Mismatch shocks and the natural rate of unemployment during the Great Recession*

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September 2011

Abstract

We estimate a DSGE model which features both nominal rigidities and search and matching frictions in the labor market. We evaluate the importance of shocks to the efficiency of the matching function in accounting for the recent behavior of the Beveridge curve. We find that matching efficiency shocks are driving both the actual and the natural rate of unemployment down during the Great Recession. We conclude that the bulk of the recent increase in unemployment is due to cyclical factors.

Keywords: DSGE models, Beveridge curve, search and matching frictions, mismatch shocks, natural rates.

JEL codes: E32, C51, C52

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*The views expressed in this paper do not necessarily reflect the views of Norges Bank and the Reserve Bank of New Zealand. We thank our discussant Federico Ravenna, and Klaus Adam, Regis Barnichon, Larry Christiano, Marco Del Negro, Wouter Den Haan, Rochelle Edge, Chris Edmond, Pedro Gomes, Steinar Holden, Peter Ireland, Jinill Kim, Dirk Krueger, Jesper Linde, Ellen McGrattan, Elmar Mertens, Ed Nelson, Samad Sarferaz, Martin Seneca, Tommy Sveen, Lawrence Uren and Karl Walentin for useful comments. We thank also active participants at 2011 SWIM workshop in Auckland, 2011 workshop in Economic Dynamics at NHH Bergen, 2011 CEF conference in San Francisco, 2011 NBRE in Venastul, 2011 Australasia Workshop in Macroeconomic Dynamics in Brisbane, 2011 EEA congress in Oslo, 2011 Central Bank Macroeconomic Modelling Workshop in Ottawa and seminar participants at the University of Melbourne, the Board of Governors of the Federal Reserve System, the University of Oslo and the Reserve Bank of New Zealand.

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1 Introduction

The unemployment rate in the U.S. rose from 4.5 percent in mid 2007 to 9.5 percent in mid 2009. Since then, it has remained roughly steady at this extremely high level (Figure 1). Figure 2 shows the recent evolution of the Beveridge curve. Between 2009:Q3 and 2010:Q3, the vacancy rate has increased by 20 percent while the unemployment rate has not decreased at all. These observations have caused some commentators to believe that the Beveridge curve has shifted outward over that period, and that this shift was explained by a less efficient matching process in the labor market. Members of the Federal Open Market Committee disagree on why is unemployment so high and on whether the recent evolution of the unemployment rate is compatible with the Federal Reserve's dual goal of price stability and maximum sustainable employment. Kocherlakota has advocated that the rise in the unemployment rate was driven by an increase in the degree of mismatch between vacant jobs and unemployed workers. He has argued that the fall in the efficiency of the labor market matching process has caused the natural rate of unemployment to rise.

"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)

Bernanke, instead, attributes the high level of the unemployment rate to the extreme weakness of aggregate demand following the recent financial crisis.

"Overall my assessment is that the bulk of the increase in unemployment since the recession began is attributable to the sharp contraction in economic activity that occured in the wake of the financial crisis and the continuing shortfall of aggregate demand since then, rather than to structural factors." (Ben Bernanke, October 2010)

In this paper we address this issue from a quantitative point of view in the context of a dynamic stochastic general equilibrium (DSGE) model. 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 (the so-called "cyclical unemployment"), and search and matching frictions in the labor market, that prevent immediate matches between open vacancies and unemployed workers ("structural or natural unemployment").[1] Our goal is to investigate whether the proposition by Kocherlokota that the persistent rise in unemployment is driven by an increase in mismatch find some support in the aggregate data.

Our model combines the standard ingredients of the New Keynesian literature (nominal rigidities in prices and wages, variable capacity utilization and real rigidities in consumption 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 (2008), henceforth GST, who were the first to estimate a medium-scale DSGE model with labor market frictions.[2]

[1] In the context of our model, the concept of structural (or frictional) unemployment is equivalent to the natural rate of unemployment defined by Friedman (1968): it is a measure of unemployment that fluctuates over time in response to real shocks and that is independent from monetary factors. This corresponds to the rate of unemployment that emerges in the model when nominal rigidities are shut down, i.e.when prices and wages are flexible.

[2] The use of search and matching frictions in business cycle models was pionereed by Merz (1995) and Andolfatto (1996) in the Real Business Cycle literature. More recently, the same labor market frictions have been studied in the New Keynesian model by Krause and Lubik (2007), Krause, Lubik and López Salido (2008), Ravenna and Walsh (2008 and 2011), Sveen and Weinke (2008 and 2009), Trigari (2006 and 2009) and Walsh (2005) among many others. More recent contributions that estimate a DSGE model with unemployment are Christiano, Trabandt and Walentin (2011), Christoffel, Kuester and Linzert (2009), Faccini, Millard and Zanetti (2011), Galí, Smets and

Here, we extend the GST set-up by using an additional data series in the estimation (we rely on a new series for vacancies put together by Barnichon 2010) and by introducing an additional shock (a shock to the matching efficiency in the labor market), that has not been considered so far in estimated medium-scale DSGE models, and that should, we hope, capture the essence of the Kocherlakota 's argument.[3]

Matching efficiency shocks are like technology shocks to the aggregate matching function and, therefore, they induce shifts in the Beveridge curve. They capture exogenous variations in the degree of search and matching frictions, possibly driven by the different sources of mismatch indicated by Kocherlakota (2010). The most direct interpretation is that they reflect skill and geographical mismatch (Sahin, Song, Topa and Violante, 2011 and Herz and van Rens, 2011), possibly exacerbated by house-locking effects (Estevão and Tsounta, 2010).[4] We believe that if the structural factors described by Kocherlakota (2010) are important, our shock to the matching efficiency should emerge as a prominent driver of the surge in the unemployment rate during the Great Recession.

Using data up to 2010:Q3 on eight key macro variables, we do not find any evidence of an increase in the natural rate of unemployment. Instead, our estimated model suggests that the natural rate has declined slightly during the Great Recession and was lying around 4 percent in 2010:Q3. In starking contrast with the intuition behind the proposition of Kocherlakota, we find that the current very high rate of unemployment reflects insufficient aggregate demand, mainly caused by adverse financial factors and nominal rigidities, and that the efficiency of the matching process in the labor market has improved during the Great Recession. This last finding is surprising but is perfectly consistent with a recent influential paper by Michaillat (2011) that shows that matching frictions become almost irrelevant in recessions when the bulk of unemployment is cyclical. This is the case because in recessions there is a large shortage of jobs, labor market tightness is low and

Wouters (2011) and Groshenny (2009 and 2010).

[3]Shocks to the matching efficiency are present in Arsenau and Chugh (2007), Cheremukhin and Restrepo-Echavarria (2011) and Lubik (2009). However, none of these papers focus on the role of these shocks as drivers of structural unemployment.

[4]Alternative and looser interpretations involve other possible sources of structural unemployment like 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 and in dispersion in the unemployment pool (cf. Barnichon and Figura, 2011a) or variations in labor supply due to demographic factors and fluctuations in participation (cf. Barnichon and Figura, 2011b).

recruiting is easy and inexpensive. Search frictions, instead, are relevant in booms when the labor market is tight, and the bulk of unemployment is frictional.

Furthermore, we look at the dynamics of the Beveridge curve and find that, conditional on the estimated matching efficiency shocks alone, the Beveridge curve would have shifted inward during the Great Recession, not outward as suggested by Kocherlakota. The recent increase in the vacancy rate that is combined with a seemingly unusual absence of decrease in the unemployment rate is explained by our model through a combination of shocks and reflects a particular phase in a typical evolution of the Beveridge curve over the business cycle. Our model suggests that the mix of shocks underlying the Great Recession is very similar to the mix of shocks that generated the 2001 recession and the subsequent jobless recovery. The main difference is that, in the Great Recession, the magnitude of the shocks hitting the economy is much larger. Hence, the story about the 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 Beveridge curve, stretching the cloud of points in all directions. The data on vacancies and unemployment between 2009:Q3 and 2010:Q3, that were interpreted by some commentators as reflecting an outward shift of the Beveridge curve caused by an increase of mismatch, were, according to our model, a particular phase in the cycle of the Beveridge curve around a magnified ellipse.

Our paper is related to at least two strands of the literature. Our paper aims at quantifying the importance of matching efficiency shocks in unemployment dynamics during the Great Recession by estimating a general equilibrium model with aggregate data. We contribute to the literature on the role of structural factors as a potential source of unemployment dynamics. Most contributions in this literature are empirical analysis in the context of reduced form models. 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 sectoral 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). More recently, Barnichon and Figura (2011b) present an empirical framework to identify the relative importance of changes in labor demand, in labor supply and in the efficiency of matching in explaining cyclical movements in unemployment. They find that changes in labor demand are the dominant source of unemployment fluctuations at business cycle frequencies, although labor supply shocks play a non negligible role at low frequencies. Changes in the matching efficiency generally play a very small role although their importance increases during recessions. According to their analysis, lower matching efficiency added about 1.5 percentage points to the unemployment rate during the recent Great Recession.

Our paper relates also to a recent literature that studies the output gap derived from estimated New Keynesian models (Sala, Södestrom and Trigari 2010, Justiniano, Primiceri and Tambalotti 2011).[5] 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 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 and their sample period does not include the Great Recession.

The paper proceeds as follows: Section 2 briefly describes the model and the econometric strategy. Section 3 describes the results of our estimation. Section 4 confirms our main result in the context of a model with post-match hiring costs. Section 5 concludes.

2 Model and econometric strategy

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, un-

[5] 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).

employment 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-markup shock, a government spending shock and a monetary policy shock. GST 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. The most important innovation is that we include an eighth shock, the shock to the efficiency of the matching function in the labor market, and that we use data on unemployment and vacancies in the estimation. Moreover, we extend the sample period until 2010:Q3 to include the Great Recession. Importantly, we use pre-match hiring costs (in the form of linear cost of posting a vacancy, as in Pissarides 2000) rather than post-match hiring costs (in the form of quadratic training costs, as in GST). 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 (2011a).[6] There are other small differences compared to GST: 1) As in Smets and Wouters (2007), we have a risk premium shock, rather than a preference shock, to capture variations in the degree of financial frictions. We consider the preference shock in our sensitivity analysis; 2) In our model new matches become productive immediately (i.e. within the quarter) and workers that separate for exogenous reasons can search for a job in the same period (in GST 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 (Rotemberg 1982) and in wages (Arsenau and Chugh 2008) instead of staggered contracts (Calvo 1983 for prices, Gertler and Trigari 2008 for wages) and by using a Dixit-Stiglitz aggre-

[6] This point was brought to our attention by Larry Christiano in a private conversation few years ago. The same concept is expressed in a little note written by Thijs van Rens and available at http://www.crei.cat/~vanrens/notes_comments/Gertler_Trigari_comment.pdf

At that time, the point was relevant to understand the nature of the labor market frictions in the Gertler and Trigari (2008) model, and there was no discussion on matching effciency shocks.

gator with constant elasticity of substitution across goods rather than a Kimball aggregator with endogenous elasticity.

