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Optimal Monetary Policy in Response to Shifts in the Beveridge Curve

by Mariya Mileva

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Abstract:

I build a dynamic stochastic general equilibrium model with search and matching frictions in the labor market and analyse the optimal monetary policy response to an outward shift in the Beveridge curve. The results cover several cases depending on the reason for the shift. If the shift is due to a fall in the efficiency of matching, then the optimal response of the central bank is to stabilize inflation. On the other hand, if the shift arises from an increase in the elasticity of employment matches with respect to vacancies, then the policy maker faces a trade-off between stabilizing inflation and unemployment. The optimal policy response to the efficient labor market shock changes when real wages are sticky but remains unchanged when home and market goods are imperfect substitutes, compared to the case when they are not. When contrasted to a Taylor rule that targets inflation and output growth, the optimal monetary policy is more aggressive in pursuit of its objectives.

Keywords: Beveridge curve, Optimal monetary policy, Labor market, Search and matching.

JEL classification: E24, E32, E52, J68

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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 build a dynamic stochastic general equilibrium (DSGE) 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.

In a model where unemployment arises due to search and matching frictions, the BC can shift for three reasons, an increase in the job separation rate, a fall in the efficiency of matching and a change in the elasticity of matches with respect to vacancies. A decrease in the match efficiency would result in a parallel outward shift in the BC 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. If the separation rate increases, the BC curve again shifts out proportionately but for a different reason. A given level of employment would now produce a higher number of inflows into unemployment which would have to be balanced by a larger number of vacancy postings to generate the same steady state level of flows out of unemployment. A change in the elasticity of matches with respect to vacancies makes the curve pivot. If the economy is operating on the lower portion of the curve, as seems to be the case at the end of the Great Recession where vacancies are low and unemployment high, then the BC would pivot counterclockwise. In that case, a rise in the elasticity can be interpreted as an outward shift because it would make vacancy postings less reactive to a given unemployment rate. In other words, for a given vacancy-unemployment ratio, the hiring rate becomes less elastic and thus less responsive to aggregate labor market conditions. The JOLTS hiring rate shows a substantial decline which would be consistent with a rise in the match elasticity. The JOLTS data, however, also show that total non-farm separation rates actually declined from 4% to 3% in the post recession period. Therefore, a change in either the efficiency or the elasticity is more likely to be the source of the shift.

Petrongolo and Pissarides [23] show that the US labor market frictions can be described by a simple matching function :

$$m_t = dv_t^{\alpha} u_{t-1}^{1-\alpha}, \tag{1}$$

where m_t is the hiring rate, v_t is the job openings rate, u_t is the unemployment rate, d is the efficiency of matching and $0 < \alpha < 1$ is the elasticity of matching with respect to vacancies. I estimate equation (1) and report the results in table 1. They suggest that after the Great Recession the efficiency of matching

declined by 0.074 while the elasticity increased by 0.033. This estimation exercise should be taken with a grain of salt because it ignores multicollinearity issues and potential bias due to omitted variables and the small sample for the post-recession period.

However, there are a number of empirical studies such as Kirkegaard [19], Borowczyk-Martins et al. [6], Sahin et al. [26], and Kannan et al. [17] who use more sophisticated econometric methods and document an outward shift of the US Beveridge curve as a result of the crisis. Elsby et al. [9], Kocherlakota [20], Sahin et al. [26] argue that the outward shift is due to a fall in the matching efficiency of labor markets. A temporary fall in matching efficiency results from either sectoral or geographical mismatch. Most of the unemployed workers after the Great Recession come from the construction and manufacturing sector while the bulk of vacancies are in the education and health sector. The low resale value of workers' houses limits their geographical mobility from areas with few job openings to areas with more available vacancies. Alternatively, Barnichon and Figura [2] attribute the decline in the matching efficiency after the Great Recession to an increase in the dispersion in labor market conditions, the fact that tight labor markets coexist with slack ones. Only Lubik [21] considers both an efficiency shock and an elasticity shock as potential sources for the shift of the Beveridge curve. His results seem to suggest that the most likely source of the shift is a fall in the efficiency of matching.

There is 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 [32], Walsh [33], Faia [10], Faia [11], Sala et al. [27], Thomas [31], Gertler et al. [14], Christoffel et al. [7], Blanchard and Gali [5],and Ravenna and Walsh [24]. The most closely related paper is Ravenna and Walsh [24] 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.

My contribution to the literature is that I introduce two new types of shocks that shift the Beveridge curve and analyze the optimal monetary policy response to them. I also make two additional modifications to the Ravenna and Walsh [24] framework because I want to analyze their effect on policy trade-offs arising from unemployment volatility. First, I make real wages sticky. This assumption generates inefficient fluctuations in the way the surplus from an employment match is shared between the worker and the firm. Shimer [30] demonstrates that matching with flexible real wages set by Nash bargaining cannot generate the level of unemployment volatility seen in the data. Introducing a real wage rigidity increases the volatility of unemployment. Second, I make home goods

and market goods imperfect substitutes.[1] This highlights the fact that fluctuations in the marginal rate of substitution between home and market goods affect the payoffs of unemployed workers. Thus, a time-varying marginal rate of substitution makes unemployment and inflation more volatile.

The results indicate that the monetary policy response depends on the source of the shift of the BC. If the efficiency of matching falls, unemployment does not fluctuate relative to its efficient level and the unemployment gap remains stable. The central bank that acts optimally need not deviate from a policy of price stability and it lowers the nominal interest rate in order to offset the fall in inflation. However, if the elasticity of matches with respect to vacancies rises, the economy deviates from its efficient equilibrium because the search friction is exacerbated. The elasticity shock acts like a cost push shock; it presents the policy maker with a trade off between stabilizing the unemployment gap and inflation. The optimal policy is still to lower the interest rate in order to offset the rise in the unemployment gap but the central bank has to put the economy though 17 quarters of inflation in order to achieve its goal.

I also explore the implications for two assumptions of the model about the optimal behavior of the central bank and the dynamics of key variables. For this reason, I only show the optimal policy response to a fall in the efficiency of matching, a shock which does not result in a deviation from the efficient equilibrium except for its inflationary impact. The assumption of sticky wages makes the economy deviate from its efficient equilibrium in response to the shock. As a result, the presence of real wage rigidity presents the central bank with a trade off between stabilizing inflation and the unemployment gap. On the other hand, 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, only increases the volatility of inflation which fluctuates in response to changes in the relative price of market and home goods. Hence, the central bank needs to lower the nominal interest rate more in order to stabilize inflation.

