

Ramsey Optimal Monetary Policy in Response to Shifts in the Beveridge Curve*

Mariya Mileva

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Kiel Institute for the World Economy, Kiellinie 66, Kiel 24105, Germany, +49-431-8814-601,
mariya.mileva@ifw-kiel.de

Abstract

I use a dynamic stochastic general equilibrium model with search and matching frictions in the labor market and analyze the optimal monetary policy response to an outward shift in the Beveridge curve. The shift results from an exogenous decline in the efficiency of matching unemployed workers to vacant jobs. The results cover several cases depending on type of the shift, temporary versus permanent, and efficient versus inefficient. Whether the shock is temporary and persistent versus permanent affects the length of the adjustment, with the adjustment after a persistent temporary shift taking twice as long the adjustment after a permanent one. Whether the shock is efficient or not affects the goals of optimal monetary policy. In response to an efficient shock, it is optimal to maintain price stability while in response to an inefficient shock it is optimal to both stabilize prices and inefficient fluctuations in unemployment. The goals of monetary policy are critical for the way the shock affects inflation and, more importantly, for the way it affects fluctuations in unemployment and vacancies.

Beveridge curve shift, optimal monetary policy, labor market, search and matching
JEL classifications: E24, E32, E52

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1 Introduction

The recent global crisis originated in the financial sector but the subsequent impact on the US labor market is unusual. Figure 1 shows a plot with the US unemployment rate on the horizontal axis and the job openings rate on the vertical axis. This negative relationship is described with a solid downward sloping line called the Beveridge curve (BC). Each point on it represents a different degree of output. Recessions typically result in a downward movement along the Beveridge curve as unemployment rises and the job opening rate falls. The standard monetary policy prescription in such recessions is to engage in expansionary actions. Figure 1 suggests that after the Great recession the US Beveridge curve shifted outward as both the unemployment and the job opening rates rose. I use a dynamic stochastic general equilibrium (DSGE) model with search and matching frictions in the labor market to analyze the optimal monetary policy response to an outward shift in the Beveridge curve.

Rightward shifts in Beveridge curve like the one in figure 1 have coincided with increases in the natural rate of unemployment. The natural rate of unemployment (NAIRU) is the rate of unemployment arising from all sources except fluctuations in aggregate demand. The effect of the shift in the Beveridge curve on the natural rate of unemployment largely depends on whether it is permanent or not. Various recent studies which examine the potential causes of the shift in Beveridge curve conclude that these factors are mostly transitory but very persistent. However, after the Great Recession the CBO increased its projection of the natural *long-term* unemployment rate. This suggests that the CBO believes that the shift in the BC curve might not be purely transitory but permanent. Hence, I distinguish between transitory and permanent shifts in the BC curve when the optimal monetary policy response.

In a model where unemployment arises due to search and matching frictions, the BC shifts outward because of a decline in the efficiency of matching. This is because for a given number of unemployed the number of vacancies would have to be higher in order to generate the same number of new hires. I use a model where the labor market is described by a simple matching function :

$$m_t = d_t v_t^\alpha s_t^{1-\alpha}, \quad (1)$$

where m_t is the number of hires, v_t is the number of job openings, s_t is the number of job searchers in period t , d_t is the efficiency of matching and $0 < \alpha < 1$ is the elasticity of matching with respect to vacancies. Petrongolo and Pissarides [2001] summarize empirical evidence that documents that the US labor market is well described with a matching function where $1 - \alpha$ is between 0.5 and 0.7. Thus, I set $\alpha = 0.5$ and rewrite equation 1 in log-form as follows:

$$\log(d_t) = \log(m_t) - 0.5\log(v_t) - 0.5\log(s_t). \quad (2)$$

I use the three variables on the right hand side as observables in order to recover a series for the efficiency of matching. Figure 2 shows a plot of the implied series for the residual $\log(d_t)$. It shows a sharp decline in matching efficiency during the Great Recession (shaded area), a decline which persists for 24 quarters after the end of the recession. Estimating an AR(1) model on the residual series where $\log(d_t) = c + \rho_d \log(d_{t-1}) + \epsilon_d$ reveals that the decline in matching efficiency is very persistent with $\hat{\rho}_d = 0.965$. The hypothesis that the residual ϵ_d is normally distributed with mean zero and standard deviation $\hat{\sigma}_d = 0.032$ cannot be rejected by the Jarque-Bera test (statistic=2.481 with p-value=0.289). An Augmented Dickey-Fuller test cannot reject the null hypothesis of a unit root in $\ln(d_t)$ which suggests that the increase might have permanent effects.¹

I treat matching efficiency as a Solow residual of the matching function; in that sense, it can be interpreted as catch-all shocks for structural features in the labor market that have changed during the Great recession. A number of studies endogenize the series $\ln(d_t)$ and find that its decline contributes to the persistent rise in US unemployment since the Great Recession. The decline in the efficiency of matching during the Great Recession has been attributed to a number of factors, such as the degree of skill mismatch between jobs and workers (Sahin et al. [2014]; Herz and Van Rens [2015]); the importance of geographical mismatch that might have been exacerbated by house-locking effects (Sterk [2015]); workers search intensity that may have been reduced by the extended duration of unemployment benefits Fujita [2011]; Baker and Fradkin [2015]); firms recruiting efforts (Davis et al. [2010]); and shifts in the composition of the unemployment pool, such as a rise in the share of long-term unemployed or fluctuations in participation due to demographic factors (Barnichon and Figura [2015]). Note that all these factor would contribute to the rise both in actual unemployment rate and in the natural unemployment rate.

Other studies treat the series $\ln(d_t)$ as exogenous and take the general equilibrium approach by estimating the impact of matching efficiency shocks in the context of DSGE models with search and matching frictions. The advantage of this approach is that it allows to distinguish between the actual unemployment rate and the natural unemployment rate. In these models the natural unemployment rate is unemployment under flexible prices and efficient goods and labor markets while the actual unemployment rate is unemployment under sticky

¹The ADF statistic is -0.635115 (p-value=0.4377) with the test performed with AIC optimal lag of 3 and no intercept in the underlying regression but the null hypothesis of unit root still cannot be rejected if I assume the presence of an intercept.

prices and/or inefficient goods and labor markets. In some estimated models such as Lubik [2009], and Krause et al. [2008]) matching efficiency shocks are responsible for a large share of unemployment fluctuations while in others such as (Justiniano and Michelacci [2011]; and Sala et al. [2012]) their contribution to unemployment fluctuations is limited. Furlanetto and Groshenny [2012] argue this may be due to modeling assumptions about the nature of vacancy posting costs, whether they are pre- or post-match. Most recently, Furlanetto and Groshenny [2014] estimate that matching efficiency contributes to raise the actual unemployment rate by 1.25 percentage points and the natural rate by 2 percentage points since the Great Recession.

My contribution to this literature is that I analyze the role of monetary policy for the propagation of matching efficiency shocks in general equilibrium models with search and matching frictions. In that sense, I also contribute to a growing literature on monetary policy in response to unemployment in the context of search and matching labor markets within a general equilibrium model. Examples include Walsh [2003], Walsh [2005], Faia [2008], Faia [2009], Sala et al. [2008], Thomas [2008], Gertler et al. [2008], Christoffel et al. [2009], Blanchard and Gali [2010a], and Ravenna and Walsh [2011]. The most closely related paper is Ravenna and Walsh [2011] which explicitly derives the objective function of the policymaker as a second order approximation to the welfare of the representative agent. They show that if the policymaker ignores fluctuations in vacancies when he sets the optimal nominal interest rate, there is a substantial loss in welfare. The economic intuition behind the policy trade-offs can be easily traced to the fundamental frictions that impact labor markets and firms' price setting behavior. This makes their model very suited to analyze optimal monetary policy problems.

I use their model but interpret monetary policy either as a Taylor rule, or as an optimal policy response of a Ramsey planner using the nominal interest rate as an instrument. I distinguish between a Taylor rule where the nominal interest rate just responds to fluctuations in inflation and a Taylor rule where it responds to both fluctuations in inflation and in output relative to its steady state. I consider Ramsey optimal policy because it allows me to distinguish between two cases: first, when a decline in matching efficiency causes efficient fluctuations in unemployment (output) and the goal of the Ramsey planner is just to stabilize inflation in response to a decline in matching efficiency; and second, when a decline in matching efficiency causes inefficient fluctuations in unemployment (output) and the goal of the Ramsey planner is to stabilize prices as well as fluctuations in the unemployment (output) gap, defined as deviation of unemployment relative to its efficient level.² I find that the goals of monetary policy-maker are critical for how the matching efficiency shock propagates to the rest of the economy. If the goal of the monetary policy maker is only to stabilize inflation, a temporary decline in matching efficiency implies a fall in inflation and consequently, a fall in the nominal interest rate. Under Ramsey optimal policy the planner is able to maintain perfectly stable inflation while the shock lasts. In contrast, if the goal of the policy maker is to stabilize inflation as well as fluctuations unemployment (output), a temporary decline in matching efficiency implies a rise in inflation and consequently a rise in the nominal interest rate. This is because when the monetary policy maker stabilizes fluctuations in unemployment as well as inflation, inflation expectations are no longer stabilized. A persistently less efficient matching process implies a rise in expected hiring costs and inflation and hence a rise in current inflation. Under Ramsey optimal policy the planner raises the nominal interest just enough to limit the rise in current inflation but not enough to eliminate it completely and overturn the fall in the real interest rate resulting from higher inflation expectations. Thus, he faces a trade off between stabilizing inefficient fluctuations in unemployment by maintaining low real interest rates and stabilizing fluctuations in current inflation by maintaining a higher nominal interest rate.

I also highlight how the persistence of the shock affects the correlation between vacancies and unemployment. Similarly to Furlanetto and Groshenny [2012] I find that a less persistent shock implies a lower correlation between vacancies and unemployment. I also analyze how monetary policy affects this correlation. I find that when that when monetary policy aims to only stabilize prices this correlation is lower than when it aims to stabilize both prices and output. In fact, under a reasonably persistent shock to match efficiency ($\rho_d = 0.6$), the conditional correlation between unemployment and vacancies turns negative when monetary policy aims to only stabilize inflation. This is important as it suggests that matching efficiency shocks might be an important driver of the business cycle in countries with inflation targeting regimes.

