Mismatch shocks and unemployment during the Great Recession (preliminary)*

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Abstract

We build a DSGE model that features nominal rigidities and search and matching frictions in the labor market. We introduce two non-standard features in the model: a shock to the efficiency of the matching function, and a generalized hiring costs function as in Yashiv (2006). We estimate the model using Bayesian techniques and aggregate data up to 2010:Q3 on eight key macro variables, including unemployment and matching efficiency.We find that matching efficiency shocks are almost irrelevant for unemployment fluctuations in normal times. However, they play a somewhat larger role during the Great Recession when they explain at most one percent of the increase in unemployment.These shocks are dominant drivers of the natural rate of unemployment.

Keywords: Mismatch; Search and matching frictions; DSGE models.

JEL codes: E32, C51, C52

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"The inverse relationship between unemployment and job openings was extremely stable throughout the 2000-01 recession, the subsequent recovery, and on through the early part of this recession. Beginning in June 2008, this stable relationship began to break down, as the unemployment rate rose much faster than could be rationalized by the fall in the job openings rate. Over the past year, the relationship has completely shattered. The job openings rate has risen by about 20 percent between July 2009 and June 2010. Under this scenario, we would expect unemployment to fall because people find it easier to get jobs. However, the unemployment rate actually went up slightly over this period. What does this change in the relationship between job openings and unemployment connote? In a word, mismatch. Firms have jobs, but can't find appropriate workers. The workers want to work, but can't find appropriate jobs. There are many possible sources of mismatch - geography, skills, demography and they are probably all at work. Whatever the source, though, it is hard to see how the Fed can do much to cure this problem. Monetary stimulus has provided conditions so that manufacturing plants want to hire new workers. But the Fed does not have a means to transform construction workers into manufacturing workers." (Narayana Kocherlakota, August 2010)

1 Introduction

The unemployment rate in the US has increased markedly during the Great Recession from a value of 4.5 percent in mid 2006 to a peak of 10% in the fall 2009. Since then it has recovered slowly and almost three years after its peak is still above 8 percent. Some policymakers have related the persistently high level of unemployment to an increase in sectoral and geographical mismatch (e.g. Kocherlakota, 2010). This view has received some support from a series of studies that identify a large decline in matching efficiency during the Great Recession (cf. Barlevy, 2011, Barnichon and Figura, 2011 and Veracierto, 2011). In this paper we take a general equilibrium quantitative perspective and we investigate the macroeconomic consequences of a decline in matching efficiency through the lens of an estimated medium-scale New Keynesian (NK) model with search and matching frictions in the labor market.[1]

In our model, unemployment is the result of both nominal rigidities, that prevent the goods and the labor market to adjust immediately in response to shocks, and search and matching frictions in the labor market, that prevent immediate matches between open vacancies and unemployed workers. Importantly, the magnitude of the search frictions is not constant but fluctuates in response to exogenous shocks to the matching efficiency (henceforth also mismatch shocks). These shocks are like technology shocks to the aggregate matching function and they can be seen as the Solow residual of the matching function. Mismatch shocks have a clear empirical counterpart and they can be measured by using data on new hires, unemployment and vacancies, i.e. the ingredients of the aggregate matching function.[2] The most direct interpretation is that they reflect skill mismatch (cf. Sahin, Song, Topa and Violante, 2011 and Herz and van Rens, 2011) and geographical mismatch, possibly exacerbated by house-locking effects (cf. Nenov, 2011). Alternative and looser interpretations involve reduction 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 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, 2011) and variations in labor supply due to demographic factors or fluctuations in participation (cf. Barnichon and Figura, 2012). We believe that if the structural factors described by Kocherlakota (2010) are important, the shock to the matching efficiency should emerge as a prominent driver of the surge in the unemployment rate during the Great Recession.

Our model combines the standard ingredients of the New Keynesian literature (nominal rigidities in prices and wages, variable capacity utilization and real rigidities in con-

[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 and by Trigari (2009) and Walsh (2005) in the NK literature. A non-exaustive list of estimated DSGE models with unemployment include also Christiano, Trabandt and Walentin (2011), Christoffel, Kuester and Linzert (2009), Faccini, Millard and Zanetti (2011), Galí, Smets and Wouters (2011), Gertler, Sala and Trigari (2008), Groshenny (2009 and 2012) and Krause, Lubik and López Salido (2008).

[2] In that sense the mismatch shock has a structural interpretation, unlike a more dubiously structural labor market shock like the wage mark-up shock that does not have a clear counterpart in the data (cf. Chari, Kehoe and McGrattan, 2009).

sumption and investment) that are necessary to obtain a good fit of the data (cf. Smets and Wouters, 2003 and 2007, and Christiano, Eichenbaum and Evans, 2005) together with search and matching frictions in the labor market that give rise to equilibrium unemployment. In that sense, our model is similar to Gertler, Sala and Trigari, henceforth GST, (2008) who were the first estimating a medium-scale DSGE model with labor market frictions. As already anticipated, we extend the GST set-up by introducing the mismatch shock that we construct prior to estimation by using data on job finding rates, unemployment and vacancies.[3] Moreover, we extend the GST model in a second direction by using a more complete specification for the hiring cost function that combine a pre-match component (cost of posting a vacancy, as in Pissarides, 2000) and a post match component (training cost, as in Gertler and Trigari, 2008) following Yashiv (2006). The use of a generalized hiring cost function is essential for the question at hand: in a companion paper (Furlanetto and Groshenny, 2012a) we show that shocks to the matching efficiency propagate only when hiring costs are pre-match. GST (2007) use only post-match hiring costs and, therefore, unemployment is invariant to fluctuations in matching efficiency in that set-up. The use of a generalized hiring function allow use to estimate the weight of the pre-match component which is essential for the propagation of the mismatch shock.

Using data from 1957 Q1 up to 2010:Q3 on eight key macro variables, our estimated model suggests that shocks to the matching efficiency play a very limited role for business cycle fluctuations. This is due to the fact that the data, despite an agnostic prior, favor a dominant role for the post-match component in the generalized hiring cost function. Moreover, shocks to the matching efficiency generate a positive conditional correlation between unemployment and vacancies in our model whereas this correlation is strongly negative in the data. Nevertheless, mismatch shocks can be important in selected periods and, in fact, these shocks play a larger role in the Great Recession rather than in the Great Moderation period. However, they explain only up to 1 percentage point of the

[3]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 focuses on the role of shocks to the matching effciency during the Great Recession or on the shock's propagation mechanism.

large increase in unemployment during the Great Recession. Interestingly, our general equilibrium model estimated on aggregate data delivers results that are consistent with a series of studies that have measured mismatch unemployment using more disaggregated data (cf. Herz and van Rens, 2012, Sahin, Song, Topa and Violante, 2012, Barnichon and Figura, 2011 and 2012) and find that an upper bound for mismatch unemployment during the Great Recession is around 1.5 percent.

Our results confirm to a limited extent the argument put forward by Kocherlakota (2010) on the importance of structural factors for an outward shift of the empirical Beveridge curve.[4] In fact, mismatch shocks are the only shocks in our model that generate a positive conditional correlation between unemployment and vacancies.[5] However, our model suggests that the bulk of unemployment dynamics during the Great Recession is driven by a series of negative demand shocks. The distinctive feature of the Great Recession is that the magnitude of the shocks hitting the economy is much larger than in normal periods. Hence, the story about the empirical Beveridge curve during the Great Recession that the model tells us is that large shocks have magnified the scale of the typical ellipse depicted by the empirical Beveridge curve, stretching the cloud of points in all directions. The data on vacancies and unemployment between 2009:Q3 and 2010:Q3 are, according to our model, a particular phase in the cycle of the empirical Beveridge curve around a magnified ellipse.

Shocks to the matching efficiency have limited importance for fluctuations in actual unemployment but are a dominant source of variation for the natural rate of unemployment, that we define as the counterfactual rate of unemployment that emerges in a version of the model with flexible prices and wages, constant price mark up and constant bargaining power following the previous literature (cf. Smets and Wouters, 2007 and Sala, Soderstrom and Trigari, 2008). According to this definition, in our model the natural

[4] We define as "the empirical Beveridge curve" the negative relationship that holds in the data between unemployment and vacancies. According to our model, the empirical Beveridge curve is the outcome of the interaction between the model based Beveridge curve (obtained by combining the law of motion for employment and the definitions of the matching function and unemployment) and the job creation condition. The same distinction can be made for the Phillips curve.