Both the assumption of real wage rigidity and imperfect substitution between home and market consumption make unemployment more volatile along the business cycle. This result is important because assuming imperfect substitution is a way to resolve the Shimer puzzle. Shimer [30] shows that unemployment in search and matching models is not volatile enough along the business cycle because most of the adjustment is done by the real wage. Assuming sticky real wages or shocks that generate a deviation from the real wage implied by Nash Bargaining are mechanisms to generate more volatile unemployment. However, since 1984 the average variability of real wages in the US has increased and a number of studies have shown that the real wages of new hires are the most volatile. Imperfect substitutability between home and market goods is an appealing alternative assumption that generates higher unemployment volatility in search and matching models.

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[1]Ravenna and Walsh [24] assume that home and market goods are perfect substitutes

Finally, the optimal policy response is compared to the case where the central bank acts according to a Taylor rule that targets inflation and output growth. In response to both types of shocks, the behavior of the optimal policy maker is more aggressive than in the case of a Taylor rule. When the efficiency of matching falls, the Taylor rule central bank lowers the nominal interest rate by less than is optimal because it does not put such high weight on inflation stability as the optimal policy maker. When the elasticity of matching rises, the roles are reversed. The Taylor rule again implies a more muted response to the rise in the unemployment gap but because it puts higher weight on inflation variability than on unemployment variability in response to this particular shock.

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

$$C_t = \left[a(C_t^m)^\phi + (1-a)(C_t^h)^\phi \right]^{1/\phi}, \tag{2}$$

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:

$$U(C_t) = \frac{C_t^{1-\sigma}}{1-\sigma}. \tag{3}$$

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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

$$MRS_t = \frac{MU(C_t^h)}{MU(C_t^m)} = \left(\frac{1-a}{a}\right)\left(\frac{C_t^h}{C_t^m}\right)^{\phi-1}. \tag{4}$$

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:

$$C_t^h = w^u(1 - N_t), \tag{5}$$

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

$$C_t^m \leq \left[\int_0^1 C_t^m(j)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}}. \tag{6}$$

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

$$C_t^m(j) = \left[\frac{P_t^m(j)}{P_t^m}\right]^{-\epsilon} C_t^m \tag{7}$$

$$P_t^m = \left\{\int_0^1 [P_t^m(j)]^{1-\epsilon} dj\right\}^{\frac{1}{1-\epsilon}} \tag{8}$$

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

$$P_t^m C_t^m + B_t = W_t N_t + (1 + i_{t-1})B_{t-1} + T_t \tag{9}$$

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 maximimization problem results in a standard Euler equation

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$$\frac{\lambda_t}{P_t^m} = \beta E_t \frac{\lambda_{t+1}}{P_{t+1}^m}(1 + i_t) \tag{10}$$

where $\lambda_t = aC_t^{1-\sigma-\phi}(C_t^m)^{\phi-1}$ 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:

$$P_t^h = MRS_t P_t^m \tag{11}$$

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:

$$Y_t^w = ZN_t, \tag{12}$$

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

$$v_t \leq \left(\int_0^1 v_t(j)^{\frac{\epsilon-1}{\epsilon}}dj\right)^{\frac{\epsilon}{\epsilon-1}}. \tag{13}$$

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

$$v_t(j) = \left(\frac{P_t^m(j)}{P_t^m}\right)^{-\epsilon}v_t. \tag{14}$$

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,

$$\int_0^1 P_t^m(j)C_t^m(j)dj + k\int_0^1 P_t^m(j)v_t(j)dj = \int_0^1 P_t^m(j)(C_t^m(j) + kv_t(j))dj$$

$$= \int_0^1 P_t^m(j)Y_t^d(j)dj = \int_0^1 P_t^m(j)((\frac{P_t^m(j)}{P_t^m})^{-\epsilon}C_t^m + k(\frac{P_t^m(j)}{P_t^m})^{-\epsilon}v_t)dj$$

$$= \int_0^1 ((P_t^m(j))^{1-\epsilon}dj(P_t^m)^\epsilon(C_t^m + kv_t) = P_t^m C_t^m + P_t^m kv_t$$

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 $Y_{t+i}(j) = Y_{t+i}^d(j) = \left[P_t^m(j)/P_{t+i}^m\right]^{-\epsilon}Y_{t+i}^d$, 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:

$$\frac{P_t^m(j)}{P_t^m} = \frac{\varepsilon \sum_{i=0}^\infty \left\{(\omega\beta)^i E_t\left[D_{i,t+i,}\left(\frac{P_{t+i}^w}{P_{t+i}^m}\right)Y_{t+i}^d\right]\right\}}{(\varepsilon-1)(1+s)\sum_{i=0}^\infty \left\{(\omega\beta)^i E_t\left[D_{i,t+i,}\left(\frac{1}{P_{t+i}^m}\right)Y_{t+i}^d\right]\right\}}. \tag{15}$$

2.4. Market Clearing

Total retail demand must equal supply

$$Y_t = A_t\left(C_t^m + kv_t\right). \tag{16}$$

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

$$C_t = \left[a(Y_t - kv_t)^\phi + (1-a)(w^u(1-N_t)^\phi\right]^{1/\phi}. \tag{17}$$

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 unemployed at the end of period t is

$$u_t = 1 - N_t + \rho N_t = 1 - (1 - \rho)N_t, \tag{18}$$

where ρ is the exogenous job separation rate.