2.1 Model

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.[7] 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 according to

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

where δ denotes the depreciation rate. The function $\pounds$ 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

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

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 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 $b_t = \tau W_{ss,t}$.[8] 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.

The family's period t budget constraint is given by

$$\begin{aligned} P_t C_t + P_t I_t + \frac{B_t}{\epsilon_{bt} R_t} \leq \; & B_{t-1} + W_t N_t + (1 - N_t) b_t + r_t^K u_t \overline{K}_{t-1} \\ & - P_t a(u_t) \overline{K}_{t-1} - T_t + D_t. \end{aligned} \tag{4}$$

As in Smets and Wouters (2007), the shock ϵ_{bt} drives a wedge between the central bank's policy 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.[9] 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 $i.i.d.N(0, \sigma_b^2)$.

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

[9] Several shocks, including investment-specific shocks, generate a negative correlation between consumption and investment. This implies that standard DSGE models tend to underestimate the unconditional correlation between consumption and investment which is positive in the data. See Furlanetto and Seneca (2010) for a discussion and a possible solution to this problem.

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, $\rho N_{t-1}(i)$ olds 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 (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

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

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

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

where $0 < \rho_\zeta < 1$, and $\varepsilon_{\zeta t}$ 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 linear pre-match hiring costs, measured in terms of the finished good and given by

$$\phi_V V_t(i) Y_t \tag{12}$$

The parameter ϕ_V governs the magnitude of the pre-match hiring costs.[10] This kind of hiring cost is standard in the theoretical literature on search and matching frictions in the labor market (Pissarides 2000). Interestingly, the empirical literature has so far preferred a specification with post-match hiring costs, that can be interpreted as training costs (GST, Groshenny 2009 and 2010, Christiano, Trabandt and Walentin 2011). We will discuss the role of training costs in section 4 (cf. also Furlanetto and Groshenny 2011a).

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

$$Y_t(i) = A_t^{1-\alpha} K_t(i)^\alpha N_t(i)^{1-\alpha}. \tag{13}$$

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

$$\ln z_t = (1 - \rho_z) \ln z + \rho_z \ln z_{t-1} + \varepsilon_{zt}, \tag{14}$$

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.

[10] Yashiv (2006) proposes a more general specification of the hiring cost function. The fact that hiring costs inherit the common stochastic trend ensures that the unemployment rate remains stationary along the balanced growth path.

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

$$\frac{\phi_P}{2}\left(\frac{P_t(i)}{\pi_{t-1}^{\varsigma}\pi^{1-\varsigma}P_{t-1}(i)}-1\right)^2 Y_t. \tag{15}$$

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 (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

$$\frac{\phi_W}{2}\left(\frac{W_t(i)}{z\pi_{t-1}^{\varrho}\pi^{1-\varrho}W_{t-1}(i)}-1\right)^2 N_t(i)\,Y_t, \tag{16}$$

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.[11]

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

$$W_t(i) = \arg\max\left(\Delta_t(i)^{\eta_t}\, J_t(i)^{1-\eta_t}\right). \tag{17}$$

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

$$\Delta_t(i) = \frac{W_t(i)}{P_t} - \frac{b_t}{P_t} + \beta\chi E_t\left(1-s_{t+1}\right)\frac{\Lambda_{t+1}}{\Lambda_t}\Delta_{t+1}(i), \tag{18}$$

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

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

given by

$$J_t(i) = \xi_t(i)(1-\alpha)\frac{Y_t(i)}{N_t(i)} - \frac{W_t(i)}{P_t} - \frac{\phi_W}{2}\left(\frac{W_t(i)}{z\pi_{t-1}^{\varrho}\pi^{1-\varrho}W_{t-1}(i)} - 1\right)^2 Y_t + \beta\chi E_t\frac{\Lambda_{t+1}}{\Lambda_t}J_{t+1}(i), \tag{19}$$

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

$$\ln\eta_t = \left(1-\rho_\eta\right)\ln\eta + \rho_\eta\ln\eta_{t-1} + \varepsilon_{\eta t}, \tag{20}$$

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 goods-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

$$\left(\int_0^1 Y_t(i)^{(\theta_t-1)/\theta_t}\,di\right)^{\theta_t/(\theta_t-1)} \geq Y_t, \tag{21}$$

where θ_t is a shock to the intermediate goods-producing firm's markup. This disturbance follows the autoregressive process

$$\ln\theta_t = (1-\rho_\theta)\ln\theta + \rho_\theta\ln\theta_{t-1} + \varepsilon_{\theta t}, \tag{22}$$

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 rule

$$\ln\frac{R_t}{R} = \rho_r\ln\frac{R_{t-1}}{R} + (1-\rho_r)\left(\rho_\pi\ln\frac{(P_t/P_{t-4})^{1/4}}{\pi} + \rho_y\ln\frac{(Y_t/Y_{t-4})^{1/4}}{z}\right) + \ln\epsilon_{mpt}. \tag{23}$$

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

$$\ln \epsilon_{mpt} = \rho_{mp} \ln \epsilon_{mpt-1} + \varepsilon_{mpt}, \tag{24}$$

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

The government budget constraint is of the form

$$P_t G_t + (1 - N_t)\, b_t = \left(\frac{B_t}{R_t} - B_{t-1}\right) + T_t, \tag{25}$$

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

$$G_t = \left(1 - \frac{1}{\epsilon_{gt}}\right) Y_t, \tag{26}$$

where ϵ_{gt} evolves according to

$$\ln \epsilon_{gt} = \left(1 - \rho_g\right) \ln \epsilon_g + \rho_g \ln \epsilon_{gt-1} + \varepsilon_{gt}, \tag{27}$$

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

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.

2.2 Econometric strategy

Calibrated parameters Because of identification issues, we calibrate thirteen parameters prior to estimation (Lubik 2009). 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 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). Consistently with microevidence on price-setting behavior, the degree of indexation to past inflation is set close to zero. Finally, the steady-state values of output growth, inflation, the interest rate and the unemployment rate are set equal to their sample mean over the period 1957:Q1-2010:Q3. 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.[12] The estimation period is 1957:Q1 - 2010:Q3. The eight observable variables are: the growth rate of real output per 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, the unemployment rate and the vacancy rate. The appendix describes the data set in detail. The series for vacancies has been put together by Barnichon (2010), combining information on both print and online help-wanted advertising.

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.

3 Results

Our objective is to measure the contribution of mismatch shocks in the recent evolution of both the actual and the natural rate of unemployment. Following Sala,

[12]Prior to estimation, we normalize the price-markup shock and the bargaining-power shock, so that they enter with a unit coefficient in the model's equations. Such procedure facilitates the identification of the shocks' standard deviations.

Söderström and Trigari (2008) and most of the related literature on the output gap (Smets and Wouters 2003 and 2007, GST, Groshenny 2010, 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 mark-up and the bargaining power were constant.[13] This definition of the natural rate is shared by monetary policymakers. In particular, our approach is fully consistent with Kocherlakota's view of the Fed's mission.

"...[T]he primary role for monetary policy is to offset the impact of what economists term nominal rigidities - that is, the sluggish adjustment of prices and inflation expectations to shocks. ...[M]y slides 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 accomodation should track the gap between the observed unemployment rate and u^*. The challenge for monetary policymakers is that u^* changes over time and is unobservable." (Narayana Kocherlakota, March 2011)

We first document some evidence on the business cycle properties of our model and on the propagation of mismatch shocks. We then present our estimates of the natural rate. Finally, we investigate what role have mismatch shocks played in shaping fluctuations in the natural rate of unemployment and the Beveridge curve during Great Recession.

3.1 Mismatch shocks and business cycles

In Figure 3, we show the impulse responses of both vacancies and unemployment to each of the eight structural shocks. The purpose of this figure is to understand how each shock affects the Beveridge curve. Shocks that trigger a negative correlation between vacancies and unemployment generate a downward sloping Beveridge

[13] 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 errors that is provided by Justiniano, Primiceri and Tambalotti (2011). The interpretation of inefficient shocks in the New Keynesian model is the object of a recent literature (Chari, Kehoe and McGrattan 2009, Sala, Söderström and Trigari 2010, Galí, Smets and Wouters 2011, and Justiniano, Primiceri and Tambalotti 2011) but is outside the scope of our present paper.

curve, as we predominantly observe in the data. As we see in figure 3, this is the case for all shocks except the matching efficiency shock. Matching efficiency shocks move vacancies and unemployment in the same direction and therefore generate a counterfactual, positively-sloped Beveridge curve.[14] Whenever the efficiency of the aggregate matching function improves for exogenous reasons, the probability of filling a vacancy increases for all firms in the economy. Firms can now achieve their desired level of employment by posting fewer vacancies and thereby saving on search costs. However, even if the number of vacancies decreases, the open vacancies are more likely to be filled and, overall, the number of matches increases, thereby reducing unemployment. A positive transitory matching efficiency shock temporarily shifts the whole Beveridge curve inward. Hence, consistent with Kocherlakota's insight, negative matching efficiency shocks could, at least partially, help explain what looks like an outward shift of the Beveridge curve between 2009:Q3 and 2010:Q3. Figure 4 makes the same point in a different way by plotting the Beveridge cloud generated by each shock.

The model's variance decomposition (Table 5) delivers a conventional picture of postwar US business cycles. Investment-specific technology shocks and neutral technology shocks are the main sources of business cycles.[15] Not surprisingly, matching efficiency shocks play only a minor role in shaping macroeconomic fluctuations (otherwise, we would observe a positively sloped Beveridge curve). These disturbances account for less than 10 percent of the variance of labor market variables. Moreover, their effects do not propagate beyond the labor market.

3.2 Mismatch shocks and the natural rate

Figure 5 plots the observed unemployment rate together with our estimates of the natural rate. The grey shaded band represents the 99 percentiles of the posterior

[14] In a companion paper, Furlanetto and Groshenny (2011b), we show that this result is driven by the presence of nominal and real rigidities. There, we show analytically that positive shocks to the matching efficiency imply a negative response of vacancies under the same conditions that guarantee a negative response of hours worked to a positive technology shock, i.e. nominal rigidities and not too aggressive monetary policy (Galí 1999) or real rigidities in the form of habit persistence and investment adjustment costs (Francis and Ramey 2005).

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

probability distribution of the natural rate. Our results suggest that the flex-price rate of unemployment fluctuates significantly. At low frequencies, the model's natural rate shares the downward trend observed in the actual rate of unemployment over the Great Moderation period. Most strikingly, at business cycle frequencies, the flex-price rate of unemployment appears to be negatively correlated with the actual rate. Our results suggest that the natural rate was lying around 4 percent in 2010:Q3. Finally, we also notice that the variance of the natural rate has decreased over the period.