[5] As shown by Furlanetto and Groshenny (2012a), a positive conditional correlation emerges when prices are sufficiently rigid and when the shock has high persistence, which is the case in our estimated model.

rate of unemployment has increased during the Great Recession up to 8 per-cent. This is due to the fact that mismatch shocks, unlike all other shocks, propagate much more in the model with no nominal rigidities. All the other shocks, instead, propagate very little as a manifestation of the unemployment volatility puzzle described in Shimer (2005).[6]

Our paper is related to at least two strands of the literature. We contribute to the literature initiated by Lilien (1982) on the importance of reallocation shocks, and more generally of structural factors, as a source of unemployment fluctuations.[7] Abraham and Katz (1986) and Blanchard and Diamond (1989) look at shifts in the sectoral composition of demand and estimate a series of regressions to disentangle the importance of reallocation shocks and aggregate demand shocks. Both papers emphasize the primacy of aggregate demand shocks in producing unemployment fluctuations and find that reallocation shocks are almost irrelevant at business cycle frequencies (although they have some explanatory power at low frequencies). Our contribution to this literature is the use of an estimated dynamic general equilibrium model rather than a reduced form model. A similar exercice with a focus on European countries is conducted in Sala, Söderström and Trigari (2012).

Our paper relates also to a recent literature that studies the output gap derived from estimated New Keynesian models (cf. Sala, Södestrom and Trigari, 2010, and Justiniano, Primiceri and Tambalotti, 2011).[8] Often in this literature, the labor market is modeled only along the intensive margin (hours worked). Notable exceptions are Galí, Smets and Wouters (2011) and Sala, Söderström and Trigari (2008). Galí, Smets and Wouters (2011) estimate a model with unemployment and compute also a measure of the natural rate. However, in that model, unemployment is due only to the presence of sticky wages (there are no search and matching frictions) so that the natural rate fluctuates only in response

[6]Notice that there is no unemployment volatility puzzle in the baseline version of our model. Nominal rigidities are powerful propagators for all shocks but mismatch shocks. For the role of sticky wages cf. Shimer (2005), Hall (2005) and Pissarides (2009), whereas for the role of sticky prices cf. Barnichon (2010) and Furlanetto and Groshenny (2012b).

[7]In that sense 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).

[8]Earlier contributions include Andrés, López-Salido and Nelson (2005), Edge, Kiley and Laforte (2008), Galí, Gertler and López-Salido (2007), Levin, Onatski, Williams and Williams 2005) and Nelson (2005).

to wage mark-up shocks. In our model instead, unemployment is due to both nominal rigidities and search and matching frictions. Moreover, our measure of the natural rate fluctuates in response to all efficient shocks. Sala, Söderstrom and Trigari (2008) provide a similar model-based measure of the natural rate. Their model, however, does not feature matching efficiency shocks, which are prominent drivers of the natural rate, and their sample period does not include the Great Recession.

The paper proceeds as follows: Section 2 briefly describes the model. Section 3 focuses on the econometric strategy and on choice of the observable variables in the estimation. Section 4 presents the results of our estimation exercise. Section 5 considers some policy implications based on a definition of the natural rate of unemployment that is standard in the literature. Finally, section 6 concludes and offers an outline of our ongoing research.

2 The model

The model merges the New Keynesian model with the search and matching model of unemployment, thereby allowing us to study the joint behavior of inflation, unemployment and monetary policy. The model incorporates the standard features introduced by Christiano, Eichenbaum and Evans (2005) to help fit the model to postwar U.S. macro data. Moreover, as in the benchmark quantitative macroeconometric model of Smets and Wouters (2007), fluctuations are driven by seven exogenous stochastic disturbances: a shock to the growth rate of total factor productivity (TFP), an investment-specific technology shock, a risk-premium shock, a price-markup shock, a wage bargaining shock, a government spending shock and a monetary policy shock. GST (2008) have shown that such a model fits the macro data as accurately as the Smets and Wouters (2007) model.

Our model is similar to GST (2008). The most important innovation is that we include an eighth shock, the shock to the matching efficiency, and that we use data on unemployment and matching efficiency in the estimation. Moreover, we extend the sample period until 2010 Q3 to include the Great Recession. Importantly, to make our exercise interesting we use a generalized hiring function as in Yashiv (2000) rather than a post-match hiring cost as in GST (2008). This is because shocks to the matching efficiency do not propagate in a model with post-match hiring cost, as shown in Furlanetto and Groshenny (2012a). There are other small differences compared to GST (2008): 1) as in Smets and Wouters (2007), we have a risk premium shock, rather than a preference shock, to capture disturbances in the financial markets. Given the financial flavor of the Great Recession we believe it is important to have a financial shock in the model. 2) In our model new matches become productive in the quarter and workers that separate for exogenous reasons can search for a job in the same period (in GST (2008) they cannot). This follows the timing proposed originally by Ravenna and Walsh (2008) and used also by Blanchard and Galí (2009) and allows for larger fluctuations in unemployment. 3) We simplify the model in some dimensions that are not essential for our analysis by using quadratic adjustment in prices (cf. Rotemberg, 1982) and in wages (cf. Arsenau and Chugh, 2008) instead of staggered contracts (cf. Calvo, 1983, for prices and Gertler and Trigari, 2008, for wages) and by using a Dixit-Stiglitz aggregator with constant elasticity of substitution across goods rather than a Kimball aggregator with endogenous elasticity.

The model economy consists of a representative household, a continuum of intermediate goods-producing firms, a representative finished goods-producing firm, and monetary and fiscal authorities which set monetary and fiscal policy respectively.

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.[9] Following Merz (1995), we assume that family members pool their income before allowing the head of the family to optimally choose per capita consumption.

The representative family enters each period $t = 0, 1, 2, ...$, with B_{t-1} bonds and $\overline{K}_{t-1}$ units of physical capital. 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 $t+1$.

The representative household owns the stock of physical capital $\overline{K}_t$ which evolves

[9] The model abstracts from the labour force participation decision.

according to

$$\overline{K}_t \leq (1-\delta)\,\overline{K}_{t-1} + \mu_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t, \tag{1}$$

where δ denotes the depreciation rate. The function S captures the presence of adjustment costs in investment, as in Christiano, Eichenbaum and Evans (2005). An investment-specific technology shock μ_t affects the efficiency with which consumption goods are transformed into capital. This shock follows the process

$$\ln(\mu_t) = \rho_\mu \ln(\mu_{t-1}) + \varepsilon_{\mu t}, \tag{2}$$

where $\varepsilon_{\mu t}$ is $i.i.d.N\left(0, \sigma_\mu^2\right)$.

The household chooses the capital utilization rate, u_t, which transforms physical capital into effective capital according to

$$K_t = u_t \overline{K}_{t-1}. \tag{3}$$

Following Christiano, Eichenbaum and Evans (2005), the household faces a cost $a(u_t)$ of adjusting the capacity-utilization rate. The household rents effective capital services to firms at the nominal rate r_t^K.

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_t, financed through lump-sum taxes. Unemployment benefits b_t are proportional to the nominal wage along the steady-state balanced growth path $b_t = \tau W_{ss,t}$.[10] During period t, the representative household receives total nominal factor payments $r_t^K K_t + W_t N_t + (1-N_t)\, b_t$ as well as profits D_t. The family uses these resources to purchase finished goods, for both consumption and investment purposes.

[10] The fact that unemployment benefits grow along the balanced growth path ensures that unemployment remains stationary.

The family's period t budget constraint is given by

$$P_tC_t + P_tI_t + \frac{B_t}{\epsilon_{bt}r_t} \leq B_{t-1} + W_tN_t + (1 - N_t)\,b_t + r_t^K u_t \overline{K}_{t-1} - P_t a(u_t)\,\overline{K}_{t-1} - T_t + D_t. \tag{4}$$

As in Smets and Wouters (2007), the shock ϵ_{bt} drives a wedge between the central bank's instrument rate r_t and the return on assets held by the representative family. As noted by De Graeve, Emiris and Wouters (2009), this disturbance works as an aggregate demand shock and generates a positive comovement between consumption and investment[11]. The risk-premium shock ϵ_{bt} follows the autoregressive process

$$\ln \epsilon_{bt} = \rho_b \ln \epsilon_{bt-1} + \varepsilon_{bt}, \tag{5}$$

where $0 < \rho_b < 1$, and ε_{bt} is $i.i.d.N\left(0, \sigma_b^2\right)$.

The family's lifetime utility is described by

$$E_t \sum_{s=0}^{\infty} \beta^s \ln\left(C_{t+s} - hC_{t+s-1}\right) \tag{6}$$

where $0 < \beta < 1$ and $h > 0$ captures internal habit formation in consumption.