The matching function is

$$m_t = d_t v_t^{\alpha_t} u_{t-1}^{1-\alpha_t} = d_t \theta_t^{\alpha_t} u_{t-1}, \tag{19}$$

where $\theta_t \equiv v_t/u_{t-1}$ is the labor market tightness and $0 < \alpha_t < 1$ is the elasticity of matching with respect to vacancies. α_t follows an AR(1) process with persistence ρ_α and standard deviation σ_α. 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

$$N_t = (1 - \rho)N_{t-1} + m_t = (1 - \rho)N_{t-1} + d_t \theta_t^{\alpha_t} u_{t-1}. \tag{20}$$

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:

$$q_t J_t = k, \tag{21}$$

where q_t is the job-filling probability defined as

$$q_t \equiv \frac{m_t}{v_t}. \tag{22}$$

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

$$J_t = \frac{P_t^w}{P_t^m} Z - \frac{W_t}{P_t^m} + (1 - \rho)\beta E_t D_{t,t+1} J_{t+1} \tag{23}$$

Defining the real wage as

$$w_t \equiv \frac{W_t}{P_t^m} \tag{24}$$

the payoff from hiring a worker can be rewritten as

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

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,

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

Similarly, the firm's reservation wage is the wage

$$w_t^{rf} = \frac{P_t^w}{P_t^m}Z + (1-\rho)\beta E_t D_{t,t+1}\frac{k}{q_{t+1}}. \qquad (26)$$

Define the job finding probability for a worker as

$$pr_t \equiv \frac{m_t}{u_{t-1}}.$$

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,

$$V_t^e = w_t + \beta E_t D_{t,t+1}\left\{(1-\rho)V_{t+1}^e + \rho\left[pr_{t+1}V_{t+1}^e + (1-pr_{t+1})V_{t+1}^u\right]\right\}. \quad (27)$$

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 value of w^u in terms of market goods can be interpreted as an unemployment benefit. The payoff from being unemployed is the sum of the 'unemployment benefit' and the future payoff from staying unemployed or from becoming employed adjusted for the job finding probability

$$V_t^u = MRS_t w^u + \beta E_t D_{t,t+1}\left[(1-pr_{t+1})V_{t+1}^u + pr_{t+1}V_{t+1}^e\right]. \qquad (28)$$

The surplus from employment over unemployment is:

$$V_t^s = V_t^e - V_t^u = w_t - MRS_t w^u + \beta(1-\rho)E_t D_{t,t+1}(1-pr_{t+1})V_{t+1}^s. \qquad (29)$$

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 $V_t^s = 0$:

$$w_t^{rw} = MRS_t w^u - \beta(1-\rho)E_t D_{t,t+1}(1-pr_{t+1})V_{t+1}^s \tag{30}$$

If a matched worker and firm form a Nash bargain over the wage, the bargaining set is determined by the two reservation wages: $[w_t^{rw}, w_t^{rf}]$. The wages are negotiated according to the game described by Hall [15] which delivers a real wage rigidity in the form of a social norm.

$$w_t = \lambda \left[b w_t^{rf} + (1-b)w_t^{rw} \right] + (1-\lambda)w_{t-1}. \tag{31}$$

The wage is a weighted average of the Nash bargaining wage and the past wage, where λ is a parameter that governs the degree of real wage stickiness and b describes the degree of bargaining power of workers.

Setting $\lambda = 1$ and and 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 (2.28), 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

$$\eta_t \equiv \left(\frac{1}{1-b}\right)\frac{k}{q_t} - (1-\rho)\beta E_t D_{t,t+1}\left(\frac{k}{q_{t+1}}\right)\left(\frac{1}{1-b}\right)(1-bpr_{t+1}) + MRS_t w^u. \tag{32}$$

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 though a standard aggregate demand channel.

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3. Optimal Policy

The policymaker maximizes the welfare of the representative agent

$$W = max \sum_{i=0}^{\infty} \beta^i U(C_{t+i}) \tag{33}$$

subject to a list of the structural equations describing the economy, including the optimality conditions of the competitive equilibrium economy, the market clearing conditions and relevant definitions and laws of motion. The number of endogenous variables that the policymakers choose exceeds the number of constraints by the number of policy instruments that the policymakers have at their disposal. Here the policymaker has only one policy instrument which is the nominal interest rate i_t.

The optimal policy problem is solved using the Lagrangian method. The general form of the problem can be summarized, using Lagrange multipliers as:

$$max_{x_t} E_t \left\{ \sum_{i=0}^{\infty} \beta^i b(x_{t+i-1}, x_{t+i}, x_{t+i+1}, \epsilon_{t+i}) \right.$$

$$\left. + \sum_{i=-\infty}^{\infty} \beta^i \lambda_{t+i} E_{t+i}^I \left[f(x_{t+i-1}, x_{t+i}, x_{t+i+1}, \epsilon_{t+i}) \right] \right\} \tag{34}$$

where x_t is the vector of endogenous variables, λ_t is a column vector of Lagrange multipliers and E_t^I is an expectation operator over an information set including all past and future realizations of the policy variables, and distributions of future shocks ϵ_t. The expectation operator E_t integrates over an information set including only the past values of the variables and the distributions of ϵ_t. The constraints f take place at all times, and are conditioned on the current period $t+i$ as the policymaker knows that the agents at time $t+i$ will use all available information in that period. The maximization problem results in the following first order conditions written in general form:

$$E_t \left\{ \frac{\partial}{\partial x_t} \left[b(x_{t-1}, x_t, x_{t+1}, \epsilon_t) \right] + \beta \frac{\partial}{\partial x_t} \left[b(x_t, x_{t+1}, x_{t+2}, \epsilon_{t+1}) \right] \right.$$

$$\beta^{-1} \lambda_{t-1} \frac{\partial}{\partial x_t} \left[f(x_{t-2}, x_{t-1}, x_t, \epsilon_{t-1}) \right]$$

$$\lambda_t \frac{\partial}{\partial x_t} \left[f(x_{t-1}, x_t, x_{t+1}, \epsilon_t) \right]$$

$$\left. + \beta \lambda_{t+1} E_{t+1} \left[\frac{\partial}{\partial x_t} f(x_t, x_{t+1}, x_{t+2}, \epsilon_{t+1}) \right] \right\} = 0 \tag{35}$$

The advantage of the Lagrangian approach is that it highlights the different information sets that the policymaker faces when making an optimal policy decision. The problem specified above describes the optimal policy under commitment when the policymaker acts according to the *timeless perspective*

approach. The idea is that the policymaker chooses the policy in the distant past and promises to optimize according to equation (32). The constraints in f are valid from the infinite past to the infinite future and the policy has started before period 0, sometime in the distant past.