All the DSGE papers above analyze the propagation of transitory matching efficiency shocks. In contrast, I also analyze the transition following a permanent one time decline in matching efficiency. In the long-run it implies an outward shift in the Beveridge curve and a corresponding increase in the steady state unemployment and vacancies. When the shift occurs in an inefficient model (where the Hosios condition is violated) the shift implies a bigger rise in unemployment and a smaller rise in vacancies in the long run than in the efficient model (where the Hosios condition holds). The transition to the new steady state is also different in the inefficient and the efficient model. The transition after a permanent shock can takes two years in the efficient model and about eight years in the inefficient model. Note that this length of transition is significantly shorter than the adjustment following a temporary persistent shock where the assumed persistence coefficient implies that the shock lasts at least sixteen years. In the efficient model, the Ramsey planner maintains price stability throughout the transition by lowering the nominal interest rate. In the inefficient model, the Ramsey planner

²Efficient unemployment is unemployment in a model where prices are flexible, the markup of retail firms is constant and equal to one and the Hosios condition holds.

faces a trade-off between stabilizing inflation and stabilizing unemployment (output). Similarly to the case of a temporary shock, the Ramsey planner finds it optimal to raise the nominal interest rate in order to limit the rise in current inflation resulting from the rise in expected inflation due to less efficient matching process. However, he also finds it optimal to accommodate inflation expectations, so that the rise in expected inflation is large enough to generate a fall in the real interest rate via the Fisher equation. A lower interest rate during the transition is optimal because it stimulates vacancy posting which is inefficiently low due to the inefficiently high bargaining power of workers.

Finally, I also analyze the role of the assumption that market and home production are perfect substitutes for the propagation of the shock. Assuming imperfect substitution between home and market production, implies that the value of home production fluctuates with changes in the composition of home and market goods which affects the reservation value of unemployed workers. When matching efficiency declines, the relative supply of home goods rises, which lowers the value of home production relative to market production. This results in a decline in the reservation value of unemployed workers and a larger decline in real wages than in the perfect substitutes case. Thus, firms face lower marginal costs than under the perfect substitutes. This affects the vacancy response of firms. In the case of a temporary shock, the decline of vacancies is smaller. In the case of a permanent shock the rise in vacancies is bigger both in the short and long run. However, this also means that the marginal rate of substitution between home and market goods decline making households more reluctant to have unemployed members in the imperfect substitutes model than in the perfect substitutes one. Thus, in the imperfect substitutes case the rise in unemployment is smaller in response to a decline in matching efficiency than in the perfect substitutes case.

The assumption of imperfect substitutes does not affect the goals of the Ramsey optimal policy because it does not cause inefficient fluctuations in unemployment in response to the shock. As in the perfect substitutes model, it is optimal to maintain price stability throughout the transition. However, it affects the magnitude of the response. In the case of a temporary shock, the central bank needs to lower its interest rate by less under imperfect substitutes than under perfect substitutes in order to maintain price stability. Note that the response of the interest rate is three times smaller under imperfect substitutes. I also show that if the persistence of the shock is lower, the direction of the response can also change. In the case of a permanent shock, the optimal monetary policy response is also smaller during the transition.

Section 2 describes the theoretical framework used for analysis. Section 3 presents the optimal monetary policy problem while section 4 discusses calibration and methodology. Section 5 interprets the results and section 6 concludes.

2 Theoretical Model

The model consists of three types of agents. Households derive utility from the consumption of market and home produced goods. Home and market goods are assumed to be substitutes. In the baseline version of the model they are perfect substitutes and their relative price is constant. The case of imperfect substitutes with a diminishing marginal rate of substitution is also considered. The production process has two stages. There are wholesale firms who employ labor to produce a wholesale good which is sold in a perfectly competitive market. Retail firms transform the wholesale good into differentiated final goods which they sell to households in an environment of monopolistic competition. The labor market is characterized by search frictions. Wholesale firms use up retail goods in order to post vacancies and form productive employment matches. Households members are either employed or searching for a job. The real wages are a weighted average between last period's wage and the current Nash bargaining real wage. Retail firms adjust prices according to a standard Calvo specification.

2.1 Households

The household consists of a continuum of individuals, of whom some are employed and some unemployed. The employed produce market goods and the unemployed produce home goods. The household consumes a bundle

$$C_t = [a(C_t^m)^\phi + (1-a)(C_t^h)^\phi]^{1/\phi}, \quad (3)$$

where $0 < a < 1$ governs preferences of market versus home goods and $\epsilon_h = 1/(1-\phi)$ is the elasticity of substitution between home and market goods. The baseline model treats home and market goods as perfect substitutes where $\phi = 1$ and $C_t = C_t^m + C_t^h$. The household derives utility from the basket of goods based on preferences with constant risk parameter σ :

$$U(C_t) = \frac{C_t^{1-\sigma}}{1-\sigma}. \quad (4)$$

This utility specification implies that the marginal rate of substitution is a decreasing and convex function of the relative consumption of home to market goods C_t^h/C_t^m , where

$$MRS_t = \frac{MU(C_t^h)}{MU(C_t^m)} = \left(\frac{1-a}{a}\right) \left(\frac{C_t^h}{C_t^m}\right)^{\phi-1}. \quad (5)$$

In the case of perfect substitution between home and market consumption the marginal rate of substitution is constant $MRS_t = 1$.

The total labor force is one and is divided between market goods production N_t and home goods production $1 - N_t$. N_t is the number of people engaged in market production. Employment adjusts only along the extensive margin. The home goods production function is:

$$C_t^h = w^u(1 - N_t), \quad (6)$$

where w^u can be interpreted as a constant productivity parameter in the production function of the home good.

Market consumption is a continuum of goods purchased from retail firms

$$C_t^m \leq \left[\int_0^1 C_t^m(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}. \quad (7)$$

The expenditure minimization problem over the bundle of market goods delivers the following relative demand function and a price index

$$C_t^m(j) = \left[\frac{P_t^m(j)}{P_t^m} \right]^{-\epsilon} C_t^m \quad (8)$$

$$P_t^m = \left\{ \int_0^1 [P_t^m(j)]^{1-\epsilon} dj \right\}^{\frac{1}{1-\epsilon}} \quad (9)$$

P_t^m is the market consumer price index which is used to construct the standard measure of inflation.

The household receives income from its members employed in the market sector who obtain a nominal wage W_t , interest income from one period risk free bonds delivering a nominal return i_t and dividend income from ownership of the monopolistic retailers T_t . The household's expenditures include consumption C_t^m and risk-free bond purchases B_t . The household budget constraint is given by

$$P_t^m C_t^m + B_t = W_t N_t + (1 + i_{t-1})B_{t-1} + T_t \quad (10)$$

The household maximizes the present discounted value of its utility $E_t \sum_{i=0}^{\infty} \beta^i C_{t+i}^{1-\sigma} / (1-\sigma)$ subject to the budget constraint and chooses C_t^m and B_t . Its utility maximization problem results in a standard Euler equation

$$\frac{\lambda_t}{P_t^m} = \beta E_t \frac{\lambda_{t+1}}{P_{t+1}^m} (1 + i_t) \quad (11)$$

where $\lambda_t = a C_t^{1-\sigma-\phi} (C_t^m)^{\phi-1}$ is the marginal utility of one unit of market consumption.

The household trades off optimally between home and market goods as long as the implicit price of the home good relative to the price of the market good is equal to the marginal rate of substitution. I use this optimal condition to define an implicit price index for the home good:

$$P_t^h = MRS_t P_t^m \quad (12)$$

Note that in the baseline version of the model when home and market goods are perfect substitutes, this implicit price is equal to P_t^m .

2.2 Wholesale Firms

The wholesale producers are identical and operate in a perfectly competitive market. They possess constant returns to scale technology that is linear in employment:

$$Y_t^w = Z N_t, \quad (13)$$

where Z is a productivity parameter that is normalized to one at the steady state.

The firm sells its output Y_t^w to final producers at price P_t^w , hires workers N_t at a wage W_t and buys a continuum of final goods $v_t(j)$ at prices $P_t^m(j)$ to post vacancies at a period cost k . Its value in terms of final consumption units is the present discounted sum of its revenues less its employment and hiring expenditures:

$$F_t = \frac{P_t^w}{P_t^m} Y_t^w - \frac{W_t}{P_t^m} N_t - \frac{k \int_0^1 P_t^m(j) v_t(j) dj}{P_t^m} + \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) F_{t+1}.$$

To post vacancies v_t , firms buy $v_t(j)$ units of each final good variety j subject to the constraint

$$v_t \leq \left(\int_0^1 v_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}}. \quad (14)$$

Firms minimize their expenditure over a basket of final goods varieties which delivers the following demand function:

$$v_t(j) = \left(\frac{P_t^m(j)}{P_t^m} \right)^{-\epsilon} v_t. \quad (15)$$

The intermediate producer faces the same prices as the household. The firm keeps v_t vacancy open at a cost per period k , so that its total expenditure on vacancies is $k \int_0^1 P_t^m v_t(j) dj$.

The total expenditure on final goods by wholesalers and households can be aggregated as follows,

$$\begin{aligned} \int_0^1 P_t^m(j) C_t^m(j) dj + k \int_0^1 P_t^m(j) v_t(j) dj &= \int_0^1 P_t^m(j) (C_t^m(j) + k v_t(j)) dj \\ &= \int_0^1 P_t^m(j) Y_t^d(j) dj = \int_0^1 P_t^m(j) \left(\frac{P_t^m(j)}{P_t^m} \right)^{-\epsilon} C_t^m + k \left(\frac{P_t^m(j)}{P_t^m} \right)^{-\epsilon} v_t dj \\ &= \int_0^1 (P_t^m(j))^{1-\epsilon} dj (P_t^m)^\epsilon (C_t^m + k v_t) = P_t^m C_t^m + P_t^m k v_t \end{aligned}$$

2.3 Retail Firms

The nominal marginal cost faced by a retail firm is the price paid for its wholesale input P_t^w . The retailer differentiates the wholesale output at no cost based on a constant returns to scale technology $Y_t(j) = Y_t^w(j)$. The retail firm minimizes its real cost $\min_{Y_t^w(j)} P_t^w Y_t^w(j) / P_t^m$ subject to $Y_t(j) = Y_t^w(j)$, where the optimal condition and the envelope theorem give a definition of the real marginal cost as P_t^w / P_t^m .

