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Structural factors, unemployment and monetary policy: the useful role of the natural rate of interest

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Structural Factors, Unemployment and Monetary Policy: the Useful Role of the Natural Rate of Interest[*]

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Abstract

We study the role of monetary policy in response to variations in unemployment due to structural factors, modeled as exogenous changes in matching efficiency and in the size of the labor force. We find that monetary policy should play a role in such a scenario. Both negative shocks to the matching efficiency and negative shocks to the labor force increase inflation, thus calling for an increase in the interest rate when policy is conducted following Taylor-type rules. However, the natural rate of interest declines in response to both shocks. The optimal Ramsey policy prescribes small deviations from price stability and lowers the interest rate, thus tracking the natural rate of interest in response to both shocks. Structural factors in the labor market may have contributed to the recent decline in the natural rate of interest in the US.

Keywords: Optimal Monetary Policy; Taylor Rules; Natural Rate of Interest; Natural Rate of Unemployment; Labor Force Shocks. *JEL* codes: E32

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1 Introduction

In the aftermath of the Great Recession, a number of policymakers have attributed unemployment's slow recovery to structural factors (cf. Kocherlakota 2010; Lacker 2012; and Plosser 2012). Partial support for this view has emerged from a series of recent studies showing that structural factors account for a small but non-negligible share of unemployment dynamics (cf. Barnichon and Figura, 2015, Elsby, Hobijn, and Sahin, 2010, and Sahin, Song, Topa, and Violante, 2014). In such a scenario, the conventional wisdom on the role of monetary policy is well summarized by the following quote from Plosser (2012): *"You can't change the carpenter into a nurse easily, and you can't change the mortgage broker into a computer expert in a manufacturing plant very easily. Eventually that stuff will work itself out...Monetary policy can't retrain people. Monetary policy can't fix those problems."* More recently, the steep decline in the US labor force participation rate has also been mentioned as an important structural factor driving labor market dynamics that should not be addressed by monetary policy (cf. Bullard, 2014).

In this paper we reconsider the role of monetary policy in the context of a simple New Keynesian model with search frictions in which unemployment is driven by matching efficiency shocks and by shocks to the size of the labor force. We focus on these two shocks as, we believe, they capture the bulk of unemployment fluctuations induced by structural factors or, put differently, as these shocks are arguably the main drivers of the natural rate of unemployment. This view is supported by some recent empirical evidence. On the one hand, matching efficiency shocks are the dominant drivers of the natural rate of unemployment in the estimated Dynamic Stochastic General Equilibrium (DSGE) model by Furlanetto and Groshenny (2016b). On the other hand, labor supply factors, though not considered in recent analysis of the natural rate of unemployment, turn out to be important drivers of unemployment in the long run in the Vector Autoregression (VAR) model estimated by Foroni, Furlanetto and Lepetit (2015). While all shocks (and not only shocks originating in the labor market) are supposed to affect the natural rate of

unemployment and while other shocks (like shocks to unemployment benefits) may also be used to summarize the dynamics induced by structural factors, we believe that the two selected shocks are the best candidates to develop our argument.

In contrast with the conventional view, we find that monetary policy should react to variations in unemployment due to structural factors. However, the kind of response depends on the monetary policy framework. Both negative matching efficiency shocks and negative shocks to the labor force call for an increase in the nominal interest rate when policy is conducted following a Taylor-type rule. In contrast, the optimal Ramsey monetary policy prescribes a reduction in the interest rate, thus tracking the natural rate of interest, which declines on impact of both shocks.

We proceed in three steps. First, we investigate the transmission mechanism of the shocks when the monetary policy authority reacts to the state of the economy following a Taylor-type rule responding to inflation and output growth (in the presence of interest rate smoothing). A reduction in matching efficiency increases hiring costs for firms and creates inflationary pressures, an increase in unemployment and a decrease in output. An increase in inflation calls for an increase in the interest rate when monetary policy follows a Taylor-type rule, despite the recessionary effects of the shocks on output. Thus, monetary policy responds to an increase in unemployment even though this increase is due to structural factors. Notably, the same effects are at play in response to a negative shock to the labor force, although in this case unemployment decreases.

In a second step we compute the optimal Ramsey monetary policy that sets the interest rate in order to limit the inefficiencies due to monopolistic competition, sticky prices and search frictions in the labor market. For a broad range of parameterizations, it is optimal to lower the nominal interest rate in response to both shocks. The reason is that the optimal policy calls only for mild deviations from price stability and thus tracks somewhat closely the natural rate of interest, i.e. the counterfactual level of the interest rate that emerges in the absence of nominal rigidities. Notably, the natural rate of interest declines in our model, since search frictions induce a hump-shaped response in employment that emerges independently from the degree of nominal rigidities and that requires an increase in the natural rate of interest to induce hump-shaped dynamics also in consumption.

Thus, while a Taylor-type rule moves the policy rate and the natural rate in opposite directions, the optimal policy moves them in the same direction.

Finally, in a third step we introduce a time-varying intercept (given by the natural rate of interest) in the Taylor-type rule. Such a rule approximates relatively well the dynamics obtained under optimal policy, thus confirming the importance of the natural rate of interest in the formulation of the monetary policy strategy, as also highlighted by Barsky, Justiniano and Melosi (2014) and Canzoneri, Cumby and Diba (2015).

This paper contributes to the literature on optimal monetary policy in the presence of labor market frictions. Cooley and Quadrini (2004) consider the optimal policy in response to productivity shocks in a model with search frictions and a cost channel. We use the methodology developed by Schmitt-Grohe and Uribe (2004) and applied by Faia (2009) to study technology and government spending shocks. While many papers have discussed the properties of matching efficiency shocks (cf. Andolfatto, 1996; Furlanetto and Groshenny, 2016a and 2016b; Justiniano and Michelacci, 2011), the optimal policy response to these disturbances is discussed only in Mileva (2013) where, however, the connection with the natural rate of interest is not explored.[1] Furthermore, the optimal policy response to shocks to the labor force has not been studied in the literature.

We also contribute to the growing literature on the natural rate of interest. The usefulness of this concept for monetary policy purposes has been highlighted by Barsky, Justiniano and Melosi (2014), Canzoneri, Cumby and Diba (2015), Orphanides and Williams (2002) and Woodford (2001). Curdia, Ferrero, Ng and Tambalotti (2015) find evidence that the Fed has responded to the natural rate of interest in its reaction function. Carvalho, Ferrero and Nechio (2016) discuss the link between demographic factors and real interest rates. In addition, several papers (cf. Hamilton, Harris, Hatzius and West, 2015; Laubach and Williams, 2015, and the references therein) document a decline in the nat-

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[1]Alternatively, Ravenna and Walsh (2011 and 2012) and Thomas (2008) use the linear quadratic approach based on a first order approximation of the competitive equilibrium conditions and on a second order approximation of the utility function. Those papers assume a non-distorted steady-state obtained by introducing appropriate subsidies and by imposing the Hosios (1990) condition at all states and times. Since we use the Ramsey approach, our steady state is distorted and we do not need to impose the Hosios condition. Furthermore, these papers consider demand, productivity and wage bargaining shocks but do not discuss shocks that have a large impact on the natural rate of unemployment (i.e. matching efficiency and labor supply shocks).

ural rate of interest in the aftermath of the Great Recession. While many factors may have played a role, our paper shows that shocks originating in the labor market may also have contributed to this recent decline.

The paper proceeds as follows: Section 2 briefly describes the model, Section 3 presents our results when monetary policy is conducted following a Taylor-type rule, Section 4 proposes the optimal monetary policy exercise and Section 5 concludes.