When the policymaker acts under commitment, he faces a time inconsistency problem as the optimal conditions for x_{t+1} in period t and for x_{t+1} in period $t+1$ might differ. In this case, the policymaker has the incentive to re-optimize every period and deviate from the optimal condition in the previous period. His optimal policy is not credible. The timeless perspective implies that the initial conditions for the backward multipliers are ignored. The optimization is performed numerically with DYNARE++ using second order perturbation methods on the optimal monetary policy conditions.

The disadvantage of the Lagrangian approach is that it does not highlight economically inefficient tradeoffs present in the policy maker's objective function. Since the policymaker faces a number of tradeoffs, the objective function does not simply minimize the fluctuations of variables relative to their steady state levels. The job of the policymaker who acts optimally is to minimize the fluctuation of *gaps* of dynamic variables versus their time-varying efficient counterparts. For example, the central bank should not stabilize the unemployment gap relative to its steady state level, defined as $\hat{u}_t = u_t/u_{ss} - 1$, but the gap of unemployment relative to its efficient level, $\tilde{u}_t = \hat{u}_t/\hat{u}_t^e - 1$.[2] The optimal benchmark of the policymaker is not the steady state but the efficient *dynamic* equilibrium of the economy. Hence, the drawbacks of the Lagrangian approach are two. First, the objective function of the policymaker is not derived explicitly as a function of fluctuations of gaps of unemployment and inflation. Second, the dynamic efficient benchmark of the policymaker is not characterized explicitly.

It is important how efficiency is defined. There are four inefficiencies in the model, including monopolistic competition in the final goods sector, sticky retail prices, sticky real wages 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. The real wage rigidity increases the aggregate cost of search and results in an inefficient composition of the home versus market consumption good basket.

An efficient dynamic equilibrium eliminates these inefficiencies. The sticky prices inefficiency is eliminated by imposing a constant markup $\mu_t = \mu$ and maintaining price stability. The monopolistic inefficiency is eliminated by imposing a markup equal to one $\mu = 1$. The search friction can usually be eliminated by imposing the Hosios condition where the elasticity of the matching

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[2]Note that $\hat{u}_t = \frac{u_t}{u_{ss}} - 1$ and $\hat{u}_t^e = \frac{u_t^e}{u_{ss}^e} - 1$.

function with respect to unemployment is set equal to the bargaining share of workers, $1 - \alpha = b$. Finally, the real wage rigidity is eliminated by changing the social norm and setting $\lambda = 1$.

4. Parametrization and Methodology

The parametrization is based on standard parameters taken from the literature. Table 2 gives a list of the parameter values for the baseline version where home and market goods are perfect substitutes. Table 3 reports the parametrization under the version when home and market consumption are imperfectly substitutable. The source of the values for standard parameters is Ravenna and Walsh [24]. The choice of values of the non-standard parameters is discussed below.

In both versions of the model, the vacancy cost k is set to to deliver a steady state ratio of vacancies to employment v/N of 11 percent which is close to the average quarterly value of 10% based on JOLTS. The productivity parameter w^u is calibrated to deliver a steady state replacement ratio of unemployment benefits to real wages of about 0.54 in the base line version and 0.56 in the imperfect substitution version.

The steady state level of the efficiency of the matching function d is set to deliver a steady state job finding probability of about 0.9 in the baseline version and 0.86 in the imperfect substitutes version. The values are relatively higher compared to the standard estimate of 0.71 but it is in line with the recent estimates of Davis et al. [8] who report a daily job-filling probability of around 5 percent. This implies a quarterly probability of filling a vacancy q of 0.98.

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. [4] set this elasticity equal to 5 in their most preferred specification. In McGrattan et al. [22] the estimated elasticity is slightly less than 2, while in Schorfheide [28] the estimate is around 2.3. Using micro data, Rupert et al. [25] estimate a value of around 1.8, Aguiar and Hurst [1] estimate a value of around 2 and Gelber and Mitchell [13] estimate a value of around 2.5. Karabarbounis [18] estimates it at 3.393.

The preference parameter a in the consumption aggregate is set to 0.6 and is based on estimate of Karabarbounis [18].

I set the parameters that describe the stochastic process of the efficiency of matching to a persistence ρ_d of 0.8 and a standard deviation σ_d of 0.05. The estimation of the matching function for the post recession period implied that the efficiency of matching fell by 0.074. However, this result may be subject to a bias due to omitted variables or a small sample. Therefore, I parametrize the behavior of the efficiency shock based on two empirical studies. Sedlacek [29] relaxes the assumption of a constant matching function and shows that fluctuations in the efficiency of matching are an important determinant of job finding rate variation. Estimates of the matching function are severely complicated by poor data on vacancies. However, he estimates a model where not only match

efficiency but also vacancies are unobserved. The results show that match efficiency is procyclical and can explain 26-35% of job finding rate variation. He estimates a persistence parameter of about 0.719 and a standard deviation of 5.9% percent along the business cycle. Beauchemin and Tasci [3] construct a multiple-shock version of the Mortensen-Pissarides labor market search model to investigate the basic model's well-known tendency to under predict the volatility of key labor market variables. Data on U.S. job finding and job separation probabilities are used to help estimate the parameters of a three-dimensional shock process comprising labor productivity, job separation, and matching or 'allocative' efficiency. They estimate the parameters of the efficiency shock to be $\hat{\rho}_d = 0.807$ and $\hat{\sigma}_d = 0.051$.

The standard deviation σ_α and the persistence ρ_α of the matching elasticity shock are assumed to be 0.1 and 0.8, respectively. The estimation of the matching function for the post recession period implied that the elasticity of matching rose by about 0.033 However, this standard deviation is too small to result in a substantial shift in the model based Beveridge curve. The variability in the unemployment and inflation is not sufficient in order to get a sense of the trade offs that the central bank faces after an elasticity shock. That is why the standard deviation of the shock was set to 0.1, a number large enough to generate a substantial rise in unemployment on impact (about 2%) . This value was also chosen based on Lubik [21] who uses a Bayesian approach to estimate a dynamic version of the search and matching labor model. He finds that in the post recession period the elasticity of matching rose by about 0.16.