The retail firms choose prices in a monopolistically competitive setting via a Calvo mechanism. Each period only a fraction $1 - \omega$ of firms is allowed to adjust prices. This mechanism results in sticky prices and in the case of inflation, in an inefficient dispersion of consumption across different varieties. Monopolistic competition with Calvo pricing implies that the firms maximize the present discounted value of their current and future profits $\sum_{i=0}^{\infty} (\omega\beta)^i E_t \{ D_{i,t+i} [(1+s)P_t^m(j) - P_{t+i}^w] Y_{t+i}(j) / P_{t+i}^m \}$ subject to the demand curve $Y_{t+i}(j) = Y_{t+i}^d(j) = [P_t^m(j) / P_{t+i}^m]^{-\epsilon} Y_{t+i}^d$, where s is a monopolistic competition subsidy and $D_{i,t+i} = \lambda_{t+i} / \lambda_t$ is the relative growth of marginal utility of consumption from period t to period $t+i$. This profit maximization problem is formulated in terms of market consumption units and results in the following optimal condition for prices:

$$\frac{P_t^m(j)}{P_t^m} = \frac{\varepsilon \sum_{i=0}^{\infty} \left\{ (\omega\beta)^i E_t \left[D_{i,t+i} \left(\frac{P_{t+i}^w}{P_{t+i}^m} \right) Y_{t+i}^d \right] \right\}}{(\varepsilon - 1)(1 + s) \sum_{i=0}^{\infty} \left\{ (\omega\beta)^i E_t \left[D_{i,t+i} \left(\frac{1}{P_{t+i}^m} \right) Y_{t+i}^d \right] \right\}}. \quad (16)$$

2.4 Market Clearing

Total retail demand must equal supply

$$Y_t = A_t (C_t^m + k v_t). \quad (17)$$

where $A_t \equiv \int_0^1 [P_t^m(j) / P_t^m]^{-\epsilon} dj$ is a price dispersion term. The economy-wide resource constraint requires that total consumption must equal total production

$$C_t = [a(Y_t - k v_t)^\phi + (1 - a)(w^u(1 - N_t)^\phi)]^{1/\phi}. \quad (18)$$

2.5 Labor Market

Search frictions are present in the labor market. Each period a share ρ of the matches m_t , defined as filled job openings, in period t is destroyed. The number of workers searching for a job in period t is

$$s_t = 1 - N_{t-1} + \rho N_{t-1} = 1 - (1 - \rho) N_{t-1}, \quad (19)$$

where ρ is the exogenous job separation rate. Note that s_t is a pre-determined variable while the number of unemployed workers is a state variable which depends on employment in period t such that:

$$u_t = 1 - N_t \quad (20)$$

The matching function is

$$m_t = d_t v_t^\alpha s_t^{1-\alpha} = d_t \theta_t^\alpha s_t, \quad (21)$$

where $\theta_t \equiv v_t/s_t$ is the labor market tightness and $0 < \alpha < 1$ is the elasticity of matching with respect to vacancies. d_t is a parameter that governs the efficiency of matching and follows an AR(1) process with persistence ρ_d and standard deviation σ_d .

The flow of employed workers has the following law of motion

$$N_t = (1 - \rho)N_{t-1} + m_t = (1 - \rho)N_{t-1} + d_t \theta_t^\alpha s_t. \quad (22)$$

The value of a vacancy is zero in equilibrium implying that the expected value of a filled job this period has to be equal to the unit cost of posting a vacancy:

$$q_t J_t = k, \quad (23)$$

where q_t is the job-filling probability defined as

$$q_t \equiv \frac{m_t}{v_t}. \quad (24)$$

The value of a filled job is equal to the firm's current period profit plus the discounted value of having a match in the following period. If the marginal worker produces Z of output units and W_t is the nominal wage paid to the worker, then the value of a filled job in terms of the market consumption is

$$J_t = \frac{P_t^w}{P_t^m} Z - \frac{W_t}{P_t^m} + (1 - \rho)\beta E_t D_{t,t+1} J_{t+1} \quad (25)$$

Defining the real wage as

$$w_t \equiv \frac{W_t}{P_t^m} \quad (26)$$

the payoff from hiring a worker can be rewritten as

$$J_t = \frac{P_t^w}{P_t^m} Z - w_t + (1 - \rho)\beta E_t D_{t,t+1} J_{t+1}. \quad (27)$$

The reservation wage for the firm is the wage which gives at least a surplus $J_t = 0$,

$$w_t^{rf} = \frac{P_t^w}{P_t^m} Z + (1 - \rho)\beta E_t D_{t,t+1} J_{t+1}.$$

Substituting for the firm's surplus from the job posting condition delivers an expression which says that the real marginal benefit from employing a worker must equal the real marginal cost,

$$\frac{P_t^w}{P_t^m} Z = w_t + \frac{k}{q_t} - (1 - \rho)\beta E_t D_{t,t+1} \frac{k}{q_{t+1}}. \quad (28)$$

Similarly, the firm's reservation wage is the wage

$$w_t^{rf} = \frac{P_t^w}{P_t^m} Z + (1 - \rho)\beta E_t D_{t,t+1} \frac{k}{q_{t+1}}. \quad (29)$$

Define the job finding probability for a worker as

$$pr_t \equiv \frac{m_t}{s_t}.$$

The real value of being employed is a sum of the real wage and the future payoff from being employed adjusted for the job survival probability and for the likelihood of being fired and getting V_{t+1}^u ,

$$V_t^e = w_t + \beta E_t D_{t,t+1} \left\{ (1 - \rho)V_{t+1}^e + \rho [pr_{t+1} V_{t+1}^e + (1 - pr_{t+1}) V_{t+1}^u] \right\}. \quad (30)$$

An unemployed worker stays at home and produces a w^u units of home goods whose value in terms of market goods is $P_t^h/P_t^m = MRS_t$. The payoff from being unemployed is the sum of the value of home production and the future payoff from staying unemployed or from becoming employed adjusted for the job finding probability

$$V_t^u = MRS_t w^u + \beta E_t D_{t,t+1} [(1 - pr_{t+1})V_{t+1}^u + pr_{t+1}V_{t+1}^e]. \quad (31)$$

The surplus from employment over unemployment is:

$$V_t^s = V_t^e - V_t^u = w_t - MRS_t w^u + \beta(1 - \rho)E_t D_{t,t+1}(1 - pr_{t+1})V_{t+1}^s. \quad (32)$$

The workers' payoff from a match is affected by the size of the unemployment benefit which has a fixed component w^u and an endogenous component MRS_t . The time-varying component fluctuates with unemployment and inflation. A rise in unemployment increases the relative quantity of home goods, reduces the marginal rate of substitution MRS_t and the unemployment benefit. A rise in inflation lowers the relative price of home goods $\frac{P_t^h}{P_t^m}$ and also reduces the unemployment benefit. The reservation wage for a worker is the wage that delivers a surplus $V_t^s = 0$:

$$w_t^{rw} = MRS_t w^u - \beta(1 - \rho)E_t D_{t,t+1}(1 - pr_{t+1})V_{t+1}^s \quad (33)$$

If a matched worker and firm form a Nash bargain over the wage, the bargaining set is determined by the two reservation wages: $[w_t^{rw}, w_t^{rf}]$.

$$w_t = bw_t^{rf} + (1 - b)w_t^{rw}. \quad (34)$$

The wage is a weighted average of the two reservation wages and b describes the degree of bargaining power of workers.

Using the fact that $V_t^s = bJ_t/(1 - b) = bk/[(1 - b)q_t]$ yields the following expression for the real wage,

$$w_t = w^u MRS_t + \left(\frac{1}{1 - b}\right) \frac{k}{q_t} - (1 - \rho)\beta E_t D_{t,t+1} \left(\frac{k}{q_{t+1}}\right) \left(\frac{b}{1 - b}\right) (1 - pr_{t+1}).$$

Substituting this result into 28, I obtain that the relative price of wholesale goods in terms of retail goods is

$$\frac{P_t^w}{P_t^m} = \frac{1}{\mu_t} = \frac{\eta_t}{Z},$$

where η_t is the effective cost of labor and is defined as

$$\eta_t \equiv \left(\frac{1}{1 - b}\right) \frac{k}{q_t} - (1 - \rho)\beta E_t D_{t,t+1} \left(\frac{k}{q_{t+1}}\right) \left(\frac{1}{1 - b}\right) (1 - bpr_{t+1}) + MRS_t w^u. \quad (35)$$

The marginal rate of substitution affects inflation through η_t . A rise in the marginal rate of substitution corresponds to an increase in the value of home relative to market goods. This increases wages in the wholesale sector and raises the wholesale prices relative to retail prices. The resulting rise in the marginal cost of the retail firms and fall in the retail price markup increases inflation.

Monetary policy also affects inflation through η_t . A rise in the nominal interest rate lowers $D_{t,t+1}$ and lowers the value of a future match. This raises the current marginal cost because it reduces the value of any future recruitment cost savings the firm has obtained due to having formed a match in the current period. The fact that hiring costs are directly affected by the nominal interest rates indicates that the monetary policy works through a cost channel as well as through a standard aggregate demand channel.

3 Parametrization and Methodology

The parametrization is based on the US economy. One group of parameters are set based on the literature of monetary business cycle models. I assume that the household maximizes the log utility of final consumption so that $\sigma = 1$ and that its discount factor is $\beta = 0.99$. The elasticity of substitution between final varieties ϵ is set to 6 which would usually imply a steady state markup of 20 % but it is offset with steady state subsidy so that the steady state $\mu = 1$. The average duration of price stickiness is four quarters, corresponding to $\omega = 0.75$.

A second group of parameters is taken from the search and matching literature. The exogenous separation rate is set at $\rho = 0.1$. I follow Blanchard and Gali [2010b] and set the vacancy cost k so that the steady state ratio of total vacancy costs to output kv/Y of 1 percent. The steady state employment N is set to 0.94 which implies a 6 percent steady state unemployment. The steady state vacancy filling probability is chosen to be $q = 0.7$. The value of the productivity parameter for home production w^u and the steady state efficiency matching parameter d are derived from the steady-state conditions. The elasticity in the matches with respect to vacancies is set to $\alpha = 0.5$, which is in the range of plausible values proposed by Petrongolo and Pissarides [2001]. The degree of the bargaining power parameter b is set to 0.5 to satisfy the Hosios condition which ensures an efficient steady state.

When home and market goods are perfect substitutes, the elasticity of substitution parameter is set to $\phi = 1$ which ensures that the marginal rate of substitution is constant. When home and market consumption are imperfect substitutes, the parameter ϕ is set to fit an elasticity of substitution between market and home goods of 3. Benhabib et al. [1991a] set this elasticity equal to 5 in their most preferred specification. In McGrattan et al. [1997] the estimated elasticity is slightly less than 2, while in Schorfheide [2003] the estimate is around 2.3. Using micro data, Rupert et al. [1995] estimate a value of around 1.8, Aguiar and Hurst [2007] estimate a value of around 2 and Gelber and Mitchell [2009] estimate a value of around 2.5. Karabarbounis [2010] estimates it at 3.393.