2   The Model

The model economy consists of a representative household, a continuum of intermediate good-producing firms, a continuum of monopolistically competitive retail firms, and monetary and fiscal authorities that set monetary and fiscal policy, respectively. The model is purposely simple and largely builds on Ravenna and Walsh (2008), Faia (2009), Furlanetto and Groshenny (2016a) and Kurozumi and Van Zandweghe (2010).

The Representative Household   The representative household is a large family, made up of a continuum of individuals of measure L_t that represents the size of the labor force and evolves exogenously following an autoregressive process

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

where L denotes the steady-state value of the labor force (that is set equal to 1), while ρ_L measures the persistence of the shock, and ε_{Lt} is $i.i.d.N(0, \sigma_L^2)$. Family members are either working or searching for a job. Following Merz (1995), we assume that family members pool their income and share the same level of consumption.

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

Each period, N_t family members are employed. Each employee works a fixed amount of hours and earns the nominal wage W_t. The remaining $(L_t - N_t)$ family members are

unemployed and each receives nominal unemployment benefits b, financed through lump-sum nominal taxes T_t. Unemployment benefits b are proportional to the steady-state nominal wage: $b = \tau W$. The representative household owns retail firms and receives each period the accumulated profits (D_t).

The family's period t budget constraint is given by

$$P_t C_t + \frac{B_t}{R_t} \leq B_{t-1} + W_t N_t + (L_t - N_t) b - T_t + D_t, \tag{2}$$

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

The family's lifetime utility is described by

$$E_t \sum_{s=0}^{\infty} \beta^s \ln C_{t+s}, \tag{3}$$

where $0 < \beta < 1$.

Intermediate Good-Producing Firms Each intermediate good-producing firm $i \in [0,1]$ enters in period t with a stock of $N_{t-1}(i)$ employees. Following Ravenna and Walsh (2008), new matches become productive in the period. Before production starts, $\rho N_{t-1}(i)$ old jobs are destroyed. The job destruction rate ρ is constant. The workers who have lost their jobs start searching immediately and can possibly still be hired in period t with a probability given by the job-finding rate. 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 $M_t(i) = Q_t V_t(i)$. The term $V_t(i)$ denotes vacancies posted by firm i in period t and Q_t is the aggregate probability of filling a vacancy, defined as $Q_t = \frac{M_t}{V_t}$.

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

$$N_t = (1 - \rho) N_{t-1} + M_t. \tag{4}$$

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

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matching function

$$M_t = E_t S_t^\sigma V_t^{1-\sigma}, \tag{5}$$

where S_t denotes the pool of job seekers in period t

$$S_t = L_t - (1 - \rho) N_{t-1}, \tag{6}$$

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

$$\ln E_t = (1 - \rho_E) \ln E + \rho_E \ln E_{t-1} + \varepsilon_{Et}, \tag{7}$$

where E denotes the steady-state value of the matching efficiency, while ρ_E measures the persistence of the shock, and ε_{Et} is $i.i.d.N\left(0, \sigma_E^2\right)$. Note that the pool of searchers is determined by exogenous fluctuations in the labor force, unemployed from the previous period and workers that separated before production starts. For simplicity, employed workers do not search in our model (for an extension with on-the-job search, cf. Krause and Lubik, 2006).

The job-finding rate (F_t) is defined as $F_t = \frac{M_t}{S_t}$ and aggregate unemployment is $U_t \equiv L_t - N_t$. Since newly hired workers are immediately productive, the firm can adjust its output instantaneously through variations in the workforce. However, firms face hiring costs measured in terms of the finished good $(H_t(i))$ that represent the cost of posting vacancies and follow a standard linear specification

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

The parameter ϕ_N governs the magnitude of the hiring cost.

Each period, firm i uses $N_t(i)$ employees to produce $Y_t(i)$ units of intermediate good

i according to the constant-returns-to-scale technology described by

$$Y_t(i) = N_t(i).$$

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

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

(10)

where Λ_t represents the marginal utility of consumption. Since the firm is owned by the representative household, profits are discounted using the household's discount factor.

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

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

(11)

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

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

(12)

The firm's surplus in real terms is given by

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

(13)

Retail Firms   There is a continuum of retail goods-producing firms indexed by $j \in [0,1]$ that transform the intermediate good into a final good $Y_t^f(j)$ that is sold in a monopolistically competitive market at price $P_t(j)$. Cost minimization implies that the real marginal cost is equal to the real price of the intermediate good (Z_t) that is common

across firms. Demand for good j is given by $Y_t^f(j) = C_t(j) = (P_t(j)/P_t)^{-\theta}C_t$, where θ represents the elasticity of substitution across final goods. Firms choose their price subject to a scheme in which every period a fraction α is not allowed to re-optimize, whereas the remaining fraction $1 - \alpha$ optimally chooses its price $(P_t^*(j))$ by maximizing the discounted sum

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

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

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

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

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

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

The government budget constraint takes the form

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

Aggregate Resource Constraint   The aggregate resource constraint reads

$$Y_t = Y_t^f + H_t^k, \tag{18}$$

where $Y_t^f = \int_0^1 Y_t^f(j) \, dj$. Notice that market clearing for each retail good implies that $Y_t^f(j) = C_t(j)$. Aggregating across firms, we obtain $Y_t^f = \Gamma_t C_t$. Price dispersion across

firms $\left(\Gamma_t \equiv \int_0^1 (P_t(j)/P_t)^{-\theta} dj \right)$ drives a wedge between final output and consumption.

Parameterization   Our parameterization is based on the US economy and is summarized in Table 1.[2] A first set of parameters is taken from the literature on monetary business cycle models. The discount factor is set at $\beta = 0.99$, the elasticity of substitution across final goods at $\theta = 11$, thus implying a steady-state markup of 10 percent. The parameters in the monetary policy rule are $\rho_r = 0.8$, $\rho_\pi = 1.5$, $\rho_y = 0.5$. The average degree of price duration is four quarters, corresponding to $\alpha = 0.75$.

A second set of parameter values is taken from the literature on search and matching in the labor market. The degree of exogenous separation is set at $\rho = 0.085$, while the steady-state value of the unemployment rate is $U = 0.06$. The elasticity on unemployment in the matching function is $\sigma = 0.6$, in the middle of the interval suggested by Petrongolo and Pissarides (2001). In the absence of convincing empirical evidence on the value for the bargaining power parameter η, we set it equal to 0.6 to satisfy the Hosios condition but we will consider a broad range of values in the optimal policy exercise. The vacancy filling rate Q is set equal to 0.70. We follow Blanchard and Galí (2008) and we set ϕ_N such that steady-state hiring costs are equal to one percent of steady-state output. The value of unemployment benefits is derived from the steady-state conditions. These choices are common in the literature and avoid the indeterminacy issues that are widespread in this kind of model, as shown by Kurozumi and Van Zandweghe (2010) among others. Finally, the degree of persistence for the matching efficiency process is set at 0.90, in keeping with the estimate in Furlanetto and Groshenny (2016b). We adopt the same value for the persistence of the shock to the labor force.

The log-linear first-order conditions are listed in Table 2. Lower scale variables stand for the capital variables expressed in log-deviation from the steady state. The non-linear equilibrium conditions are listed in the Appendix together with the description of the steady-state.

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[2]Our objective is not to calibrate parameters to match moments in the model and in the data. Such an exercise would require the unrealistic assumption that the business cycle is driven only by shocks originating in the labor market. Less ambitiously, our objective is to illustrate some simple economic mechanisms under a plausible parameterization that is standard in the literature.

3 Results under a Taylor-type rule

In this section we describe the macroeconomic effects of the two labor market shocks when the monetary policy authority follows a Taylor-type rule as in (16).

