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The (Ir)relevance of Real Wage Rigidity in the New Keynesian Model with Search Frictions*

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Abstract

We explore the role of real wage dynamics in a New Keynesian business cycle model with search and matching frictions in the labor market. Both job creation and destruction are endogenous. We show that the model generates counterfactual inflation and labor market dynamics. In particular, it fails to generate a Beveridge curve: vacancies and unemployment are positively correlated. Introducing real wage rigidity leads to a negative correlation, and increases the magnitude of labor market flows to more realistic values. However, inflation dynamics are only weakly affected by real wage rigidity. This is because of the presence of labor market frictions, which generate long-run employment relationships. The measure of real marginal cost that is relevant for inflation dynamics via the Phillips curve contains a dynamic component that does not necessarily move with real wages.

JEL CLASSIFICATION: E24, E32, J64

KEYWORDS: Labor Market, Real Wage, Search and Matching,
New Keynesian Model, Beveridge Curve

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1 Introduction

Recent research suggests that New Keynesian business cycle models can explain persistent effects of monetary shocks only with a sufficient degree of real rigidity.¹ In the labor market, the source of this rigidity is real wage rigidity. Since firms set prices as markups over real marginal costs, the cyclical nature of the real wage affects the dynamics of inflation. However, in a neoclassical labor market, real wages are strongly procyclical unless an implausible degree of individual labor supply elasticity is assumed. In order to explain real wage rigidity, some labor market imperfections, such as efficiency wages or search and matching frictions, are likely to be important. Furthermore, they may provide an additional propagation mechanism for business cycle shocks.²

In this paper, we study the role of labor market frictions for the dynamics of inflation and real wages, as well as vacancies and unemployment. To this end, we embed a frictional labor market in a standard New Keynesian business cycle model with monopolistically competitive firms and sticky prices. The frictions make the search of workers and firms for a suitable match time-consuming. Jobs in the model are subject to idiosyncratic shocks which generate simultaneous job creation and job destruction flows even in steady state. Simulation of the model shows that labor market frictions as such do not suffice to generate plausible labor market dynamics. Real wages are too procyclical and only weakly autocorrelated, in contrast to the data. Vacancies and unemployment are positively correlated, failing to exhibit a Beveridge curve, and vacancies are less volatile than unemployment. In general, the volatility of labor market variables is too low. Furthermore, inflation is highly correlated with the real wage, while in the data, it is almost uncorrelated.

We trace these shortcomings to the same factor emphasized by Shimer (2003) and Hall (2003): excessive real wage flexibility arising from the nature of wage determination in the model. As is standard in search and matching models we assume that wages are set according to the Nash bargaining solution. This means that worker and firm share the total surplus from their match, typically in equal proportions. It also implies that wages depend linearly on the tightness of the labor market. Any improvement in labor market conditions

¹See, for examples, Jeanne (1998) and Chari, Kehoe, and McGrattan (2000).

²Hall (1999) states that “persistence [in employment] arises naturally from the time-consuming process of placing unemployed workers in jobs following an adverse impulse”.

immediately translates into wages, thus reducing the incentive for firms to create vacancies. In fact, a fall in unemployment makes it more difficult for firms to find workers, leading to a reduction in vacancy creation, so that a Beveridge curve cannot arise.

Incorporating real wage rigidity improves the performance of the model in a number of dimensions. Obviously, it reduces the volatility of the real wage. At the same time, it strongly increases the incentive for firms to increase employment, since they share less of the benefit with workers. Hence vacancies rise in response to a technology shock, while unemployment falls, as in the data. However, the rise in the vacancy-unemployment ratio is so strong that the total number of new matches created actually falls, rather than rises. This is because of the congestion that reduces the likelihood of finding a worker. While the volatility of both job creation and job destruction rates increases, they are positively correlated, in contrast to the data. Our interpretation is that the job destruction margin is too flexible because firms find it more profitable to raise employment by shedding less labor than in steady state, rather than hiring new workers.

Surprisingly, inflation is barely affected by the introduction of real wage rigidity, neither qualitatively, nor quantitatively. This runs counter to the idea that inflation is driven by marginal costs dynamics. The main reason is that in models with labor market frictions, real marginal costs are not equal to the real wage. Due to the long-run attachment between workers and firms, the relevant real marginal cost concept is the marginal contribution to the present discounted value of profits of the firm. This need not move with real wages. In fact, even when real wages are entirely rigid, the markup is still highly procyclical, and inflation countercyclical in response to a technology shock.³

The main contribution of the paper is twofold. We show that in dynamic general equilibrium, real wage rigidity is of central importance for the dynamics of the labor market, as Hall and Shimer stress. Wage rigidity greatly amplifies labor market responses to aggregate disturbances, as it allows firms to benefit from increasing employment in a boom. Secondly, the presence of frictions separates real marginal cost and inflation dynamics. What counts for the price setting decision is the shadow value of the marginal contribution of additional employment to the firm's value, not the current real wage. This suggests that observable

³See also Goodfriend and King (2001) for discussion of the role of the long-run attachment between workers and firms for the relationship between real wages and “effective” real marginal cost.

measures of real marginal costs may be unsuitable for the estimation of the New Keynesian Phillips curve.

Two other recent papers incorporate search and matching frictions and endogenous job destruction into New Keynesian models. Walsh (2003b), who builds on den Haan et al. (2000) in his formulation of the labor market, focuses on how labor market frictions affect the response of the economy to money shocks. However, his macroeconomic structure features a ‘cost channel’ of monetary policy transmission, which we abstract from to highlight the effects of labor market frictions. Trigari (2003) follows Cooley and Quadrini (1999) in her description of the labor market, but focuses on the implications of labor market search for inflation and the ability to explain employment fluctuations at the intensive and extensive margins. Her model differs from the baseline New Keynesian framework in that it also assumes habit formation in consumption. Even though this improves the quantitative performance of the model, the role of labor market frictions for the cyclicalities of real wages becomes difficult to assess.

A modelling detail of interest is that we embed both price setting and employment adjustment decisions within a single, representative firm. This differs from the earlier literature, which separates the economy into two sectors, one monopolistically competitive in the product market, producing differentiated goods, and the other selling an intermediate input, hiring labor from the frictional labor market. Our unified approach highlights the use of the firing decision as the main margin of employment adjustment for firms. It also clarifies the dynamic nature of real marginal costs as the shadow value of employment.

There is a small stock of papers which analyse labor market frictions in real models of the business cycle. The first to do so are Merz (1995) and Andolfatto (1996), building on Pissarides (1990). Chéron and Langot (2001) study the behavior of the real wage, but in a framework with exogenous job destruction, as do Merz (1995) and Andolfatto (1996). Imposing exogenous job destruction artificially forces all employment adjustment into the job creation and hiring decision. Since then higher vacancy creation must coincide with lower unemployment, these models are able to generate a Beveridge curve almost by assumption.⁴ Chéron and Langot (2000) do in fact analyse the behavior of labor markets

⁴Merz (1996) reports a less than perfect negative correlation between unemployment and vacancies in the simulations of her model. This arises from the endogenous search intensity by workers in her model, which leads to shifts of Beveridge curve.

in a monetary model, but still have a fixed job destruction intensity.