Why is the natural rate of unemployment procyclical? Figure 6 offers the historical decomposition of the natural rate. Fluctuations in the natural rate are primarily driven by variations in the efficiency of the labor market matching process. During booms, when the labor market is tight, search frictions prevail and the labor market is relatively inefficient at matching unemployed workers and vacant jobs together. Instead, in bad times, when the labor market is slack, search frictions vanish and the labor market matching process is more efficient. For this reason, the natural rate tends to increase during booms and to decrease in recessions. This finding is consistent with a recent and influential paper by Michaillat (2011) and contradicts the hunch of Kocherlakota that mismatch has increased during the Great Recession and caused the natural rate of unemployment to rise.

Michaillat (2011) also considers the relative importance of nominal rigidities and search and matching frictions in an elegant small-scale model calibrated on US data and driven by technology shocks only. He finds that search frictions do not explain unemployment dynamics in recessions when, instead, cyclical factors are dominant. We find the same result in the more general context of an estimated medium-scale model driven by several shocks. Interestingly, Michaillat (2011) finds an even larger role for cyclical factors in recessions: in his model when unemployment reaches eight per cent, the cyclical part increases above six per cent whereas the structural part is below two per cent.[16]

The dominant role of matching shocks in explaining the natural rate is also due to the fact that the efficient shocks (neutral technology, investment-specific and government spending shocks) propagate very little under flexible prices and wages,

[16]Notice that our concept of structural unemployment and the concept in Michaillat (2011) are different given the different set of shocks in the two models.

as reported in figure 7. Mismatch shocks, instead, have larger effects under flexible prices and wages.[17]

Finally, we can use our estimates of the natural rate of unemployment and of the natural level of output to construct time series of the model consistent unemployment gap and output gap. Figure 8 shows that the gaps are successful at “picking up”the NBER recessions. Our estimate of the output gap is equal to roughly -5 percent in 2010 Q3. This figure is consistent with the CBO's measure. Finally, we note that the output gap was negative over the period 2003-2006, which suggests that the accomodative stance of monetary policy was appropriate. This finding is in line with Groshenny (2010) and Justiniano and Primiceri (2010).

3.3 The Beveridge curve during the Great Recession

Why is unemployment so high since 2008? Figure 9 shows the historical decomposition of actual unemployment since 2000. The figure shows that adverse risk-premium shocks were the dominant source of upward pressure on unemployment at the onset of the financial crisis. These shocks increase the spread between the effective interest rate faced by households and firms and the policy rate. These disturbances are meant to help the model capturing time variations in the degree of financial frictions. Interestingly, adverse risk-premium shocks were also the main drivers of the 2001 recession. Notice also the expansionary role played by monetary policy shocks from 2002 until the end of 2005.

As the financial crisis was turning into the Great Recession, we see that wage-markup shocks contributed to maintain the unemployment rate at extremely high levels. Wage-markup shocks capture time variations in workers' bargaining power. The adverse realizations of the wage-markup shocks during the Great Recession reflect the presence of downward nominal wage rigidities: Given the extreme slack of the U.S. labour market, the model predicts that nominal wages should be much lower than they actually are. The model accounts for this discrepancy through exogenous temporary increases in the workers' bargaining power. Notice also that expansionary

[17] This confirms the so-called unemployment volatility puzzle emphasized by Shimer (2005 and 2009) in a Real Business Cycle model driven by technology shocks. Notice, however, that the same shocks propagate much more in the model with sticky prices and sticky wages. As shown in Furlanetto and Groshenny (2011b), nominal rigidities and multiple shocks are a possible solution to the unemployment volatility puzzle.

fiscal policy shocks have been partially offsetting the upward pressures on unemployment generated by the risk-premium shocks and the wage-markup shocks.

Finally, a long string of persistent positive matching efficiency shocks is hitting the U.S. economy since the 2001 recession to nowadays. These shocks probably reflect the slack of the labour market throughout this period marked by the stock market burst in 2001, the jobless recovery of 2003-2005, the 2007-2009 financial crisis and the Great Recession. In bad times, when the labor market is slack, search frictions vanish and the matching process of the labor market is more efficient.

What happened to the Beveridge curve? We now use our structural model to isolate the effects of matching efficiency shocks on the Beveridge curve over the period.2008:Q1 - 2010:Q3. Figure 10 shows that the intuition of Kocherlakota is not confirmed in our model. Mismatch has not increased during the Great Recession. On the contrary, our results suggest that the labor market has been particularly efficient at matching vacant jobs and unemployed workers. Conditional on our inferred positive matching shocks since 2008:Q1, the Beveridge curve would be upward sloping and the unemployment rate in 2010:Q3 would be about 20 percent below its 2008:Q3 value while vacancies would be at approximately the same level. If we now isolate the role of risk-premium shocks, we see that these disturbances drove the economy down along the Beveridge curve in 2008.

3.4 Pre-match vs post-match hiring costs

As shown in Furlanetto and Groshenny (2011a), the distinction between pre-match and post-match hiring shocks is crucial for the transmission of shocks to the matching efficiency. With post-match hiring costs, in fact, the shock is neutral and does not propagate.[18] A positive shock to the matching effciency makes it easier to fill a vacancy (q_t increases) but firms react by posting fewer vacancies. The two effects compensate and new hires, unemployment and all the other variables are invariant to shocks to the matching efficiency (the decrease in V_t exactly offsets the increase in q_t). Figure 11 illustrates that point. To investigate the role of mismatch during the Great Recession (and thereby address the proposition of Kocherlakota), we have

[18] We use use the same specification for the post-match hiring cost as in GST. The cost is given by $\frac{\phi_N}{2}\left[\frac{q_t V_t(i)}{N_t(i)}\right]^2 Y_t$ and is interpreted as a training cost.

therefore opted for a model with pre-match hiring costs. Nevertheless, we believe that it is interesting to also look at the natural rate in a model with post-match hiring costs for two reasons. First, this is the specification that so far has been dominant in the empirical literature (GST, Groshenny, 2009 and 2010, Christiano, Trabandt and Walentin, 2011). Post-match hiring costs, in fact, amplify the volatility and the persistence of labor market variables, as shown in Pissarides (2009). Second, post-match hiring costs are quantitatively more important than pre-match hiring costs in the data, at least according to estimates in Yashiv (2000) and Silva and Toledo (2009). Hence, even tough we know from the outset that mismatch shocks will be irrelevant, we estimate a version of our model that features post-match (instead of pre-match) hiring costs and back out the natural rate. Table 6 reports the infinite horizon forecast error variance decomposition (computed at the posterior mode) of this alternative model. Not surprisingly, we observe that the contribution of mimatch shocks is nil for all variables but vacancies. Table 7 compares the log marginal likelihoods of the two models. The data clearly favors our baseline specification that features with vacancy posting costs and where mismatch shocks affect all variables.

Looking at figure 12, we see that the natural rate has not increased during the Great Recession in this model either. The irrelevance of matching efficiency shocks in this context implies that the procyclicality and volatility of the natural rate are substantially reduced. In this model, the natural rate does not decrease during the Great Recession and lies around six percent in 2010:Q3 (instead of four percent in the model with pre-match hiring costs).

In figure 13 and 14, we plot the historical decompositions of the natural and actual rates of unemployment respectively. The contribution of most shocks follows a pattern which is similar to the what we observed in the baseline model.[19] Figure 15 shows the estimates of the unemployment gap and output gap in the model with post-match hiring costs.

We draw two conclusions from the analysis of the model with post-match hiring costs. First, the form of the hiring costs is crucial for the behavior (volatility and

[19]Wage bargaining shocks are an exception in this respect. However, in the model with post-match hiring costs too, these shocks are estimated to be nearly white noises. We could thus interpret them as measurement errors, as proposed by Justiniano, Primiceri and Tambalotti (2011).

procyclicality) of the natural rate.[20] Second, our finding that the behavior of the unemployment rate during the Great Recession can be attributed mainly to cyclical factors is confirmed.

4 Conclusions

Using aggregate data up to 2010:Q3, we have estimated a monetary DSGE model with search and matching frictions characterized by pre-match hiring costs. We have then used the estimated model to back out the path of the natural rate of unemployment and identify the drivers of unemployment during the Great Recession. We find no evidence of an increase in the natural rate. Our main result is that mismatch shocks cannot explain the surge in unemployment and the evolution of the Beveridge curve that we have observed during the Great Recession. We find that the Great Recession is a time characterized by very little mismatch in the labour market. Our findings suggest that the unemployment rate rose in 2008 because of large adverse risk-premium shocks, and remained stubbornly high since then mainly because of downward nominal rigidities. We conclude that the accomodative stance of monetary policy until 2010:Q3 was appropriate.

Our analysis focuses on the role of matching efficiency shocks and clearly omits several determinants of the natural rate such as fluctuations in hours per worker, fluctuations in the labor force participation rate, variations in the rate of job destruction and the duration of unemployment benefits. Although these factors could affect our estimate of the natural rate, they lie beyond the scope of the present paper. We leave these issues for future research.

References

Abraham, K., Katz, L.F., 1986. Sectoral shifts or aggregate disturbances? *Journal of Political Economy* 94, 507-522.

Andolfatto, D., 1996. Business cycles and labor market search. *American Economic Review* 86, 112-132.

[20] Yashiv (2000) and Silva and Toledo (2009) offers some evidence that training costs account for the bulk of hiring costs. Hence, we guess that the procyclicality of the natural rate would be dampened in a model featuring both pre-match (i.e. advertizing and screening) and post-match (i.e. training) hiring costs such as the one proposed by Yashiv (2006).

Andrés, J., Lópes-Salido, D., Nelson, E., 2005. Sticky-price models and the natural rate hypothesis. *Journal of Monetary Economics* 52, 1025-1053.

Arsenau, D. and Chugh, S. 2007. Fiscal shocks, job creation and countercyclical labor markups. Manuscript.

Arsenau, D. and Chugh, S. 2008. Optimal fiscal and monetary policy with costly wage bargaining, *Journal of Monetary Economics* 55, 1401–1414.

Barnichon, R., 2010. Building a composite Help-Wanted index. *Economic Letters* 109, 175-178.

Barnichon, R., Figura, A., 2011a. What drives matching efficiency? A tale of composition and dispersion. Manuscript.

Barnichon, R., Figura, A., 2011b. What drives movements in the unemployment rate? A decomposition of the Beveridge curve. Manuscript.

Blanchard, O.J., Diamond, P., 1989. The Beveridge curve. *Brooking papers on Economic Activity* 1, 1-76.

Blanchard, O.J., Galí, J., 2010. Labor markets and monetary policy: a New Keynesian model with unemployment. *American Economic Journal: Macroeconomics* 2, 1-33.

