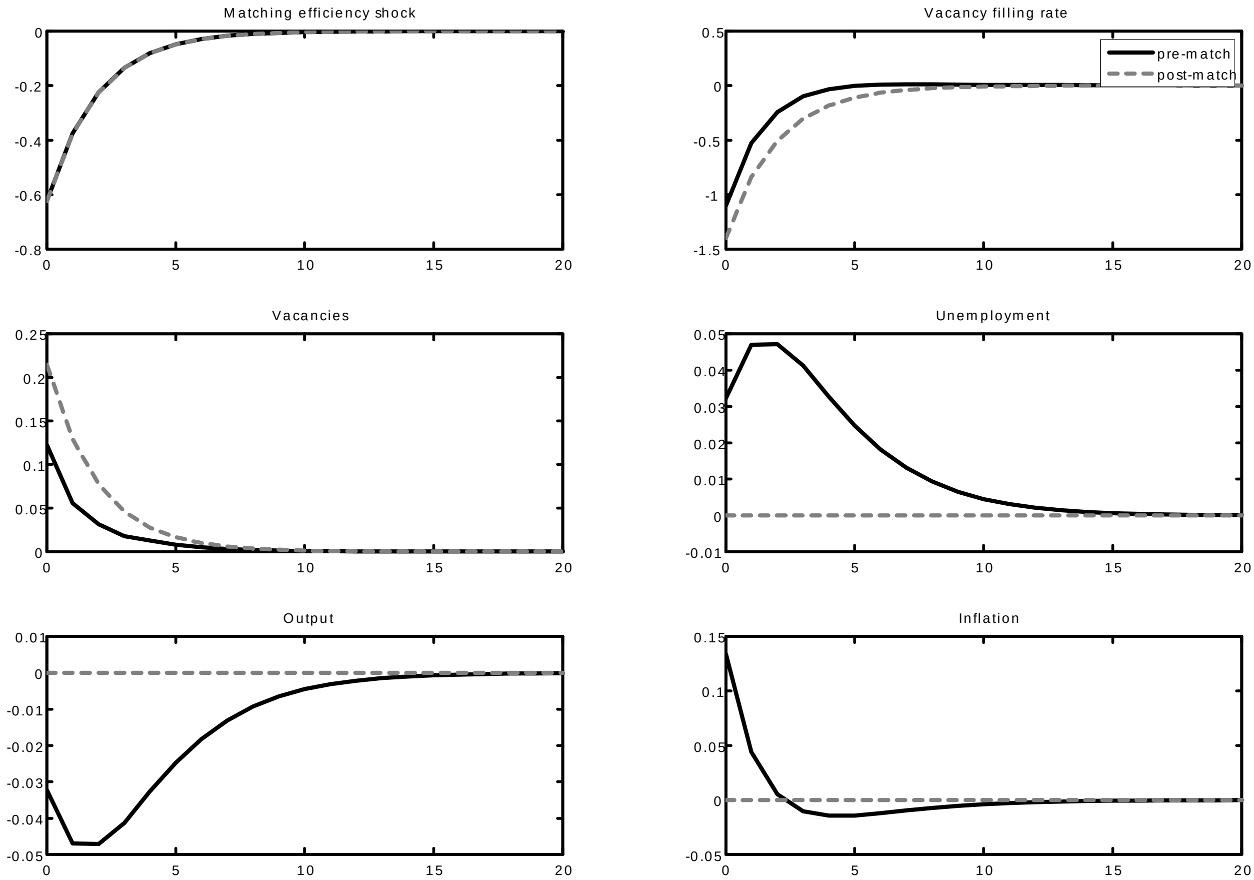

Figure 1: Impulse responses to a negative matching efficiency shock in the model with pre-match hiring costs (solid lines) and in the model with post-match hiring costs (dashed lines). The standard deviation of the shock is set equal to one percent. Impulse responses are expressed in percentage points.