Matching efficiency shocks To set the scene for the policy analysis, we plot in Figure 1 impulse responses to a negative matching efficiency shock in a version of our baseline model with flexible prices (dashed lines). When matching efficiency declines, the probability of filling a vacancy drops and hiring becomes more expensive since more vacancies have to be posted to hire a worker. In response to the increase in hiring costs, firms hire fewer workers and, given the assumption of instantaneous hiring, employment and output decline on impact of the shock while unemployment increases. Finally, higher hiring costs lead to an increase in prices in order to maintain a constant real marginal cost, as is optimal under flexible prices. The solid lines in Figure 1 refer to the same model in the presence of sticky prices. In this case firms cannot increase prices optimally to restore profits impaired by the increase in costs. Prices increase less than in the flexible price case, the fall in aggregate demand is less pronounced and the contraction in hiring is more limited.

Thus far we have highlighted the transmission mechanism of a matching efficiency shock, as discussed in Furlanetto and Groshenny (2016a and 2016b). We now turn to the analysis of monetary policy, which constitutes the distinctive contribution of this paper. In our baseline model with sticky prices and a Taylor-type rule, higher inflation calls for an increase in the interest rate, whereas a decline in output calls for a reduction in the interest rate. Given the high coefficient in response to inflation in (16), the central bank chooses to tighten policy.[3] This result is somewhat counterintuitive because it prescribes to tighten policy in response to an increase in unemployment. Nevertheless, it follows naturally from the specification of the Taylor-type rule and shows that policy is not

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[3]The interest rate increase would be larger in the presence of a monetary policy rule responding to the output gap, with the output gap defined as the difference between output and its potential level, i.e. the counterfactual level of output that emerges in the absence of nominal rigidities. We use output growth in our baseline policy rule because the model-based output gap is usually radically different from estimates of the output gap used by central banks that assume a smooth trend as a measure of potential output. This discrepancy is even larger in the case of shocks originating in the labor market (like matching efficiency shocks and labor force shocks) which have a larger impact on potential than on actual output.

inactive as advocated by the conventional view described in the Introduction.

Before investigating whether such an outcome is desirable, we discuss the response of the natural rate of interest, defined as the counterfactual level of the interest rate emerging in a version of our baseline model with flexible prices. In Figure 1 we show that the response of the natural rate of interest to a negative matching efficiency shock is negative, thus highlighting a negative co-movement between the nominal interest rate (determined by the policy rule) and the natural rate of interest.

Why does the natural rate of interest decline? This is due to the hump-shaped dynamics generated by the shock. A negative matching efficiency shock reduces production, employment and consumption on impact and even further for a few quarters. The natural rate of interest declines on impact (and increases slightly after a few periods) to induce an hump-shaped profile in the consumption response, thus equalizing demand and supply in the goods market. Why then do the employment, output and consumption responses feature this hump-shaped profile? On impact of the shock, the increase in hiring costs leads to a marked decline in the creation of new matches that translates immediately into a decline in employment (given the assumption of instantaneous hiring), as shown by the solid lines in Figure 2. Notice that the maximum effect on hiring is always on impact, as is the case for the response of investment to a technology shock (cf. McCallum, 1989, among others).[4] The monotonic response in new hires, however, does not translate into a monotonic response in employment. Employment after one period will be lower than on impact as long as the number of new hires is lower than the number of separations in the previous period. This point can be seen by using (4) as follows:

$$N_{t+1} \leq N_t \iff M_{t+1} \leq \rho N_t \tag{19}$$

This condition is satisfied in our model since the decline in hiring is still sizeable for a few periods after the shock. The number of new hires is then back to its steady-state level and higher than the number of separations until employment reverts to its steady-state level.

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[4]McCallum (1989) shows that only with complete capital depreciation can the standard RBC model generate a hump-shaped response in output in response to a technology shock. Some form of capital adjustment costs is needed to generate a hump-shaped response in investment.

Since hiring costs account only for a minor share of production in our simple economy, the hump-shaped response in employment translates into a hump-shaped response in consumption, and this leads to a decline in the natural rate of interest on impact.

Condition (19) highlights two parameters that are key to generating hump-shaped dynamics: the separation rate (appearing on the right-hand side) and the persistence of the shock (which largely governs the persistence of the response in new hires). Just for the sake of argument, let us consider the case with complete separation ($\rho = 1$), represented by dashed lines in Figure 2. In this extreme but instructive case, the monotonic response of new hires is inherited by employment (the two variables now coincide) and the natural rate of interest increases on impact and converges monotonically to zero. This simple experiment shows how the long-term relationships between workers and firms generated by search frictions are key to generating hump-shaped dynamics. Furthermore, the assumption about the shock's persistence is not innocuous. In fact, the negative comovement between the policy rate and the natural rate materializes only when the shock is sufficiently persistent, as shown in Figure 3. When we lower the persistence to 0.5 (cf. dashed lines), the natural rate of interest exhibits a zero impact response, whereas the actual and the natural rate positively comove when the shock is iid (cf. solid lines). The intuition for this result is very simple: when the shock is short-lived, the decline in hiring is also short-lived so that the natural rate increases to induce a declining consumption and employment path.[5] However, while it is important to recognize that persistence matters, our baseline parameterization with high persistence finds strong empirical support in the estimated models by Furlanetto and Groshenny (2016b), Justiniano and Michelacci (2011) and Sala, Södeström and Trigari (2013).

Shocks to the labor force In Figure 4 we plot impulse responses to a negative shock to the labor force. As in the previous case, this is also a shock with a direct effect on the matching function: it reduces the number of searchers in the labor market and thus makes it more difficult to create a match. This leads to a decline in hiring and to contractionary effects on employment and output. There is one important difference,

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[5]Alternative specifications for the hiring cost (or employment adjustment costs) leading to a more persistent response of new hires may amplify the mechanism described here (cf. Yashiv, 2007).

however. In response to a decline in the labor force, unemployment falls as the decline in new hires is not sufficient to offset the decline in the labor force. Notably, this is also an inflationary shock and the interest rate determined by the policy rule and the natural rate of interest negatively comove, as in the case of matching efficiency shocks. Being a shock that directly affects the matching function, all our previous considerations on the hump-shaped dynamics in employment, consumption and output are confirmed in this context. We remark that, in contrast with the dynamics generated by matching efficiency shocks, a negative shock to the labor force moves the output gap and the unemployment gap in opposite directions. Moreover, the shock lowers at the same time the natural rate of interest and the natural rate of unemployment.

Carvalho, Ferrero and Nechio (2016) also emphasize that negative labor supply shocks (with a demographic interpretation) lead to a decline in the natural rate of interest in a model with overlapping generations. Our distinctive contribution is to highlight how a standard Taylor-type rule drives the actual and the natural rate of interest in opposite directions. In addition, we stress again the importance of search frictions in generating hump-shaped dynamics and a decline in the natural rate of interest. In a standard New Keynesian model with perfectly competitive labor markets, the natural rate would increase in response to a negative labor supply shock to the hours margin to generate a monotonic decline in consumption. Put differently, the negative impact of adverse labor supply factors on the natural rate of interest relies on the presence of search frictions.

While the role of search friction is crucial is driving the negative response of the natural rate of interest in response to labor market shocks, the same result does not apply to technology shocks that we briefly discuss here for the sake of completeness. We see in Figure 5 that a positive co-movement between the policy rate and the natural rate emerges when we simulate the effects of a negative technology shock in our model, independently of the degree of the shock's persistence (which is set in Figure 5 at 0.9, 0.5 or 0, as was the case in Figure 3). In fact, a technology shock drives a wedge between the hump-shaped employment dynamics generated by search frictions and the consumption dynamics, that are determined also by the monotonic process for technology. In such a case the natural rate of interest does not need to decline on impact, as was the case for the response to the

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two labor market shocks.[6] Search frictions have an impact on the transmission mechanism of technology shocks but these effects are not sufficient to induce a negative co-movement between the policy and the natural rate, that is instead easily obtained in response to shocks that have a direct effect on the matching function.