Bernanke, B., 2010. Monetary policy objectives and tools in low inflation environment. Speech available at http://www.federalreserve.gov/newsevents/speech/ bernanke20101015a.htm

Chari, V. V., Kehoe, P., McGrattan, E., 2009. New Keynesian models: Not yet useful for policy analysis', *American Economic Journal: Macroeconomics* 1(1), 242–266.

Cheremukhin, A.A., Restrepo-Echevarria, P., 2011, The labor wedge as a matching friction. Manuscript..

Christiano, L.J., Eichenbaum, M., Evans, C.L., 2005. Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy* 113(1), 1-45.

Christiano, L.J., Trabant, M., Walentin, K., 2011. Introducing financial frictions and unemployment into a small open economy model. *Journal of Economic, Dynamics* *and Control*, forthcoming.

Christoffel, K., Kuester, K., Linzert, T., 2009. The role of labor markets for Euro area monetary policy. *European Economic Review* 53, 908-936.

Davis, S., Faberman, J., Haltiwanger, J., 2010. The establishment-level behavior of vacancies and hiring. NBER working paper 16265.

De Graeve, F., Emiris, M., Wouters, R., 2009. A structural decomposition of the US yield curve. *Journal of Monetary Economics* 56, 545–559.

Edge, R.M., Kiley, M.T., Laforte, J.P., 2008. Natural rate measures in an estimated DSGE model of the US economy. *Journal of Economic Dynamics and Control* 32, 2512-2535.

Estevão, M., Tsounta E., 2010. Is US structural unemployment on the rise? Manuscript.

Faccini, R., Millard, S., Zanetti, F., 2011. Wage rigidities in an estimated DSGE model of the UK labor market. Manuscript.

Francis, N., Ramey, V., 2005. Is the Technology-Driven Business Cycle Hypothesis Dead? Shocks and Aggregate Fluctuations Revised. *Journal of Monetary Economics*, 52, 1379-1399.

Friedman, M., 1968. The role of monetary policy. *American Economic Review* 58, 1-17..

Furlanetto, F., Groshenny, N., 2011a. The (un)importance of shocks to the matching efficiency. Manuscript.

Furlanetto, F., Groshenny, N., 2011b. Is there any unemployment volatility puzzle? Manuscript.

Furlanetto, F., Seneca, M., 2010. Investment-specific technology shcoks and consumption. Norges Bank working paper 2010/30.

Furlanetto, F., Seneca, M., 2011. New Perspectives on Capital Depreciation Shocks as Sources of Business Cycle Fluctuations. Norges Bank working paper 2011/02.

Galí, J., 1999. Technology, Employment and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations? *American Economic Review*, 89, 249-271.

Galí, J., Gertler, M., López-Salido, D., 2007. Markups, Gaps and the welfare costs of business fluctuations. *Review of Economics and Statistics* 89, 44-59.

Galí, J., Smets, F., Wouters, R., 2010. Unemployment in an estimated New Keynesian model. Manuscript.

Gertler, M., Karadi, P., 2011. A model of unconventional monetary policy. *Journal of Monetary Economics* 58, 17-34.

Gertler, M., Trigari, A., 2009. Unemployment fluctuations with staggered Nash wage bargaining. J*ournal of Political Economy* 117, 38-86.

Gertler, M, Sala, L., Trigari, A., 2008. An estimated monetary DSGE model with unemployment and staggered nominal wage bargaining. *Journal of Money, Credit and Banking* 40, 1713-1764.

Groshenny, N., 2009. Evaluating a monetary business cycle model with unemployment for the Euro area. Reserve Bank of New Zealand Discussion Paper Series 2009-08.

Groshenny, N., 2010. Monetary policy, inflation and unemployment. In defense of the Federal Reserve. CAMA working paper 2010 (forthcoming in *Macroeconomic Dynamics*).

Herz, B., van Rens, T., 2011. Structural unemployment. Manuscript.

Justiniano, A., Primiceri, G., 2010. Measuring the Equilibrium Real Interest Rate. Federal Reserve Bank of Chicago *Economic Perspectives* 34(1), 14-27.

Justiniano, A., Primiceri, G., Tambalotti, A., 2010. Investment Shocks and Business Cycles. *Journal of Monetary Economics* 57, 132-145.

Justiniano, A., Primiceri, G., Tambalotti, A., 2011. Is there a trade-off between inflation and output stabilization? NBER working paper 17071.

Ireland, P., 2007. Changes in the Federal Reserve's in‡ation target: Causes and consequences. *Journal of Money, Credit and Banking* 39, 1851–1882.

Kocherlakota, N., 2010. Inside the FOMC. Speech at Northern Michigan University, Marquette, Michigan, August 17, 2010. http://www.minneapolisfed.org/news_events /pres/speech_display.cfm?id=4525

Kocherlakota, N., 2011. Labor Markets and Monetary Policy. Executive summary of Speech at 49th Annual Winter Institute, St Cloud State University, St Cloud, Minnesota, March 3, 2011. http://www.minneapolisfed.org/news_events /pres/speech_display.cfm?id=4627

Krause, M.U., Lubik, T.A., 2007. The (ir)relevance of real wage rigidity in the New Keynesian model with search frictions. *Journal of Monetary Economics* 54, 706-727.

Krause, M.U., López-Salido, D., Lubik, T.A., 2008. Inflation dynamics with search frictions: a structural econometric analysis. *Journal of Monetary Economics* 55, 892-916.

Kuang. K., Valletta, R., 2010. Extended unemployment and UI benefits. FRBSF Economic Letter.

Levin, A.T., Onatski, A., Williams, J.C., Williams, N., 2005. Monetary policy under uncertainy in micro-founded macroeconometric models. *NBER Macroeconomics Annual* 229-312.

Liu, Z., Waggoner, D.F., Zha, T., 2011. Sources of the Great Moderation: shocks, frictions, or monetary policy? *Quantitative economics,* forthcoming.

Lubik, T.A., 2009. Estimating a search and matching model of the aggregate labor market. *Federal Reserve Bank of Richmond Economic Quarterly* 95, 101-120.

Merz, M., 1995. Search in the labor market and the real business cycle. *Journal of Monetary Economics* 36, 269–300.

Michaillat, P., 2011. Do matching frictions explain unemployment? Not in bad times. *American Economic Review*, forthcoming.

Mortensen, D.T., Pissarides, C.A., 1994. Job creation and job destruction in the theory of unemployment. *Review of Economic Studies* 61, 397-415.

Nelson, E., 2005. Inflation dynamics, marginal cost and the output gap: evidence from three countries. *Journal of Money, Credit and Banking* 37, 1019-1045.

Pissarides, C.A., 2000. Equilibrium unemployment theory. MIT Press.

Pissarides, C.A., 2009. The unemployment volatility puzzle: is wage stickiness the answer? *Econometrica* 77, 1339-1369.

Ravenna, F., Walsh, C., 2008. Vacancies, unemployment and the Phillips curve. *European Economic Review* 52, 1494-1521.

Ravenna, F., Walsh, C., 2011. Welfare-based optimal monetary policy with unemployment and sticky prices: a linear-quadratic framework. *American Economic Journal: Macroeconomics* 3, 130-162.

Sahin, A., Song, J., Y., Topa., G., Violante, G., 2011. Measuring mismatch in the US labor market. Manuscript.

Sala, L., Söderström, U., Trigari, A., 2008. Monetary policy under uncertainty in an estimated model with labor market frictions. *Journal of Monetary Economics* 55, 983-1006.

Sala, L., Söderström, U., Trigari, A., 2010. The output gap, the labor wedge and the dynamic behavior of hours. Sveriges Riksbank working paper series 246.

Shimer, R., 2005. The cyclical behavior of equilibrium unemployment and vacancies. *American Economic Review* 95, 25-49.

Shimer, R., 2010. Labor markets and the business cycle. Princeton University Press.

Shimer, R., 2010. Wage rigidities and jobless recoveries. Manuscript.

Sveen, T., Weinke, L., 2007. New Keynesian Perspectives on Labor Market Dynamics. *Journal of Monetary Economics* 55, 921-930.

Sveen, T., Weinke, L., 2009. Inflation and labor market dynamics revisited. *Journal of Monetary Economics* 56, 1096-1100.

Silva, J.I., Toledo, M., 2009, Labor turnover costs and the cyclical behavior of vacancies and unemployment. *Macroeconomic Dynamics* 13, 76-96.

Smets, F., Wouters, R., 2003. An estimated dynamic stochastic general equilibrium model of the Euro-area, *Journal of the European Economic Association* 1, 1123-1175.

Smets, F., Wouters, R., 2007. Shocks and frictions in US business cycles: a Bayesian DSGE approach, *American Economic Review* 97, 586-606.

Tasci, M., 2010. The ins and outs of unemployment in the long run: a new estimate for the natural rate? Federal Reserve Bank of Cleveland working paper 10-17.

Trigari, A., 2006. The role of search frictions and bargaining for inflation dynamics. IGIER Working Paper No. 304.

Trigari, A., 2009. Equilibrium unemployment, job flows and inflation dynamics. *Journal of Money, Credit and Banking* 41, 1-33..

Yashiv, E., 2000. The determinants of equilibrium unemployment. *American Economic Review* 90, 1297-1322.

Yashiv, E., 2006. Evaluating the performance of the search and matching model. *European Economic Review* 50(4), 909–936

Walsh, C., 2005. Labor market search, sticky prices and interest rate rules. *Review of Economic Dynamics* 8, 829-849.