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 job 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

[11] Several shocks, including investment-specific shocks, induce a negative conditional correlation between consumption and investment. This implies that standard DSGE model tend to undestimate the unconditional correlation between consumption and investment which is positive in the data (cf. Furlanetto and Seneca, 2010, for a discussion and a possible solution to this problem).

the aggregate probability of filling a vacancy

$$q_t = \frac{m_t}{V_t}, \tag{7}$$

where $m_t = \int_0^1 m_t(i)\,di$ 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

$$N_t = (1-\rho)\,N_{t-1} + m_t. \tag{8}$$

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

$$m_t = \zeta_t S_t^{\sigma} V_t^{1-\sigma}, \tag{9}$$

where S_t denotes the pool of job seekers in period t

$$S_t = 1 - (1-\rho)\,N_{t-1}. \tag{10}$$

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

$$\ln\zeta_t = \left(1-\rho_\zeta\right)\ln(\zeta) + \rho_\zeta \ln\zeta_{t-1} + \varepsilon_{\zeta t}, \tag{11}$$

where $\varepsilon_{\zeta t}$ is $i.i.d.N\left(0,\sigma_\zeta^2\right)$. Aggregate unemployment is defined by $U_t \equiv 1 - N_t$.

Newly hired workers become immediately productive. Hence, the firm can adjust its output instantaneously through variations in the workforce. However, firms face hiring costs $(H_t(i))$, measured in terms of the finished good and given by a generalized hiring function proposed by Yahiv (2000) that combines a pre-match and a post-match component in the following way

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

where κ relates to the size of total hiring costs and $0 \leq \phi_V \leq 1$ governs the importance of the pre-match component. When ϕ_V is equal to 0 we are back to the model with only post-match hiring costs (cf. GST, 2008). Instead, when ϕ_V is equal to 1 we obtain a model with quadratic pre-match hiring costs (cf. Pissarides, 2000). Interestingly, the empirical literature has so far preferred a specification with post-match hiring costs, that can be interpreted as training costs (cf. GST, 2008, Groshenny, 2009 and 2012). In the context of our model it is essential to include a pre-match component because shocks to the matching efficiency do not propagate with post-match hiring costs only (cf. Furlanetto and Groshenny, 2012a).

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

$$Y_t(i) = A_t^{1-\alpha} K_t(i)^{\alpha} N_t(i)^{1-\alpha}. \tag{12}$$

A_t is an aggregate labor-augmenting technology shock whose growth rate, $z_t \equiv A_t/A_{t-1}$, follows the exogenous stationary stochastic process

$$\ln(z_t) = (1-\rho_z)\ln(z) + \rho_z \ln(z_{t-1}) + \varepsilon_{zt}, \tag{13}$$

where $z > 1$ denotes the steady-state growth rate of the economy and ε_{zt} is $i.i.d.N(0, \sigma_z^2)$.

Intermediate goods substitute imperfectly for one another in the production function of the representative finished goods-producing firm. Hence, each intermediate goods-producing firm $i \in [0,1]$ sells its output $Y_t(i)$ in a monopolistically competitive market, setting $P_t(i)$, the price of its own product, with the commitment of satisfying the demand for good i at that price.

Each intermediate goods-producing firm faces costs of adjusting its nominal price between periods, measured in terms of the finished good and given by

$$\frac{\phi_P}{2}\left[\frac{P_t(i)}{\pi_{t-1}^{\varsigma}\pi^{1-\varsigma}P_{t-1}(i)}-1\right]^2 Y_t. \tag{14}$$

ϕ_P governs the magnitude of the price adjustment cost. $\pi_t = \frac{P_t}{P_{t-1}}$ denotes the gross rate of inflation in period t. $\pi > 1$ denotes the steady-state gross rate of inflation and coincides with the central bank's target. The parameter $0 \leq \varsigma \leq 1$ governs the importance of backward-looking behavior in price setting (cf. Ireland, 2007).

We model nominal wage rigidities as in Arsenau and Chugh (2007). Each firm faces quadratic wage-adjustment costs which are proportional to the size of its workforce and measured in terms of the finished good

$$\frac{\phi_W}{2}\left(\frac{W_t(i)}{z\pi_{t-1}^{\varrho}\pi^{1-\varrho}W_{t-1}(i)}-1\right)^2 N_t(i)\,Y_t, \tag{15}$$

where ϕ_W governs the magnitude of the wage adjustment cost. The parameter $0 \leq \varrho \leq 1$ governs the importance of backward-looking behavior in wage setting. The nominal wage $W_t(i)$ is determined through bargaining between the firm and each worker separately.[12]

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

$$W_t(i) = \arg\max\left[\Delta_t(i)^{\eta_t} J_t(i)^{1-\eta_t}\right]. \tag{16}$$

The worker's surplus, expressed in terms of final consumption goods, is given by

$$\Delta_t(i) = \frac{W_t(i)}{P_t} - \frac{b_t}{P_t} + \beta\chi E_t(1-s_{t+1})\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\Delta_{t+1}(i). \tag{17}$$

[12]Firms take the nominal wage as given when maximizing the discounted value of expected future profits.

where $\chi \equiv 1-\rho$, Λ_t denotes the household's marginal utility of consumption and $s_t = m_t/S_t$ is the aggregate job finding rate. The firm's surplus in real terms is given by

$$\begin{aligned} J_t(i) &= \xi_t(i)(1-\alpha)\frac{Y_t(i)}{N_t(i)} - \frac{W_t(i)}{P_t} \\ &\quad -\frac{\phi_W}{2}\left(\frac{W_t(i)}{z\pi_{t-1}^{\varrho}\pi^{1-\varrho}W_{t-1}(i)} - 1\right)^2 Y_t + \beta\chi E_t\left[\frac{\Lambda_{t+1}}{\Lambda_t}J_{t+1}(i)\right]. \end{aligned} \tag{18}$$

where $\xi_t(i)$ denotes firm i's real marginal cost. The worker's bargaining power η_t evolves exogenously according to

$$\ln \eta_t = \left(1-\rho_\eta\right)\ln \eta + \rho_\eta \ln \eta_{t-1} + \varepsilon_{\eta t}, \tag{19}$$

where $0 < \eta < 1$ and $\varepsilon_{\eta t}$ is $i.i.d.N\left(0, \sigma_\eta^2\right)$.

The representative finished goods-producing firm During each period $t = 0, 1, 2, ...,$ the representative finished good-producing firm uses $Y_t(i)$ units of each intermediate good $i \in [0,1]$, purchased at the nominal price $P_t(i)$, to produce Y_t units of the finished good according to the constant-returns-to-scale technology described by

$$\left[\int_0^1 Y_t(i)^{(\theta_t-1)/\theta_t}\, di\right]^{\theta_t/(\theta_t-1)} \geq Y_t, \tag{20}$$

where θ_t translates into a random shock to the price markup over marginal cost. This markup shock follows the autoregressive process

$$\ln(\theta_t) = (1-\rho_\theta)\ln(\theta) + \rho_\theta \ln(\theta_{t-1}) + \varepsilon_{\theta t}, \tag{21}$$

where $0 < \rho_\theta < 1$, $\theta > 1$, and $\varepsilon_{\theta t}$ is $i.i.d.N\left(0, \sigma_\theta^2\right)$.

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

$$\ln\left(\frac{r_t}{r}\right) = \rho_r \ln\left(\frac{r_{t-1}}{r}\right) + (1-\rho_r)\left[\rho_\pi \ln\left(\frac{\pi_t}{\pi}\right) + \rho_y \ln\left(\frac{Y_t/Y_{t-1}}{z}\right)\right] + \ln \epsilon_{mpt}, \tag{22}$$

The degree of interest-rate smoothing ρ_r and the reaction coefficients ρ_π and ρ_y are all positive. The monetary policy shock ϵ_{mpt} follows an AR(1) process

$$\ln \epsilon_{mpt} = \rho_{mp} \ln \epsilon_{mpt-1} + \varepsilon_{mpt},$$

with $0 \leq \rho_{mp} < 1$ and $\varepsilon_{mpt} \sim i.i.d.N\left(0, \sigma^2_{mp}\right)$.

The government budget constraint is of the form

$$P_t G_t + (1 - N_t)\, b_t = \left(\frac{B_t}{r^B_t} - B_{t-1}\right) + T_t, \tag{23}$$

where T_t denotes total nominal lump-sum transfers. Public spending is an exogenous time-varying fraction of GDP

$$G_t = \left(1 - \frac{1}{\epsilon_{gt}}\right) Y_t, \tag{24}$$

where ϵ_{gt} evolves according to

$$\ln \epsilon_{gt} = \left(1 - \rho_g\right) \ln \epsilon_g + \rho_g \ln \epsilon_{gt-1} + \varepsilon_{gt}, \tag{25}$$

with $\varepsilon_{gt} \sim i.i.d.N\left(0, \sigma^2_g\right)$.

Model solution Real output, consumption, investment, capital and wages share the common stochastic trend induced by the unit root process for neutral technological progress. In the absence of shocks, the economy converges to a steady-state growth path in which all stationary variables are constant. We first rewrite the model in terms of stationary variables, and then log-linearize the transformed economy around its deterministic steady state. The approximate model can then be solved using standard methods. We choose to estimate our model with data until 2010:Q3 and therefore we include the Great Recession in our sample period. We are aware that the use of a linearized model in a period where shocks are large and the zero-lower bound is binding can be problematic.