4   Optimal monetary policy

In the previous section we showed that the interest rate determined by the policy rule and the natural rate of interest move in opposite directions in response to a decline in matching efficiency and to a decline in the labor force. In this section we investigate the optimal monetary policy problem and we relate our results to the policy debate that has emerged in the US in recent years.

We compute the Ramsey plan following the approach proposed by Schmitt-Grohe and Uribe (2004) where the optimal equilibrium is obtained from the maximization of agents' welfare subject to the competitive equilibrium relations.

Our model features three frictions: monopolistic competition, price stickiness and search frictions in the labor market. As discussed in Faia (2009), monopolistic competition and the congestion externality implied by search frictions in the labor market call for deviations from price stability, whereas the distortion due to sticky prices is minimized when inflation is maintained at zero. The optimal monetary policy solves the trade-offs between different objectives and sets the only instrument available, i.e. the nominal interest rate, to minimize distortions.

In Figure 6 we plot impulse responses under optimal policy for our baseline model in which the Hosios condition undoes the effect of the search frictions (cf. dashed lines). In this case we notice mild deviations from price stability due to the presence of monopolistic competition (cf. Schmitt-Grohe and Uribe, 2004).[7] More generally, the optimal

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[6]Negative temporary technology shocks increase the natural rate of interest both in our model with search frictions and in the standard New Keynesian model with competitive labor markets. In contrast, negative shocks to the growth rate of technology reduce the natural rate of interest, as shown by Sims, (2012) and Christiano, Ilut, Motto and Rostagno (2010) among others. For a complete analysis of the effects of technology shocks in a model with flexible price and search frictions, cf. Mandelman and Zanetti (2014).

[7]When we increase the elasticity of substitution across different varieties to high values, the optimality

equilibrium tracks the flexible price allocation quite closely, although the allocation with fully constant mark-ups is not implementable (cf. Faia, 2009).

A key point of the paper is that the optimal interest rate decreases in response to a negative matching efficiency shock, thus tracking the behavior of the natural rate of interest. This result *per se* is not surprising as it is well known from previous research that price stability is nearly optimal, even in models where search frictions are pervasive (cf. Faia, 2009, Mileva, 2013, and Walsh, 2014). What is surprising, however, is that the optimal policy prescription is in contrast with the behavior of the interest rate determined by the Taylor-type rule, as described in the previous section.

In Figure 6 we plot impulse responses also for alternative values of the bargaining power of workers, which is increased to 0.8 (cf. dotted lines) or decreased to 0.2 (cf. solid lines). In both cases the dynamics are very similar to our baseline case, thus showing the limited importance of search frictions' intensity for optimal monetary policy purposes. In Figure 7 we replicate the same exercise in response to a negative shock to the labor force. Once again, the optimal policy closely tracks the natural rate of interest, in contrast with the outcome determined by a Taylor-type rule, and is relatively insensitive to deviations from the Hosios conditions.

Finally, we now investigate whether alternative Taylor-type rules may deliver a policy rate response with the correct sign.

In a first case we consider a rule with no interest rate smoothing, thus setting ρ_r equal to zero in (16). We see in the first two panels of Figure 8 (cf. solid lines) that under such a rule the policy rate now declines on impact of the two shocks, thus comoving with the natural rate of interest. In fact the inertia generated by interest rate smoothing moves the economy away from the strict inflation targeting outcome, which is a relatively good approximation of optimal monetary policy in our model. A closer comovement between the policy rate and the natural rate of interest can be obtained by increasing the coefficient on inflation. Dotted lines in the first two panels of Figure 8 refer to a policy rule with $\rho_r = 0$ and $\rho_\pi = 5$.

In a second case we introduce the natural rate of interest in (16) with a unitary

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of full price stability is recovered.

coefficient, while keeping the degree of interest rate smoothing as in the baseline. We see in the last two panels of Figure 8 that also such a policy rule delivers a positive co-movement between the policy rate and the natural rate in response to both shocks. This result extends the findings of Barsky, Justiniano and Melosi (2014) and Canzoneri, Cumby and Diba (2015) to a model with search frictions in the labor market driven by shocks originating in the labor market. Note, however, that we ignore here all the issues related to the unobservability of the natural rate of interest that may complicate the practical implementation of this kind of rule.

From our analysis, we conclude that it is optimal to lower the interest rate in response to a negative matching efficiency shock and to a negative shock to the labor force as long as the shocks are sufficiently persistent. This is in contrast with the outcome determined by a Taylor-type rule with interest rate smoothing that prescribes an increase in the interest rate. While simple rules have been criticized elsewhere in the literature (cf. Svensson, 2003, among others), we could find only one other case in which a Taylor-type rule delivers a response with the wrong sign for the policy rate. Christiano, Ilut, Motto and Rostagno (2010) find this result for the case of a news shock to technology that has a particularly large effect on the natural rate of interest as it enters in its equation with a unitary coefficient.

The monetary policy response to shocks to the natural rate of unemployment is a recurring theme in the policy debate. Speeches by Kocherlakota (2010), Bullard (2012), Lacker (2012), and Plosser (2011) allude to the possibility that structural factors in the labor market may explain a substantial share of unemployment dynamics. The policy prescription emerging from all these speeches is that monetary policy is not the right instrument to respond to shocks driving the natural rate of unemployment. In contrast, according to our model, monetary policy has a role to play because its intermediate targets (inflation and real variables such as output and unemployment) are affected by shocks originating in the labor market. Furthermore, as long as the shocks are persistent, the optimal policy is to lower the interest rate, as in response to negative demand shocks. We conclude that, from a purely qualitative point of view, it does not matter much whether unemployment is driven by structural factors or by aggregate demand shocks.

Finally, it is interesting to relate our findings to a large recent literature that has discussed a possible decline in the natural rate of interest (cf. Hamilton, Harris, Hatzius and West, 2015; Laubach and Williams, 2015, and the references therein). Several reasons have been advocated to explain this decline, including changes in trend growth, variations in discount rates, financial regulation, trends in inflation, bubbles and cyclical headwinds. Our paper highlights two additional reasons (possibly among many others) that may explain a decline in the natural rate of interest in recent years: a persistent decline in matching efficiency and negative shocks to the labor force.

5   Conclusion

It is well known that price stability is nearly optimal, even in models with a pervasive role for search frictions (cf. Walsh, 2014, for a broad review of this result). What is less known are the implications of such a policy when unemployment is driven by structural factors. Our contribution is to show that tracking the natural rate of interest is particularly useful in such a context. While the optimal policy is to lower the policy rate (thus tracking the natural rate dynamics), a Taylor-type rule with a constant intercept prescribes an increase in the policy rate. Nevertheless, in both cases monetary policy responds to the arguably most important drivers of the natural rate of unemployment, in contrast with conventional wisdom.