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
Job destruction rate	ρ	0.085
Elasticity of matches to unemp.	σ	0.4
Probability to fill a vacancy within a quarter	q	0.7000
Exogenous spending/output ratio	g/y	0.2000
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	$V = \frac{\rho N}{q}$
Vacancy posting cost	$\phi_V = \frac{(\phi_V V)}{V}$
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	$\frac{c}{y} = \frac{1}{\epsilon_g} - \phi_V V - \frac{i}{y}$
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	$\frac{\widetilde{w}N}{y} = \xi(1-\alpha) - (1-\beta\chi)\frac{\phi_V}{q}N$
Bargaining power	$\eta = \frac{1-\tau}{\vartheta-\tau}$ where $\vartheta \equiv \frac{\xi(1-\alpha)+\beta\chi s\frac{\phi_V}{q}N}{\frac{\widetilde{w}N}{y}}$
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	$\sigma_\theta = \left[(1+\beta\varsigma)\phi_P\right]\sigma_{\theta^*}$
Autocorrelation of (non-rescaled) bargaining power shock	$\rho_\eta = \rho_{\eta^*}$
Std dev of (non-rescaled) bargaining power shock	$\sigma_\eta = (1-\eta)\sigma_{\eta^*}$

Table 3: Priors and posteriors of structural parameters

			Posterior		
		Priors	5%	Median	95%
Vacancy cost/output ratio	$1000\phi_V V$	IGamma (5,1)	2.48	2.85	3.31
Habit in consump.	h	Beta (0.7,0.1)	0.62	0.67	0.70
Invest. adj. cost	ϕ_I	IGamma (5,1)	3.00	3.63	4.50
Capital ut. cost	ϕ_{u2}	IGamma (0.5,0.1)	0.43	0.57	0.78
Price adjust. cost	ϕ_P	IGamma (50,20)	48.4	59.2	72.6
Wage adjust. cost	ϕ_W	IGamma (50,20)	149.2	237.3	341.5
Wage indexation	ϱ	Beta (0.5,0.2)	0.84	0.92	0.98
Interest smoothing	ρ_r	Beta (0.7,0.1)	0.39	0.55	0.68
Resp. to inflation	ρ_π	IGamma (1.5,0.2)	1.62	1.78	2.00
Resp. to growth	ρ_y	IGamma (0.5,0.1)	0.38	0.46	0.59

Table 4: Priors and posteriors of shock parameters

		Prior	Posterior distributions		
		distribution	5%	Median	95%
Technology growth	ρ_z	Beta (0.3,0.1)	0.20	0.26	0.33
	$100\sigma_z$	IGamma (0.1,3)	1.18	1.27	1.35
Monetary policy	ρ_{mp}	Beta (0.5,0.2)	0.38	0.58	0.76
	$100\sigma_{mp}$	IGamma (0.1,3)	0.19	0.21	0.22
Investment	ρ_μ	Beta (0.5,0.2)	0.75	0.79	0.84
	$100\sigma_\mu$	IGamma (0.1,3)	5.85	6.90	8.09
Risk-premium	ρ_b	Beta (0.5,0.2)	0.63	0.71	0.80
	$100\sigma_b$	IGamma (0.1,3)	0.53	0.78	1.17
Matching efficiency	ρ_ζ	Beta (0.5,0.2)	0.94	0.96	0.98
	$100\sigma_\zeta$	IGamma (0.1,3)	2.84	3.06	3.29
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	0.13
Bargaining power (rescaled)	ρ_{η^*}	Beta (0.5,0.2)	0.09	0.18	0.29
	$100\sigma_{\eta^*}$	IGamma (0.1,3)	148.2	234.8	350.7
Government spending	ρ_g	Beta (0.7,0.1)	0.91	0.93	0.95
	$100\sigma_g$	IGamma (0.1,3)	0.55	0.59	0.63

Table 5: Variance decomposition of baseline model*

	Output	Unemp.	Vacancy	Inflation	Interest rate
Technology	31.3	12.9	14.7	15.4	3.3
Monetary	3.4	3.0	3.6	4.9	3.2
Investment	23.0	26.4	26.8	54.8	73.5
Matching	**0.4**	**9.4**	**6.4**	**0.1**	**0.0**
Risk-premium	16.6	11.6	16.2	13.9	16.1
Markup	7.9	22.9	15.0	6.6	1.6
Bargaining	3.1	10.6	6.7	2.6	0.7
Fiscal	14.4	3.1	10.7	0.7	1.5

* The variance decomposition is computed at the posterior mode.

Table 6: Variance decomposition of model with post-match costs*

	Output	Unemp.	Vacancy	Inflation	Interest rate
Technology	29.3	16.3	14.4	16.2	2.5
Monetary	3.1	1.8	2.35	2.0	4.4
Investment	27.5	30.9	27.4	56.2	74.0
Matching	**0.0**	**0.0**	**12.7**	**0.0**	**0.0**
Risk-premium	13.7	9.1	10.9	15.3	16.5
Markup	9.7	27.2	17.5	5.9	0.9
Bargaining	3.2	12.7	7.7	2.2	0.3
Fiscal	13.9	1.9	7.0	2.3	1.4

* The variance decomposition is computed at the posterior mode.

Table 7: Log marginal likelihood

Baseline model	Model with post-match costs
−2833.3	−2846.5

Figure 1: Unemployment rate.

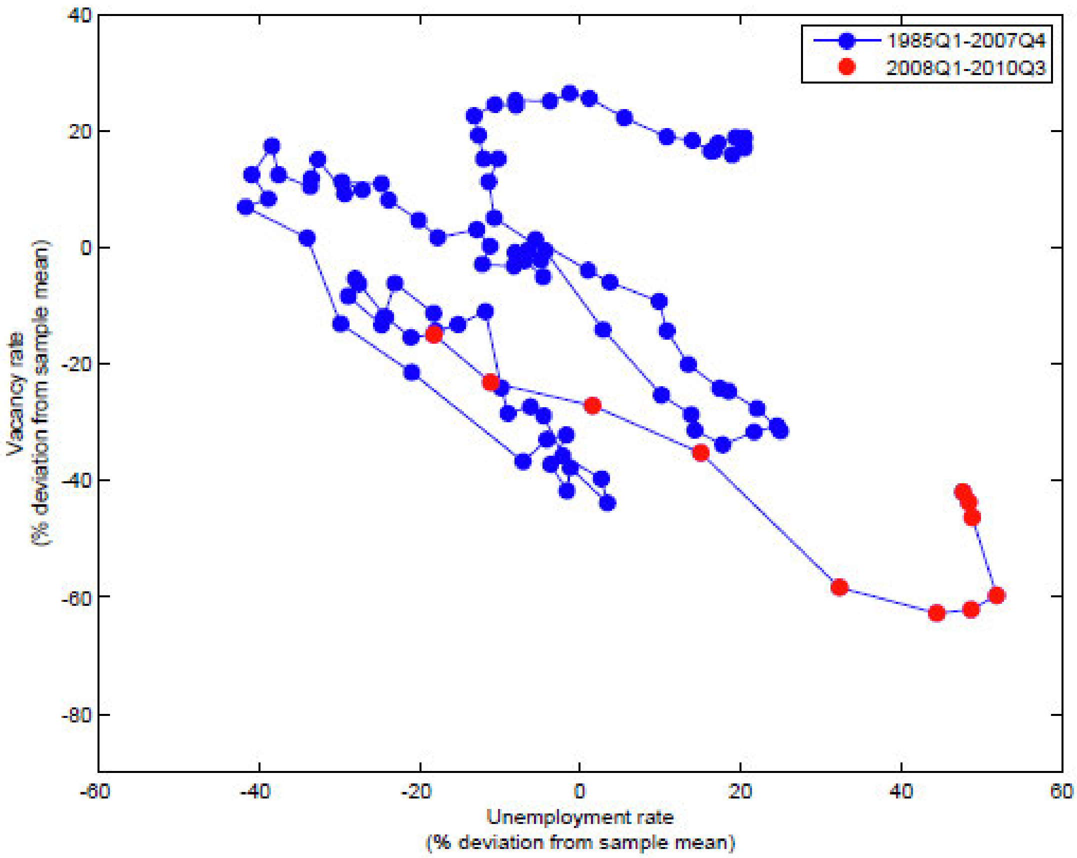

Figure 2: Beveridge curve 1985:Q1 - 2010:Q3.

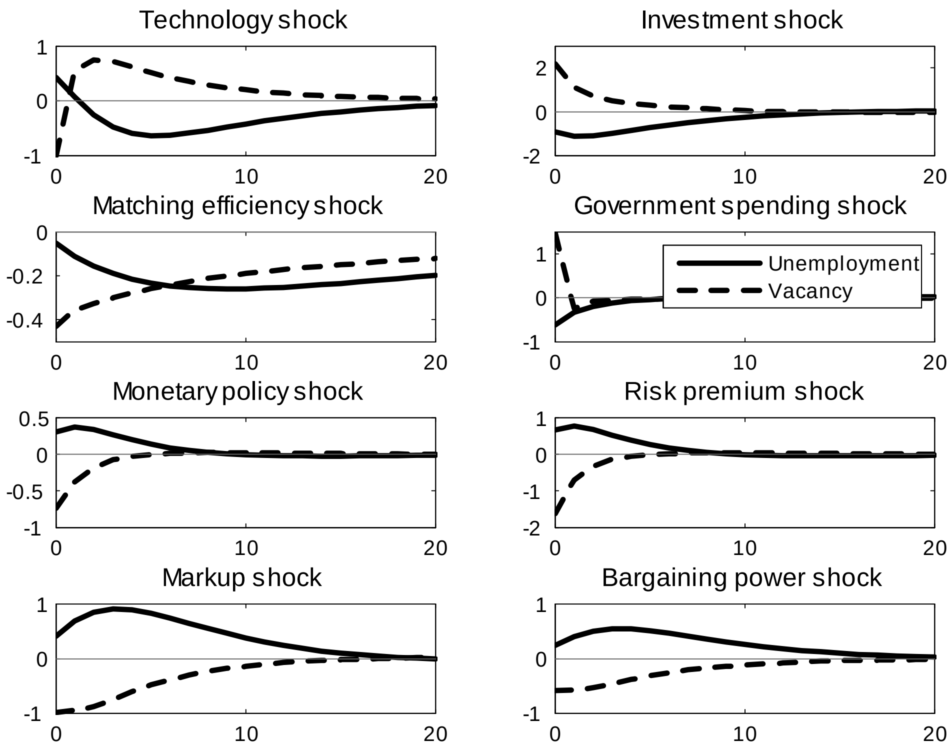

Figure 3: Impulse responses of the unemployment rate and the vacancy rate. The responses are expressed in percentage points. The size of each shock is one standard deviation.

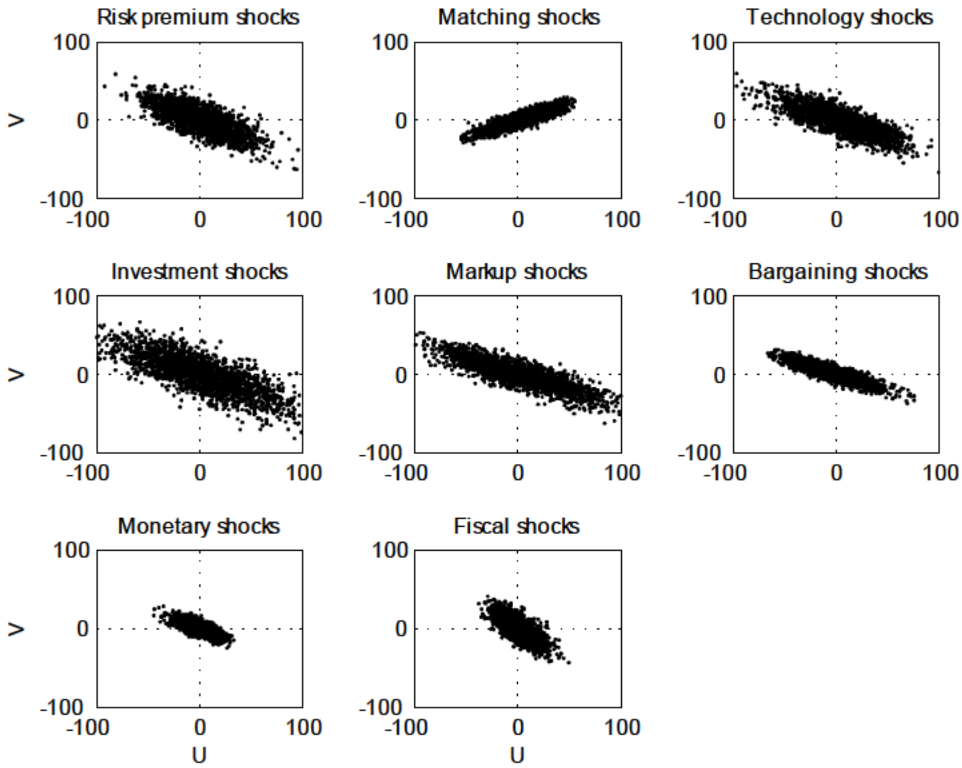

Figure 4: Theoretical Beveridge curves conditional on each disturbance. Each panel shows 1000 simulated observations of vacancies and unemployment conditional on one particular shock. The vertical axis represents the vacancy rate (in percent deviation from mean) while the horizontal axis represents the unemployment rate (in percent deviation from mean).