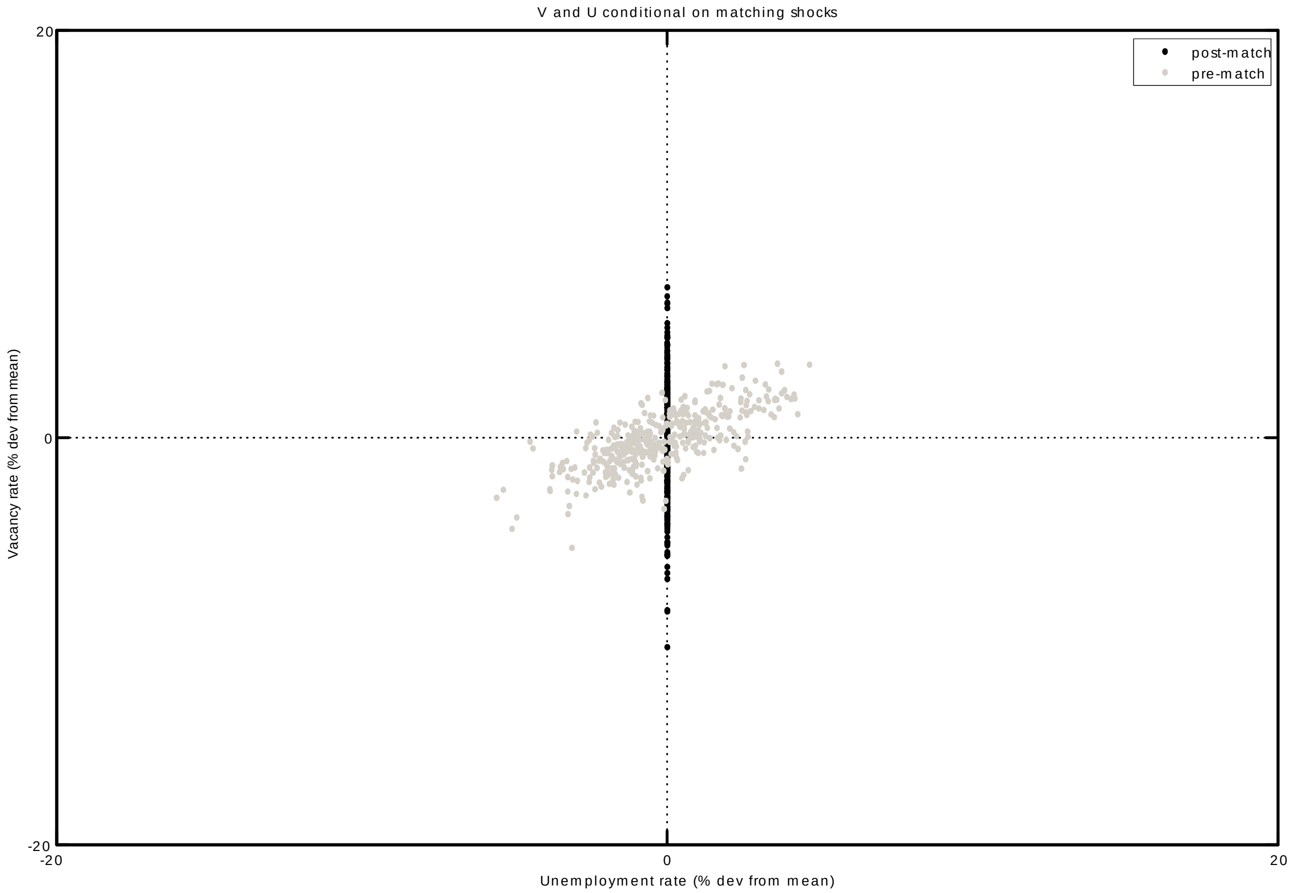

Figure 2: Simulated series for vacancies and unemployment conditional on matching efficiency shocks in the model with post-match hiting costs (black dots) and in the model with pre-match hiring costs (grey dots).