An interesting question for future research may consist of analyzing the simple mechanisms that we discovered in our simple small-scale model in the context of a more complete model suitable for empirical purposes. In particular, we believe that our analysis may be relevant to investigating the joint dynamics of the natural rate of interest and the natural rate of unemployment. In fact, our model provides an intriguing conjecture to rationalize why a substantial decline in the natural rate of interest may coexist with a relatively stable natural rate of unemployment, a situation that may arguably reflect the state of the US economy in recent years. In our model a negative shock to the labor force moves the natural rate of interest and the natural rate of unemployment in the same direction, whereas negative matching efficiency shocks imply the opposite comovement. Hence, we

may conjecture a scenario in which a series of negative shocks to the labor force may have contributed to lowering both the natural rate of interest and the natural rate of unemployment. At the same time, other negative shocks (including possibly negative matching efficiency shocks) may have amplified the decline in the natural rate of interest but offset the decline in the natural rate of unemployment. The combination of negative shocks to the labor force with other shocks may explain a decline in the participation rate, a substantial decline in the natural rate of interest and a relatively stable natural rate of unemployment. We may evaluate this conjecture in a future research project.

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Table 1: Parameterization

Discount rate	β	0.99
Elasticity of substitution between goods	θ	11
Interest rate smoothing	ρ_r	0.8
Response to inflation in the Taylor rule	ρ_π	1.5
Response to output growth in the Taylor rule	ρ_y	0.5
Calvo coefficient for price rigidity	α	0.75
Probability of filling a vacancy within a quarter	Q	0.7
Separation rate	ρ	0.085
Unemployment rate	U	0.06
Elasticity of the matching function	σ	0.6
Bargaining power	η	0.6
Hiring costs to output ratio	$\frac{H^k}{Y}$	0.01
Matching efficiency shock persistence	ρ_E	0.9
Labor force shock persistence	ρ_L	0.9

Euler equation	$c_t = E_t c_{t+1} - (r_t - E_t \pi_{t+1})$
Production function	$y_t = n_t$
Law of motion for employment	$n_t = (1 - \rho) n_{t-1} + \rho(q_t + v_t)$
Definition of unemployment	$u_t = \left(\frac{1}{U}\right) l_t - \left(\frac{N}{U}\right) n_t$
Probability of filling a vacancy	$q_t = e_t - \sigma \left(v_t + \left(\frac{(1-\rho)N}{S}\right) n_{t-1} - \frac{1}{S} l_t\right)$
Job finding rate	$f_t = e_t + (1 - \sigma) \left(v_t + \left(\frac{(1-\rho)N}{S}\right) n_{t-1} - \frac{1}{S} l_t\right)$
Definition of the hiring rate	$x_t = q_t + v_t - n_t$
New Keynesian Phillips curve	$\pi_t = \beta E_t \pi_{t+1} + \kappa z_t$
Monetary policy rule	$r_t = \rho_r r_{t-1} + (1 - \rho_r) (\rho_\pi \pi_t + \rho_y (y_t - y_{t-1}))$
Matching efficiency shock	$e_t = \rho_E e_{t-1} + \epsilon_{E,t}$
Labor force shock	$l_t = \rho_L l_{t-1} + \epsilon_{L,t}$
Job creation condition	$q_t = \left(\frac{WQ}{P\phi_N}\right) (w_t - p_t) - \left(\frac{ZQ}{\phi_N}\right) z_t + \beta (1 - \rho) (r_t - E_t \pi_{t+1} + E_t q_{t+1})$
Wage equation	$w_t - p_t = \left(\frac{\eta ZP}{W}\right) z_t - \left(\frac{\eta \beta (1-\rho) \phi_N FP}{WQ}\right) (r_t - E_t \pi_{t+1} + E_t q_{t+1} - E_t f_{t+1})$
Market clearing condition	$y_t = \left(1 - \frac{\phi_N V}{N}\right) c_t + \frac{\phi_N V}{N} v_t$

Appendix

List of equilibrium conditions in the symmetric equilibrium:

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

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

$$Y_t = N_t$$

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

$$U_t = L_t - N_t$$

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

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

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

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

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

$$Y_t = \Gamma_t C_t + \phi_N V_t$$

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

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

Steady state:

$$N = 1 - U$$

$$Y = N$$

$$S = 1 - (1 - \rho) N$$

$$V = \frac{\rho N}{Q}$$

$$Z = \frac{\theta - 1}{\theta}$$

$$R = \frac{1}{\beta}$$

$$L = Q \left(\frac{V}{S} \right)^{\sigma}$$

$$F = L \left(\frac{V}{S} \right)^{1-\sigma} .$$

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

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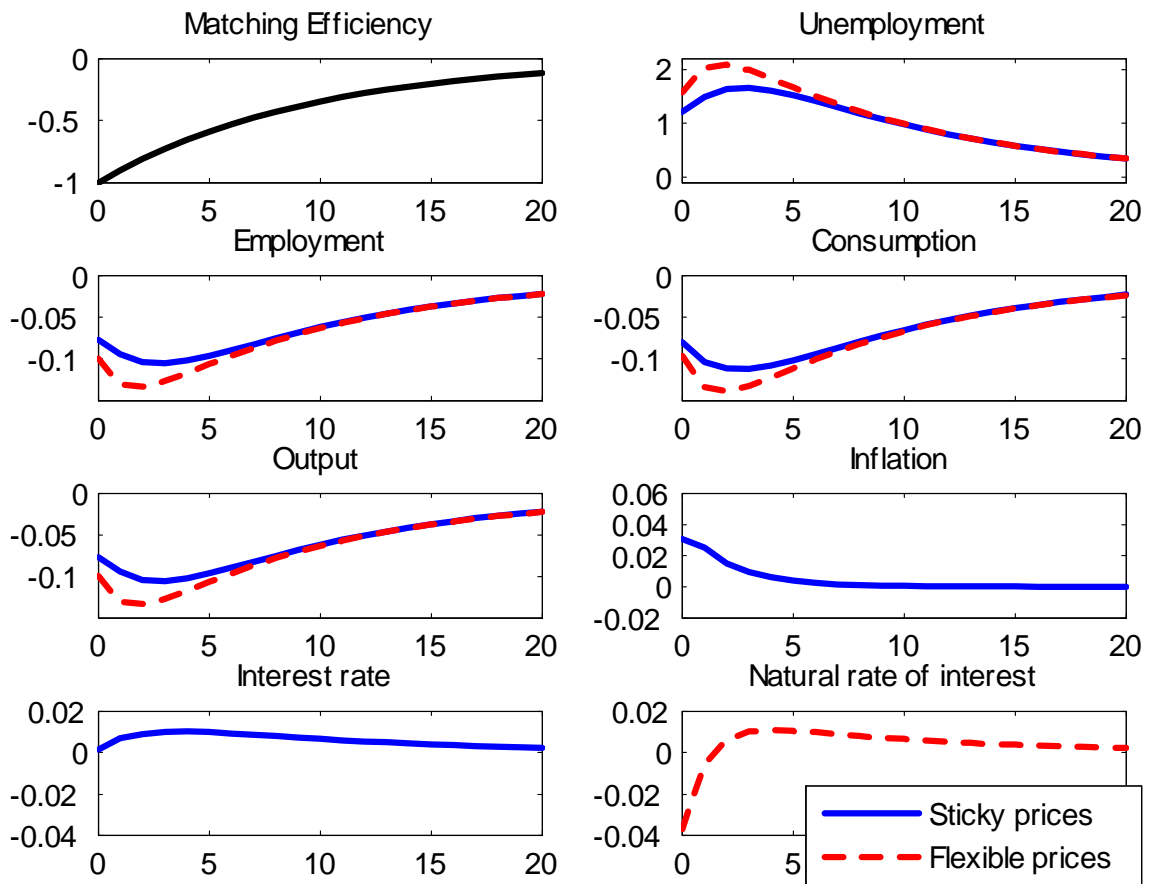
$$C = Y - \phi_N V.$$