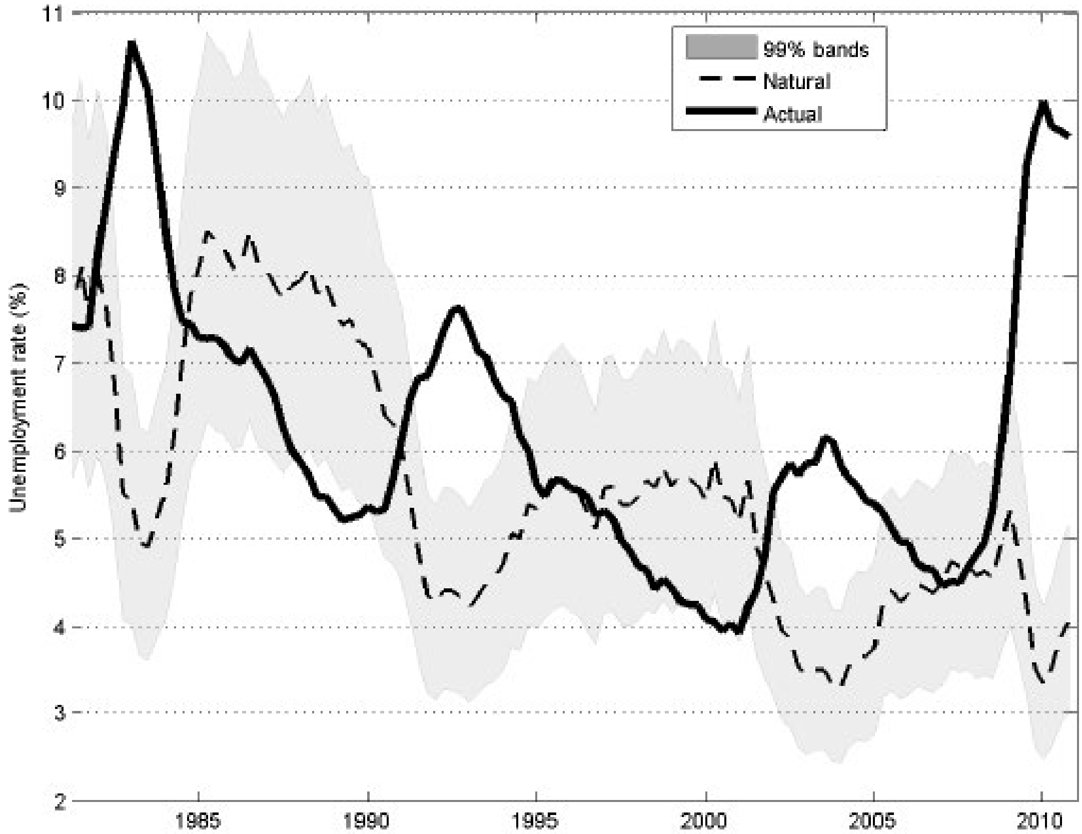

Figure 5: The actual rate and the natural rate of unemployment.

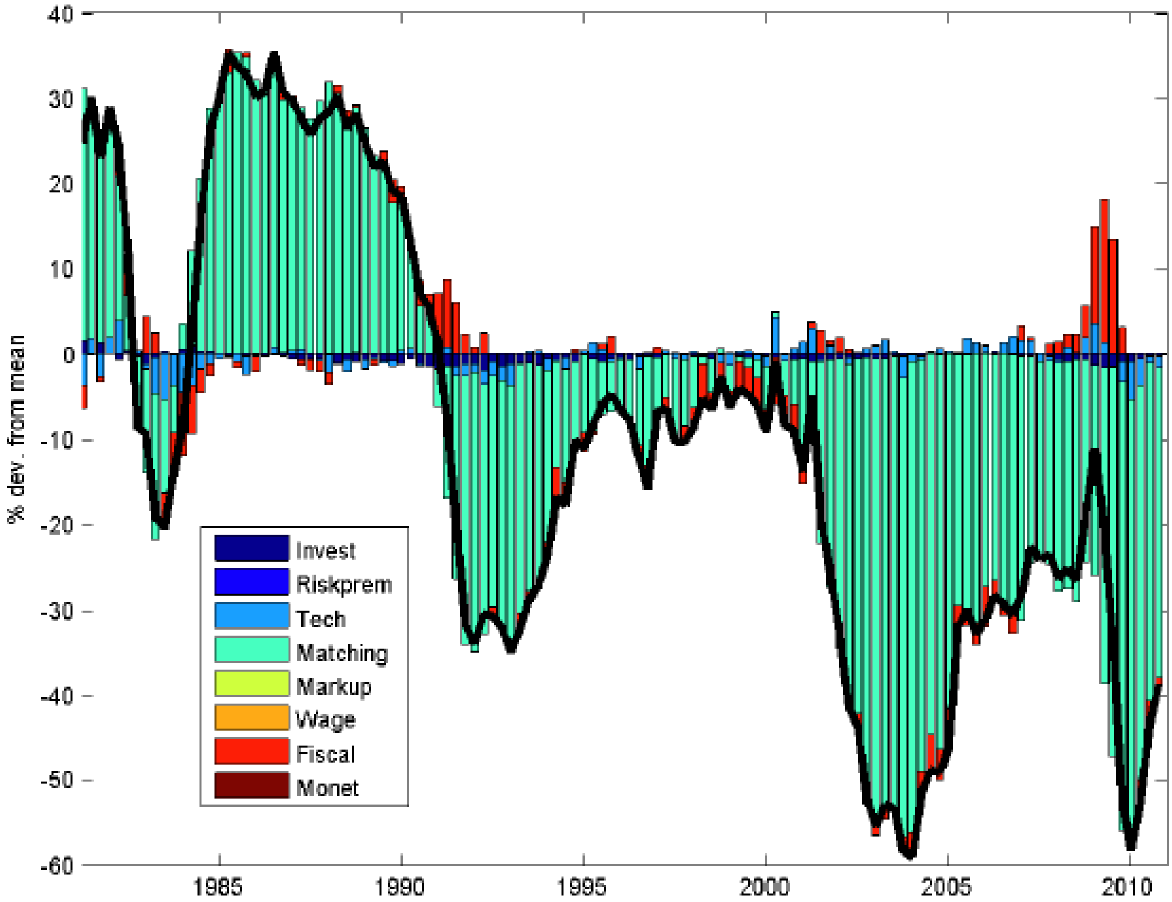

Figure 6: Historical decomposition of the natural rate of unemployment, expressed in percentage deviation from the sample mean.

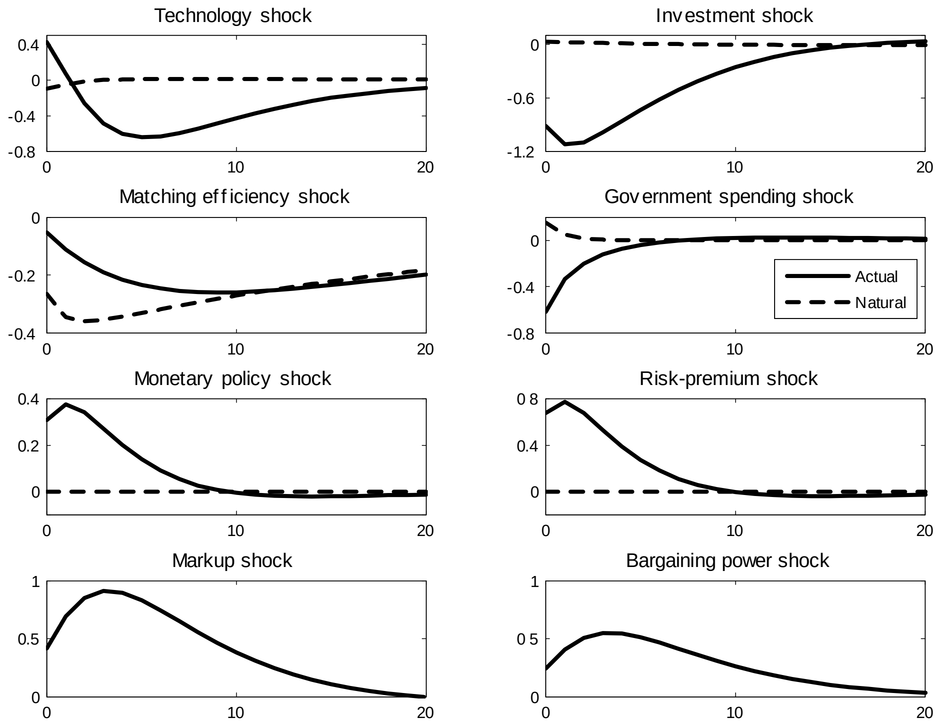

Figure 7: Impulse responses of the actual rate and the natural rate of unemployment. The responses are expressed in percentage points. The size of each shock is one standard deviation.