To avoid asymmetry in demand for market versus home goods and ensure a , the preference parameter a in the consumption aggregate is set to 0.5.

I calibrate the temporary shock process using the properties of the series $\ln(d_t)$ described above. Hence, I set $\rho_d = 0.965$ and $\sigma_d = 0.032$.

Analysis of how the shock propagates under different assumptions about sticky prices and monetary policy follows.

4 Results

4.1 Temporary matching efficiency shock

Propagation of the shock in an efficient RBC model with search and matching frictions Matching efficiency shocks are still relatively non-standard in business cycle models. To understand how monetary policy affects the propagation of the shock and how the goals of optimal monetary policy are affected by it, it is useful first to examine its effect in the context of an RBC model that is efficient.

It is important how efficiency is defined because the goals of optimal monetary policy, when implemented by a Ramsey planner are to stabilize fluctuations in model variables relative to their efficient RBC levels. Thus the efficient RBC model serves as a benchmark for optimal monetary policy. There are three inefficiencies in the model, including monopolistic competition in the final goods sector, sticky retail prices, and a search friction in the labor market. Monopolistic competition is inefficient because retail firms have market power. They set prices that are too high and lead to an inefficiently low demand. Calvo price stickiness results in an inefficient price dispersion that leads to an inefficient composition of the market consumer basket as households buy more of the cheaper varieties than they would in an efficient outcome. The search friction on the labor market results in too few productive matches and equilibrium unemployment.

An efficient dynamic equilibrium eliminates these inefficiencies. The sticky prices inefficiency is eliminated by allowing all firms to adjust their price optimally so that $\omega = 0$ and imposing a constant markup $\mu_t = \mu$. The monopolistic inefficiency is eliminated by giving a steady state subsidy to retailers ($sub = \frac{\epsilon}{\epsilon-1}$) to offset the markup so that at the steady state the markup is one. The search friction is eliminated by imposing the Hosios condition where the elasticity of the matching function with respect to unemployment is set equal to the bargaining share of workers, $1 - \alpha = b$. Thus, the efficient dynamic equilibrium can be described by a real business cycle (RBC) model where prices are flexible, the markup is constant and equal to one and the Hosios condition holds.

Figure 3 shows the impulse responses of selected variables to one standard deviation decline in matching efficiency in such a model. The effect of the persistence of the shock on its propagation and monetary policy is discussed in section 4.1. The variables are expressed in terms of percentage points relative to the steady state. The decline in matching efficiency results in fewer employment matches in the economy which reduces employment and raises unemployment on impact. Note that the number of searchers does not change on impact because it is a pre-determined variable. Thus, the response of the probability of filling a vacancy on impact is driven by the shock and the response of vacancies. Figure 3 shows that the decline in matching reduces the probability of filling a vacancy, which raises hiring costs and leads firms to post fewer vacancies on impact. Note, however, that the expected future probability of filling a vacancy declines by almost as much because of the persistent shock. This means that firms can save on hiring costs in the future if they keep the vacancies they have so that the initial decline in vacancies is quickly reversed. The decline in matching efficiency also results in a fall in real wages because workers are willing to accept a lower reservation wage due to the persistent difficulty of forming a match.

Propagation and the role of monetary policy rules Figure 4 compares the impulses responses to the negative matching efficiency shock in the RBC model under flexible prices (solid lines) to the same model but with sticky prices (dashed and dash-dot lines). In the sticky price model monetary policy is assumed to follow a policy rule where the nominal interest rate responds to inflation and the output level, i.e.

$$\beta(1 + i_t) = (1 + \pi_t)^{\gamma_\pi} \left(\frac{Y_t}{Y_{ss}}\right)^{\gamma_Y}, \quad (36)$$

where γ_π describes the degree of the response to inflation and γ_Y the degree of the response to the output level. In the first case (dashed lines), I assume an inflation targeting policy rule such that $\gamma_\pi = 2$ and $\gamma_Y = 0$. In the second case (dash-dot lines), I assume a dual mandate policy rule such that $\gamma_\pi = 2$ and $\gamma_Y = 0.5$. Figure 4 demonstrates that monetary policy plays a critical role for the propagation of the shock when prices are sticky. Given the degree of price stickiness, the accommodativeness of the monetary rule affects the sign of the response of inflation and the direction of the monetary policy.

When the policy rule is non-accommodative and the nominal interest rate only responds to inflation, a decline in matching efficiency implies a decline in inflation. Note that vacancies still decline on impact, a decline larger than the decline observed in the RBC model. This in turn implies a much smaller decline in the probability of filling vacancy on impact. However, the size of the response of the future probability of filling a vacancy remains persistently low. This increases the value of existing matches and eliminates the need to incur future job posting costs. Hence, an increase in the expected cost of future job postings lowers the effective cost of labor today and decreases inflation. This leads the central bank to engage in expansionary monetary policy and lower the nominal interest rate in response to deflation.

When the policy rule is accommodative and the nominal interest rate responds to inflation as well as the output level, the decline in matching efficiency implies a rise in inflation. Figure 4 shows that this is mostly driven by inflation expectations. Under inflation targeting inflation expectations remain relatively stable due to the commitment to a policy of price stability despite the expected persistent rise in hiring costs. Under dual mandate inflation expectations rise due to the persistent increase in future hiring costs resulting from a decline in matching efficiency. This rise in expected inflation dominates the negative effect that the increase in future hiring costs has on current hiring costs, hence, inflation. In contrast to the non-accommodative rule, here, the rise in inflation leads the central bank to engage in contractionary monetary policy and raise the nominal interest rate.

Monetary policy is also critical for the response of unemployment and output relative to their efficient levels in the RBC model. Define the output gap as fluctuations in output within the sticky price model relative to the fluctuations in output in the efficient RBC model, i.e. $\hat{Y}_t = \hat{Y}_t / \hat{Y}_t^{RBC} - 1$ where $\hat{Y}_t = Y_t / Y_{ss} - 1$ $\hat{Y}_t^{RBC} = Y_t^{RBC} / Y_{ss} - 1$. Under a non-accommodative monetary policy rule the output gap is always negative because output under sticky prices declines by more than output under flexible prices. In contrast, under an accommodative monetary policy rule, the output gap is negative on impact but turns positive quickly. This is because the expected fall in output under sticky prices and an accommodative regime is lower than under flexible prices. The opposite is true for the unemployment gap: it is always positive in a non-accommodative regime and positive on impact but turns negative quickly under an accommodative regime.

Optimal monetary policy

The optimal monetary policy is under commitment and is implemented by a Ramsey planner who maximizes household welfare subject to the structural equations of the model outlined in section 2. It is solved numerically with DYNARE. Figure 5 shows the Ramsey optimal monetary policy response to a negative matching efficiency shock when this shock results in a deviation from the efficient steady state. Within the optimal monetary policy model, if the efficiency of matching falls, unemployment does not fluctuate relative to its efficient level and the unemployment gap remains stable. In other words, the shock is efficient because it does not present the optimal monetary policy maker with a trade off between stabilizing the unemployment gap and inflation. The central bank needs not deviate from a policy of price stability. In the previous section, I showed that the shock results in a rise in inflation under a dual mandate policy rule and in a fall in inflation under an inflation targeting rule. Similarly to the inflation targeting case, the optimal monetary policy is only to maintain price stability. Thus, the shock puts a downward pressure on inflation and the optimal monetary policy is to lower the nominal interest rate in order to offset the fall in inflation. Thus, inflation targeting more closely implements the optimal policy than a dual mandate rule when the shock causes the economy to deviate from its efficient steady state.

The role of imperfect substitutes In this section, I examine the role of the assumption that home and market goods are perfect substitutes on the optimal monetary policy. The effect of home production on the propagation of shocks is not new in the business cycle literature. Benhabib et al. [1991b] and Greenwood and Hercowitz [1991] develop real business cycle models where the extent to which market expenditures and market work fall during recessions depends on the willingness of households to substitute between market-produced and home-produced goods. Assuming that home and market work are perfect substitutes is arguably extreme. A range of estimates, including a very recent paper by Aguiar et al. [2013] provide evidence that the elasticity of substitution between home and market goods is high but the range of estimates in the literature varies from 1 to 3. Thus, it is useful to examine the role of this assumption on the optimal monetary policy response.

Figure 6 provides plots of the impulse responses (dashed lines) of the optimal monetary policy in a sticky price model under imperfect substitutes against the impulse responses (solid lines) of a flexible price RBC model under imperfect substitutes. First, the figure shows that the assumption that home and market goods are imperfect substitutes does not have an effect on the monetary policy decision. It does not create inefficient

fluctuations in the unemployment gap, and the optimal monetary policy is still to stabilize inflation. However, figure 6 also compares optimal monetary policy under imperfect substitutes (dashed lines) to optimal monetary policy under perfect substitutes (dash-dot lines). It shows that the assumption changes the size of the optimal monetary policy response. When home and market goods are imperfect substitutes, and the decline in matching efficiency raises the number of unemployed, the households are less willing to substitute the decline in market goods with more home goods than in the perfect substitutes case. The marginal rate of substitution declines in response to the shock indicating home goods become less valuable to households. The decline in the value of home production also lowers the payoff from being unemployed, indicating that workers are less willing to be unemployed relative to the perfect substitutes case. As a result, the decline in market production and the rise in unemployment are much less pronounced than in the perfect substitutes case. Since the decline in market production is smaller, firms need to post more vacancies in order to achieve their hiring target. This lowers the probability of filling a vacancy much more than in the perfect substitutes case, and puts upward pressure on current hiring costs and inflation. Note however, the persistent rise in future hiring costs eliminates the need to incur job posting costs in the future which still puts downward pressure on current hiring costs and inflation. It turns out that the latter effect dominates, although the downward pressure exerted on inflation is smaller under imperfect substitutes than under perfect substitutes. Therefore, the central bank needs to lower its interest rate by less under imperfect substitutes in order to maintain price stability. Note that the response of the interest rate is three times smaller under imperfect substitutes. In the next section, I show that if the persistence of the shock is lower, the direction of the response can also change.

Note also that the decline in the value of home production lowers the reservation wage that workers are willing to accept from firms and puts a downward pressure on the Nash bargained real wage relative to the perfect substitutes case.