The paper proceeds as follows. In Section 2 we document the main stylized facts. We find a real wage that is procyclical, which, however, is driven by very high cyclicality in the 1970s. In Section 3, we develop our model and describe the calibration and simulation procedure in Section 4. Section 5 reports the main findings of the model, and discusses its implications. In Section 6, we explore the role of real wage rigidity. Section 7 concludes.

2 Some Stylized Facts

This section documents the cyclical behavior of inflation and the key labor market variables considered in the paper: the real wage, vacancies, and unemployment.⁵ All variables are quarterly and detrended using the HP-filter, with smoothing parameter 1600. The real wage is measured by average hourly earnings per employee in the U.S. private non-farm sector. The data cover the years 1964 to 2002. Figure 1 shows the relationship between detrended real wages and GDP. Real wages are procyclical, the degree of which depends on the time period considered. Particularly the 1970s feature a highly procyclical real wage, while from the 1980, it appears almost acyclical. In fact, for the full sample, the correlation between output and real wages is 0.57, whereas from 1982 onward, it is merely 0.26. As an alternative to real wages, we also consider the return to working as measured by labor productivity. Output per worker and output per hour worked are procyclical, but the degree depends on the time period considered. The former has a correlation with output of 0.69 for the full sample, but only 0.45 after 1982. The corresponding numbers for output per hour worked are 0.54 and 0.16. Standard real business cycle models with neoclassical labor market typically imply much higher correlations.

Vacancies are constructed from the U.S. Bureau of Labor Statistics' index of help-wanted advertisements (see Figure 2). The dynamics of vacancies and unemployment follow a familiar and robust pattern: vacancies are highly procyclical whereas unemployment is strongly countercyclical. In other words, the two variables exhibit a Beveridge curve. Furthermore, this pattern implies that a measure of labor market tightness, the vacancy-unemployment ratio, is also highly procyclical. This relates to the findings of Davis, Haltiwanger, and Schuh (1996) for job creation and job destruction. Both are negatively correlated over the

⁵The data used in the paper are available from the website of the U.S. Bureau of Labor Statistics.

cycle. In a recession, high job destruction goes along with low job creation, leading to rising unemployment, while the incentive to post vacancies is low. This can be interpreted as evidence of heterogeneity in individual plants' fortunes.

Figure 3 depicts the time series of inflation in relation to GDP and the real wage. Inflation is somewhat correlated with output (0.39), and the correlation with real wages is weak and negative at -0.19. This correlation is even more negative at -0.33 and inflation is less volatile for the post-1982 period. The weak correlation with real wages leads us to question the role of real wages for the dynamics of inflation.

3 The Model

In this section, we present the standard New Keynesian business cycle model with labor market frictions. Households maximize lifetime utility derived from consumption sequences of a CES aggregate of differentiated products, money holdings, and labor supply, subject to a intertemporal budget constraint. Monopolistically competitive firms maximize profits by choosing prices and employment subject to price adjustment cost and hiring frictions. Separation of workers from firms is driven by job-specific productivity shocks drawn from a time-invariant distribution, which identical for all jobs. The shocks generate a steady-state stream of workers out of employment and into unemployment. At the same time, new workers are hired in a labor market that is subject to matching frictions, represented by a matching function. The setup of the labor market is similar to Cooley and Quadrini (1999), who in turn build on Mortensen and Pissarides (1994).

3.1 Households

Consider a discrete-time economy where households maximizes lifetime utility

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma} - 1}{1-\sigma} + \chi \log \frac{M_t}{P_t} + (1 - \chi_t)b - \chi_t h \right], \quad (1)$$

choosing a consumption bundle, C_t , nominal money holdings M_t , and bonds B_t subject to the budget constraint

$$C_t + \frac{M_t}{P_t} + \frac{B_t}{P_t} = Y_t^l + T_t + \frac{M_{t-1}}{P_t} + R_{t-1} \frac{B_{t-1}}{P_t} + \Pi_t, \quad (2)$$

where Y_t^l is labor income of the household, Π_t are aggregate profits, and T_t are transfers from the government. Bonds pay a gross interest rate R_t . Labor is supplied inelastically,

with a disutility of h suffered if the agents works ($\chi_t = 1$) and a value of leisure b , enjoyed if unemployed.⁶ The composite consumption good is a CES aggregate of the differentiated products

$$C_t = \left(\int_0^1 C_{it}^{\frac{\nu-1}{\nu}} di \right)^{\frac{\nu}{\nu-1}}, \quad \nu > 1,$$

with the consumption-based price index $P_t = \left(\int_0^1 P_{it}^{1-\nu} di \right)^{\frac{1}{1-\nu}}$. Intra-temporal maximization of the household sector implies a demand function for each product

$$C_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\nu} C_t \quad i \in [0, 1],$$

which each monopolistically competitive firm faces when choosing the price of its differentiated product. In equilibrium, total consumption C_t will equal income, Y_t . Intertemporal optimization by households implies the following first-order conditions:

$$C_t^{-\sigma} = \beta R_t E_t \left[\frac{P_t}{P_{t+1}} C_{t+1}^{-\sigma} \right] \quad (3)$$

$$\frac{M_t}{P_t} = \chi \frac{R_t}{R_t - 1} C_t^\sigma \quad (4)$$

where the former is the consumption Euler equation that links present consumption with future consumption. The second condition is the standard money demand equation.

3.2 Firms

Each differentiated good is produced by a monopolistically competitive firm. Labor is the only input. Each job j at firm i produces output $A_t a_{ijt}$, which depends on aggregate productivity A_t , common to all firms, and idiosyncratic, job-specific productivity, a_{ijt} . Every period, this productivity is drawn from a distribution with c.d.f. $F(a)$ with support $[\underline{a}, \bar{a}]$ and density f . Total output at firm i is determined by the measure n_{it} of jobs, aggregate productivity and the average of the idiosyncratic productivities:

$$Y_{it} = A_t n_{it} \int_{\tilde{a}_{it}}^{\bar{a}} a \frac{f(a)}{1 - F(\tilde{a}_{it})} da \equiv n_{it} A_t H(\tilde{a}_{it}), \quad (5)$$

where the lower bound of the integral is a critical threshold \tilde{a}_{it} for the job-specific productivity, determined below. For $a_{ijt} < \tilde{a}_{it}$, job j is not profitable, therefore destroyed, and the worker on that job laid off.

⁶To avoid additional complications from heterogeneity, we follow Merz (1995) and Andolfatto (1996) in assuming a large number of members of families which perfectly insure each other against fluctuations in income.