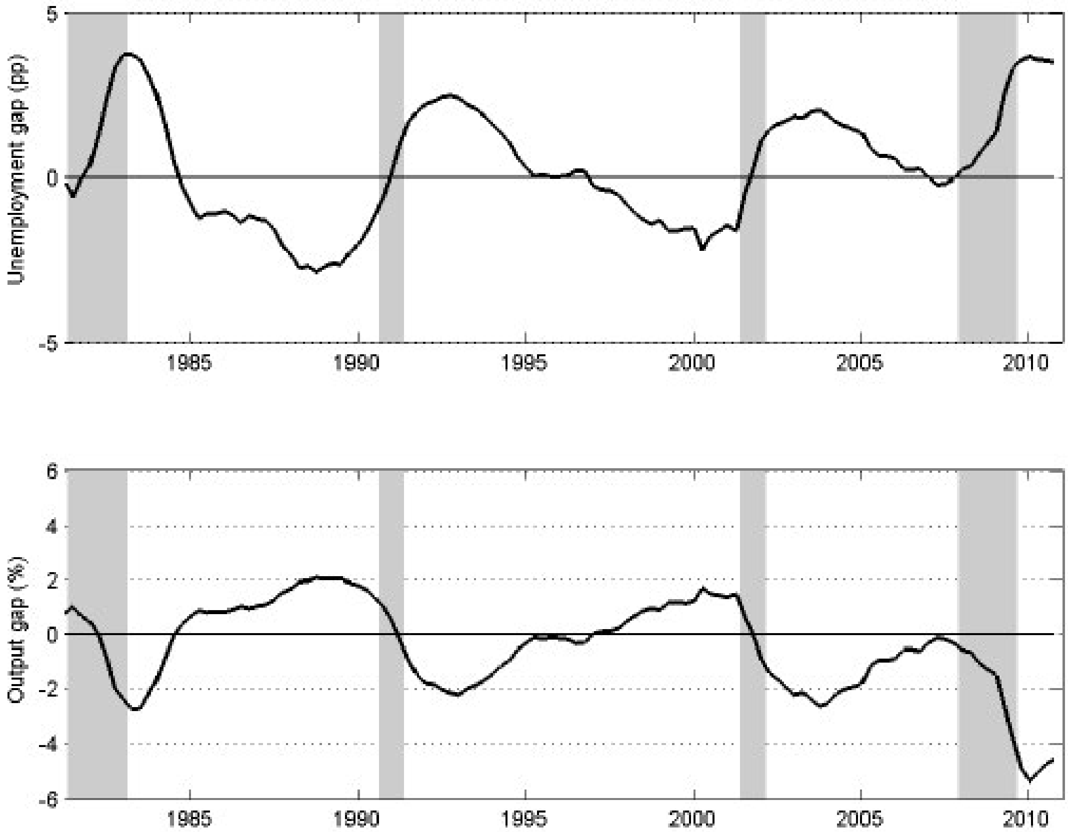

Figure 8: The unemployment gap (top panel) and the output gap (bottom panel). Shaded area mark the NBER recessions.

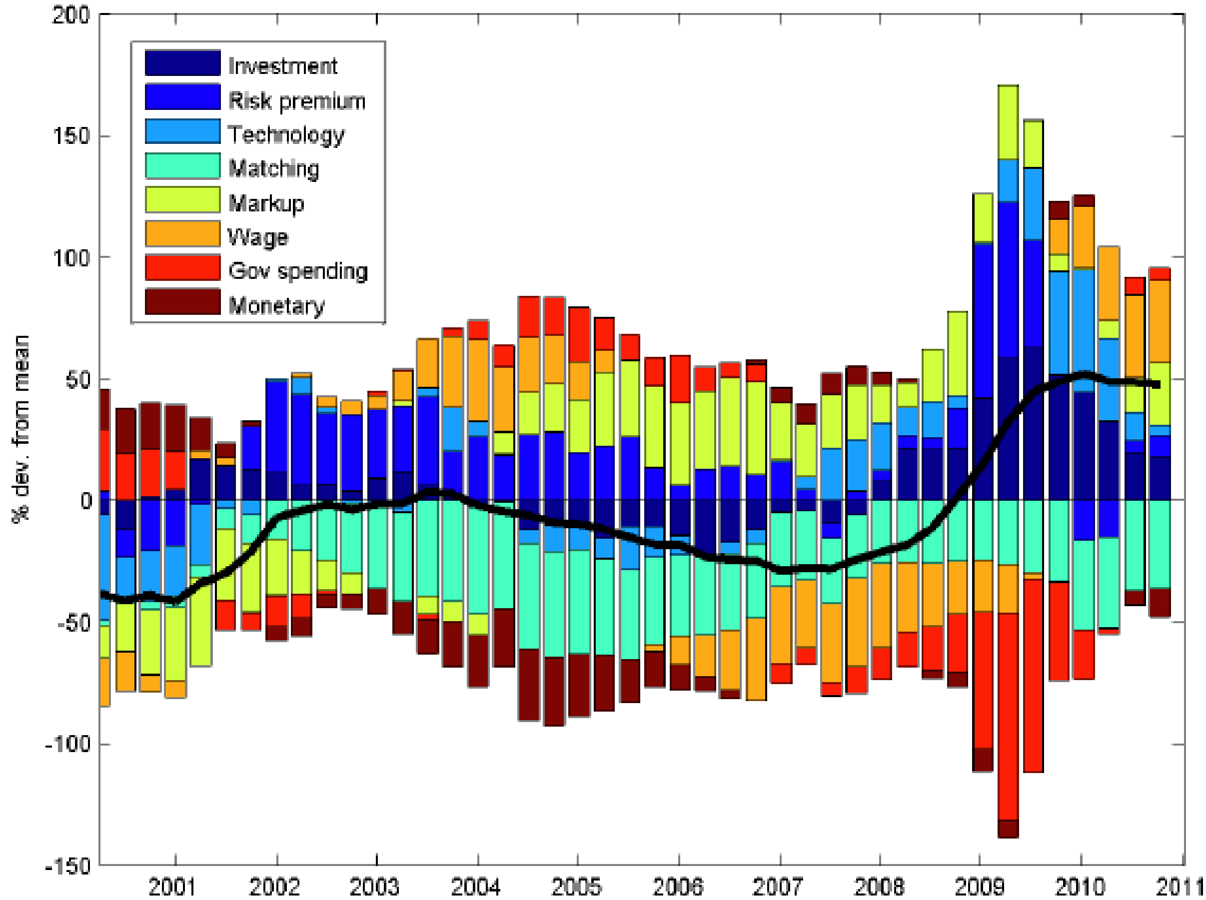

Figure 9: Historical decomposition of the unemployment rate, expressed in percentage deviation from the sample mean.

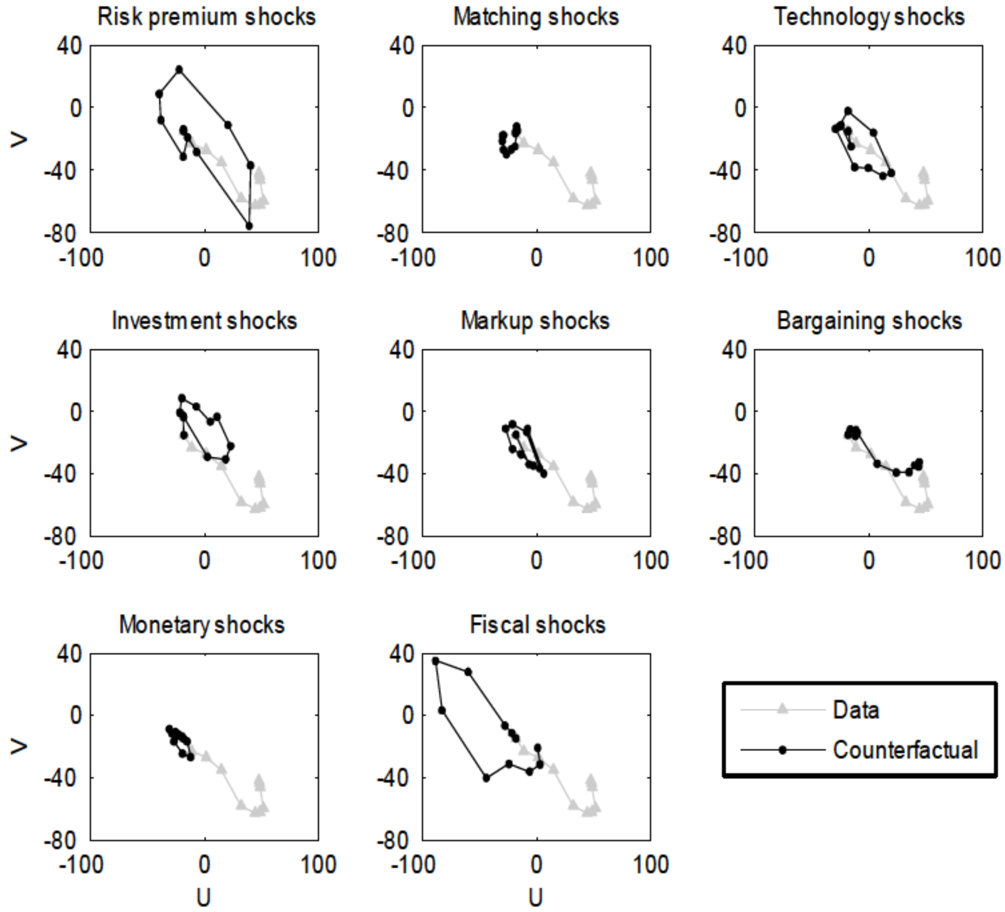

Figure 10: Actual Beveridge curve versus counterfactual Beveridge curves conditional on one shock at a time, over the period 2008:Q1 - 2010:Q3. In each panel, the vertical axis represents the vacancy rate (in percent deviation from mean) while the horizontal axis represents the unemployment rate (in percent deviation from mean). Grey triangles depict the actual data. Black dots depict the counterfactual.

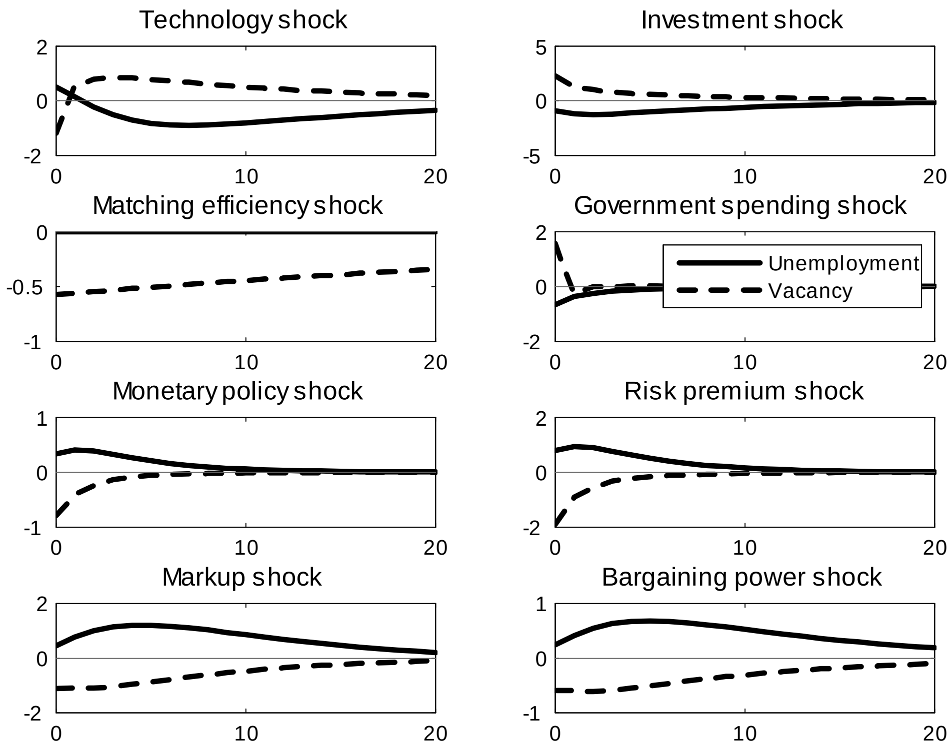

Figure 11: Impulse responses of the unemployment rate and the vacancy rate in the model with post-match hiring costs. The responses are expressed in percentage points. The size of each shock is one standard deviation.