Solving the deterministic steady state of a non-linear system of equations is non-trivial and the first order conditions for the optimal policy add considerable complexity. DYNARE++ provides a solution for the steady state of the model under the optimal policy and even calculates an initial guess for the Lagrange multipliers but it requires a good initial guess for the steady state values of the decentralized competitive model. The structural equations that are the constraints of the optimal monetary policy problem can be reduced to a non-linear expression that involves the model parameters and labor market tightness. I solve it numerically using the calibration in table 2 and obtain a root of 0.68. For the version of the the model where home and market goods are imperfect substitutes, the labor market tightness takes a value of 0.25. I use these as my measures for the steady state level of labor market tightness.

A discussion of the simulation exercises performed and the results follows.

5. Results

Four sets of results are reported in this section. First, the model is simulated under the assumption that home and market goods are perfect substitutes and real wages are flexible.[3] The optimal monetary policy to two types of shocks

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[3]All the simulations are based on the numerical solution of the optimal policy problem under timeless perspective. The numerical solution was done with a multi-step algorithm over

is analyzed. The first type is a negative one standard deviation shock to the efficiency of matching and the second is a positive one standard deviation shock to the elasticity of employment matches with respect to vacancies. Next, I analyze the effect of two modeling assumptions on the optimal monetary policy response of the central bank. The model is simulated under the assumption of sticky wages and the results are compared to the baseline version where there is no real wage rigidity. In the third set of results, home and market goods are assumed to be imperfect substitutes; the implications of this assumption for the optimal policy response are compared to the case of perfect substitution. Finally, the optimal monetary policy response is compared to the policy behavior implied by a standard Taylor rule. The impulse response functions are reported in the units of the respective variables relative to the steady state. For example, in the baseline case unemployment increases by two percent on impact in response to a negative shock to the efficiency of matching.

5.1. Optimal Policy under Flexible Wages and Perfect Substitutes

5.1.1. Shock to the Efficiency of Matching

Figure 2 shows that the fall in the efficiency of matching causes an increase in unemployment because it leads to fewer employment matches in the economy. On the firm side, worsening labor market conditions lead to a rise in hiring costs and make firms post fewer vacancies on impact. The increase in unemployed workers corresponds to a shift of resources from the market toward the home good sector. Household consumption of home goods rises at the expense of falling market good consumption. Household aggregate consumption spending falls on impact which means that it is dominated by movements in market consumption.

The fall in the efficiency of the labor market leads workers to expect that it will be harder to find a job in the future. The value of having a job today increases because the future probability of making a successful match falls. As a result, the worker is willing to take a much lower reservation wage which pushes down the real wage and the price of wholesale goods relative to retail goods. This lowers the marginal cost of retail firms and leads to a fall in inflation. Figure 2 illustrates that the optimal monetary policy in response to the shock is to lower the interest rate in order to stabilize inflation. The policy maker is not facing trade-offs in meeting the objectives of stabilizing unemployment and inflation. This is because the rise in unemployment is not inefficient; actual and "natural" unemployment rise by the same amount which leaves the unemployment gap unchanged. Hence, the central bank does not need to worry that rising unemployment will reduce welfare because consumption is falling or because the composition of the household basket between market and home goods is suboptimal. It only needs eliminate inflation because price dispersion would lead to inefficient composition of the household market consumption across different varieties.

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a 200-period sample with 100 simulations.

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5.1.2. Shock to the Elasticity of Matching

When the shift in the BC curve results from a rise in the elasticity of matching with respect to vacancies, the central bank faces a policy trade-off. This shock generates a deviation from the Hosios condition which requires that $b = 1 - \alpha_t$ and makes unemployment rise relative to its efficient counterpart (see figure 3). Vacancies are not reactive enough to changes in unemployment. Therefore, more workers than is efficient stay without a job because firms reaction is not elastic enough and vacancies do not rise as much as is efficient. The increase in α makes the hiring rate q_t temporarily less sensitive to changing labor market conditions. The decline in the expected probability of filling a vacancy makes the firms willing to offer disproportionately high wages in order to attract workers. This pushes up the real wage and inflation. The central bank faces a trade-off between stabilizing inflation and labor market variables. If it raises the interest rate, it will stabilize inflation but worsen the rise in unemployment and mute the rise in vacancies. If it lowers it, it will reduce the unemployment and the vacancies gap, but increase the rise in inflation. Figure 3 suggests that the central bank chooses to stabilize labor market variables as the nominal interest rate falls by 5% on impact. The trade-off is apparent in the fact that the economy has to suffer a 2.5% rise in inflation for about 17 quarters.

5.2. Optimal Policy under Sticky Wages and Perfect Substitutes

The optimal monetary policy in response to a fall in the efficiency of matching changes when real wages are sticky. The reported impulse response are under the assumption of a high degree of real wage rigidity where $\lambda = 0.1$. The fact that the real wage cannot fall enough to absorb the shock implies retail firms are forced to lower their markups after their hiring costs rise. This pushes up inflation. At the same time, since the real wage cannot adjust enough, unemployment becomes more volatile. Firms are forced to make fewer matches than is efficient and actual unemployment rises by more than "natural" unemployment which raises the unemployment gap. The central bank faces a trade-off between raising the interest rate in order to offset the inflationary impact of the shock and lowering the interest rate in order to close the unemployment gap. Figure 4 illustrates that the optimal monetary policy maker is not able to meet either of his objectives perfectly. He lowers the nominal interest rate in order to weaken the rise in unemployment but he is not aggressive enough to prevent unemployment from rising by more than under flexible wages. The third panel of figure 4 also shows that central bank is forced to suffer persistent inflation both as a consequence of the shock and of its expansionary policy actions.

5.3. Optimal Policy under Flexible Wages and Imperfect Substitutes

The results under the assumption that home and market goods are imperfect substitutes are reported next. The optimal policy response is simulated under the assumption the elasticity of substitution is 3 and that there is a slight home bias $a = 0.6$ towards the consumption of market goods. The first panel of figure

5 shows that the nominal interest rate falls by more than under the assumption of perfect substitutes. This is because inflation volatility increases as home and market goods become imperfect substitutes. Equation (32) demonstrates the fluctuations in the relative price of home and market goods lead to fluctuations in the effective cost of labor and more fluctuations in inflation. The fall in the efficiency of matching leads to a shift of workers from the market toward the home sector and generates a rise in the relative supply of home goods. This reduces the relative value of the "unemployment benefit" which lowers inflation more than when home and market goods are perfect substitutes. In order to stabilize inflation, the central bank needs to lower the nominal interest rate by a larger amount.