Job creation is subject to matching frictions. The aggregate flow of new matches in period $t + 1$ is given by a matching function $m(u_t, v_t) = mu_t^\xi v_t^{1-\xi}$, $0 < \xi < 1$, as a function of the period- t total number of unemployed (and searching) workers, u_t , and the total number of vacancies, $v_t = \int_0^1 v_{it} di$, with v_{it} is the measure of vacancies posted by firm i . The probability of a vacancy being filled in period $t + 1$ is $q(\theta_t) \equiv m(u_t, v_t)/v_t = m(u_t/v_t, 1)$ with labor market tightness $\theta_t = v_t/u_t$, and the flow of new hires for an individual firm in $t + 1$ is $v_{it}q(\theta_t)$.

Job destruction at firm i is given by the probability ρ^x of exogenous and constant job separations and the endogenous probability $\rho_{it}^n = F(\tilde{a}_{it})$. Total separations are therefore $\rho_{it} = \rho(\tilde{a}_{it}) \equiv \rho^x + (1 - \rho^x)F(\tilde{a}_{it})$. Both new and old jobs are subject to idiosyncratic shocks. Therefore, total employment at firm i evolves according to:

$$n_{it+1} = (1 - \rho_{it+1})(n_{it} + v_{it}q(\theta_t)). \quad (6)$$

Denote the total wage bill at firm i by $W_{it} = n_{it} \int_{\tilde{a}_{it}}^{\bar{a}} w_t \frac{f(a)}{1-F(\tilde{a}_{it})} da$, where $w_t = w_t(a)$ reflects the fact that the wage may depend on a job's idiosyncratic uncertainty as well as other, time-varying, factors. The precise expression for the wage is derived below.

Firm i 's optimization problem is to choose its optimal price, employment, vacancy rate, and job destruction threshold, to maximize the present discounted value of profits

$$\Pi_{it} = \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0} \left[\frac{P_{it}}{P_t} Y_{it} - W_{it} - c^h v_{it} - \frac{\psi}{2} \left(\frac{P_{it}}{P_{it-1}} - \pi \right)^2 Y_t \right], \quad (7)$$

subject to the output constraint

$$Y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\nu} Y_t = n_{it} A_t H(\tilde{a}_{it}) \quad (8)$$

and the equation for the evolution of employment. The first term in the maximand are real revenues, followed by the wage bill, the costs, c^h , of the posted vacancies, and a quadratic term representing a price adjustment cost paid by firm i . For any deviation of the change of the firm's price from steady state inflation, the firm pays a cost that is increasing in the size of the price change. Output of each firm is consumed, such that $Y_{it} = C_{it}$ and $Y_t = C_t$. Perfect capital markets imply that the firm discounts using the household's subjective discount factor.

The first-order conditions are

$$n_{it} : \quad \mu_t = \epsilon_t A_t H(\tilde{a}_t) - \frac{\partial W_t}{\partial n_t} + \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) (1 - \rho_{t+1}) \mu_{t+1} \quad (9)$$

$$v_{it} : \quad \frac{c^h}{q(\theta_t)} = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) (1 - \rho_{t+1}) \mu_{t+1} \quad (10)$$

$$P_{it} : \quad 1 - \psi(\pi_t - \pi)\pi_t + \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left[\psi(\pi_{t+1} - \pi)\pi_{t+1} \frac{Y_{t+1}}{Y_t} \right] = (1 - \epsilon_t)\nu \quad (11)$$

$$\tilde{a}_{it} : \quad \mu_t \rho'(\tilde{a}_t)(n_{t-1} + v_{t-1}q(\theta_{t-1})) = \epsilon_t n_t A_t H'(\tilde{a}_t) - \frac{\partial W_t}{\partial \tilde{a}_t} \quad (12)$$

where, by symmetry, the subscripts for firm i have been dropped. μ_t and ϵ_t are the Lagrange multipliers on the employment and output constraints, respectively. The multiplier μ_t gives the current period value of an additional worker before the job-specific shock a has determined the productivity of the worker. The second condition equalizes the expected cost of an open vacancy with the expected benefit of a hired worker. The multiplier ϵ_t is the contribution of an additional unit of output to the firms revenue. In equilibrium, it must equal the real marginal cost that firms face.

The third condition is standard for models with quadratic price adjustment. In its linearized form, it yields the New Keynesian Phillips curve.⁷ It determines inflation dynamics in terms of real marginal cost and is derived by using symmetry of firms and the definition $\pi_t = P_t/P_{t-1}$. Intuitively, if inflation is expected to be higher than the steady-state level π , firms increase their prices today. In steady state, when $\pi_t = \pi$, the pricing relationship collapses to the condition $\epsilon = (\nu - 1)/\nu$, which implies a (net) steady state mark-up of $(\nu - 1)^{-1}$.⁸

Substituting the second into the first constraint yields a job creation condition which relates the expected cost of vacancy creation (flow cost c^h times the expected duration $1/q$) to its expected return.

$$\frac{c^h}{q(\theta_t)} = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left[(1 - \rho_{t+1}) \left(\epsilon_{t+1} A_{t+1} H(\tilde{a}_{t+1}) - \frac{\partial W_{t+1}}{\partial n_{t+1}} + \frac{c^h}{q(\theta_{t+1})} \right) \right]. \quad (13)$$

⁷The dynamic properties of the linearized price setting equation are identical to those of the familiar price setting equation based on Calvo (1983). The only conceptual difference is that, here, all firms adjust their prices to some extent after a shock. In contrast, with the Calvo-assumption only a fraction of firms resets their price. It is the assumption of quadratic price adjustment, along with symmetry of firms, which makes it possible to integrate the price setting and employment decision of the firm.

⁸In a decentralized, two-sector setup (for example Walsh, 2003b), the real marginal cost P^w/P takes the place of ϵ . The variable P^w is the price of an intermediate homogeneous input produced by firms that hire workers in a frictional labor market.

The optimal critical threshold for job destruction is such that the expected benefit from hiring new workers equals the benefits of shedding old workers. This can be seen by combining the shadow value of employment μ_t with the first-order condition for the optimal threshold:

$$\left[\epsilon_t A_t H(\tilde{a}_t) - \frac{\partial W_t}{\partial n_t} + \frac{c^h}{q(\theta_t)} \right] \rho'(\tilde{a}_t)(n_{t-1} + v_{t-1}q(\theta_{t-1})) = \epsilon_t n_t A_t H'(\tilde{a}_t) - \frac{\partial W_t}{\partial \tilde{a}_t}.$$

Use the equation for the evolution of employment and the relationships $\rho'(\tilde{a}_t) = (1 - \rho^x)F'(\tilde{a}_t) = (1 - \rho^x)f(\tilde{a}_t)$ and $H'(\tilde{a}_t) = f(\tilde{a}_t)/(1 - F(\tilde{a}_t))(H(\tilde{a}_t) - \tilde{a}_t)$ to obtain:

$$\epsilon_t A_t H(\tilde{a}_t) - \frac{\partial W_t}{\partial n_t} + \frac{c^h}{q(\theta_t)} = \epsilon_t A_t H(\tilde{a}_t) - \epsilon_t A_t \tilde{a}_t - \frac{1 - \rho_t}{n_t \rho'(\tilde{a}_t)} \frac{\partial W_t}{\partial \tilde{a}_t}. \quad (14)$$

Finally, use the derivatives of the wage bill to get:⁹

$$\epsilon_t A_t \tilde{a}_t - w_t(\tilde{a}_t) + \frac{c^h}{q(\theta_t)} = 0. \quad (15)$$

This equation implicitly defines the critical threshold \tilde{a}_t for idiosyncratic productivity below which jobs are destroyed. Once an expression for the wage is derived, the threshold can be solved for explicitly.