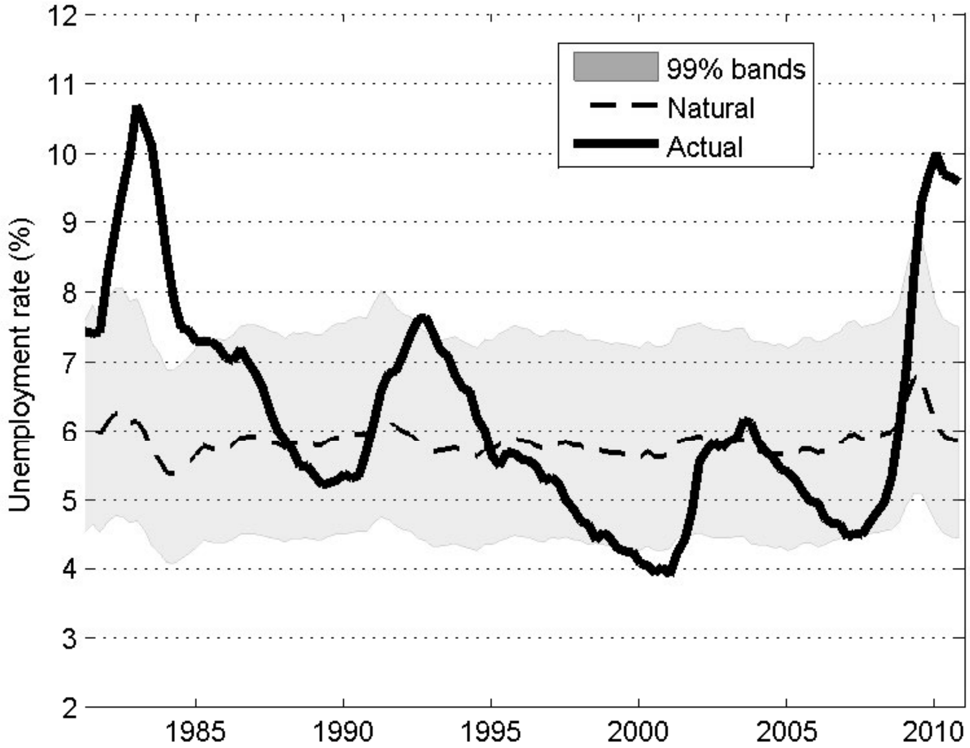

Figure 12: The actual rate and the natural rate of unemployment in the model with post-match hiring costs.

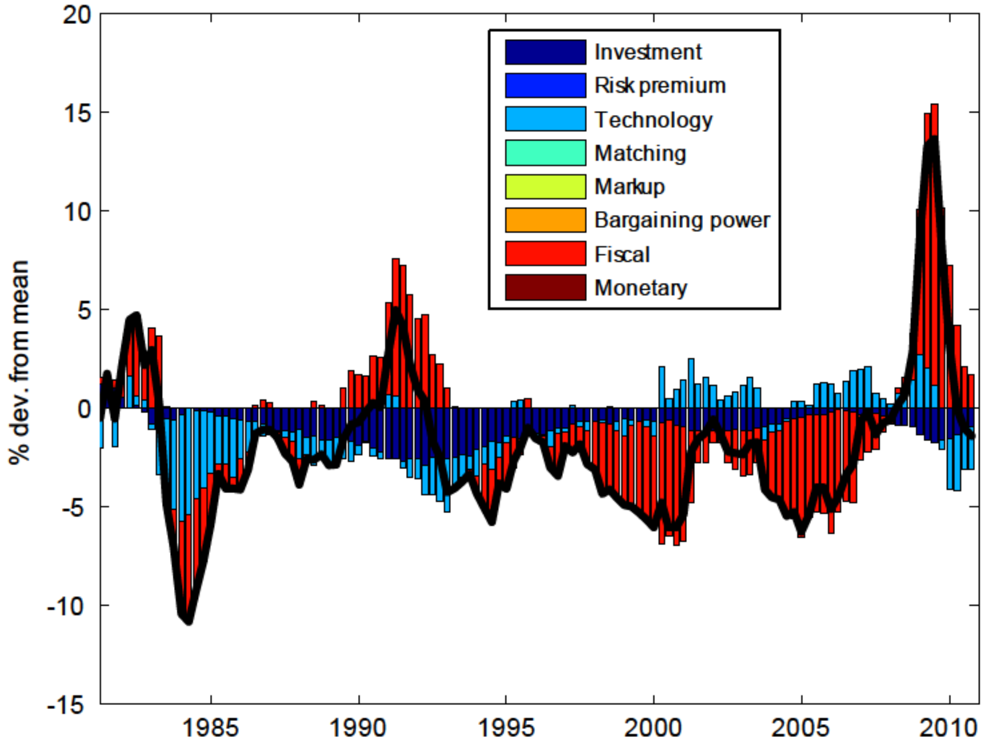

Figure 13: Historical decomposition of the natural rate of unemployment in the model with post-match hiring costs. The decomposition is expressed in percentage deviation from the sample mean.

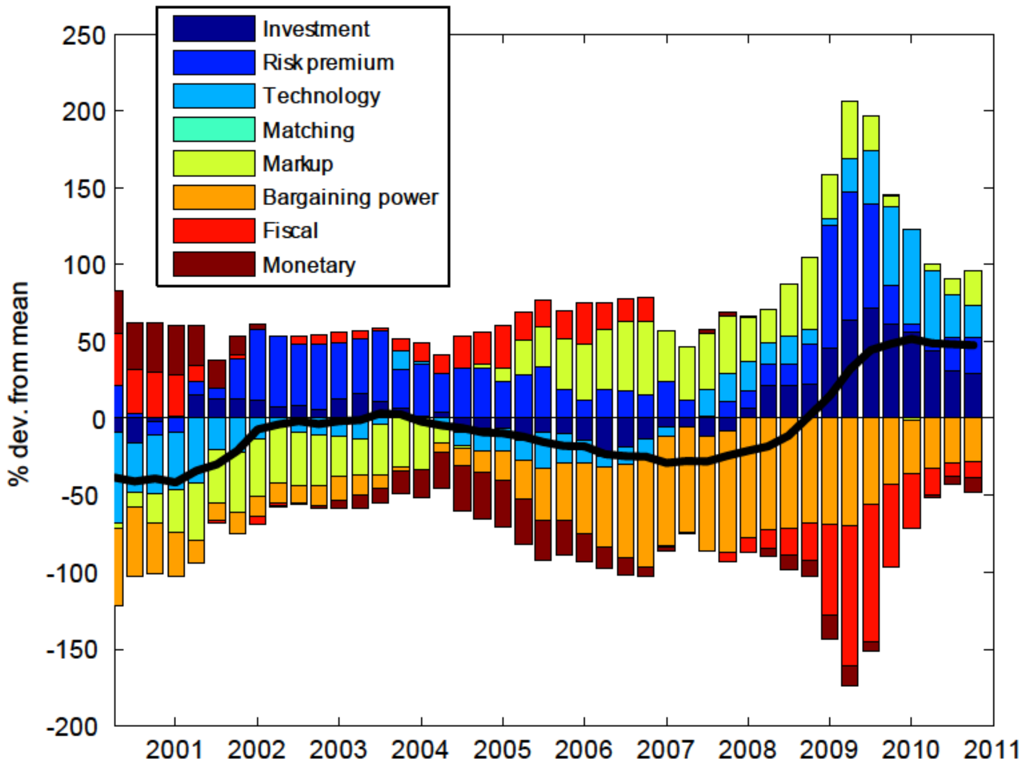

Figure 14: Historical decomposition of the unemployment rate in the model with post-match hiring costs. The decomposition is expressed in percentage deviation from the sample mean.

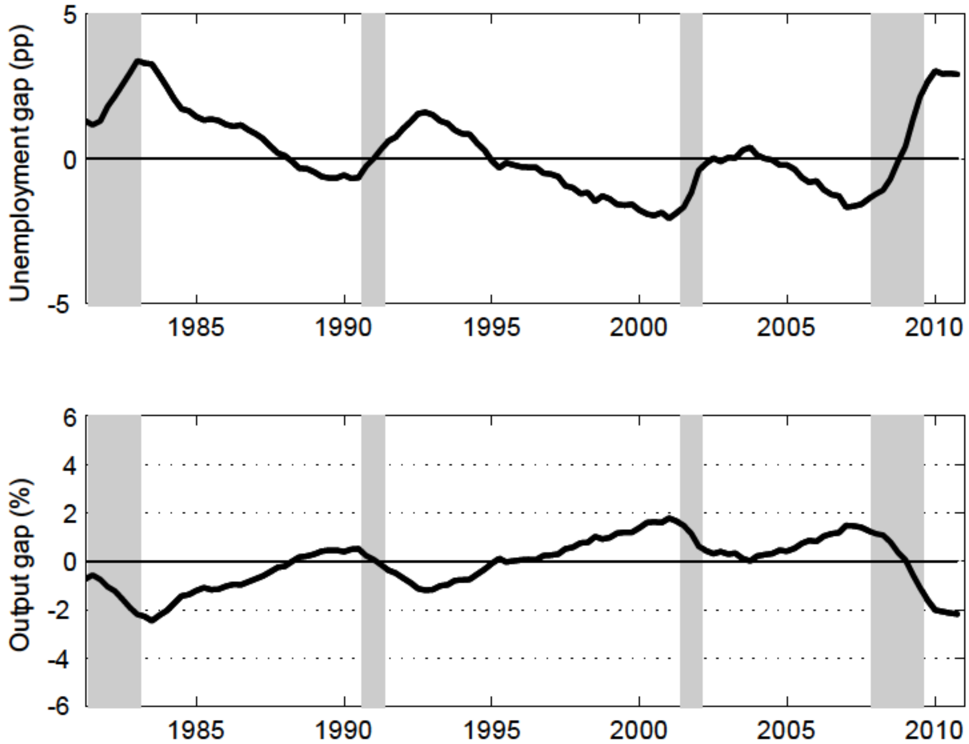

Figure 15: The unemployment gap (top panel) and the output gap (bottom panel) in the model with post-match hiring costs. Shaded area mark the NBER recessions.