Inefficient shock

So far the matching efficiency shock has not presented the optimal policy maker with a trade off between stabilizing prices and the rest of the economy. This is because the shock did not result in inefficient fluctuations in the unemployment gap. In this section I analyze how the optimal monetary policy alters when the shock results in inefficient fluctuations in the real side of the economy. In order to make the shock inefficient, I increase the bargaining power parameter b from 0.5 to 0.65 while leaving $\alpha = 0.5$. This generates a deviation from the Hosios condition and worsens the search and matching friction in the model. Intuitively, when workers bargaining weight is inefficiently high, firms find it less profitable to create vacancies. Thus unemployment is higher than in the efficient outcome. Figure 7 compares impulse responses to a negative matching efficiency shock in three models: (1) the solid line refers to the efficient model where the monetary authority maintains a policy of price stability and the Hosios condition is met ($b = 1 - \alpha = 0.5$), (2) the dashed line refers to the inefficient model where the monetary authority still maintains a policy of price stability but the Hosios condition is violated ($b = 0.65 > 1 - \alpha = 0.5$), and (3) the dash-dot line refers to the model where the monetary authority maintains optimal Ramsey policy and the Hosios condition is violated. Comparing the efficient and inefficient model under price stability (solid to dashed lines) reveals that unemployment is higher when the Hosios condition is violated and the bargaining power of workers is inefficiently high. This is because the firms bargaining power is low and they have less incentive to post vacancies which reduces the profitability of a vacancy as well as the number of vacancies. The difference between the solid and the dashed line measures the excess of unemployment (shortage of vacancies) stemming from the inefficiency. In this case the monetary authority that acts optimally has an incentive to deviate from a policy of price stability and to engage in “accommodative” monetary policy in order to fight the implied increase in the unemployment gap and the inefficiently low vacancy posting. As figure 7 shows (comparing solid to dash-dot lines) when the Hosios condition is violated, the optimal monetary policy is very different because it is optimal to raise the nominal interest rate as opposed to the efficient case where it was optimal to lower it.

Recall that under an accommodative dual mandate monetary policy and sticky prices, inflation expectations are no longer stable. A very persistent decline in matching efficiency causes a persistent rise in future hiring costs and raises expected inflation which lowers the real interest rate via the Fischer equation. A lower real interest rate, in turn, raises the current value of a match to the firm and stimulates vacancy creation. Thus, the Ramsey planner can stimulate vacancy creation by accommodating the rise in inflation expectations and raising the nominal interest rate just enough to control current inflation and not offset the fall in the real interest rate resulting from higher expected inflation. If the Ramsey planner were to lower the nominal interest rate, then he would raise aggregate demand, lower markups and increase the current profitability of a match to the firm. But this will come at a cost of even higher inflation. Furthermore, he would create deflationary expectations via the vacancy channel of monetary policy which would offset the fall in the real interest rate created by the inflation expectations produced by the shock.³ By accommodating inflation expectations, the

³This is because a fall in the nominal interest rate would further lower the real interest rate. A real interest rate fall, by raising consumption demand, increases firms’ current vacancy posting and hence raises the level of employment available for production in current and subsequent periods. Hence, the interest rate fall raises future output supply. At the same time, such a rate fall prompts households to substitute future with current consumption, and thus firms expect consumption demand to fall after its current rise. From this expected fall in future demand and the higher future supply, firms anticipate a strong contraction of future

Ramsey planner can stimulate vacancy creation and reduce the rise in the unemployment gap. By raising the nominal interest rate he can control current inflation via an aggregate demand channel although he is not able to eliminate it completely because that would imply eliminating inflation expectations and having inefficiently low vacancy creation. Thus, when the Hosios condition is violated, a decline in the matching efficiency generates an inefficiently high unemployment gap and the optimal monetary policy maker faces a trade off between stabilizing prices and stabilizing unemployment.

Less persistent shock Table 1 shows that the persistence of the shock affects the conditional correlation between unemployment and vacancies. In the efficient RBC model where prices are completely flexible a very persistent shock generates a positive conditional correlation between the two variables while under a less persistent shock the correlation is negative. This is because a more persistent shock means that filling a vacancy in the future is expected to be costly for a while. So, this raises the present discounted value of current vacancies and leads firms to lower their vacancy by less on impact than under a less persistent shock. In addition, future hiring costs rise more with the persistence of the shock which raises the current profitability of a match to the firm and stimulates vacancy creation, so that vacancies not only fall by less but also rise by more afterward under a more persistent shock. This explains why under a very persistent shock there is a positive correlation between unemployment and vacancies and under a less persistent shock there is negative correlation.

As table 1 shows there is a similar effect on the correlation between vacancies and unemployment in the inflation targeting sticky price version of the model. A more persistent shock also reduces the volatility of inflation in the inflation targeting regime. Note that in that model a smaller decline in vacancies also implies a smaller decline in labor market tightness and the wage and hence a smaller decline in inflation.

In the dual mandate sticky price model, the correlation between vacancies and unemployment is also higher when the shock is more persistent. However, it remains positive (even if $\rho_d = 0$ the correlation is 0.2948). This is due to the different response in vacancies. A very persistent shock causes a fall in vacancies on impact while a less persistent shock ($\rho_d = 0.6$) would imply a rise in vacancies on impact. This is because when the shock is less persistent the decline in output is expected to be smaller and less persistent which means that firms need to raise their vacancies in order to achieve their hiring targets.

Furlanetto and Groshenny [2012] show that when the persistence of the shock is low the response of vacancies depends on the degree of price stickiness. According to their results in a flexible price model vacancies decline on impact in response to a negative matching efficiency shock while in a sticky price model vacancies rise on impact. They explain the different response with the fact that prices are rigid. They also mention that another condition that affects the sign of the vacancy response on impact is inertia of monetary policy. The results in 1 demonstrate that it is the accomodativeness of monetary policy that matters rather than the inertia of monetary policy. In section 4.1 I show that the accomodativeness of monetary policy also matters for the sign of the inflation response as well as for the fluctuations in the unemployment gap. Furlanetto and Groshenny [2012] estimate a model with search and matching frictions and sticky prices on US data and find that the unemployment gap falls in response to a decline of matching efficiency. The results in section 4.1 demonstrate that this response is conditional on a dual mandate monetary policy while under an inflation targeting regime the opposite is expected to happen. This suggests that a similar estimation conducted on an inflation targeting country might lead to different result about the impact of matching efficiency shocks on the unemployment gap.

In a dual mandate regime hiring costs are also expected to be lower relative to the more persistent case which lowers expected inflation and reduces the inflationary impact of the shock. Table 1 shows that a less persistent shock lowers inflation volatility in the dual mandate regime while it increases it in the inflation targeting regime. The reason behind this is that under inflation targeting inflation expectations remain relatively stable due to the commitment to a policy of price stability despite the lower persistence of the shock. Under dual mandate inflation expectations fall relative to the more persistent case due to the less persistent increase in future hiring costs resulting from the decline in matching efficiency.

In the optimal monetary policy model when the Hosios condition holds and the shock is efficient, the effect of a less persistent shock is identical to the efficient RBC model as the Ramsey planner is able to perfectly stabilize inflation.

In the optimal monetary policy model when the Hosios condition is violated and the shock is inefficient, the effect of a less persistent shock is similar to the dual mandate model. The conditional correlation between unemployment and vacancies declines under a less persistent shock. Less persistent shock also generates lower volatility of inflation and the nominal interest rate because the rise in expected inflation is smaller as a result of the shock.

vacancy posting. This lowers expected future real marginal cost via the job creation condition, and hence expected future inflation. Therefore, the vacancy channel leads a fall in the real interest rate to lower expected future inflation.

4.2 Permanent matching efficiency shock

Transition and the role of optimal monetary policy Figure 8 (solid lines) shows the transition paths of selected variables in response to a one time immediate and permanent fall in matching efficiency. The size of the fall is the same as the standard deviation of the temporary stochastic shock: 0.032. The variables are measured in percentage point deviation from the pre-shock steady state. The solid line represents the transition in the model where the Hosios condition holds, prices are sticky, home and market goods are perfect substitutes and the Ramsey planner sets monetary policy. Not surprisingly, inflation is zero throughout the transition (for brevity not shown on the figure). This is because when the Hosios condition holds the shock does not create inefficient fluctuations in unemployment and the Ramsey planner maintains an optimal policy of price stability. Recall that this is similar to an inflation targeting regime, where a decline in matching efficiency today caused a fall in the expected probability of filling a vacancy tomorrow. This raised expected hiring costs next period and but lowered hiring costs today because it eliminated the need for firms to incur future job posting costs. Lower hiring costs today would have caused a fall in inflation. Thus the Ramsey planner lowers the nominal interest rate in order to eliminate this potential fall in inflation.

Figure 8 also shows that a permanent decline indeed results in a permanent shift in the Beveridge curve. It takes the economy about two years to converge to a steady state with higher unemployment and higher vacancies. The transition is slow because the number of searchers in the economy is a backward looking variable. Job search is costly process and it takes one period for the number of searchers to react to the shock. That is why on impact vacancies and matches undershoot their steady state values. When the shock hits, the number of matches in the economy declines which causes a decline in the probability of filling a vacancy. This causes current hiring costs to rise which induces firms to decrease their vacancy posting on impact. Thus, the number of matches falls even more than the shock would imply. Note that labor market tightness also declines on impact due to the fall in vacancies.

In the period after the shock hits, the job searchers in the economy react to the less efficient hiring process and starts to slowly increase until they converge to their higher steady state value. This cause the number of matches to rise relative to the preceding period. This in turn results in a slight increase in the job filling probability and a slight decline in hiring costs. This causes vacancies to start recovering in the period after the shock. But as the adjustment of job searchers is slow, and vacancy posting is costly, it takes time for vacancies to increase sufficiently until they converge to their new higher steady state value.

The role of imperfect substitutes Figure 8 also compares the adjustment path of the model where home and market goods are imperfect substitutes (dashed lines) to the adjustment path of the model where home and market goods are perfect substitutes (solid lines). The simulation again shows the adjustment following a permanent and immediate decline in the matching efficiency. The Ramsey policy remains unchanged. As in the perfect substitutes model, it is optimal to maintain price stability throughout the transition (for brevity inflation not shown on figure).

The long run outcome of the shock remains qualitatively unchanged under the imperfect substitutes model. There is a permanent outward shift in the BC curve although figure 8 reveals that the imperfect substitutes model implies a shift to a point on the lower portion of the new BC than the perfect substitutes model.⁴ The presence of imperfect substitutes implies a smaller rise in unemployment and a larger rise in vacancies. The decline in matching efficiency increases the supply of home goods relative to market goods and in the imperfect substitutes this lowers the value of home production. The marginal rate of substitution falls which means that households are more reluctant to have unemployed members in the imperfect substitutes model than in the perfect substitutes one. The decline in the value of home production also reduces the reservation value of the worker and the real wage. Firms pay lower wages per worker and can afford to post more vacancies than in the perfect substitutes model.