On the other hand, however, we see the benefit of including four years of data with rich dynamics. Moreover, in a recent paper Stock and Watson (2012) show that during the Great Recession the economy responded in an historically predictable way to shocks that were significantly larger than the ones previously experienced. According to this result, the use of a linearized model can be less problematic than what was previously thought.

3 The econometric strategy

Calibrated parameters Due to identification problems, we calibrate fourteen parameters. Table 1 reports the calibration. The quarterly depreciation rate is set equal to 0.025. The capital share of output is calibrated at 0.33. The elasticity of substitution between intermediate goods is set equal to 6, implying a steady-state markup of 20 percent as in Rotemberg and Woodford (1995). The vacancy-filling rate is set equal to 0.70. This is just a normalization. The steady-state government spending/output ratio is set equal to 0.20. The steady-state values of output growth, inflation, the interest rate and the unemployment rate are set equal to their respective sample average over the period 1957Q1-2010Q3. The value for the elasticity of the matching function with respect to unemployment is based on Blanchard and Diamond (1989). The calibration of the job destruction rate is based on Yashiv (2006). The calibration of the replacement rate is a conservative value based on Shimer (2005) and Yashiv (2006). Based on results from preliminary estimation rounds we set the degree of indexation to past inflation equal to zero and the hiring cost/output ratio equal to 0.3 percent. Table 2 reports the parameters whose values are derived from the steady-state conditions.

Bayesian estimation We estimate the remaining 26 parameters using Bayesian techniques. The estimation uses quarterly U.S. data on eight key macro variables. The model thus includes as many shocks as observables.[13] The estimation period is 1957:Q1 - 2010:Q3. The first seven observable variables are: the growth rate of real output per

[13] Prior to estimation, we normalize two disturbances, the price-markup shock $\widehat{\theta}_t$ and the wage-markup shock $\widehat{\eta}_t$, so that they enter with a unit coefficient in the model's equations. Such procedure facilitates the identification of the shocks' standard deviations.

capita, the growth rate of real consumption per capita, the growth rate of real investment per capita, the growth rate of real wages, the inflation rate, the short-term nominal interest rate and the unemployment rate. The appendix describes the data in detail.

Prior distributions are standard. We use the Random-Walk Metropolis-Hasting algorithm to generate 250,000 draws from the posterior distribution. The algorithm is tuned to achieve an acceptance ratio between 25 and 30 percent. We discard the first 125,000 draws. Tables 3 and 4 summarize the priors and the posteriors.

The choice of the 8th observable Given that we introduce a new shock in the model (the mismatch shock), we have to use an 8th observable variable to identify it. This choice happens to be crucial. A first obvious choice is to use the series for vacancies put together by Barnichon (2010). Interestingly, by combining few log-linear equilibrium conditions, it is possible to derive an expression for the mismatch shock series that depends only on the observable variables

$$\hat{\zeta}_t = -\left(\frac{U}{\rho(1-U)}\right)\hat{U}_t + (1-\rho)\,U\left(\frac{1}{\rho(1-U)} - \frac{\sigma}{\rho+(1-\rho)\,U}\right)\hat{U}_{t-1} - (1-\sigma)\,\hat{V}_t$$

Given that in our model the separation rate (ρ), the elasticity of the matching function (σ) and rate of unemployment in steady state (U) are calibrated, the use of data on unemployment and vacancies uniquely identifies a series for matching efficiency shocks prior to estimation. Calibrated values for the steady state quarterly separation rate range in literature from 0.05 in Krause, Lubik and Lopez-Salido (2008) to 0.15 in Andolfatto (1996). We set our baseline value for ρ at 0.085 in keeping with most of the literature (cf. Yashiv, 2006) and for σ at 0.4, in keeping with Blanchard and Diamond (1989) and at the lower end of the range of plausible values suggested by Petrongolo and Pissarides, 2001. Importantly, we see from figure 1 the choice of σ and ρ has dramatic implications for the behavior of the matching efficiency series. When we set the parameters at their baseline values, we see that the matching efficiency series is very volatile, with a positive trend since the beginning of the 80s. Most importantly, in that case we obtain positive mismatch shocks during the Great Recession.[14] A reasonable calibration delivers a model based series for matching efficiency that is in contrast with any reduced form estimate of matching efficiency during the Great Recession. In fact, Barlevy (2011), Barnichon and Figura (2011) and Veracierto (2011) estimate a large deterioration of matching efficiency in that period. Furthermore, Sahin, Song, Topa and Violante (2012) construct a mismatch index that increases sharply during the Great Recession. Moving σ to higher values changes somewhat the picture but even for values at the upper end of the range suggested by Petrongolo and Pissarides (2001), like σ equal to 0.7 (as in Barnichon and Figura, 2011), we are able to identify only a limited decline in matching efficiency during the Great Recession. Importantly, according to that series matching efficiency would be above its steady state level at the of the Great Recession rather than at historically low level as suggested by the other studies. We can find a sharp decline in matching effciency only when we combine σ equal to 0.7 with a very low value for the separation rate (ρ equal to 0.035). The message from figure 1 is that the use of data on unemployment and vacancies is not sufficient to obtain a plausible and robust estimate for the mismatch shock series.

Therefore, we adopt a different strategy that delivers results that are both more empirically plausible and less dependent on the calibration of ρ and σ. The crucial ingredient for this strategy to work is the use of data on the job finding rate together with data on unemployment and vacancies. In a first step we use data on these three series and, for given values of σ and ρ, we obtain a series for matching efficiency. In a second step, we use the resulting estimate for matching efficiency as an observable variable in the estimation of the DSGE model.

Once again, by combining few log-linear equilibrium conditions it is possible to derive an expression for the mismatch shock series that depends only on the observable variables and on the calibrated values for σ, ρ, and U:

$$\hat{\zeta}_t = \hat{s}_t - (1-\sigma)\left(\hat{V}_t - \hat{U}_t\right) - \frac{(1-\sigma)\,U\,(1-\rho)}{1-(1-\rho)\,(1-U)}\hat{U}_{t-1} - (1-\sigma)\,\hat{U}_t$$

[14] We found this result in a previous version of this paper when we used dat on unemployment and vacancies with σ equal to 0.4 and ρ equal to 0.085. We thank Larry Christiano for interesting discussions on this issue.

The use of data on the job finding rate (s_t) put more discipline in the exercise and makes our exercise more similar to Barnichon and Figura (2011) who estimate matching efficiency by regressing the job finding rate on labor market tightness (i.e. the ratio of vacancies over unemployment). Notice however, that here we are using a series of equilibrium conditions and not only the matching function equation to identify the shock. In that sense our exercise has a general equilibrium flavor that is a qualifying feature of this paper. In figure 2 we plot our new measure of matching efficiency with σ equal to 0.4 and ρ equal to 0.085 as baseline case. The series looks more plausible (at least according to the available empirical evidence) and less dependent on the calibrated parameters than the one obtained using data on unemployment and vacancies only. Now we identify a large drop in matching effciency during the Great Recession when it reaches unprecedented low levels. The cyclical properties of the series look very similar to the estimated series in Barnichon and Figura (2011) although we tend to find a larger decline in the Great Recession than what they find. An important reason for this difference, besides the general equilibrium aspect of our exercise, is that our timing assumption a la Ravenna and Walsh (2008) implies that searchers, and not unemployment, are combined with vacancies in the matching function. We plan to investigate this issues further in our research agenda but we are confident that this strategy delivers a reasonable and empirically well grounded input for our estimation exercise.

4 The role of mismatch shocks during the Great Recession

In table 3 and 4 we report the outcome of our estimation exercise. Most estimates are in line with the previous literature and seem rather reasonable. The distinctive feature of our model is the use of a generalized hiring function and, therefore, the estimate of the parameter ϕ_V is particularly interesting. Although we put an agnostic prior centered around 0.5, the data push clearly in favour of a large post-match component. In fact, ϕ_V is estimated at 0.02 at the posterior mode. Christiano, Trabandt and Walentin (2011) find a similar result in their estimated model for Sweden.[15] This result has strong implications for the propagation of mismatch shocks: as shown in Furlanetto and Groshenny (2012a), the larger the post-match component is, the lower is the effect of the shock on output and unemployment. This is confirmed in the impulse responses in figure 6 where we see that the response of the unemployment rate is very limited and delayed. The shock has of course a rather large effect on vacancies given that posting vacancies is almost costless in the model. This is confirmed in the variance decomposition in table 5 where we see that vacancies is the only variable whose dynamics are driven by the mismatch shock. Notice that the shock behaves like a supply shocks driving output and inflation in opposite directions.[16] Given the prevalence of the post-match component, mismatch shocks are almost irrelevant for business cycle fluctuations over our sample period. The relevant sources of output fluctuations in the model are neutral technology shocks, investment specific technology shocks and risk premium shocks.[17] Finally, wage bargaining shocks are almost irrelevant for output fluctuations. This result was already present in GST (2008) but, as far as we know, it has not been commented in the literature. It seems that the use of labor market variables in the estimation absorb the explanatory power of this shock that is instead important in the standard NK model where the labor market is modeled only in terms of total hours worked. Chari, Kehoe and McGrattan (2009) have criticized the NK model for its reliance on a dubiously structural shock as the wage bargaining (or wage mark-up) shock. Here we show that this criticism does not apply once the labor market is modeled in greater detail.