The second panel of figure 5 shows that when market and home when home and market goods are imperfect substitutes unemployment becomes more volatile. On impact, unemployment rises by less because households are not as willing to substitute the fall in market goods consumption with a rise in home goods consumption. However, diminishing marginal rate of substitution means that households require larger amounts of home goods in order to be compensated for each marginal decrease in the consumption of market goods. That is why unemployment rises by a greater amount later. This result implies that assuming imperfect substitutability between home and market goods is a way to resolve the Shimer puzzle. Shimer [30] shows that unemployment in search and matching models is not volatile enough along the business cycle because most of the adjustment is done by the real wage. Imperfect substitutability between home and market goods is an assumption that generates higher unemployment volatility in the search and matching labor model.

5.4. Optimal Policy versus a Taylor Rule

This section examines how the optimal monetary policy differs from the policy responses under a standard Taylor rule that includes inflation and output growth,

$$\beta(1 + i_t) = (1 + \pi_t)^{\gamma_\pi} \left(\frac{y_t}{y_{t-1}} \right)^{\gamma_y}, \tag{36}$$

γ_π and γ_y are the policy weights that determine how aggressive the policymaker is in stabilizing inflation and output fluctuations. These values of these coefficients are set in order to ensure that the model is stationary and that the behavior of the central bank satisfies the principle that the nominal interest rate should respond more than one for one to inflation fluctuations. Hence, $\gamma_\pi = 3.5$ and $\gamma_y = 0.5$.

Figure 6[4] compares the monetary policy response to a fall in the efficiency of matching. The optimal policy is to pursue price stability while the Taylor rule policy requires that the nominal interest rate responds to the fall in output growth. Comparing the dynamic paths of the nominal interest rate rule and

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[4]Real wages are assumed to be flexible.

the optimal policy suggests that Taylor rule implies a less aggressive pursuit of price stability than the optimal policy. Figure 6 shows that the central bank that acts optimally lowers the nominal interest rate by a smaller amount on average than the central bank that acts according to a Taylor rule. Therefore, under a Taylor rule inflation is not perfectly stable and household welfare is lower due to price dispersion. As firms raise their markups in order to absorb their rising hiring costs, they do not have to adjust their employment margins as much and unemployment rises by less than under the optimal policy.

Figure 7 compares the monetary policy responses to a rise in the elasticity of matching with respect to vacancies. The nominal interest rate falls less sharply on impact. The central bank acting under a Taylor rule is not able to offset the rise in unemployment as successfully as the optimal policy maker. Consequently, the economy experiences less variability in inflation compared to the case under optimal monetary policy. In fact, inflation falls on impact in the Taylor rule case.

6. Conclusion

I build a DSGE model with search and matching frictions where the home and market goods are imperfect substitutes and real wages are sticky. I use it to analyze the optimal monetary policy response to outward shifts in the Beveridge curve. The optimal response to two types of shocks is compared. The first shock is a fall in the ability of the labor markets to match unemployed workers to unfilled job openings. The second is an increase in the elasticity of matching with respect to vacancies which makes the hiring rate less responsive to labor market conditions.

The results indicate that the monetary policy response depends on the source of the shift of the BC. If the efficiency of matching falls, unemployment does not fluctuate relative to its efficient level and the unemployment gap remains stable. The central bank that acts optimally need not deviate from a policy of price stability. However, the elasticity shock acts like a cost push shock; it presents the policy maker with a trade off between stabilizing the unemployment gap and inflation. These findings suggest that it is important to identify the source of the shift of the BC. Lubik [21] draws a conclusion that the elasticity shock is an unlikely candidate. In addition, CPI inflation has been consistently low between 0 and 0.5% and relatively stable in the post recession period despite the Fed's expansionary monetary policy actions. Thus, the behavior of inflation also suggests that conditional on the assumption that the Fed acts optimally, the most likely source of the shift is a fall in the efficiency of matching.

I also explore the implications of assuming sticky real wages about the optimal behavior of the central bank in response to the efficiency shock. The presence of a real wage rigidity presents the central bank with a trade off between stabilizing inflation and the unemployment gap. Considering recent findings about the increased volatility of real wages in post-1984 US data (see Galí et al. [12]), this result implies that the central bank needs to worry about its

assumptions about real wage rigidities when it makes its monetary policy decision. Assuming highly rigid real wages can result in a monetary policy decision that is too expansionary on impact.

The current version of the model helps think about unemployment and the optimal response to fluctuations in the labor market but it excludes the intensive margin of employment and fluctuations in output per hour. The behavior of productivity in the post 1984 is puzzling because its correlation with output fell and implied that labor productivity is countercyclical. I plan to add an intensive margin to the model and explore the implied behavior of labor productivity after a shift in the BC and when the central bank acts optimally.

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Tables

Table 1: Estimation of Matching Function

	Period before and during the Great Recession 12/2000-06/2009			Period after the Great Recession 07/2009-07/2011		
	Constant	Job Openings	Unemployment	Constant	Job Openings	Unemployment
Hiring	0.247*	0.902*	0.098*	0.173*	0.935*	0.065
	(0.021)	(0.019)	(0.019)	(0.042)	(0.116)	(0.116)

Notes: The matching function is transformed with natural logarithm transformation and estimated directly using constrained linear regression. The imposed constraint is that the matching function displays constant returns to scale and the coefficients on vacancy and unemployment rates sum up to one. JOLTS monthly data series on hiring rate, job openings rate and CPS data on the unemployment rate are used for the estimation. Results are reported separately for the period before and during the Great Recession and for the period after it. "*" indicates significance at the 1% level.