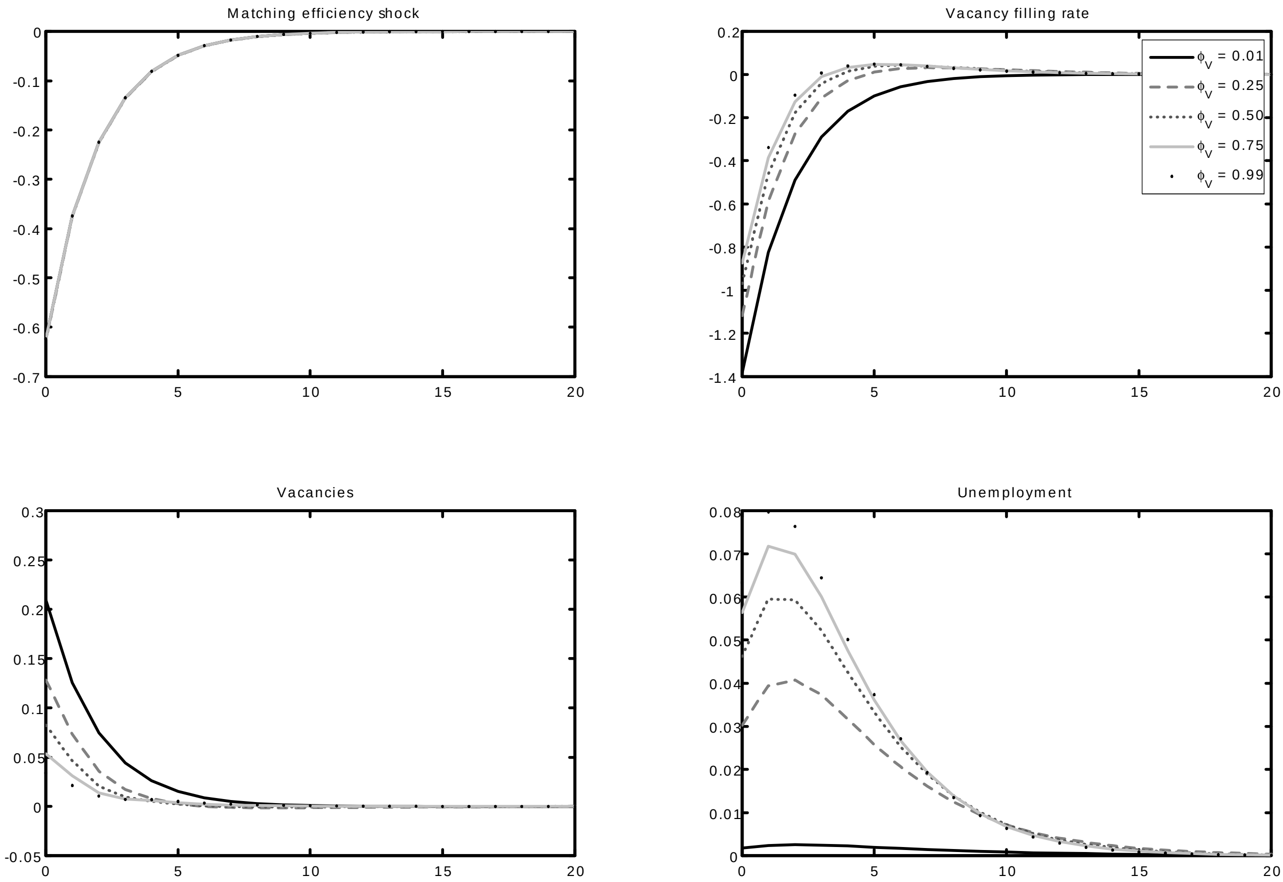

Figure 3: Impulse responses to a negative matching efficiency shock in the baseline model with a generalized hiring cost function. The standard deviation of the shock is set equal to one percent. Impulse responses are expressed in percentage points.