The transition following the shock also remains qualitatively unchanged except for vacancies and labor market tightness. In the imperfect substitutes model they rise on impact while they rose in the perfect substitutes model. Behind this changed response on impact is again the immediate decline in the value of home production following the shock. It causes an immediate drop in the reservation value of the worker and hence in the real wage which means that firms can use the savings from lower wage to immediately increase their vacancy posting despite the rise in hiring costs.

Inefficient shock

Figure 9 shows the adjustment paths of selected variables to a one time permanent decline in matching efficiency. The solid lines show the model where the Hosios condition is violated and monetary policy is to maintain perfect price stability. The dashed lines refer to the model where the Hosios condition holds and

⁴Since the parameter ϕ does not affect the steady state BC, it can be assumed that the two model economies operate on the same BC before and after the shock. In fact, the current parametrization implies that the two model economies start on the same initial point on the BC before the shock because steady state unemployment and vacancies are equal in the two models before the shock.

monetary policy is optimal. The dash-dot lines refer to the model where the Hosios condition is violated and monetary policy is optimal.

Comparing the model where the Hosios condition holds to the model where the Hosios condition is violated and monetary policy is to maintain price stability (solid to dashed lines) reveals that the transition and steady state outcomes are qualitatively similar. The differences are only quantitative. This is explained by the fact that in both models monetary policy goals are the same, to maintain price stability. Thus, these transition paths are equivalent to RBC models with corresponding steady states where prices are perfectly flexible. In the inefficient model the bargaining power of the workers is inefficiently high which implies lower vacancy creation than in the efficient model. In terms of percentage points the rise in vacancies is smaller than in the efficient model. The rise in unemployment in terms of percentage points is larger relative to the efficient model. Since the steady state Beveridge curve does not depend on the bargaining parameter b , we can assume that both model economies operate on the same Beveridge curves before and after the shock hits. Increasing the bargaining power of workers, puts the model economy on a different initial point on the BC where unemployment is higher and vacancies are lower than in the efficient model economy. Since the inefficient economy operates on the upper portion of the BC and the shock generates a parallel shift, it is not surprising that the rise in unemployment is higher and the rise in vacancies smaller than in the efficient model. In addition, the speed of adjustment in the inefficient model seems slightly slower. This is not surprising considering that violating the Hosios condition worsens the search and matching friction.

Looking at the model where monetary policy is optimal and the Hosios condition is violated reveals that the adjustment path is qualitatively different than the paths of the two models where monetary policy is to maintain price stability. Note however, that the shock implies the same long-run outward shift in the BC because unemployment and vacancies are both higher compared to the initial steady state. The steady states before and after the shock are the same in the inefficient models with price stability and optimal monetary policy. Even though monetary policy does not influence the steady state in the inefficient model, it is key for the transition after a permanent decline in match efficiency. This is because violating the Hosios condition changes the goals of the Ramsey planner because during the transition he faces a trade-off between maintaining price stability and limiting the inefficient fluctuations in the labor market resulting from the shock. The Ramsey planner has an incentive to deviate from a policy of price stability and engage in more accommodative monetary policy. This causes fluctuations in inflation expectations during the transition. Initially the shock causes a rise in the expected future probability of filling a vacancy, which raises future hiring costs and raises expected inflation. This causes inflation to be positive throughout the transition. Similarly to the case of a temporary shock, the Ramsey planner finds it optimal to raise the nominal interest rate in order to limit the rise in current inflation resulting from the rise in expected inflation. However, he also finds it optimal to accommodate inflation expectations, so that the rise in expected inflation is large enough to generate a fall in the real interest rate via the Fisher equation. A lower interest rate during the transition is optimal because it stimulates vacancy posting which is inefficiently low due to the inefficiently high bargaining power of workers.

5 Conclusion

I use a DSGE model with search and matching frictions to analyze the monetary policy response to an outward shift in the BC resulting from a decline in the efficiency of matching. I treat the decline in the efficiency of matching as exogenous and describe how the economy adjusts in response and how this adjustment is affected by monetary policy. I examine the adjustment in response to both a temporary and a permanent decline in matching efficiency.

First I characterize how a temporary shock propagates. Since it is a nonstandard shock I start the analysis in the context of an efficient RBC model where prices are fully flexible, the retail markup is constant and equal to one and the Hosios condition holds. I find that a temporary but persistent decline in the matching efficiency leads to less hiring and higher unemployment. In response to higher hiring costs, firms post fewer vacancies on impact but quickly increase their vacancy posting afterward because the increase in future hiring costs soon makes current matches very valuable.

I proceed with analyzing how the same shock propagates in a model where prices are sticky and monetary policy is described by a Taylor rule. I find that the type of rule is critical for the effect of the shock on inflation and for the direction of the monetary policy response. When the rule is strictly inflation-targeting, inflation falls and the nominal interest rate falls in response. When the rule is a dual mandate rule which implies that the interest rate responds to output as well as inflation, inflation rises and nominal interest rate also rises in response. This is because of the different response in inflation expectations. Under the inflation hiring rule, inflation expectations are stable. The decline in matching efficiency causes a rise in future hiring costs. This increases the value of existing matches and eliminates the need of firms to incur future job posting costs. Hence, an increase in the expected cost of future job postings lowers the effective cost of labor today and decreases inflation. Under the dual mandate rule, inflation expectations are no longer stable. The persistent rise in expected future hiring costs raises expected inflation which also raises current inflation. The nominal interest

rate rises in response to inflation but not enough to offset the fall in the real interest rate due to expected inflation. Thus, under a dual mandate rule, monetary policy is accommodating inflation expectations in order to lower the real interest rate and stabilize output.

Having characterized the critical role of monetary policy when interpreted as a Taylor rule, I turn to the optimal monetary policy response. Optimal monetary policy is implemented by a Ramsey planner who uses the nominal interest rate as an instrument to maximize household welfare subject to the structural conditions in the economy. I distinguish two cases: first, when the shock does not cause fluctuations in unemployment relative to its efficient level in the RBC model; second, when the shock does cause inefficient fluctuations in unemployment relative to its efficient counterpart. The difference between the two models is that in the first the Hosios condition holds and in the second the Hosios condition is violated because the bargaining power of workers is inefficiently high (higher than the elasticity of unemployment in the matching function). I find that the assumption about the Hosios condition changes the goals of the Ramsey planner which is critical for the optimal response of the nominal interest rate. In the first case the goal of the planner is to pursue a policy of price stability. Similarly, to the model with an inflation-targeting Taylor rule, the decline in matching efficiency implies a fall inflation and a fall in the nominal interest rate to stabilize inflation. In the second case the goal of the planner is both to stabilize inflation but also to stabilize fluctuations in labor market variables relative to their efficient levels. In that case the Hosios condition is violated because the bargaining power of workers is inefficiently high. This implies that the firms bargaining power is inefficiently low and they have less incentive to post vacancies which reduces the profitability of a vacancy as well as the number of vacancies. This in turn causes higher unemployment than in the model where the Hosios condition holds. In this case the planner has an incentive to deviate from a policy of price stability and to engage in “dual mandate” monetary policy in order to fight the implied increase in the unemployment gap and the inefficiently low vacancy posting. Similarly to the dual-mandate Taylor rule, the decline in matching efficiency causes a rise in inflation due to higher inflation expectations. The planner raises the nominal interest rate in response to this higher inflation but not enough to eliminate it completely because he aims to maintain lower real interest rate by accommodating inflation expectations. He has an incentive to maintain lower real interest rate because he wants to stimulate vacancy posting and fight the inefficient increase in unemployment stemming from the shock.

I also analyze how the persistence of the shock affects the correlation between unemployment and vacancies in the different models. I find that a less persistent shock reduces this correlation. Monetary policy affects the correlation. When monetary policy is to maintain price stability, the correlation is lower. In fact, for a reasonably persistent shock ($\rho_d = 0.6$), it can become negative.

I then characterize the adjustment of the optimal monetary policy economy in response to a permanent decline of matching efficiency. First, I focus on the case where Hosios condition holds and second on the case where the Hosios condition is violated. In both cases, the decline in matching efficiency cause a permanent shift in the Beveridge curve because steady state unemployment and vacancies rise following the shock. However, when the Hosios condition is violated the steady state increase in unemployment is higher and the increase in vacancies smaller than in the model where the Hosios condition holds. The transitions are also different because of different goals of the Ramsey optimal monetary policy. Similarly to the temporary shock, when the Hosios condition holds, the goal of the planner is to maintain price stability throughout the transition by lowering the nominal interest rate. In contrast, when the Hosios condition is violated, the goal of the planner is both to limit the rise in inflation and the inefficient rise in unemployment. Recall that when the Hosios condition is violated the bargaining power of firms is too low, firms have less incentive to post vacancies than is efficient and consequently unemployment is higher than is efficient. At the same time, inflation expectations are no longer stable and cause a rise in current inflation. The planner raises the nominal interest rate to limit the rise inflation during the transition but not enough to offset the decline in real interest rates caused by the higher inflation expectations. Lower real interest rates are necessary to stimulate vacancy creation and limit the rise in unemployment.

Finally, I analyze the role of the assumption that home and market goods are imperfect substitutes for the propagation of the shock and the optimal monetary policy response. I find that the assumption of imperfect substitution does not change the goals of the Ramsey planner. However, it changes the propagation of the shock and the magnitude of the optimal monetary policy response. When home and market goods are imperfect substitutes, the value of home production declines in response to the shock which reduces the reservation value of the workers. This affects the incentives of workers and firms to form matches. Workers are more reluctant to be unemployed and firms are more inclined to post vacancies relative to the perfect substitutes case.

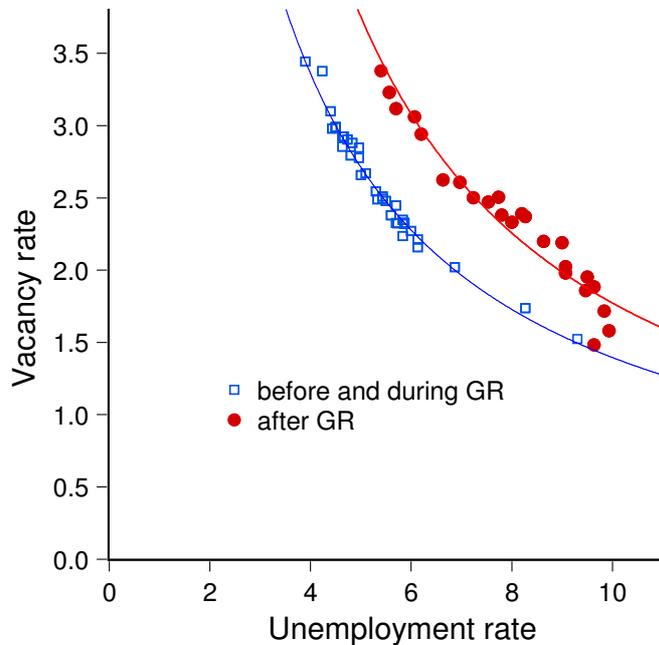
My results have two important implications. First, monetary policy is key for the propagation of a shock that shifts the Beveridge curve outward. The goals of monetary policy are critical for the way the shock affects inflation and, most importantly, for the way it affects fluctuations in unemployment and vacancies. Second, my results also indicate that the type of shock, temporary and persistent versus permanent, does not affect the goals of the optimal monetary policy. It is whether shock is efficient or not which affects these goals.