Notice that the limited importance of mismatch shocks in general does not rule out a relevant role in particular episodes. In particular, mismatch shocks can be active in periods when unemployment and vacancies move in the same direction. As it can be seen in figure 7, the matching efficiency shock is the only shock that generates a positive conditional correlation between unemployment and vacancies. In our companion paper

[15] 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 a dominant role for the post-match component.

[16] For a discussion on the propagation of mismatch shocks, cf. Furlanetto and Groshenny, 2012a.

[17] Our results are consistent with Justiniano, Primiceri and Tambalotti (2010) and GST (2008) once we take into account that the risk premium shock, proposed by Smets and Wouters (2007), limits somewhat the importance of the investment-specific shock. This fact confirms the financial friction interpretation of the investment shock proposed by Justiniano, Primiceri and Tambalotti (2010).

(Furlanetto and Groshenny, 2012a) we have shown that this happens when the shock is sufficiently persistent and when prices are rather sticky. Here the shock is estimated to be very persistent (ρ_ς is equal to 0.93 at the posterior mode) and prices are fairly sticky. Therefore, the mismatch shock fulfills the conditions to be a shifter of the empirical Beveridge curve. In figure 3 we plot the historical decomposition for the unemployment rate. The role of shocks to the matching efficiency is limited but not negligible, at least during the Great Recession when unemployment has more than doubled. Since 2009 mismatch shocks are responsible on average for at most 1 percentage point of the large increase in unemployment according to our historical decomposition. This result is in line with other studies aiming at measuring mismatch unemployment. Sahin, Song, Topa and Violante (2012) combine disaggregated data from JOLTS and HWOL to construct a mismatch index and quantify the importance of mismatch unemployment. In their baseline analysis they find that mismatch unemployment at the 2-digit industry level can account for 0.75 percentage points out of the 5.4 increase in the US unemployment from 2006 to the fall 2009. In a series of extensions they conclude that mismatch unemployment (due to skill mismatch) can account at most for 1/3 of the increase in unemployment whereas geographical mismatch does not play any role. Barnichon and Figura (2012) decompose movements in the empirical Beveridge curve into the contributions of labor demand, labor supply and matching efficiency factors. They find that the role of matching efficiency factors is somewhat limited and conclude that without any loss in matching efficiency, unemployment would have been about 150 points lower in late 2010 (cf. also Herz and van Rens, 2012). We find intriguing that studies that use very different methodologies and data find results that are in the same ballpark.

From figure 3 we see that the large increase in unemployment during the Great Recession is explained by a series of negative demand shocks. In particular, risk premium shocks (in particular during 2009) and investment specific shocks. The role of monetary policy shocks is negligible whereas fiscal policy shocks have contributed to lower unemployment over the all period since 2007. This is somewhat surprising given that the model does not include any of the features that are usually used to amplify the effects of fiscal shocks (like rule-of-thumb consumers, non-separable preferences or deep habits). One possible explanation is that our model interpret as positive fiscal shocks some positive impulses coming from abroad.

5 Mismatch shocks and the natural rate of unemployment

The objective of this section is to measure the contribution of mismatch shocks in the evolution of the natural rate of unemployment. Following Sala, Söderström and Trigari (2008) and most of the related literature on the output gap (cf. Smets and Wouters, 2003 and 2007, GST, 2008, Groshenny, 2012, and Sala, Söderström and Trigari, 2010, among others), we define the natural rate of unemployment to be the unemployment rate that would prevail if i) prices and wages were perfectly flexible and ii) the price mark-up and the degree of bargaining power were constant.[18] This is consistent with the concept of natural rate expressed in Friedman (1968), i.e. a measure of unemployment that fluctuates over time in response to real shocks and that is independent from monetary factors. Moreover, this definition is also shared by monetary policymakers. In particular, our approach is consistent with Kocherlakota's view of the Fed's mission:

> *"...the primary role for monetary policy is to offset the impact of nominal rigidities - that is, the sluggish adjustment of prices and inflation expectations to shocks... I define the natural rate of unemployment to be the unemployment rate u^* that would prevail in the absence of any nominal rigidities. To offset nominal rigidities, monetary policy accommodation should track the gap between the observed unemployment rate u and the natural rate u^*. The chal-*

[18] We adopt the standard practice of turning off the inefficient shocks to compute the natural rate. Price-markup shocks and bargaining power shocks are inefficient. The formers affect the degree of imperfect competition in the goods market. The latters induce deviations from the Hosios condition and so affect the severity of the congestion externalities that characterize the labor market in the search and matching model. This way of defining the natural rate, although dominant in the literature, is not uncontroversial. Notice that wage bargaining shocks are estimated as almost white noise processes in our model. This is consistent with the interpretation of these shocks as measurement error that is provided in Justiniano, Primiceri and Tambalotti (2011). The interpretation of inefficient shocks in the New Keynesian model is the object of a very recent literature (cf. Chari, Kehoe and McGrattan, 2009, Galí, Smets and Wouters, 2011, and Justiniano, Primiceri and Tambalotti, 2011) but is outside the scope of the current paper.

lenge for monetary policymakers is that u^* changes over time and is unobservable." (Narayana Kocherlakota, August 2011)

In figure 4 we plot the observed unemployment rate together with our estimates of the natural rate, as defined above. Our results suggest that the natural rate has been very stable around 6 percent during the Great Moderation period whereas it has increased sharply during the Great Recession up to 8 percent. Interestingly, according to our model actual unemployment was well below the natural rate over the period 2003-2007.

Shocks to the matching efficiency are the dominant source of variation in the natural rate of unemployment as it can be seen in the historical decomposition plotted in figure 5. This reflects the fact that shocks propagate very differently in models with flexible prices and wages than in models with nominal rigidities. The matching shock is the only shock that propagates more when nominal rigidities are turned off as explained in Furlanetto and Groshenny 2012a. The natural rate is driven mainly by mismatch shocks also because the other shocks (neutral technology, investment-specific and government spending shocks) propagate very little under flexible prices and wages, as reported in figure (to be added). This reflects the so called unemployment volatility puzzle emphasized by Shimer (2005 and 2009) in a Real Business Cycle model driven by technology shocks. This happens despite the presence of a dominant post-match component in total hiring costs that, according to Pissarides (2009), guarantees larger unemployment volatility than in a model with pre-match hiring costs. Notice, however, that there is no unemployment volatility puzzle in the baseline model with sticky prices and sticky wages. As shown in Furlanetto and Groshenny (2012b), nominal rigidities are a possible solution to the unemployment volatility puzzle, as long as we are willing to accept that the business cycle is driven by several shocks and not only by neutral technology shocks as in Shimer (2005).

The analysis on the natural rate of unemployment has important policy implications, at least if the Fed's mission is consistent with the view proposed above by Kocherlakota (2011) (which is not necessarily consistent with the outcome of a Ramsey optimal monetary policy in this kind of model). According to our model and to our definition of the natural rate, expansionary policies are justified by an unemployment gap of around 2 percent. Importantly, however, large mismatch shocks have increased the natural rate, thus confirming the view that both cyclical and structural factors are important to understand unemployment dynamics during the Great Recession.

6 Conclusion (to be added)

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Appendix: Description of the database

Apart from the series for vacancies which is constructed by Barnichon (Barnichon 2010), we download all series from the FREDII database maintained by the Federal Reserve Bank of St Louis. We measure nominal consumption using data on nominal personal consumption expenditures of nondurables and services. Nominal investment corresponds to the sum of personal consumption expenditures of durables and gross private domestic investment. Nominal output is measured by nominal GDP. Per capita real GDP, consumption and investment are obtained by dividing the nominal series by the GDP deflator and population. Real wages corresponds to nominal compensation per hour in the non-farm business sector, divided by the GDP deflator. Consistently with the model, we measure population by the labor force which is the sum of official unemployment and official employment. The unemployment rate is official unemployment divided by the labor force. Inflation is the first difference of the log of the GDP deflator. The nominal interest rate is measured by the effective federal funds rate.