The behavior of the aggregate labor market also follows from symmetry in equilibrium. Therefore, we have that total employment evolves according to:

$$n_{t+1} = (1 - \rho_{t+1})(n_t + v_t q(\theta_t)). \quad (16)$$

Searching workers, u_t , are equal to the currently unemployed, $1 - n_t$.

Gross job destruction in period t is equal to $\rho_t n_{t-1} - \rho^x n_{t-1}$. The second term is subtracted because it represents exogenous worker turnover, not gross destruction of employment opportunities. Gross job creation is $(1 - \rho_t)v_{t-1}q(\theta_{t-1}) - \rho^x n_{t-1}$, where, again, creation due to worker turnover need be subtracted. Dividing through by n_{t-1} yields the corresponding rates:¹⁰

$$jdr_t = \rho_t - \rho^x \quad (17)$$

⁹These derivatives are:

$$\frac{\partial W_t}{\partial \tilde{a}_t} = n_t \frac{f(\tilde{a}_t)}{1 - F(\tilde{a}_t)} \left[\int_{\tilde{a}_t}^{\bar{a}} w_t(a) \frac{f(a)}{1 - F(\tilde{a}_t)} da - w_t(\tilde{a}_t) \right] \text{ and } \frac{\partial W_t}{\partial n_t} = \int_{\tilde{a}_t}^{\bar{a}} w_t(a) \frac{f(a)}{1 - F(\tilde{a}_t)} da$$

¹⁰To correspond with the measurement used in the literature, a more precise way would be to divide by the average employment between periods, $(n_t + n_{t-1})/2$. We ignore this possibility.

$$jcr_t = \frac{(1 - \rho_t)v_{t-1}q(\theta_{t-1})}{n_{t-1}} - \rho^x. \quad (18)$$

The percentage net employment change is equal to the job creation rate minus the job destruction rate:

$$\frac{n_t - n_{t-1}}{n_{t-1}} = \frac{(1 - \rho_t)v_{t-1}q(\theta_{t-1})}{n_{t-1}} - \rho_t. \quad (19)$$

3.3 Wage Setting

The derivation so far has treated the wage as given. We derive a wage that is match-specific, depending on the idiosyncratic productivity of the job. Wages are assumed to be bargained over individually between each worker and the firm, and set according to the Nash bargaining solution. To this end, it is convenient to use expressions for the marginal value of jobs and vacancies, as well as the value of employment and unemployment to the worker.

3.3.1 Bellman Equations

Write the marginal benefit of an existing job with realized idiosyncratic productivity a_t in terms of the Bellman equation:

$$J_t = \epsilon_t A_t a_t - w_t + \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left[(1 - \rho_{t+1}) \int_{\tilde{a}_{t+1}}^{\bar{a}} J_{t+1} \frac{f(a)}{1 - F(\tilde{a}_{t+1})} da \right]. \quad (20)$$

Recall that we have already imposed symmetry. The value of a job depends on real revenue minus the real wage, plus the discounted continuation value. With probability $1 - \rho_{t+1}$, the job remains filled, and earns the expected value. With probability ρ_{t+1} , the job is destroyed and has zero value. This implies an alternative to the equation found earlier, now in terms of J_{t+1} :

$$\frac{c^h}{q(\theta_t)} = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left[(1 - \rho_{t+1}) \int_{\tilde{a}_{t+1}}^{\bar{a}} J_{t+1} \frac{f(a)}{1 - F(\tilde{a}_{t+1})} da \right]. \quad (21)$$

Turning to workers, the value to a worker matched to the firm is:

$$\mathcal{W}_t = w_t + \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left[(1 - \rho_{t+1}) \int_{\tilde{a}_{t+1}}^{\bar{a}} \mathcal{W}_{t+1} \frac{f(a)}{1 - F(\tilde{a}_{t+1})} da + \rho_{t+1} U_{t+1} \right]. \quad (22)$$

The value of being unemployed is given by

$$U_t = b + \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left[\theta_t q(\theta_t) (1 - \rho_{t+1}) \int_{\tilde{a}_{t+1}}^{\bar{a}} \mathcal{W}_{t+1} \frac{f(a)}{1 - F(\tilde{a}_{t+1})} da + (1 - \theta_t q(\theta_t) (1 - \rho_{t+1})) U_{t+1} \right] \quad (23)$$

3.3.2 Nash Bargaining

Wages are determined by the Nash bargaining solution. Worker and firm share the joint surplus of their match with share $0 < \eta < 1$ going to the worker. The usual optimality condition is:¹¹

$$\mathcal{W}(a_t) - U_t = \frac{\eta}{1 - \eta} J(a_t), \quad (24)$$

where $\mathcal{W} - U$ is the surplus of the worker (or loss in case of separation) and J is the surplus of the firm (or loss in case of separation). Inserting the value functions yields the wage equation:

$$w_t(a_t) = \eta \left(\epsilon_t A_t a_t + \theta_t c^h \right) + (1 - \eta)b. \quad (25)$$

Real wages depend on aggregate conditions as well as firm-specific factors. Labor market tightness, real marginal costs, firm specific productivity and aggregate productivity all increase wages. The average real wage is the weighted average of the individual wages paid:

$$w_t = \int_{\tilde{a}_t}^{\bar{a}} w_t(a) \frac{f(a)}{1 - F(\tilde{a}_t)} da = \eta \epsilon_t A_t \int_{\tilde{a}_t}^{\bar{a}} a \frac{f(a)}{1 - F(\tilde{a}_t)} da + \eta \theta_t c^h + (1 - \eta)b \quad (26)$$

Note that jobs are endogenously destroyed whenever $J(a) \leq 0$ (which is equivalent to $\mathcal{W}(a) - U \leq 0$). Therefore, the critical value of a below which separation takes place is given by $J(\tilde{a}_t) = 0$. Using the individual real wage, the job destruction threshold becomes:

$$\tilde{a}_t = \frac{1}{\epsilon_t A_t} \left(b + \frac{c^h}{1 - \eta} \left(\eta \theta_t - \frac{1}{q(\theta_t)} \right) \right). \quad (27)$$

3.4 The New Keynesian Phillips Curve and Labor Market Frictions

The presence of labor market frictions introduces a wedge between the real wage and the relevant real marginal cost that firms face, which in turn determine inflation dynamics. Consider the log-linearized version of the price-setting condition. Assuming zero net inflation in steady state, the New Keynesian Phillips curve is

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa \hat{\epsilon}_t,$$

where $\kappa = 1/\varphi$. Current inflation is a function of expected future inflation and real marginal cost.¹² The key difference between the Phillips curve in our model and in models with

¹¹See, for example, Pissarides (2000).