6 Tables and Figures

Table 1: Temporary shock persistence effect on unemployment-vacancy correlation and inflation and nominal interest rate volatility

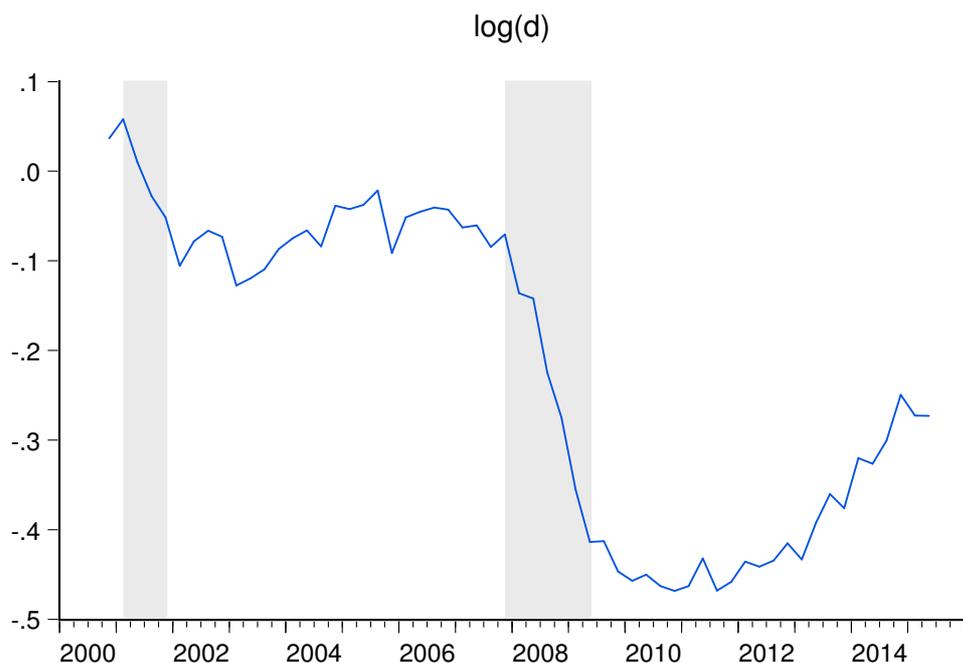
	correlation between unemployment and vacancies		volatility of inflation		volatility of nominal interest rate	
	$\rho_d = 0.965$	$\rho_d = 0.6$	$\rho_d = 0.965$	$\rho_d = 0.6$	$\rho_d = 0.965$	$\rho_d = 0.6$
efficient RBC model	0.9322	-0.2042				
sticky price model with inflation targetting Taylor rule	0.6567	-0.4763	0.0003	0.0006	0.0007	0.0011
sticky price model with dual mandate Taylor rule	0.8710	0.6879	0.0086	0.0014	0.0084	0.0010
optimal monetary policy model with an inefficient shock	0.9215	-0.0860	0.0009	0.0003	0.0007	0.0003

Figure 1: Beveridge Curve



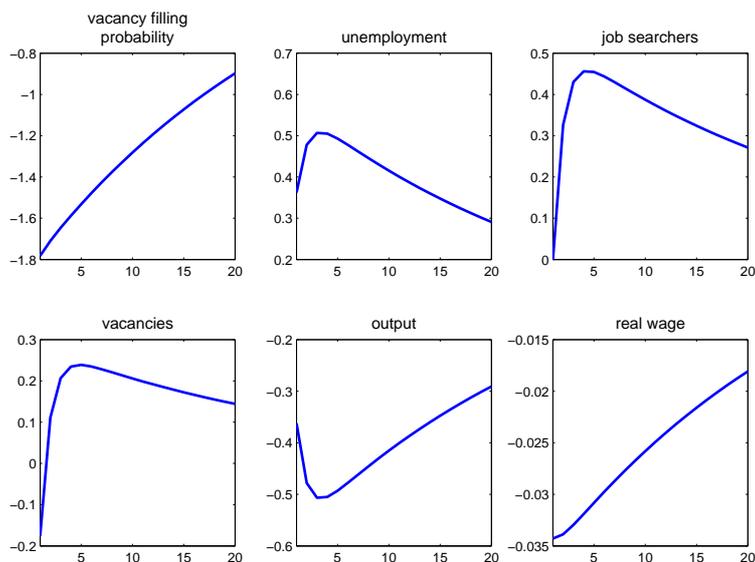
Notes: The US Bureau of Labor Statistics provides monthly data releases on unemployment via the Current Population Survey (CPS) and on job openings via the Job Openings and Labor Turnover Survey (JOLTS). Both unemployment and vacancies are normalized by the labor force and converted to quarterly series by taking the monthly average within a quarter. The plot encompasses the period from 2000Q4 to 2015Q2. The leftward solid line shows an inverse relationship between the unemployment and the job opening rates for the period before and during the Great Recession, from 2000Q4 to 2009Q2. The rightward solid line describes the US BC for the period after the Great recession, from 2009Q3 to July 2015Q2.

Figure 2: Matching function residual



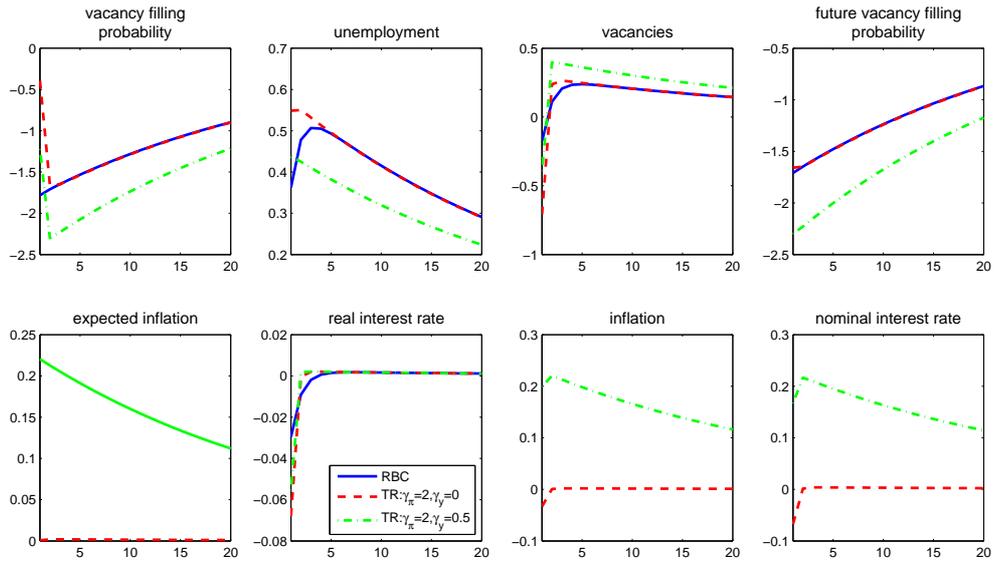
Notes: $\log(d_t) = \log(m_t) - 0.5\log(v_t) - 0.5\log(s_t)$. The source of data on total hires (m_t) and job openings (v_t) is JOLTS which publish labor market data from the last quarter of 2000. The data series for s_t is constructed based on the CPS series of the unemployment rate assuming exogenous quarterly separation rate of 0.1. Note that $s_t = 1 - (1 - \rho)(1 - u_{t-1}) = 1 - (1 - \rho - u_t + \rho u_t) = \rho - u_{t-1} - \rho u_{t-1}$ where u_{t-1} is the unemployment rate in period $t - 1$ and ρ is the exogenous separation rate. All three observables are normalized by the size of the labor force and converted from monthly to quarterly series by taking the quarterly average.

Figure 3: benchmark RBC



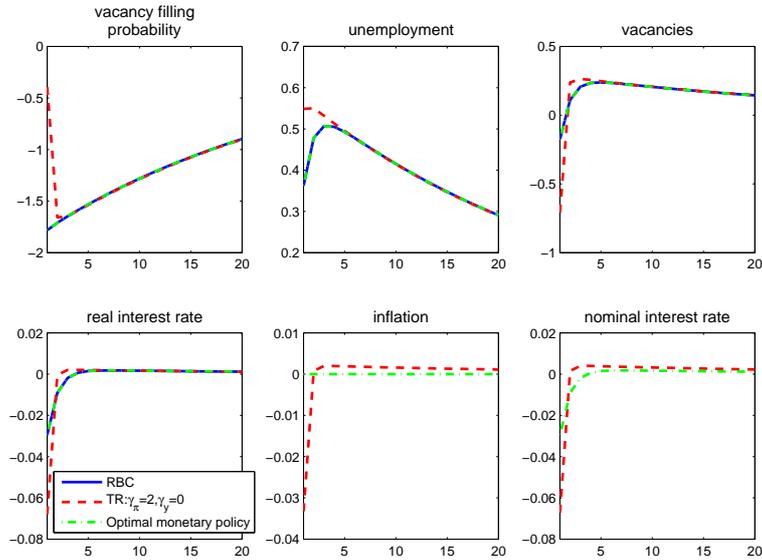
Impulse responses to a negative matching efficiency shock in the efficient RBC model. The standard deviation of the shock is calibrated to 0.032 and the persistence parameter to 0.965. Impulse responses are expressed in percentage points deviation from the steady state.