Table 1: Calibrated parameters

Capital depreciation rate	δ	0.0250
Capital share	α	0.33
Elasticity of substitution btw goods	θ	6
Backward-looking price setting	ς	0.01
Replacement rate	τ	0.25
Hiring cost/output ratio	$\frac{\kappa}{2}\aleph^2$	0.003
Job destruction rate	ρ	0.085
Elasticity of matches to unemp.	σ	0.4
Probability to fill a vacancy within a quarter	q	0.7
Exogenous spending/output ratio	g/y	0.2
Unemployment rate	U	0.0595
Quarterly gross growth rate	z	1.0038
Quarterly gross inflation rate	π	1.0087
Quarterly gross nominal interest rate	R	1.0136

Table 2: Parameters derived from steady-state conditions

Employment rate	$N = 1 - U$
Vacancy	$V = \frac{\rho N}{q}$
Matches	$m = qV$
Discount factor	$\beta = \frac{z\pi}{R}$
Job survival rate	$\chi = 1 - \rho$
Mean of exogenous spending shock	$\epsilon_g = \frac{1}{1-g/y}$
Real marginal cost	$\xi = \frac{\theta-1}{\theta}$
Quarterly net real rental rate of capital	$\widetilde{r}^K = \frac{z}{\beta} - 1 + \delta$
Capital utilization cost first parameter	$\phi_{u1} = \widetilde{r}^K$
Capital/output ratio	$\frac{k}{y} = \frac{\alpha\xi}{\widetilde{r}^K}$
Investment/capital ratio	$\frac{i}{k} = z - 1 + \delta$
Investment/output ratio	$\frac{i}{y} = \frac{i}{k}\frac{k}{y}$
Consumption/output ratio	$\frac{c}{y} = \frac{1}{\epsilon_g} - \frac{\kappa}{2}\aleph^2 - \frac{i}{y}$
Pool of job seekers	$S = 1 - \chi N$
Matching function efficiency	$\zeta = q\left(\frac{V}{S}\right)^{\sigma}$
Job finding rate	$s = \zeta\left(\frac{V}{S}\right)^{1-\sigma}$
Employees' share of output	$\frac{\widetilde{w}N}{y} = \xi\left(1-\alpha\right) - \frac{(1-\beta)\chi}{\rho}2\left(\frac{\kappa}{2}\aleph^2\right)$
Bargaining power	$\eta = \frac{1-\tau}{\vartheta-\tau}$ where $\vartheta \equiv \frac{\xi(1-\alpha)+\left(1+\beta\chi\frac{s}{\rho}\right)2\left(\frac{\kappa}{2}\aleph^2\right)}{\frac{\widetilde{w}N}{y}}$
Effective bargaining power	$\text{Ŋ} = \frac{\eta}{1-\eta}$
Autocorrelation of (non-rescaled) markup shock	$\rho_\theta = \rho_{\theta^*}$
Std dev of (non-rescaled) markup shock	$\sigma_\theta = \left[\left(1+\beta\varsigma\right)\phi_P\right]\sigma_{\theta^*}$
Autocorrelation of (non-rescaled) bargaining power shock	$\rho_\eta = \rho_{\eta^*}$
Std dev of (non-rescaled) bargaining power shock	$\sigma_\eta = \left(1-\eta\right)\sigma_{\eta^*}$

Table 3: Priors and posteriors of structural parameters

			Posteriors		
		Priors	5%	Median	95%
Weight of pre-match cost in total hiring cost	ϕ_V	Beta (0.5,0.25)	0.01	0.04	0.09
Habit in consump.	h	Beta (0.7,0.1)	0.60	0.65	0.69
Invest. adj. cost	ϕ_I	IGamma (5,1)	2.89	3.48	4.24
Capital ut. cost	ϕ_{u2}	IGamma (0.5,0.1)	0.44	0.59	0.82
Price adjust. cost	ϕ_P	IGamma (50,20)	45.62	58.72	76.04
Wage adjust. cost	ϕ_W	IGamma (50,20)	130.32	207.98	307.31
Wage indexation	ϱ	Beta (0.5,0.2)	0.87	0.94	0.98
Interest smoothing	ρ_r	Beta (0.7,0.1)	0.44	0.60	0.69
Resp. to inflation	ρ_π	IGamma (1.5,0.2)	1.57	1.70	1.88
Resp. to growth	ρ_y	IGamma (0.5,0.1)	0.39	0.48	0.58

Table 4: Priors and posteriors of shock parameters

			Posteriors		
		Priors	5%	Median	95%
Technology growth	ρ_z	Beta (0.3,0.1)	0.19	0.26	0.33
	$100\sigma_z$	IGamma (0.1,3)	1.19	1.27	1.37
Monetary policy	ρ_{mp}	Beta (0.5,0.2)	0.30	0.48	0.70
	$100\sigma_{mp}$	IGamma (0.1,3)	0.19	0.21	0.22
Investment	ρ_μ	Beta (0.5,0.2)	0.76	0.80	0.85
	$100\sigma_\mu$	IGamma (0.1,3)	5.52	6.50	7.67
Risk premium	ρ_b	Beta (0.5,0.2)	0.66	0.74	0.83
	$100\sigma_b$	IGamma (0.1,3)	0.41	0.63	0.95
Matching efficiency	ρ_ζ	Beta (0.5,0.2)	0.89	0.93	0.96
	$100\sigma_\zeta$	IGamma (0.1,3)	8.59	9.19	9.85
Price markup (rescaled)	ρ_{θ^*}	Beta (0.5,0.2)	0.85	0.92	0.96
	$100\sigma_{\theta^*}$	IGamma (0.1,3)	0.10	0.12	0.14
Bargaining power (rescaled)	ρ_{η^*}	Beta (0.5,0.2)	0.08	0.17	0.27
	$100\sigma_{\eta^*}$	IGamma (0.1,3)	130.89	209.25	306.77
Government spending	ρ_g	Beta (0.7,0.1)	0.90	0.92	0.94
	$100\sigma_g$	IGamma (0.1,3)	0.54	0.58	0.62

Table 5: Variance decomposition (in %)

	Output	Unemp.	Vacancy	Inflation
Technology	30	18	11	16
Monetary	3	2	2	2
Investment	27	31	20	57
Matching	0	0.2	38	0
Risk-premium	14	9	8	15
Markup	9	26	12	6
Bargaining	3	12	5	2
Fiscal	14	2	5	2

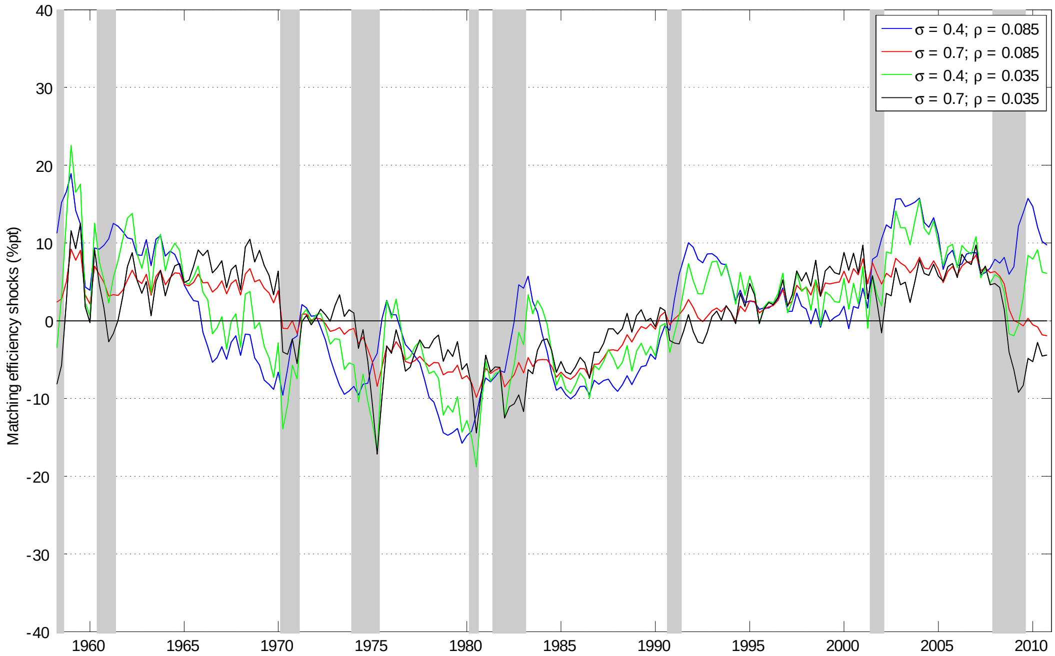


Figure 1: Matching efficiency shocks implied by the model when unemployment and vacancies are used as observables for alternative calibrations of the matching elasticity (σ) and the job separation rate (ρ).