Table 2: Values of Structural Parameters Under Perfect Substitution

Parameter	Description	Value	Source
β	Household discount factor	0.99	Ravenna and Walsh [24]
σ	Risk aversion	2	Ravenna and Walsh [24]
w^u	Unemployment benefit	0.42	Target $\frac{w^u}{w_{ss}} = 0.54$
ω	Fraction of firms adjusting prices each period	0.75	Ravenna and Walsh [24]
ρ	Average probability of job destruction	0.1	Ravenna and Walsh [24]
k	Vacancy posting cost	0.49	Target $\frac{v_{ss}}{Y_{ss}} = 0.11$
α	Elasticity of the matching function to vacancies	0.5	Ravenna and Walsh [24]
d	Steady state efficiency of matching	0.75	Target $q_{ss} = 0.9$ and $N_{ss} = 0.94$
b	Bargaining power of workers	0.5	Ravenna and Walsh [24]
σ_d	Standard deviation of efficiency shock	0.05	Sedlacek [29]
ρ_d	Persistence of the efficiency shock	0.8	Sedlacek [29]
σ_α	Standard deviation of the elasticity shock	0.1	Lubik [21]
ρ_α	Persistence of the elasticity shock	0.8	Assumed
s	Monopolistic competition subsidy	0.2	Ravenna and Walsh [24]
ϵ	Elasticity of substitution between intermediate inputs	6	Ravenna and Walsh [24]

Table 3: Values of Structural Parameters Under Imperfect Substitution

Parameter	Description	Value	Source
ϕ	Elasticity of substitution between home and market goods	2/3	Karabarbounis [18]
a	Weight on consumption of market goods	0.6	Karabarbounis [18]
β	Household discount factor	0.99	Ravenna and Walsh [24]
σ	Risk aversion	2	Ravenna and Walsh [24]
w^u	Unemployment benefit	0.3	Target $\frac{w^u}{w_{ss}} = 0.56$
ω	Fraction of firms adjusting prices each period	0.75	Target $\frac{MRS_{ss}w^u}{w_{ss}} = 0.54$
ρ	Average probability of job destruction	0.1	Ravenna and Walsh [24]
k	Vacancy posting cost	0.9	Target $\frac{v_{ss}}{Y_{ss}} = 0.11$
α	Elasticity of the matching function to vacancies	0.5	Ravenna and Walsh [24]
d	Steady state efficiency of matching	0.43	Target $q_{ss} = 0.86$
b	Bargaining power of workers	0.5	Ravenna and Walsh [24]
σ_d	Standard deviation of efficiency shock	0.05	Sedlacek [29]
ρ_d	Persistence of the efficiency shock	0.8	Sedlacek [29]
σ_α	Standard deviation of elasticity shock	0.1	Sedlacek [29]
ρ_α	Persistence of the elasticity shock	0.8	Sedlacek [29]
s	Monopolistic competition subsidy	0.2	Ravenna and Walsh [24]
ϵ	Elasticity of substitution between intermediate inputs	6	Ravenna and Walsh [24]

Figure 1: Beveridge Curve

US Beveridge Curve
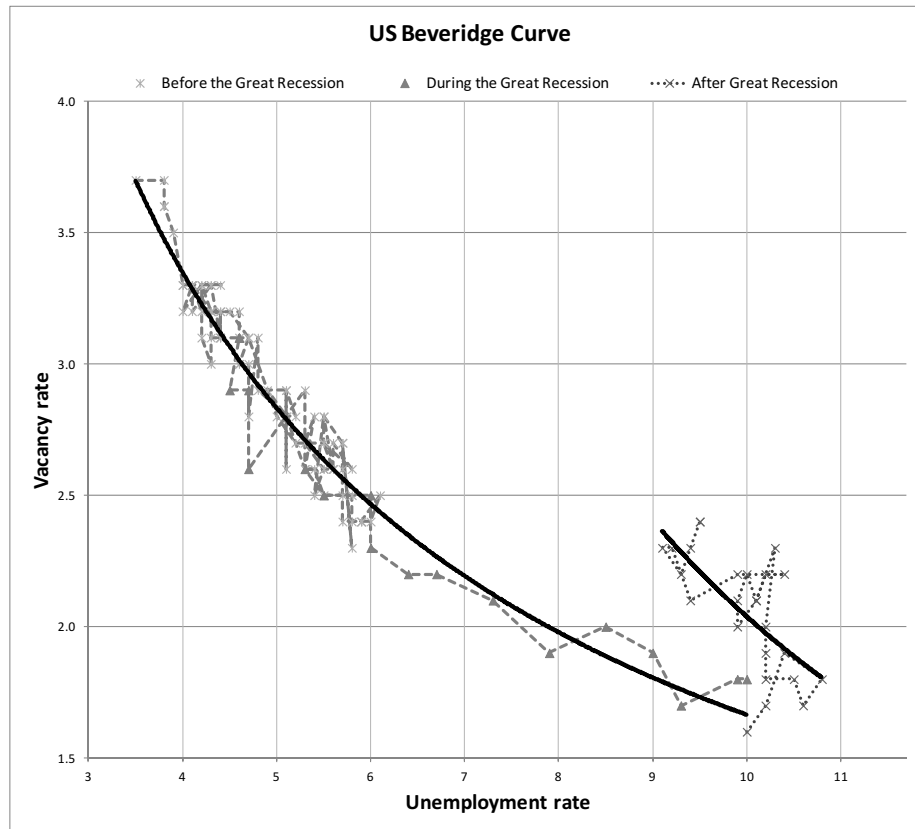
Notes: The US Bureau of Labor Statistics provides monthly data releases on unemployment via the Current Population Survey (CPS) and on job openings via the Job Openings and Labor Turnover Survey (JOLTS). The plot encompasses the period from December 2000 to July 2011. The leftward solid line shows an inverse relationship between the unemployment and the job opening rates for the period before and during the Great Recession, from December 2000 to June 2009. The rightward solid line describes the US BC for the period after the Great recession, from July 2009 to July 2011.