¹²Recall that the parameter φ stems from the quadratic adjustment cost function. In models where price setting is constrained following Calvo (1983), κ is determined by the parameter that governs the frequency of price adjustment.

neoclassical labor markets is, however, the behavior of the real marginal cost term. In competitive labor market, ϵ_t is given by

$$\epsilon_t = \frac{W_t/P_t}{MPL_t}, \quad (28)$$

i.e., the real marginal cost of labor equals the real wage divided by marginal productivity.¹³

In the present model, we can re-write the first-order condition for employment (9) to get:

$$\epsilon_t = \frac{\partial W_t / \partial n_t}{A_t H(\tilde{a}_t)} + \frac{\mu_t - c^h / q(\theta_t)}{A_t H(\tilde{a}_t)}. \quad (29)$$

The first term on the right hand side is the real marginal wage bill, divided by the marginal product of labor, corresponding to the equation above. The second term reflects the presence of labor market frictions. It depends on the difference between the current value of the average worker and the expected cost of posting a new vacancy. The cyclical behavior of this term may differ substantially from the behavior of real marginal costs with a frictionless labor market. Furthermore, in steady state, $\mu > c^h / q(\theta)$. Thus the fact that firms cannot instantaneously hire workers increases their real marginal cost. Since $\epsilon = (\nu - 1) / \nu$ in steady state, the wage bill has to be lower than without frictions. In this model with constant returns to scale, this can only be achieved by a lower wage bill (holding $H(\tilde{a}_t)$ constant), which, from the wage equation, requires labor market tightness to be lower, or unemployment higher.

The expression for ϵ_t makes explicit the difference between the real wage and “effective” real marginal cost that arises in the presence of frictions. Hiring frictions generate a surplus for existing matches which gives rise to long-term employment relationships. These in turn reduce the allocative role of current-period real wages. As has been stressed by Goodfriend and King (2001), the effective real marginal cost can change even if the wage does not change.¹⁴ Typically, attempts to estimate the New Keynesian Phillips curve use a proxy for (28), for example, the labor share.¹⁵ However, this would no longer be appropriate in the presence of frictions. We leave this issue to future research.

¹³See, for example, Walsh (2003, p.235).

¹⁴See also Galí’s (2000) discussion of an earlier version of Goodfriend and King’s paper.

¹⁵See Walsh (2003a, chapter 5).

3.5 Closing the Model

The final step is to find the aggregate quantities. Aggregate income flowing to households is found by integrating over the outputs of all producing worker-firm units and subtracting the resources going into search activity by firms:

$$Y_t = n_t A_t \int_{\tilde{a}_t}^{\infty} a \frac{f(a)}{1 - F(\tilde{a}_t)} da - c^h v_t. \quad (30)$$

All output is consumed in equilibrium: $C_t = Y_t$. The government budget constraint is given by:

$$\frac{M_t - M_{t-1}}{P_t} + \frac{B_t}{P_t} - \frac{R_{t-1} B_{t-1}}{P_t} + T_t = 0, \quad (31)$$

so that any seignorage revenue is rebated to the household. We assume that monetary policy follows a simple money growth rule:

$$\phi_t = \phi_{t-1}^{\rho_m} \cdot e^{\epsilon_{m,t}}, \quad (32)$$

where $\phi_t = \frac{M_t}{M_{t-1}}$, $0 < \rho_m < 1$, and $\epsilon_{m,t} \sim N(0, \sigma_m^2)$. Alternatively, we could have modeled the money supply process by using an interest-rate rule as in Trigari (2003). Since equilibrium money balances and the nominal rate are linked via the money demand Eq. (4), these two approaches are conceptually almost identical.¹⁶ Our focus, however, is on labor market dynamics over the post-war period during which the conduct of monetary policy changed several times. Moreover, calibrating the shock process in the interest rate rule is not straightforward due to identification problems. For these reasons we introduce monetary shocks as money growth innovations.

4 Model Solution and Calibration

The equations describing the model economy are collected in the Appendix. We proceed by computing the non-stochastic steady state around which the equation system is linearized. The resulting linear rational expectations model is then solved using standard methods, e.g. Sims (2002). For our quantitative analysis we need to assign numerical values to the structural parameters. Since pertinent information may not be available for some parameters,

¹⁶It is well known that an interest rate rule could lead to indeterminate outcomes, which can be avoided by implementing a sufficiently anti-inflationary policy stance. Simulation of our model with an interest rate rule did not produce different results. See Lubik and Marzo (2003) for further discussion of monetary policy rules in the New Keynesian model.

we compute these indirectly from the steady-state values of endogenous variables. In what follows we describe our benchmark parameterization, which we then modify in subsequent sections.

We start with the separation probabilities and set $\rho_x = 0.068$ and the steady-state separation rate $\rho = 0.1$. Since $\rho^n = (\rho - \rho^x)/(1 - \rho^x)$, we find the threshold \tilde{a} from $\tilde{a} = F^{-1}(\rho^n)$. We assume that $F(\cdot)$ is the lognormal c.d.f with parameters $\mu_{\ln} = 1$ and $\sigma_{\ln}^2 = (0.15)^2$.¹⁷ In the linearized model we require the threshold elasticity of the c.d.f. $\frac{\partial F(\tilde{a})}{\partial \tilde{a}} \frac{\tilde{a}}{F(\tilde{a})} = \frac{\tilde{a}f(\tilde{a})}{F(\tilde{a})}$, where $f(\cdot)$ is the density function. For the conditional expectation of a given \tilde{a} : $H(\tilde{a}) = \int_{\tilde{a}}^{\infty} a \frac{f(a)}{1-F(a)} da$ we find the semi-elasticity $\frac{\partial H(\tilde{a})}{\partial \tilde{a}} \tilde{a} = \frac{\tilde{a}f(\tilde{a})[H(\tilde{a})-\tilde{a}]}{H(\tilde{a})[1-F(\tilde{a})]}$.

The employment rate is set to $n = 0.94$, which implies an unemployment rate of 6%. The corresponding mass of workers participating in the matching market is given by $u = 1 - n$. Setting the worker and firm matching rates to $\theta q(\theta) = 0.6$ and $q(\theta) = 0.7$, respectively, we can calculate the number of vacancies that must be available for matching in steady state: $v = u\theta$. For the matching function itself, we choose a Cobb-Douglas functional form with elasticity parameter $\xi = 0.4$, so that $m = \theta q(\theta)(u/v)^\xi$. The worker's share in the surplus of the match is $\eta = 0.5$.