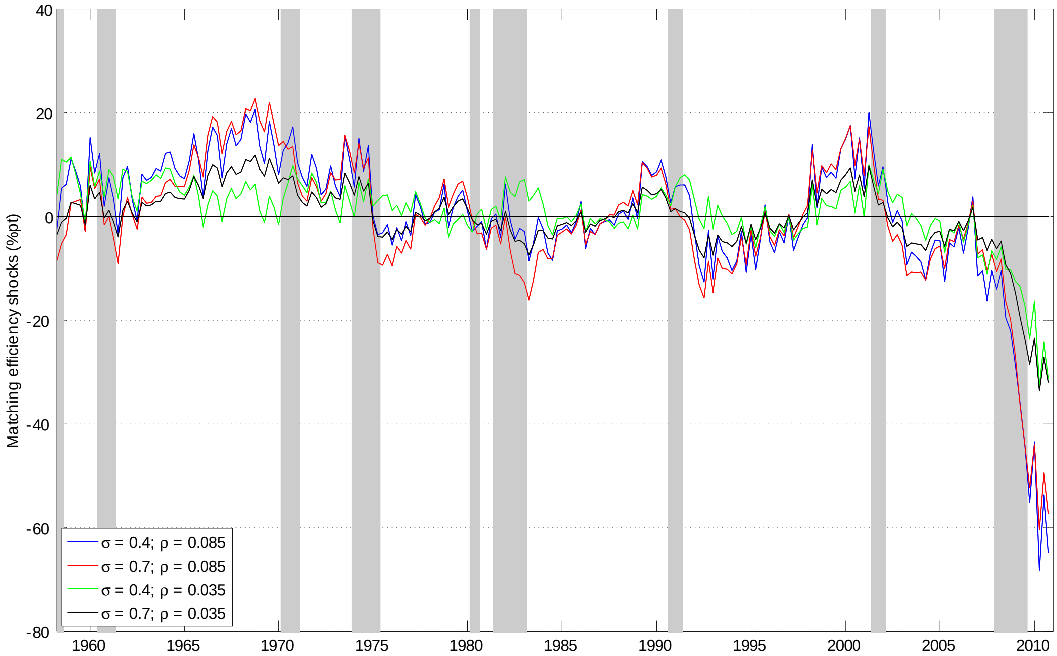


Figure 2: Matching efficiency shocks implied by the model when the job finding rate and the vacancy/unemployment ratio are used as observables for alternative calibrations of the matching elasticity (σ) and the job separation rate (ρ).