Figure 4: Taylor rules



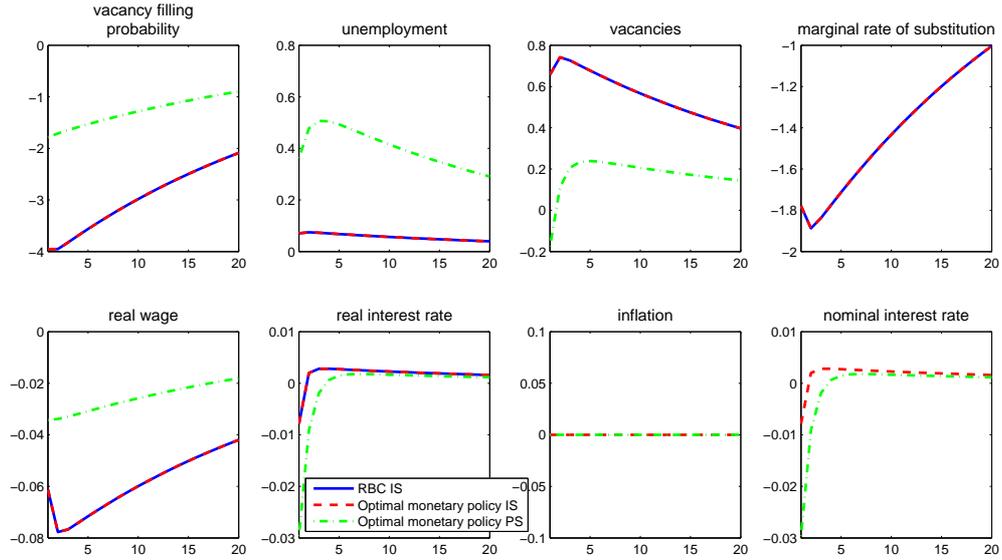
Impulse responses to a negative matching efficiency shock in the efficient RBC model (solid lines), in the model with inflation targetting Taylor rule (dashed lines), and in the model with dual-mandate Taylor rule (dash-dot lines). The standard deviation of the shock is calibrated to 0.032 and the persistence parameter to 0.965. Impulse responses are expressed in percentage points deviation from the steady state.

Figure 5: Optimal Monetary Policy



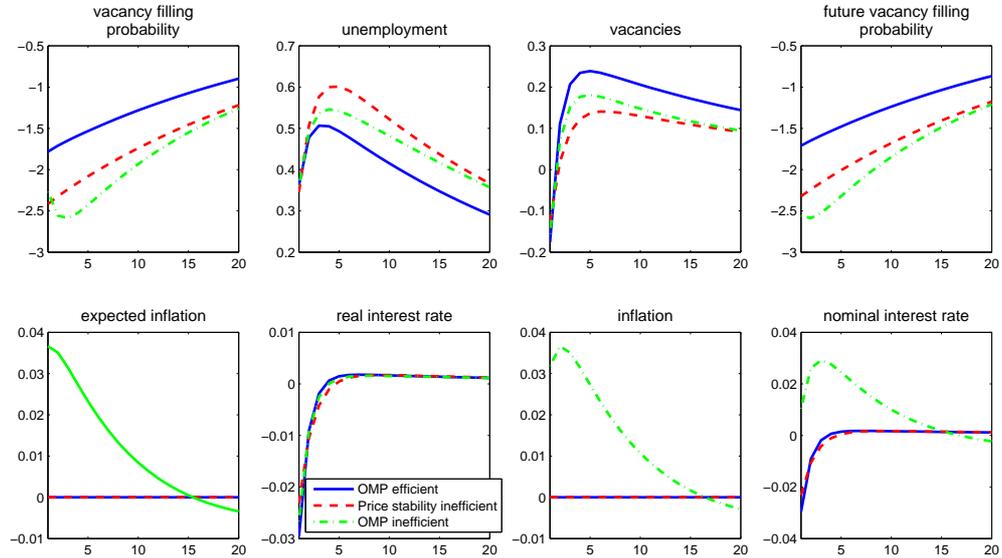
Impulse responses to a negative matching efficiency shock in the efficient RBC model (solid lines), in the model with inflation targetting Taylor rule (dashed lines), and in the model where the Hosios condition holds and monetary policy is conducted by Ramsey planner (dash-dot lines). The standard deviation of the shock is calibrated to 0.032 and the persistence parameter to 0.965. Impulse responses are expressed in percentage points deviation from the steady state.

Figure 6: Optimal Monetary Policy under imperfect substitutes



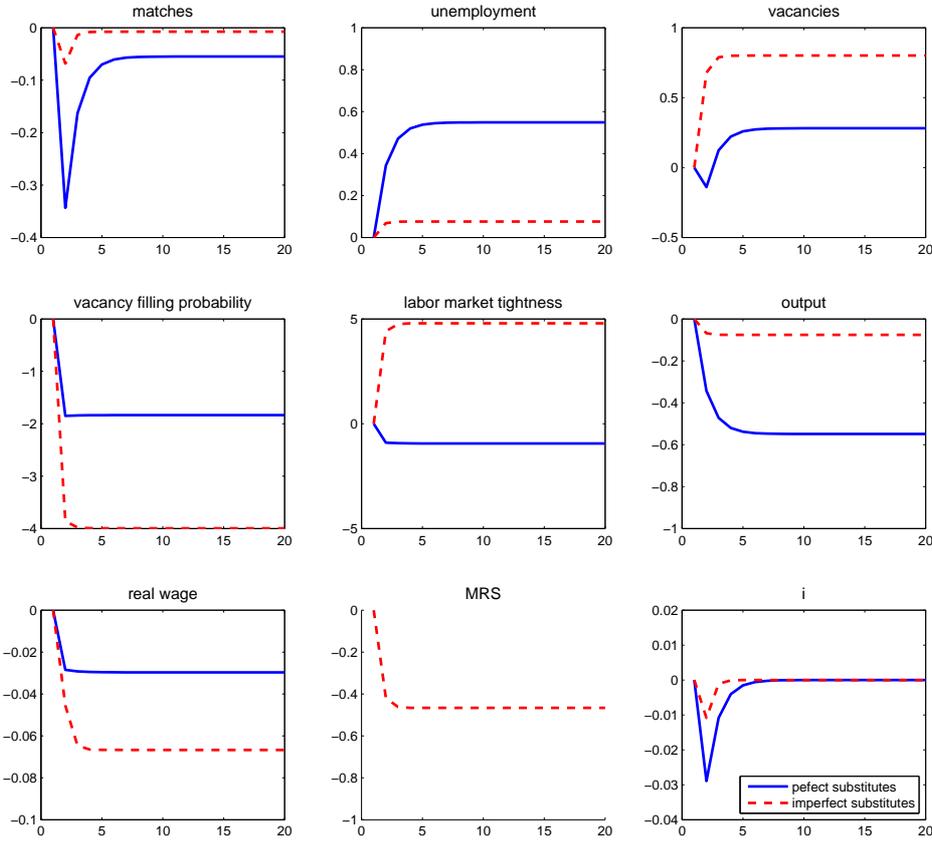
Impulse responses to a negative matching efficiency shock in the efficient RBC model where home and market goods are imperfect substitutes (solid lines), in the sticky price model where home and market goods are imperfect substitutes, the Hosios condition holds and monetary policy is conducted by Ramsey planner (dash-dot lines), and in the sticky price model where home and market goods are *perfect* substitutes, the Hosios condition holds and monetary policy is conducted by Ramsey planner (dash-dot lines). The standard deviation of the shock is calibrated to 0.032 and the persistence parameter to 0.965. Impulse responses are expressed in percentage points deviation from the steady state.

Figure 7: Optimal Monetary Policy to an Inefficient shock



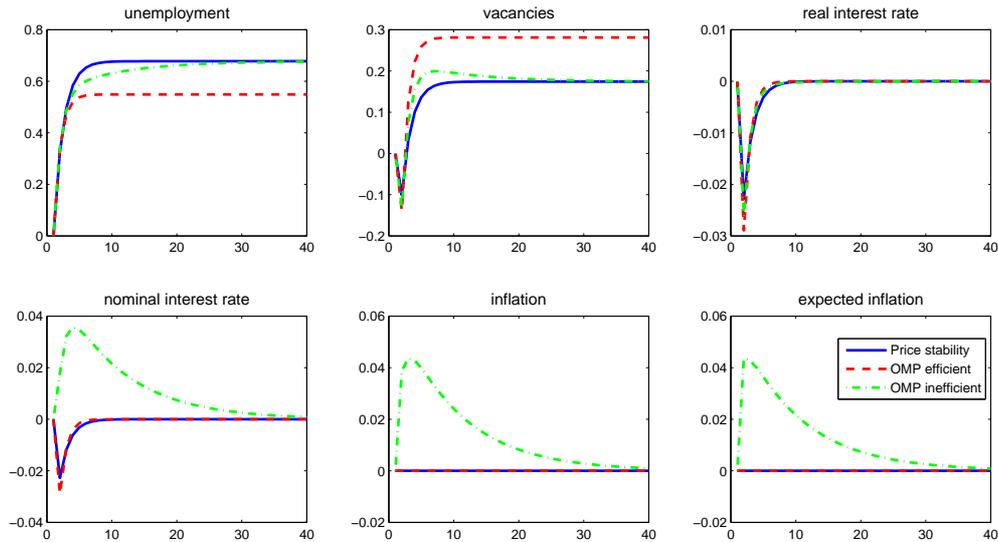
Impulse responses to a negative matching efficiency shock in the sticky price model where the Hosios condition holds and monetary policy is conducted by Ramsey planner (solid lines), in the sticky price model where the Hosios condition is violated and monetary policy is to maintain perfect price stability (dashed lines), and in the sticky price model where the Hosios condition is violated and monetary policy is conducted by Ramsey planner (dash-dot lines). The standard deviation of the shock is calibrated to 0.032 and the persistence parameter to 0.965. Impulse responses are expressed in percentage points deviation from the steady state.

Figure 8: Optimal monetary policy and transition after a permanent efficient shock



Dynamic adjustment paths of variables in response to one time permanent decline in matching efficiency in the sticky price model where home and market goods are *perfect* substitutes, the Hosios condition holds and monetary policy is conducted by Ramsey planner (solid lines), and in the sticky price model where home and market goods are *imperfect* substitutes, the Hosios condition holds and monetary policy is conducted by Ramsey planner (dashed lines). The size of the decline is equal to 0.032. Adjustment paths are expressed in percentage points deviation from the pre-shock steady state except for the real wage and MRS which are in percent deviation from the pre-shock steady state.

Figure 9: Optimal monetary policy and transition after a permanent inefficient shock



Dynamic adjustment paths of variables in response to one time permanent decline in matching efficiency in the sticky price model where the Hosios condition is violated and monetary policy is to maintain perfect price stability (solid lines), in the sticky price model where the Hosios condition holds and monetary policy is conducted by a Ramsey planner (dashed lines), and in the sticky price model where the Hosios condition is violated and monetary policy is conducted by Ramsey planner (dash-dot lines). The size of the decline is equal to 0.032. Adjustment paths are expressed in percentage points deviation from the pre-shock steady.

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