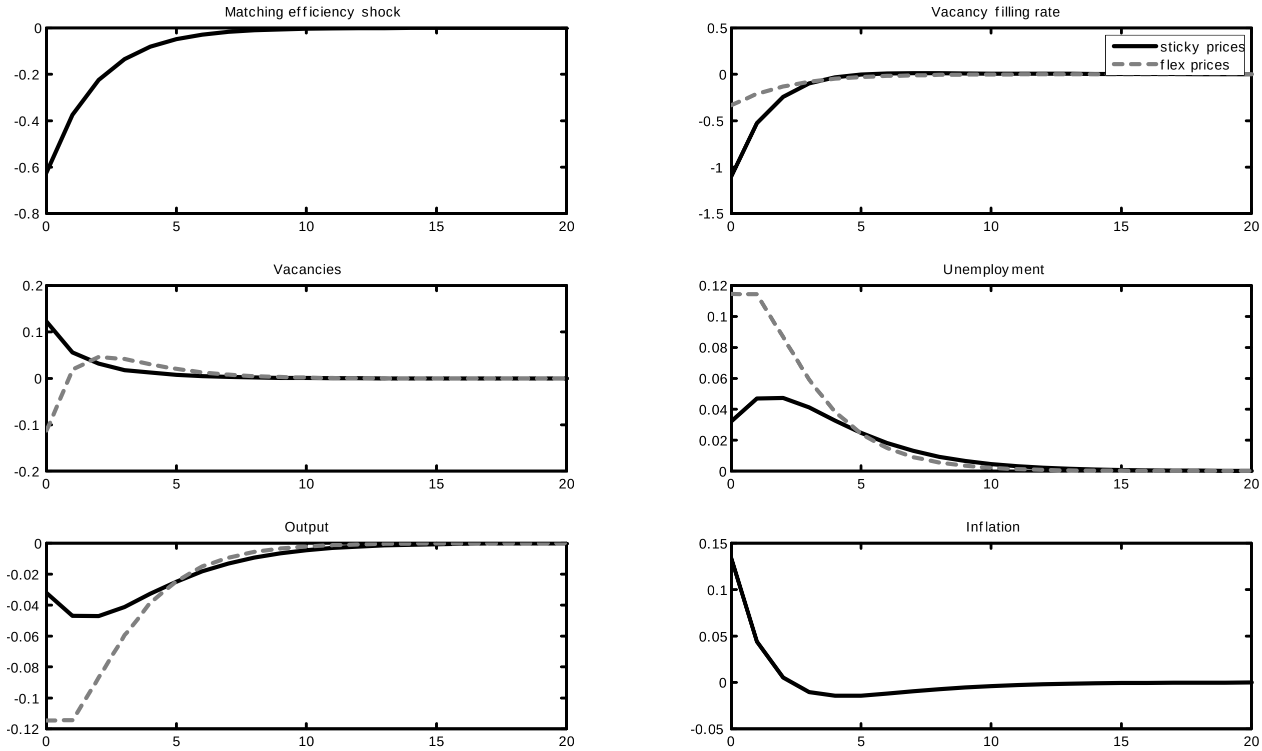

Figure 4: Impulse responses to a negative matching efficiency shock in the model with pre-match hiring costs with sticky prices (bold lines) and with flexible prices (dashed lines). The standard deviation of the shock is set equal to one percent. Impulse responses are expressed in percentage points.