Figure 1: Impulse responses to a negative matching efficiency shock in the baseline model
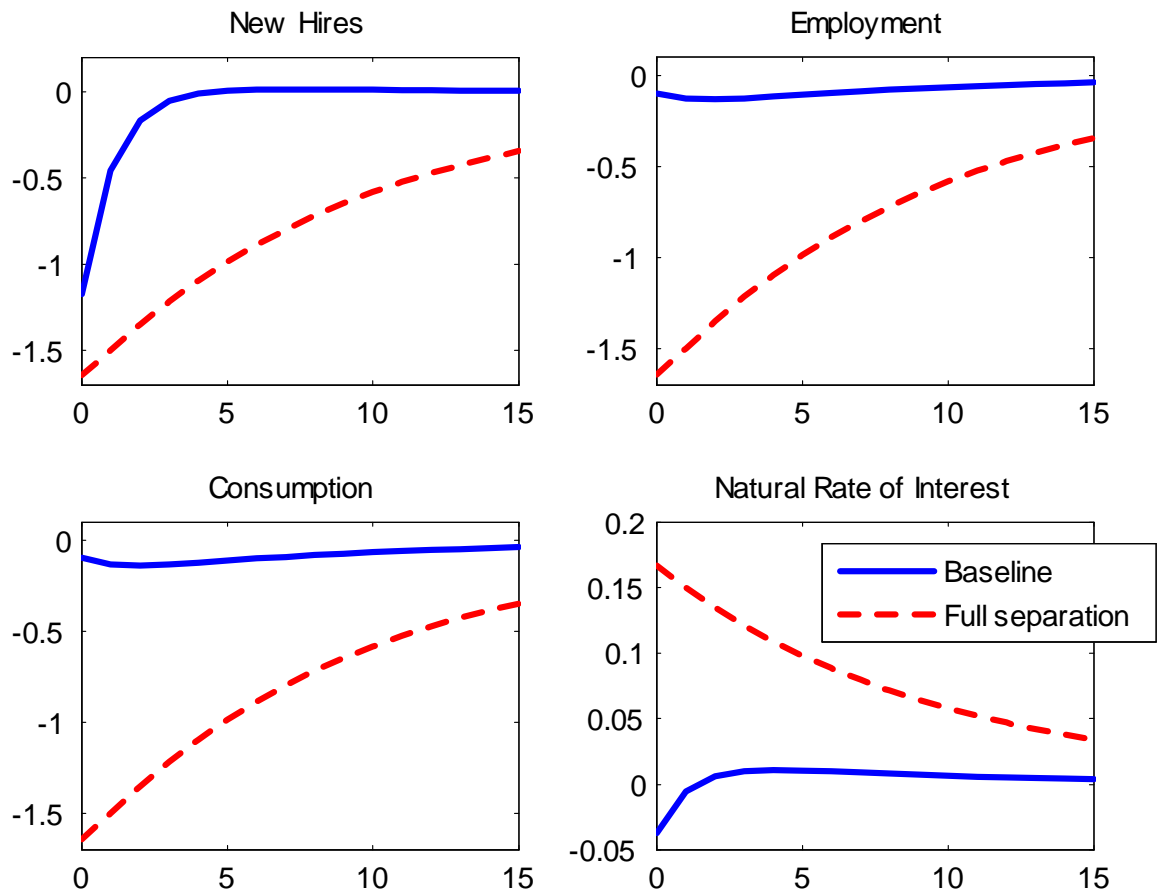
Figure 2: Impulse responses of selected variables in the baseline model under flexible prices
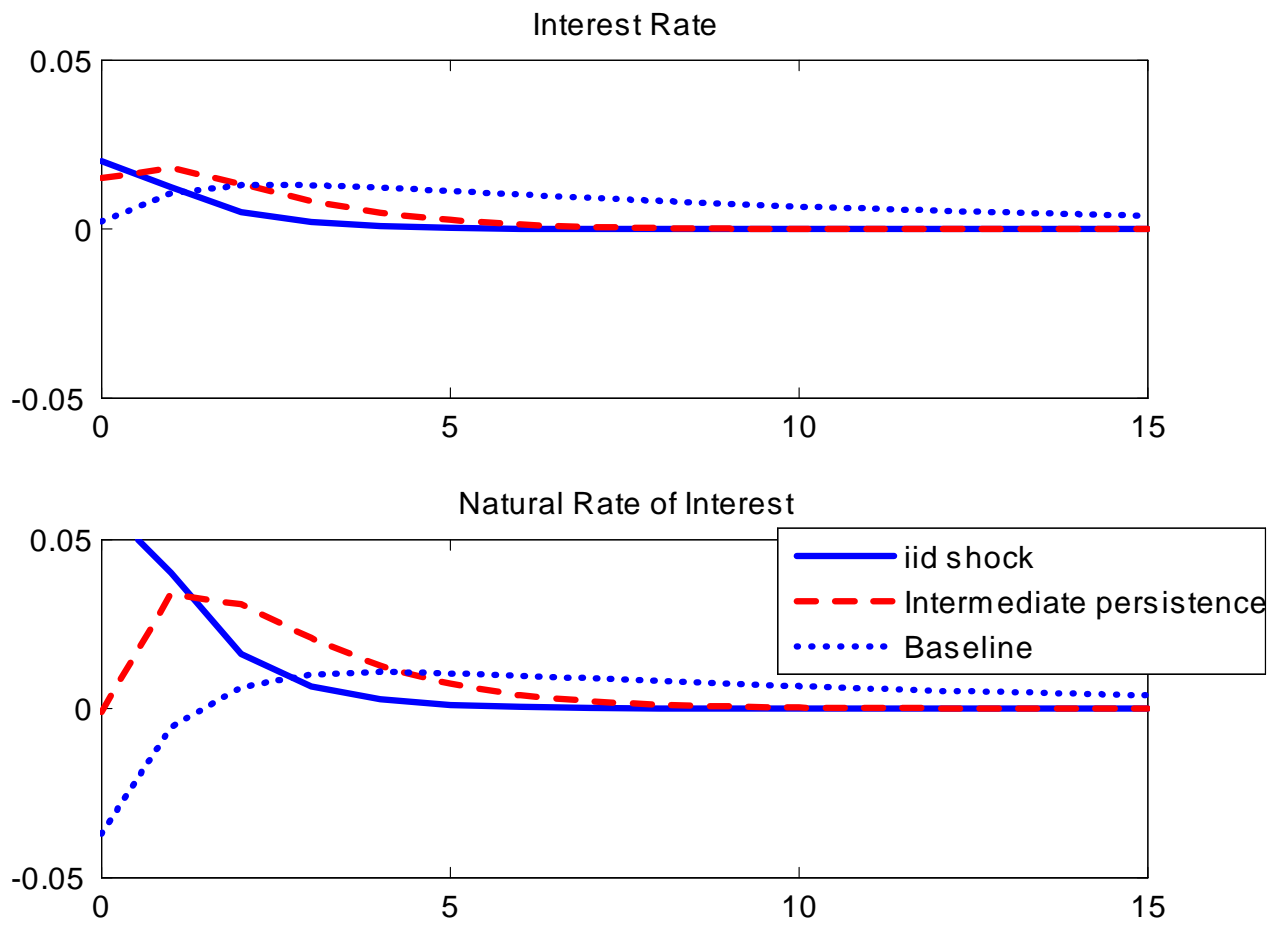
Figure 3: Impulse responses to a negative matching efficiency shock in the baseline model for different degrees of shock's persistence
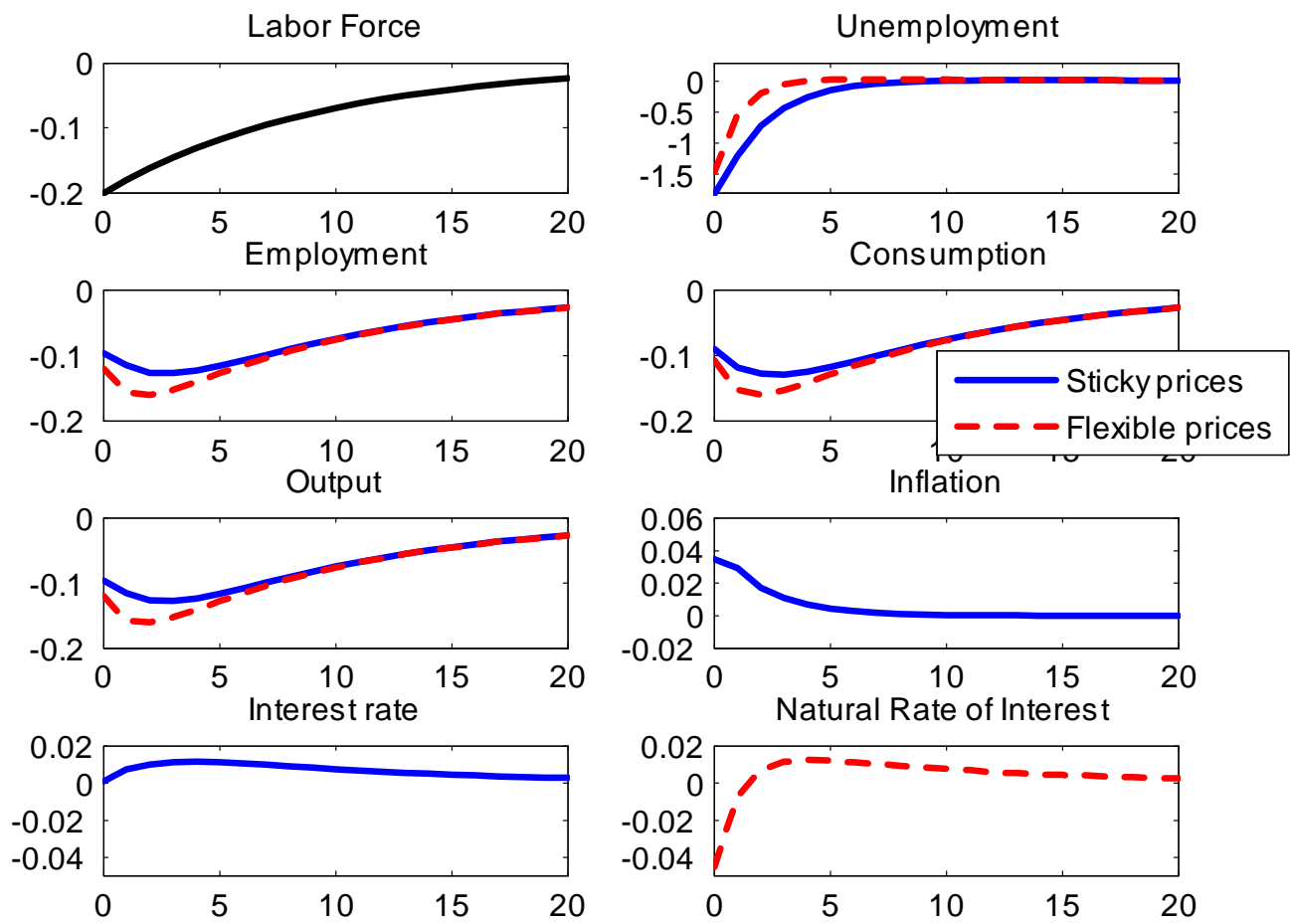