The parameters describing the household are standard. We choose a coefficient of relative risk aversion $\sigma = 2$, the substitution elasticity for retail goods is $v = 11$, which implies a steady state mark-up of 10%. More problematic is the price adjustment cost parameter φ which governs the degree of nominal rigidity. It was chosen to match evidence on average contract length, which is roughly 4 quarters.¹⁸ To be precise, the model has no direct analogue to contract length, due to the assumption of quadratic adjustment costs. But φ can be chosen such that the linearized Phillips curve is identical to the one derived from Calvo type contracts of random duration. We also report findings from a model with substantially higher price stickiness. Steady state inflation is set to $\pi = 1$.

Finally, we need to calibrate the shock processes. The logarithm of the money growth rate follows an AR(1) process. We use the same values as reported in Cooley and Quadrini (1999) and set $\rho_m = 0.49$ and the standard deviation of the innovation $\sigma_m = 0.00623$. The (logarithm of the) aggregate productivity shock is assumed to follow an AR(1) process with

¹⁷The implied variance of the associated normal density is $\sigma_n = \ln(2\mu_{\ln} + \sigma_{\ln}^2) - 2\ln\mu_{\ln}$. The mean is $\mu_n = \log\mu_{\ln} - 1/2\sigma_n$.

¹⁸See Taylor (1999).

coefficient $\rho_A = 0.95$. As is common in the literature we choose an innovation variance such that the baseline model's predictions match the standard deviation of U.S. GDP, which is 1.62%. While this is not a robust procedure, it is not essential for our approach since we do not evaluate the model along this dimension. The standard deviation of technology is consequently set to $\sigma_\varepsilon = 0.0064$.

5 Benchmark Results

This section reports the main findings of our benchmark model. To recapitulate, we have developed a monetary, New Keynesian model with job search and matching and endogenous job destruction. In the benchmark specification, wages are determined entirely by Nash bargaining. First, we report impulse responses for technology and monetary policy shocks and discuss their robustness. Then, summary statistics from the data are compared with the corresponding statistics from the simulated model.

5.1 Impulse Response Analysis

Consider first the dynamic effects of a unit monetary shock. The impulse response functions are depicted in Figure 4. Output and employment rise, as does the real wage. In contrast to the empirical evidence, labor productivity falls. This is due to the strong initial jump in employment, which reduces output per worker. Employment increases proportionally more than production since the fall in the critical threshold for idiosyncratic productivity preserves firm-worker matches that would otherwise have been unprofitable. There is a small initial in job creation, whereas the job destruction rate falls considerably. The rise in employment is mirrored in the decline in unemployment, i.e. the number of effectively searching workers. This is due to the sharp drop in separations, ρ . In fact, the fall in unemployment is so strong that firms' incentive to create new vacancies goes down, rather than up. It becomes more difficult to find workers when labor market tightness, the vacancy unemployment ratio, rises. Finally, inflation rises in response to the shock. This is because real marginal costs (the inverse of the markup indicated by μ in the diagram) rise from the survival of worse matches, the rise in wages, and the difficulty to find new workers.

Next, we study the economy's response to a technology shock in Figure 5. As expected, output rises. Since technology is fairly persistent this carries over to output. Employment

falls initially, which arises from the assumption of sticky prices: with constant prices and money, aggregate demand remains unchanged *ceteris paribus*.¹⁹ With higher aggregate productivity, the same level of output can be produced with less labor input. As time progresses, inflation declines, aggregate demand rises, so that after two quarters, employment finally rises. Real wages also increase only with a lag. This is due to both the initially weak response of labor market tightness and the strong rise in the markup, which implies a fall in ‘effective’ real marginal cost which also enters the wage bargain. Only later, when labor markets tighten, do real wages rise, following the increase in labor productivity. One can see that separations initially rise, but then fall below steady state as employment increases. Similarly, the job destruction rate increases before falling below steady state, while job creation initially stays flat, then increases substantially before declining. The interplay of these effects generates the overall employment dynamics. Productivity shocks also produce a hump-shaped output response, which is driven by the initial fall in employment.

We now discuss the implications of deviating from our benchmark calibration.²⁰ An obvious starting point is to increase price rigidity by setting $\varphi = 185$. In general, the effects from a monetary shock are more pronounced under sticky prices. Output and employment respond more, while inflation is more sluggish. Counterfactually, real wages and labor productivity move in opposite directions, even more strongly than in Figure 4. The same conclusion can be drawn for the case of productivity shocks. The negative effect on employment is much more pronounced when prices are rigid and produces a delayed peak in output after 6 quarters.

We also considered various values for the worker’s share η in the Nash bargain. Our benchmark simulations assume $\eta = 0.5$. Decreasing this parameter reduces output, employment and wage responses marginally, while the job creation and destruction peaks increase. The shapes of the impulse response functions remain qualitatively unaffected. For small enough η , the job destruction rate actually falls on impact (it increased in the benchmark case) and stays below job creation for a few periods. When workers’ bargaining power is small, each matched worker-job pair is more valuable to a firm. This reduces the incentive for the firm to destroy existing matches. Increasing the bargaining power of the firms, on

¹⁹This relates to the discussion of whether technology shocks are contractionary. See Galí (1999).

²⁰We do not present the impulse response functions which are, however, available from the authors upon request.

the other hand, does not change the other dynamic responses qualitatively since the opposing effects on employment now move in the same direction. It is apparent that the share parameter is potentially important for the volatility of employment fluctuations, which has been pointed out before by Cooley and Quadrini (1999).

5.2 Business Cycle Statistics

We now turn to a discussion of the business cycle statistics computed from our benchmark model. Table 2 shows selected sample moments for the labor market variables of interest. We first evaluate the success of our benchmark model in matching the standard deviations in the data conditional on technology and monetary shocks. Since we calibrated the variance of technology shocks to match the volatility of U.S. GDP we only evaluate the model's predictions based on relative volatilities. We find that, in general, the variables in the model conditional on technology shocks alone are less volatile than in the data, in particular, vacancies, unemployment, and labor market tightness. Interestingly, real wage volatility matches that in the data exactly, while inflation in the data is almost twice as volatile. This already highlights the wedge between real wages and real marginal cost that exists in a model with search frictions.

The picture is different for the case with money shocks alone. All variables relative to GDP are more volatile by several orders of magnitude, although the (absolute) standard deviation of GDP is only 0.18%. Naturally, this suggests that the benchmark calibration may not be properly chosen. We therefore experimented with different degrees of price rigidity. For $\varphi = 105$, we are able to match the relative standard deviation of inflation, while the output volatility is too low at 0.5%. Most other variables, however, remain largely unaffected, except that higher price rigidity drives up the volatility of real wages to implausibly high levels. The extreme case of even higher price rigidity at $\varphi = 185$ makes the direction of the effects clear.