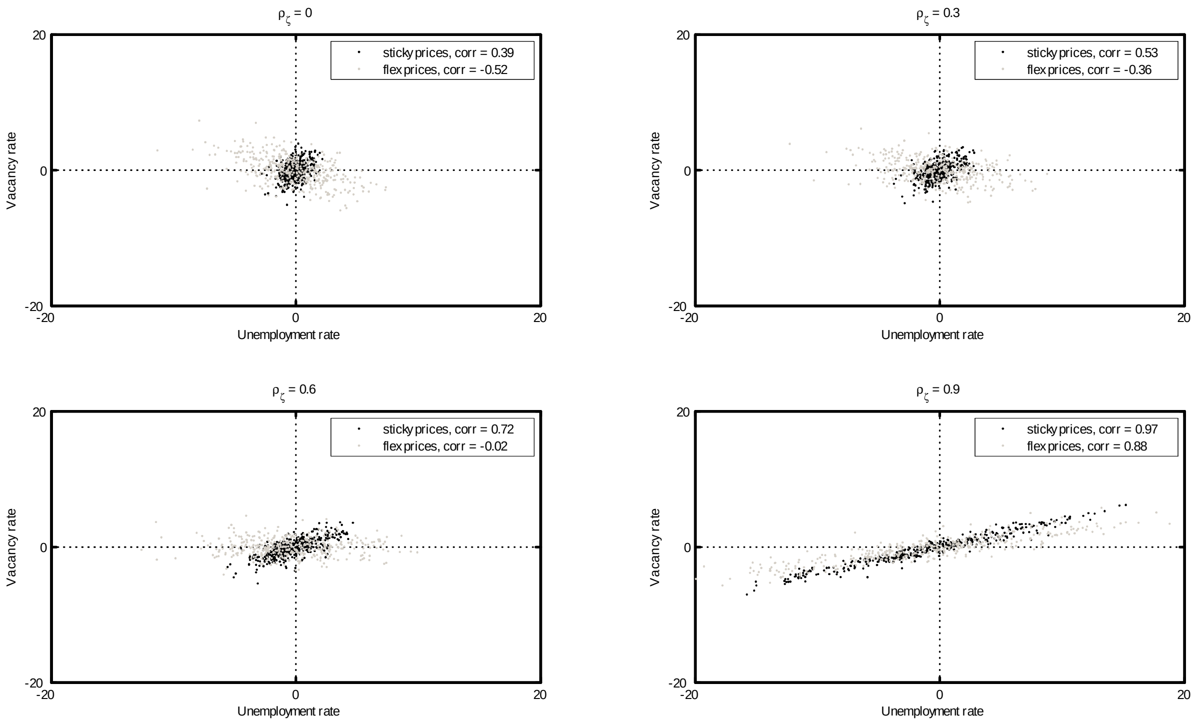

Figure 5: Simulated series for vacancies and unemployment conditional on matching efficiency shocks in the model with pre-match hiring costs with sticky prices (black dots) and with flexible prices (grey dots) for different values of persistence in the shock process.