Figure 4: Impulse responses to a negative shock to the labor force in the baseline model
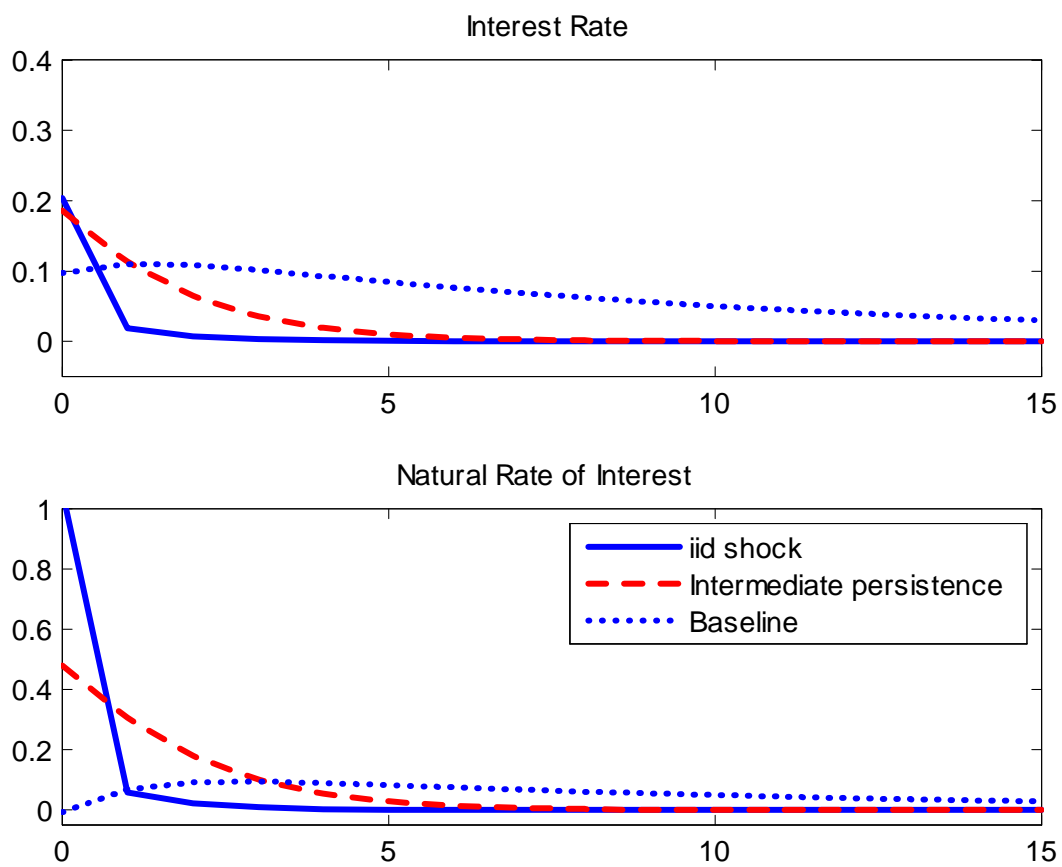
Figure 5: Impulse responses to a negative technology shock in the baseline model for different degrees of shocks's persistence
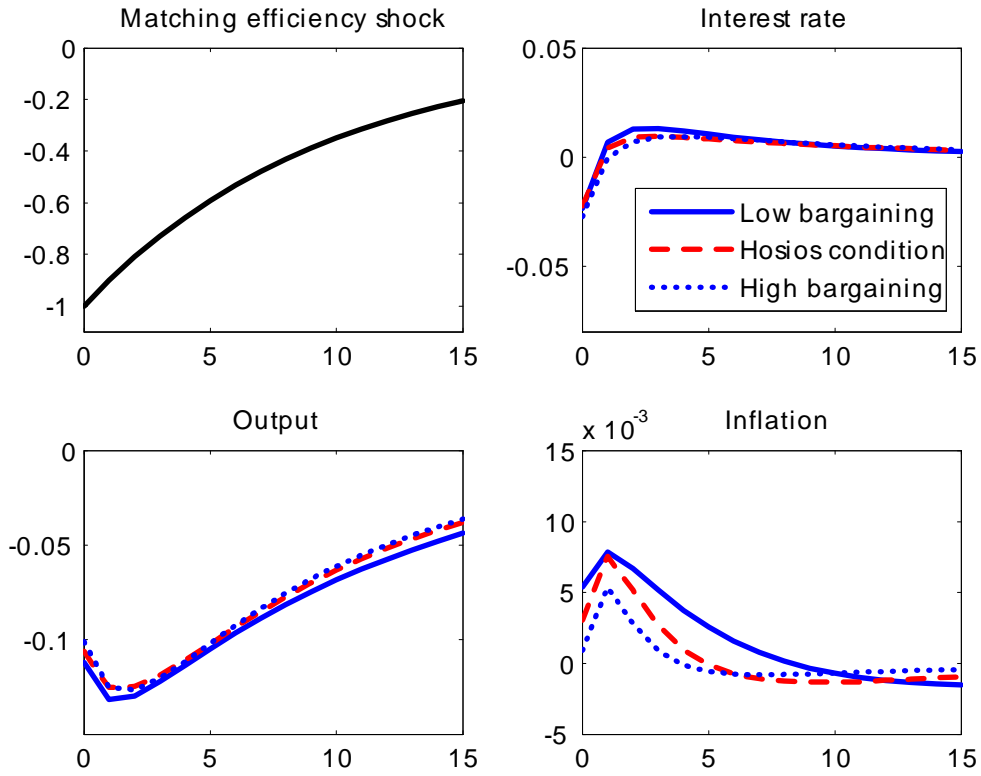
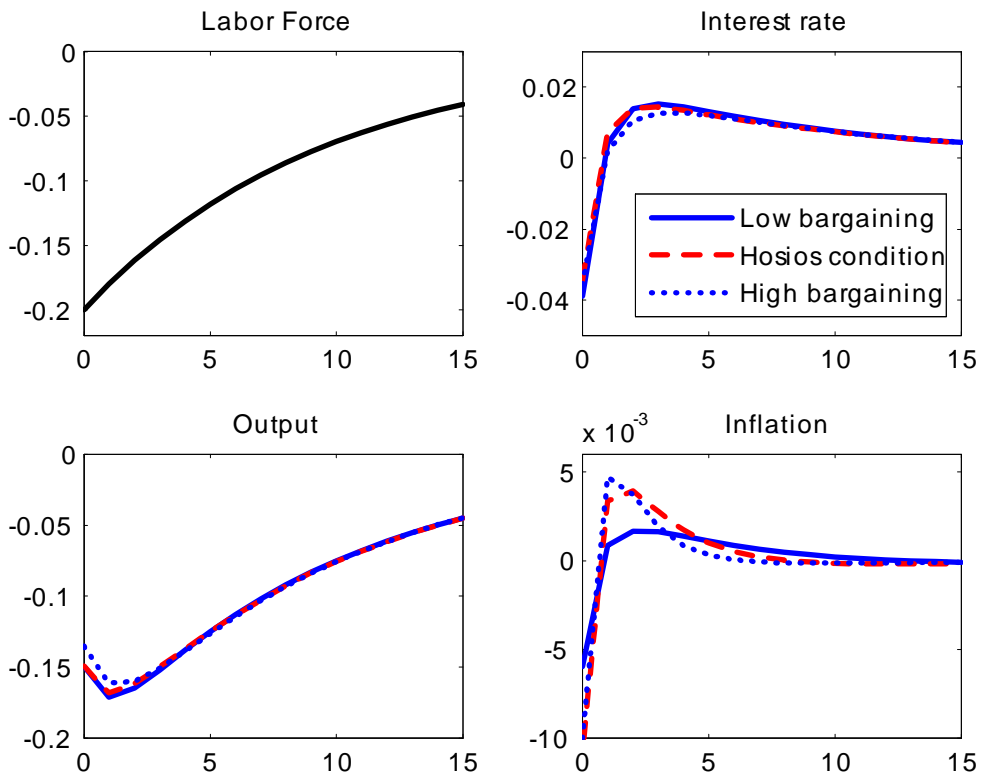Figure 6: Impulse responses to a negative matching efficiency shock under optimal policy