Now consider the behavior of the model economy under both shocks and $\varphi = 10$. Since output volatility induced by nominal shocks is small compared to technology shocks the joint behavior is dominated by the latter. We find, however, that the volatility is much closer now to the data than before, only labor market tightness θ and employment are much too low. The low volatility of tightness of course is due to the positive correlation

of unemployment and vacancies. The volatility of the real wage is about right. Decreasing the degree of price stickiness to almost zero would allow us to match output and inflation volatility exactly, but this would further worsen the performance of the other variables. For high price rigidity, $\varphi = 185$, inflation and output show too little volatility, but the real wage becomes far too volatile. This is the result of the improved performance of the labor market tightness. Its increased response to shocks directly translates into wages, due to the assumption on bargaining, which we will further discuss below.

The New Keynesian model with job search and rather flexible prices captures the volatility of real wages as well as labor productivity well, but performs worse when nominal price rigidity is increased. The next step is to assess the contemporaneous cross-correlations and first-order autocorrelations reported in Table 3. A well-known aggregate labor market fact is that real wages are only slightly procyclical. This fact is difficult to reconcile with a neo-classical labor market where wages are determined by their marginal productivity which is highly correlated with output. The search and matching framework breaks this relationship because wages share the surplus of an employment relationship. However, our simulated value is 0.86, still higher than the correlation of 0.57 that we find between output and real wages in the data. Wages are still too procyclical.

Turning to the Beveridge-curve, the observed negative correlation between unemployment and vacancies (-0.95). Chéron and Langot (2000) have argued that monetary shocks can explain this stylized fact within a search framework. We do not find this. In all our benchmark simulations these variables are positively correlated. The key to this result is the endogeneity of job destruction in our model. As argued above, an expansionary shock lowers the job destruction threshold thus preserving previously unviable matches (see Figure 4). The resulting decrease in unemployment increases labor market tightness which makes it less likely for firms to fill vacancies, thus reducing vacancy posting. In effect, with endogenous job destruction, firing becomes the dominant margin of employment adjustment. Firing is instantaneous and costless, while hiring is time-consuming and costly.

An even more clear failure of the benchmark model with flexible wages is the correlation of job creation and destruction, which is -0.30 for the U.S. economy. In our benchmark specification we find values from 0.40 for money shocks only, to 0.77 for technology shocks. Inspection of the impulse response functions revealed that both variables move closely to-

gether after the impact period. Again, this is because most of the employment increase stems from the fall in the separation rate.

Next consider the behavior of the inflation rate. Empirically, inflation has a positive correlation with GDP of 0.39 and is negatively correlated with unemployment (-0.53). The correlation with real wage is -0.19 . In the model, inflation and GDP are slightly negatively correlated at -0.09 , while the correlation with unemployment is at a reasonable -0.61 . However, the correlation between inflation and the real wage is 0.43, in strong contrast to the data. For all model simulations the inflation rate comoves positively with the real wage.

Finally, consider the autocorrelations in Table 3. As might have been expected, the persistence of the technology shock carries over to a large extent to the model's endogenous variables. As in other New Keynesian models, the internal propagation mechanism is weak. Our model does a reasonably good job in matching the persistence of the real wage and labor productivity. This can be traced back to the fact that output is largely determined by productivity shocks. It is perhaps surprising that endogenous job creation and destruction do not provide an additional channel for the propagation of shocks. It seems plausible *a priori* that shocks which impact the endogenous job destruction rate would produce a richer pattern of employment dynamics. As is apparent from the dynamic responses in Figures 4 and 5 as well as the sample moments, this is not the case. Again, this is due to the role of the job destruction rate as the primary, and frictionless margin of employment adjustment. This removes any sluggishness that might be expected in the presence of matching frictions. Finally, neither specification adequately matches inflation persistence, a well-known deficiency of the standard New Keynesian model.

Alternative calibration of the exogenous separation probability ρ_x yields further insight. As ρ_x moves closer from its benchmark value 0.068 to the (calibrated) steady state separation rate $\rho = 0.1$, the Beveridge-curve reveals itself. For instance, $\rho_x = 0.09$ results in $\text{corr}(u_t, v_t) = -0.41$. If additionally η declines, the correlation falls further, but does not reach the observed value of -0.95 . When endogenous job destruction is small, our model has similar implications as Chéron and Langot (2000). Their explanation of the Beveridge-curve therefore rests on the implausible assumption of purely exogenous job destruction. Our model with endogenous job destruction proves to have counterfactual implications as long as it is costless for firms to adjust employment at this margin.

It may be useful to draw some conclusions at this point. The New Keynesian model with labor market frictions does not differ substantially from the model without frictions. The hoped-for higher degree of real rigidity introduced by search and matching does not materialize because wages are still highly procyclical. We also do not find anyh substantial propagation of shocks. Labor adjustment is not sluggish once job destruction is endogenous. Therefore, the model cannot explain salient labor market facts, such as the Beveridge curve, the negative comovement of job creation and destruction, and we are only able to match aggregate real wage facts at the price of giving up along other dimensions. In summary, the presence of labor market frictions as such does not help match central features of the labor market and macroeconomic aggregates.

6 Alternative Wage Setting Mechanisms

As mentioned in the introduction, Shimer (2003) notes that the joint behavior of real wages and labor market tightness poses a challenge to current theories of the natural rate of unemployment (e.g. Mortensen and Pissarides, 1999). In such models, wages are typically set according to the Nash bargaining solution. This makes the wage proportional to labor market tightness, therefore excessively volatile, which depresses vacancy creation in a cyclical upswing. To generate the required amount of vacancy creation, productivity shocks of implausible magnitude would have to be assumed. Shimer, as well as Hall (2003) see the Nash bargaining assumption at the root of the problem, and explore different forms of wage rigidity. This section takes the same approach, introducing real wage rigidity into the model. In particular, we employ a version of Hall's (2003) notion of a wage norm.²¹

The simplest alternative to the previous wage setting arrangement postulates that the real wage is the weighted average of a notional wage w^n and a wage norm, \bar{w} ; that is, $w_{it} = \gamma w_{it}^n + (1 - \gamma)\bar{w}_t$, with $0 < \gamma < 1$. We assume that the notional wage is calculated according to the Nash bargaining solution of the benchmark model, and that the wage norm is independent of idiosyncratic conditions. One possibility is to just set $\bar{w}_t = w$, for all t , where w is simply the average wage in the steady state. We also consider a wage norm that

²¹A wage norm may arise from some social convention that constrains the wage adjustment for existing and newly hired workers. It is not sufficient to assume that only wages in existing employment relationships are rigid. As Shimer shows, flexibility of wages for new hires would strongly diminish the incentive to create vacancies.

equals the last periods average wage $\bar{w}_t = w_{t-1}$. In this case, the wage is not just driven by current aggregate conditions, but exhibits dynamics of its own.