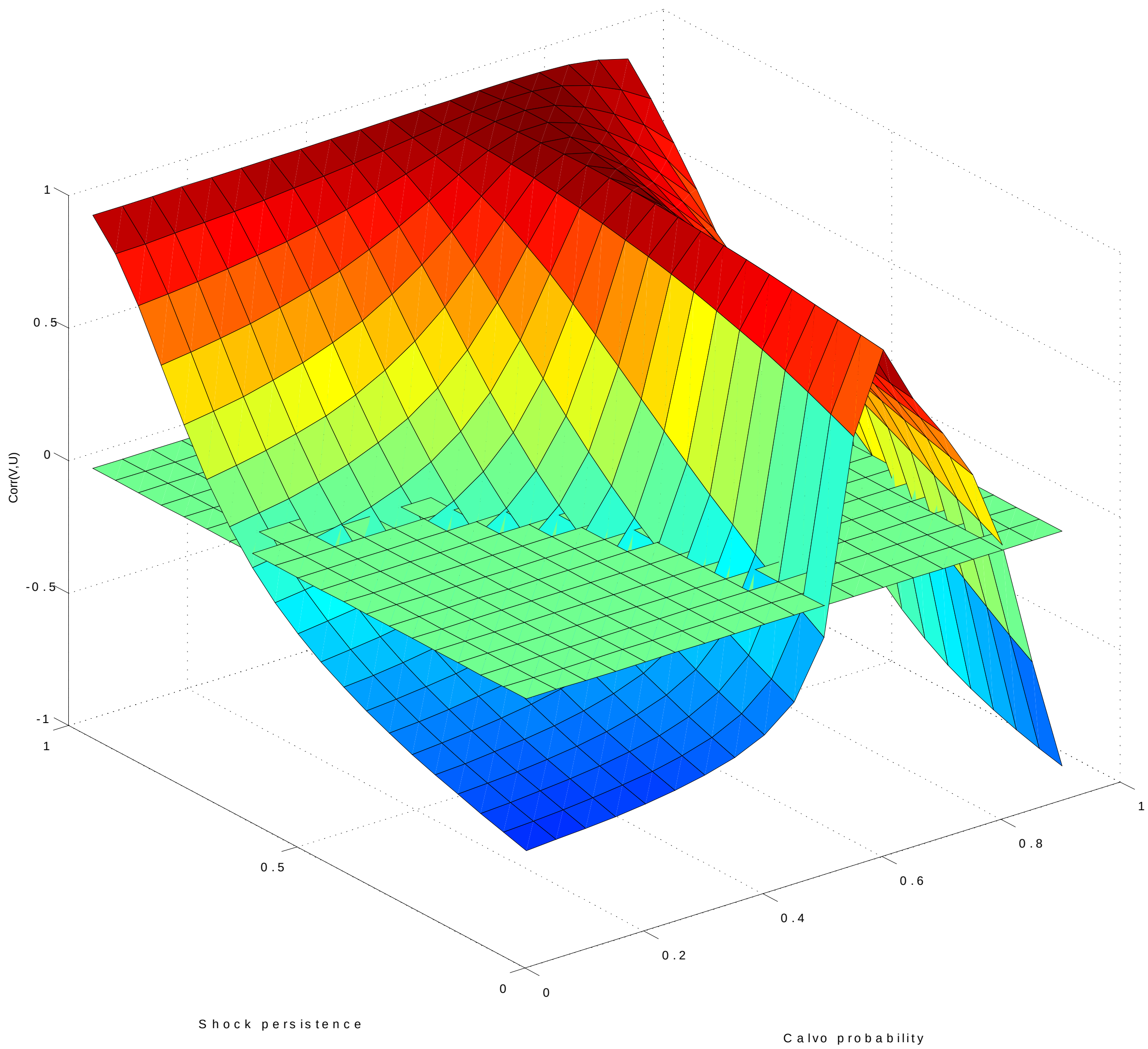

Figure 6: Conditional correlation between unemployment and vacancies (vertical axis) as a function of the degree of shock persistence (horizontal axis on the left) and of the degree of nominal rigidity (horizontal axis on the right).

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	$r_t = \rho_r r_{t-1} + (1-\rho_r)\left(\rho_\pi \pi_t + \rho_y (y_t - y_{t-1})\right)$	(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 cost

$x_t = -\left(\frac{W}{\phi_N \rho (1-2\rho) P}\right)(w_t - p_t) + \left(\frac{Z}{\phi_N \rho (1-2\rho)}\right) z_t - \frac{\beta(1-\rho)}{(1-2\rho)} (r_t - E_t \pi_{t+1} + x_{t+1})$	(T 11)
$w_t - p_t = \left(\frac{\eta Z P}{W}\right) z_t + \left(\frac{\eta 2 \phi_N \rho^2 P}{W}\right) x_t - \left(\frac{\eta \beta (1-\rho) \phi_N F \rho P}{W}\right)(r_t - E_t \pi_{t+1} + E_t x_{t+1} - E_t f_{t+1})$	(T 12)
$y_t = \left(1 - \frac{\phi_N \rho^2}{2}\right) c_t + \phi_N \rho^2 x_t + \frac{\phi_N \rho^2}{2} n_t$	(T 13)