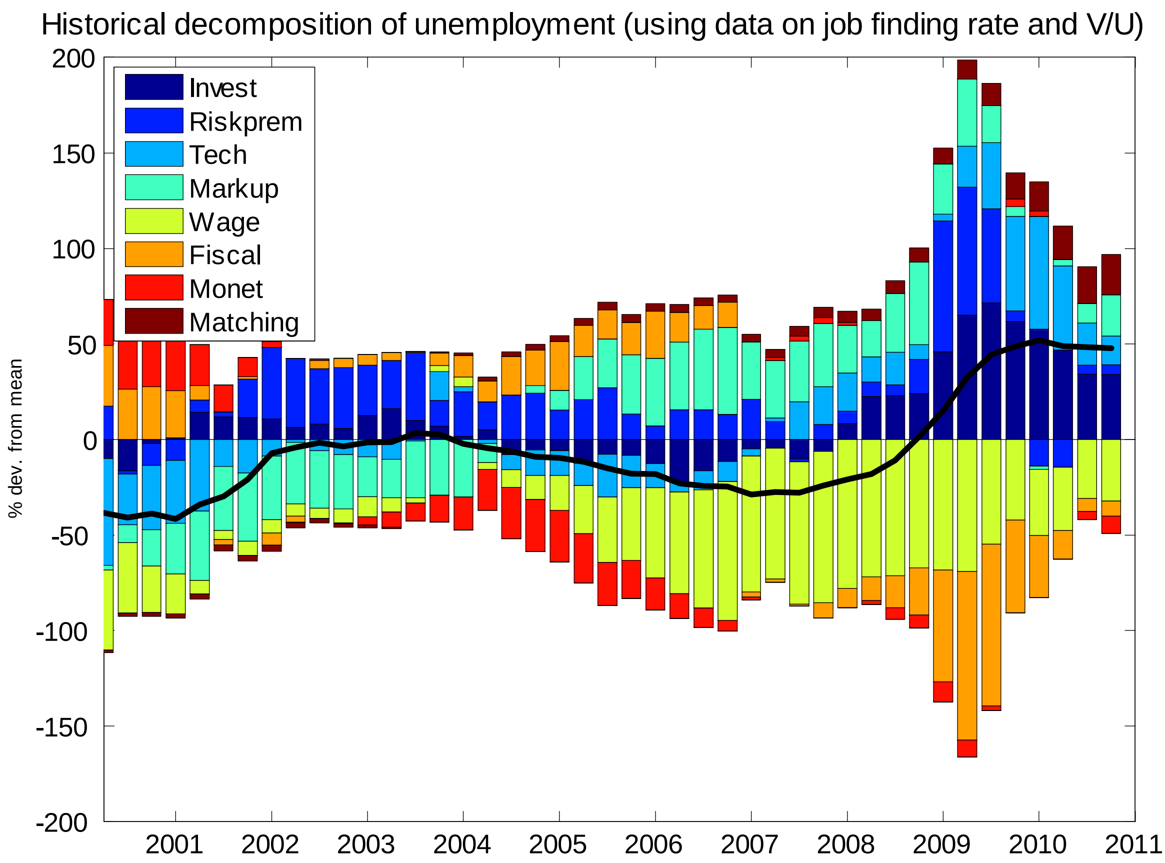


Figure 3: Historical decomposition for unemployment

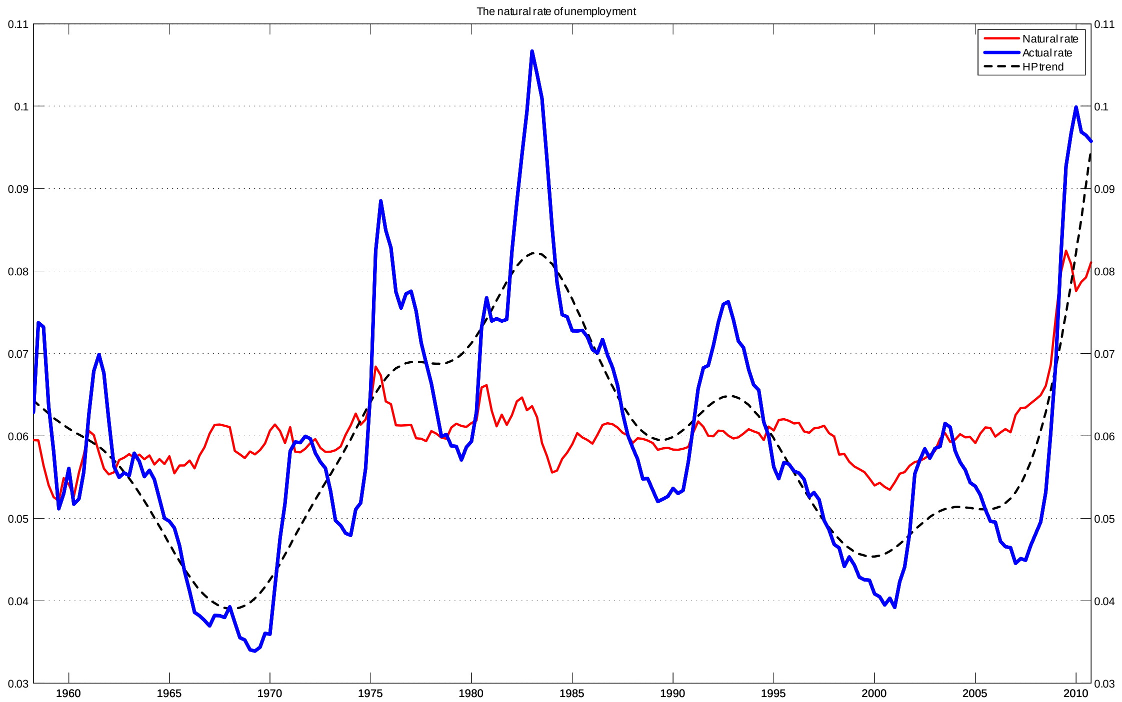


Figure 4: Evolution of the actual and of the natural rate of unemployment

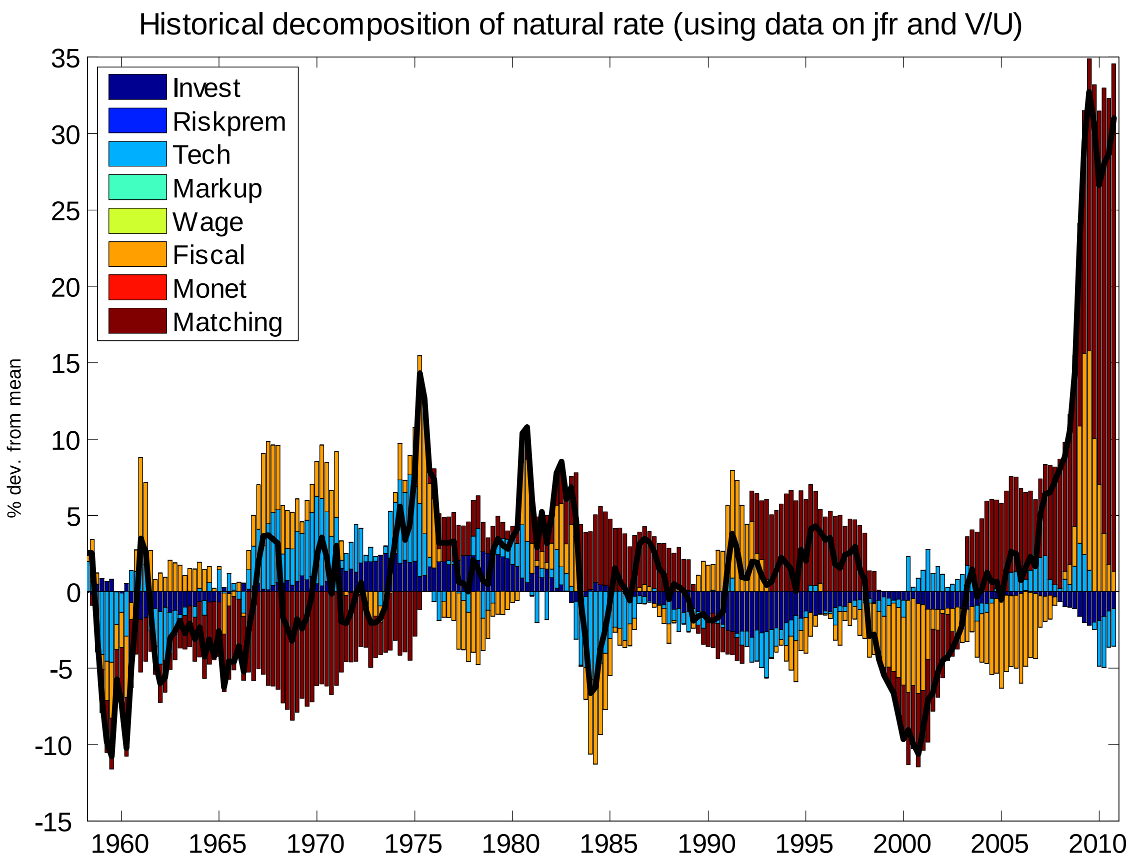
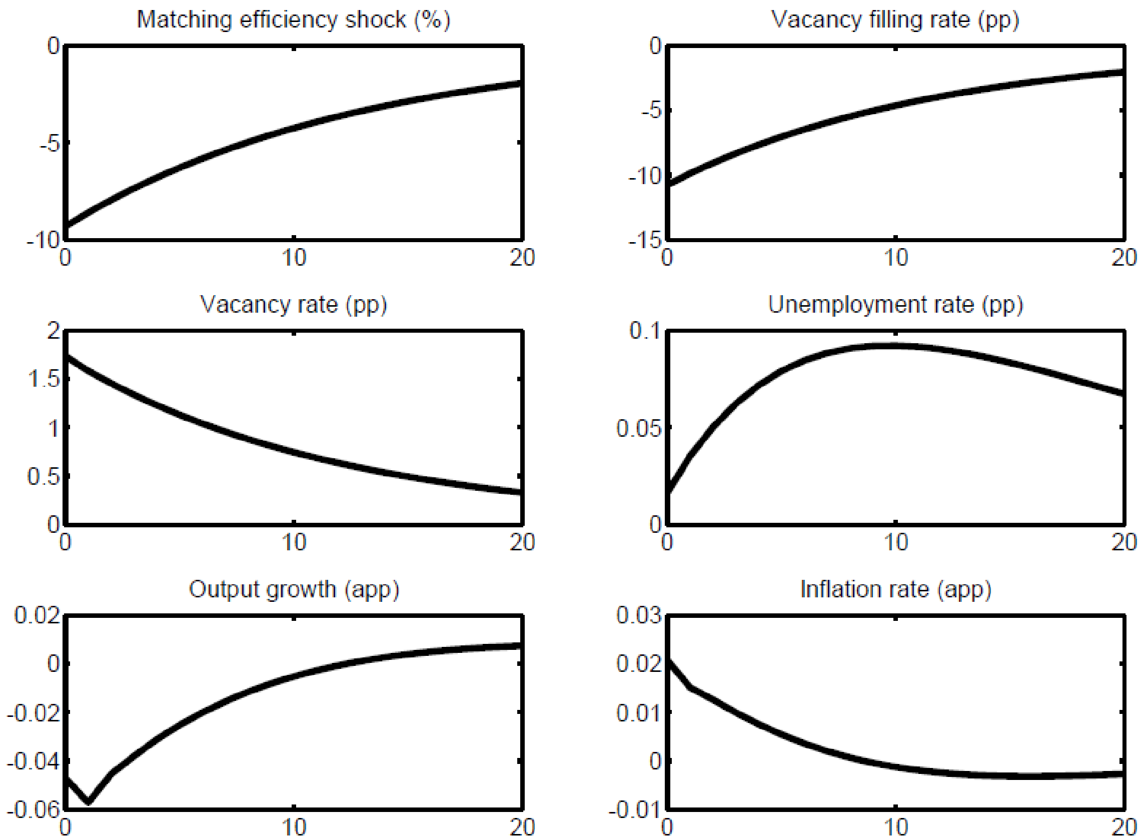
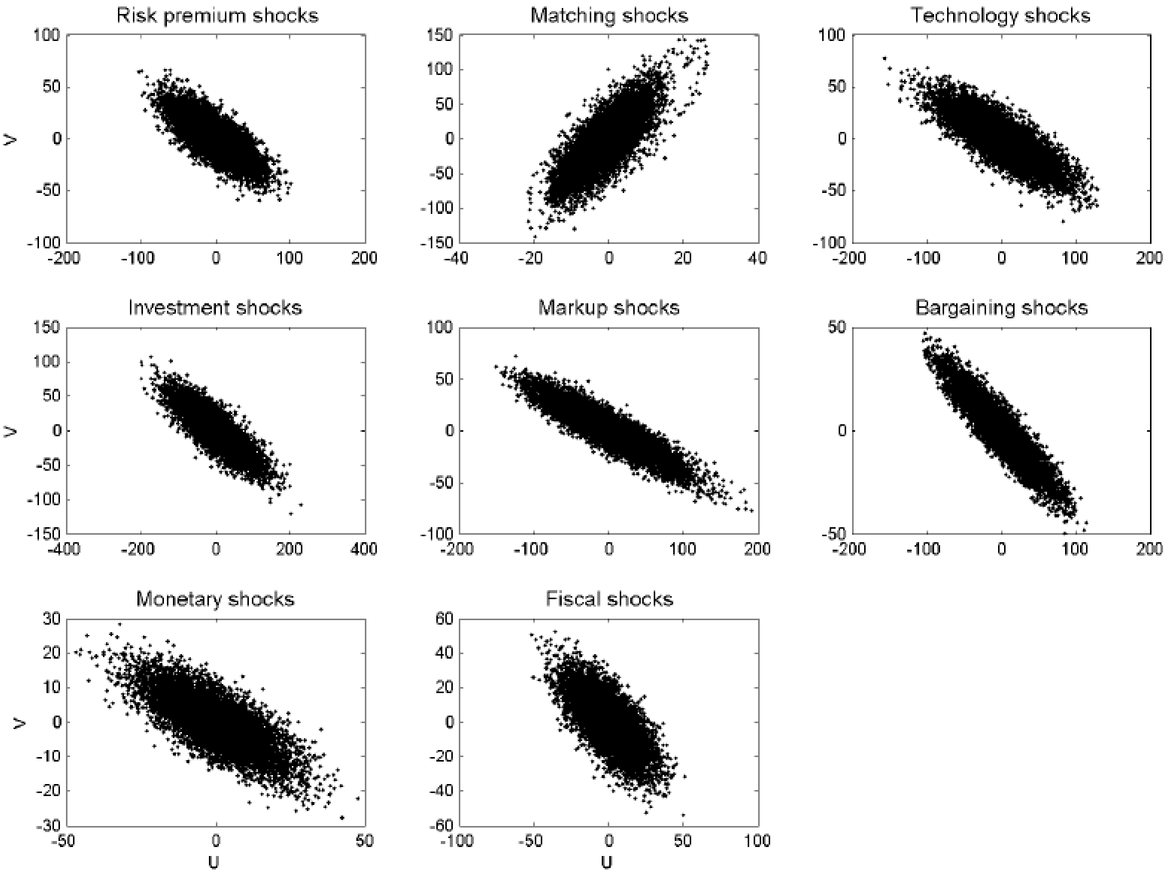


Figure 5: Historical decomposition for the natural rate of unemployment



Impulse responses to a one-std-dev negative matching efficiency shock



Simulated conditional Beveridge curves