Figure 7: Impulse responses to a negative labor force shock under optimal policy
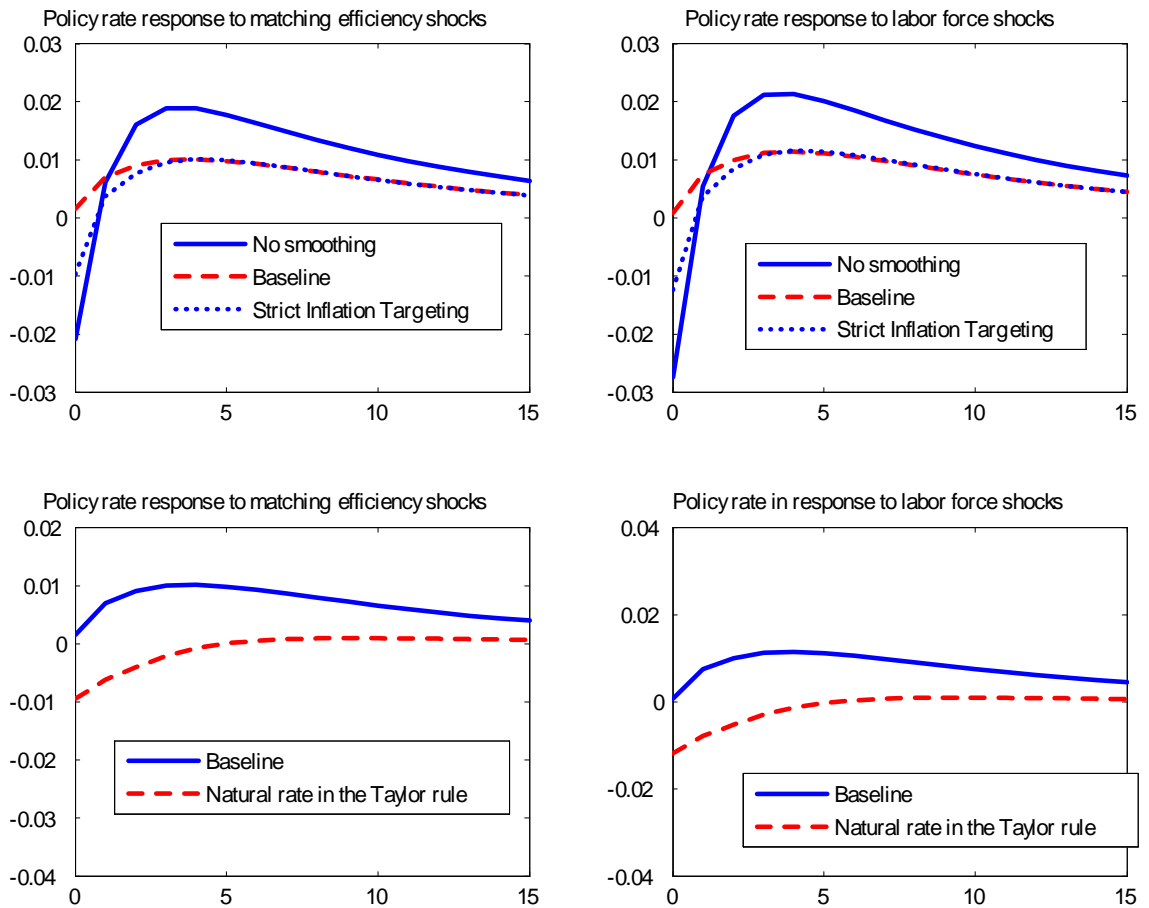
Figure 8: Sensitivity analysis to the coefficients in the monetary policy rule (first two panles) and to the inclusion of the natural rate of interest in the policy rule (last two panels)