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

$q_t = \left(\frac{WQ}{P\phi_V}\right)(w_t - p_t) - \left(\frac{ZQ}{\phi_V}\right) z_t + \beta(1-\rho)(r_t - E_t \pi_{t+1} + E_t q_{t+1})$	(T 14)
$w_t - p_t = \left(\frac{\eta Z P}{W}\right) z_t - \left(\frac{\eta \beta (1-\rho) \phi_V F P}{WQ}\right)(r_t - E_t \pi_{t+1} + E_t q_{t+1} - E_t f_{t+1})$	(T 15)
$y_t = \left(1 - \frac{\phi_V V}{N}\right) c_t + \frac{\phi_V V}{N} v_t$	(T 16)

Appendix : Analytical derivations following Galí (1999)

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 interesting) case, following step by step Galí (1999). 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 increase in the matching efficiency will be accompanied by a 2 percent decline in vacancies. Therefore, under the extreme case of exogenous money and fixed prices, the vacancy response will be always negative.[15] This is also true in our model although the decline 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 negative the vacancy response will be (as the more negative the effect of a positive technology shock on the labor input will be).[16]

[15] 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.

[16] Notice that the negative response of vacancies can be even larger in models with additional nominal (sticky wages) and real rigidities (habit persistence) and with capital accumulation (cf. Furlanetto and Groshenny, 2012). Here, we prefer to use the simplest set-up to make our point more transparent.

Appendix 2 (not intended for publication)

List of common equilibrium conditions:

$$\Lambda_t = (C_t)^{-1}$$

$$\frac{\Lambda_t}{R_t} = \beta E_t\left(\frac{\Lambda_{t+1}}{\Pi_{t+1}}\right)$$

$$Y_t = N_t$$

$$N_t = (1-\rho)\,N_{t-1} + Q_t V_t$$

$$U_t = 1 - N_t$$

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

$$Q_t = L_t\left(\frac{V_t}{S_t}\right)^{-\sigma}$$

$$F_t = L_t\left(\frac{V_t}{S_t}\right)^{1-\sigma}$$

$$P_t\,(j) = \frac{\theta}{\theta-1}\frac{E_t\sum_{s=0}^{\infty}(\alpha\beta)^s\Lambda_{t+s}P_{t+s}^{\theta}C_{t+s}Z_{t+s}}{E_t\sum_{s=0}^{\infty}(\alpha\beta)^s\Lambda_{t+s}P_{t+s}^{\theta-1}C_{t+s}}$$

Conditions specific to the model with post-match hiring costs

$$Y_t = C_t + \frac{\phi_N}{2}\left[\frac{Q_t V_t}{N_t}\right]^2 N_t$$

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

$$\phi_N X_t = Z_t - \frac{W_t}{P_t} + \phi_N X_t^2 + \beta\,(1-\rho)\,E_t\frac{\Lambda_{t+1}}{\Lambda_t}\phi_N X_{t+1}$$

Conditions specific to the model with pre-match hiring costs

$$Y_t = C_t + \phi_V V_t$$

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

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

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

$$\frac{W}{P} = Z - \phi_N \rho (1 - \rho)(1 - \beta)$$

$$\phi_N = \frac{Z\left(1 - \frac{\eta}{1 - \tau(1-\eta)}\right)}{\rho(1-\rho)(1-\beta) + \left(\frac{\eta}{1-\tau(1-\eta)}\right)(\rho^2 + \beta(1-\rho)F\rho)}$$

$$C = Y - \frac{\phi_N}{2} \rho^2 N$$

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

$$\frac{W}{P} = Z - \frac{\phi_V}{Q} (1 - \beta (1 - \rho))$$

$$\phi_V = \frac{QZ(1 - \tau(1-\eta) - \eta)}{(1 - \beta(1-\rho))(1 - \tau(1-\eta)) + \beta(1-\rho)F\eta}$$

$$C = Y - \phi_V V$$