Figure 2: Optimal Monetary Policy to a Matching Efficiency Shock
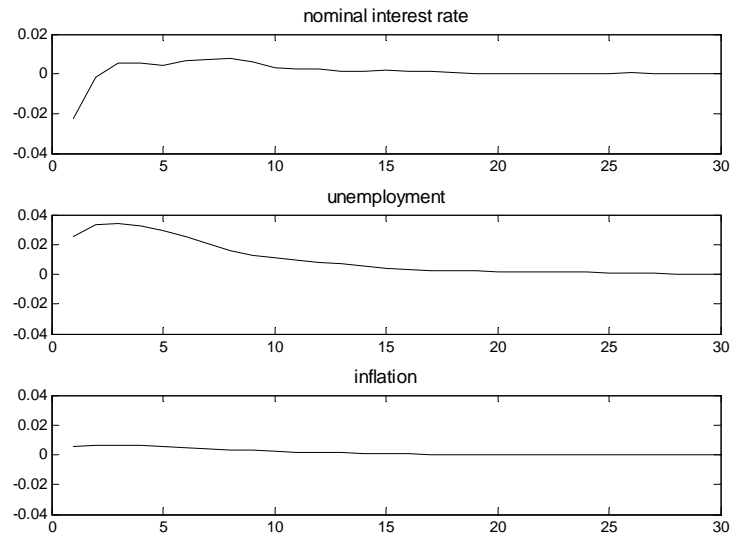
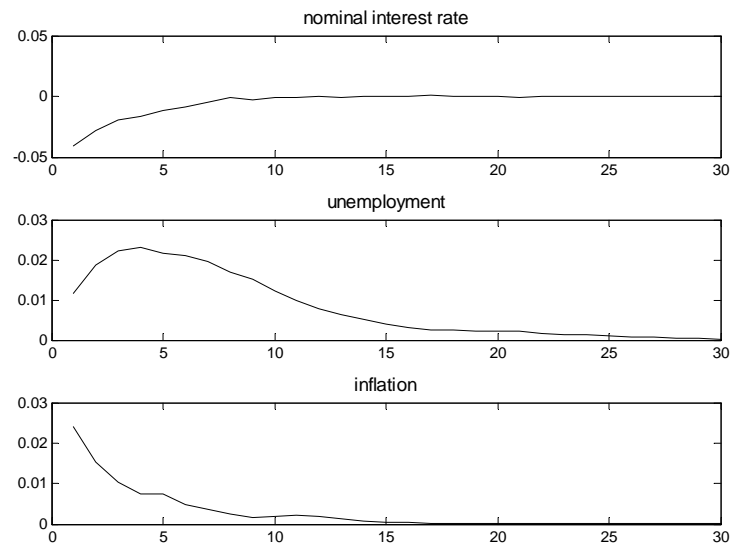Figure 3: Optimal Monetary Policy to a Matching Elasticity Shock

Figure 4: Optimal Monetary Policy to a Matching Efficiency Shock
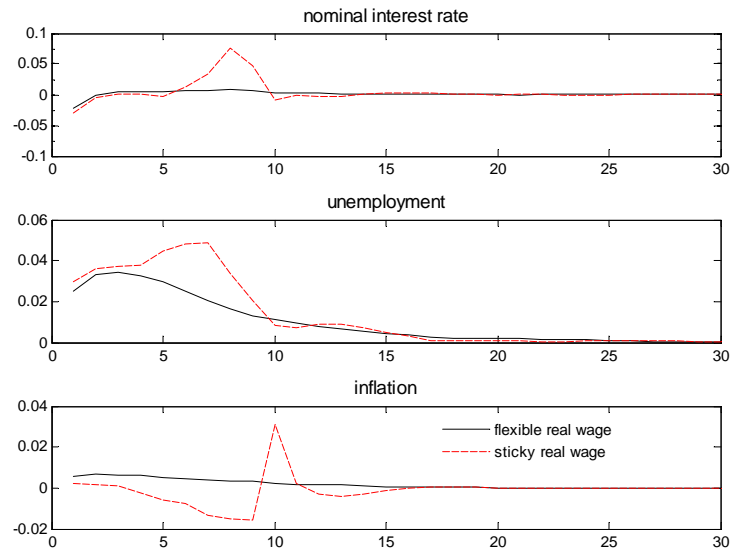

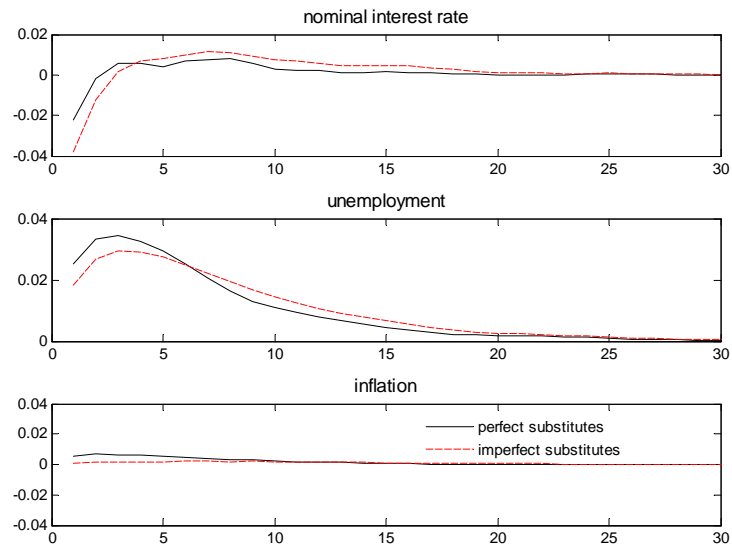Figure 5: Optimal Monetary Policy to a Matching Efficiency Shock

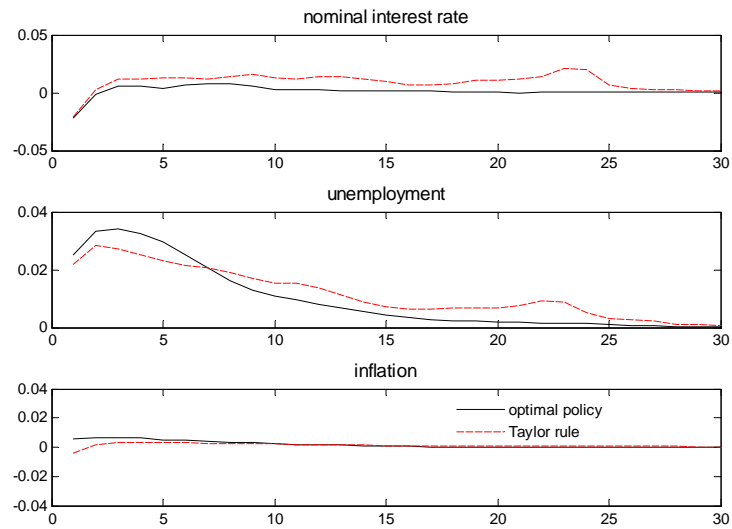Figure 6: Optimal Monetary Policy and Taylor rule to a Matching Efficiency
Shock

Figure 7: Optimal Monetary Policy to a Matching Elasticity Shock