The individual real wage can then be written as:

$$w_t(a_t) = \gamma \left[\eta \left(\epsilon_t A_t a_t + c^h \theta_t \right) + (1 - \eta)b \right] + (1 - \gamma)w, \quad (33)$$

which leads to the aggregate wage:

$$w_t = \gamma \eta c^h \theta_t + \gamma (1 - \eta)b + \gamma \eta \epsilon_t A_t \int_{\tilde{a}_t}^{\bar{a}} a \frac{f(a)}{1 - F(\tilde{a}_t)} da + (1 - \gamma)w. \quad (34)$$

Depending on the degree of wage rigidity γ , the real wage responds in a limited way to internal and external labor market conditions. Varying γ allows us to explore how wage rigidity helps the model account for the business cycle facts of interest. The separation condition can be calculated in the same way as above:

$$\tilde{a}_t = \frac{1}{(1 - \gamma \eta) \epsilon_t A_t} \left[\gamma \left((1 - \eta)b + \eta c^h \theta_t \right) + (1 - \gamma)w - \frac{c^h}{q(\theta_t)} \right]. \quad (35)$$

If $\gamma = 1$, the equation reduces to the same equation as before. In the other extreme, $\gamma = 0$, we have:

$$\tilde{a}_t = \frac{1}{\epsilon_t A_t} \left(w - \frac{c^h}{q(\theta_t)} \right). \quad (36)$$

In this case, the separation threshold changes only with aggregate factors, namely the markup, aggregate productivity, or labor market tightness. All else being equal, a higher markup $1/\epsilon_t$, makes production more profitable, thus allowing less productive matches to survive. The same holds for aggregate productivity. The second term in brackets represents the value of opening a vacancy. If it is higher, it means that matches are expected to have a higher value in the future, by virtue of the equation for $c^h/q(\theta_t)$ derived earlier. This also implies that matches today are worth preserving, thus the threshold falls. If $\gamma > 0$, this effect is muted. A higher vacancy-unemployment ratio also improves workers' outside options and therefore increases the real wage. This has a counterbalancing effect on \tilde{a} , as workers share some of the benefits of improved aggregate conditions in a boom, which reduces the number of jobs that are not destroyed. Wage rigidity leads to more jobs surviving, while in a recession more jobs are destroyed than would be under flexible wages.

This setup implies inefficient separations. Wage flexibility would allow workers in jobs with low productivity to stay employed by accepting wage cuts, as long as there is joint

match value to be preserved. This possibility is excluded here, which leads to excessive job destruction. Therefore, it may be that in recessions: $\mathcal{W} - U > 0$ and $J < 0$, while in booms, $J > 0$ and $\mathcal{W} - U < 0$. In the former case, the firm destroys the job, even though the worker has a strictly positive benefit from staying employed. Giving up some of his surplus might be sufficient to keep the job alive. The case of $\mathcal{W} - U < 0$ can occur because the outside option of the worker moves up in an expansion. Then the firm has an incentive to keep the job alive by giving up some of its surplus. It is the essence of Nash bargaining with continuous renegotiation that separations are always efficient; to wit, $\mathcal{W} - U = 0$ if and only if $J = 0$, by virtue of $\mathcal{W} - U = \eta/(1 - \eta)J$.²²

We begin our quantitative analysis by shutting down the wage-setting mechanism in its entirety, $\gamma = 0$ and $\bar{w}_t = w$. The results are reported in Table 4. That is, workers receive a constant (steady state) wage irrespective of economic conditions. This extreme form of wage rigidity implies that over the business cycle match surpluses for the firm exist that would otherwise have accrued to workers under Nash-bargaining. These ‘excess’ surpluses will affect the present value calculations behind the return to creating a job. Consider the case of a positive technology shock (see Figure 6). In marked difference to the benchmark case employment increases on impact. This is due to the substantial (percentage) decline in the separation rate, which generates opposite movements in unemployment and vacancies over the entire adjustment path: in other words, a Beveridge curve.

Why does this happen? Recall that technology shocks can reduce employment in sticky price models because firms can increase production without the expense of hiring additional workers and therefore decide to adjust at their extensive margin. With perfect wage rigidity firms do not have to pay the ‘cost’ in form of shared surplus to maintain employment relationships. Since wages are persistent and above steady state, the excess surplus of not having to adjust payments to workers increases the asset value of each job, thereby stimulating employment. Firms adjust by lowering their job destruction margin, whereas job creation remains initially unaffected. As above, the model does not create negative comovement.

Our conjecture regarding the Beveridge curve is borne out by the simulation. The correlation between unemployment and vacancies is -0.80 with both shocks combined. This

²²See also Hall (1999, 2003) for discussion and further elaboration.

correlation can be reduced further (up to -0.99) by letting the share parameter η go towards one. The bigger the surplus going to the workers, the bigger are the opportunity costs to firms. The fact that firms do not have to adjust (since wages are rigid) increases the value of each job and unemployment falls even further. Wage rigidity and the bargaining power of workers are thus important factors in deriving a Beveridge curve, even with endogenous job destruction. In this setting firms decide endogenously to adjust their employment level via job destruction.

As far as other business cycle statistics are concerned, the rigid real wage model matches the volatility of labor market tightness, as well as employment, while labor productivity is not volatile enough. Job creation and destruction comove positively and are too volatile, the reasons for which we addressed above. On the other hand, the model delivers reasonable comovement of inflation with labor market variables. Naturally, a perfectly rigid wage is not consistent with the observed real wage volatility, nor other second moments. Setting $0 < \gamma < 1$ combined with proper choice of η in principle allows us to match the Beveridge curve facts. Varying γ shows, however, that a fairly high degree of rigidity is needed to replicate the Beveridge curve unless the sharing parameter η is large. By doing so we are able to generate a reasonable standard deviation for the real wage (0.42) without giving up too much in the other dimension.

An alternative way of modelling real wage rigidity has been suggested by Jeanne (1998). He assumes an essentially ad-hoc ‘real wage function’ which determines the real wage as a function of (aggregate) variables, such as labor supply and output. Jeanne’s formulation can be shown to be consistent with both standard neoclassical labor supply and the reduced-form of, for instance, efficiency wage models (e.g. Danthine and Donaldson, 1990). We have incorporated this specification assuming that the real wage accruing to each individual worker is the same and depends only on aggregate output:

$$w_{it} = w_t = \omega(y_t). \tag{37}$$

In a sense, this specification is equivalent to a time-varying wage norm with $\gamma = 0$ and no worker-specific considerations. The real wage is rigid when $\omega = (d \log w) / (d \log y)$ is small. Simulations we conducted reveal, however, that this specification delivers essentially the same results as our benchmark model with wage norms.

Since a perfectly rigid wage cannot explain real wage dynamics we also explore a lagged time-varying wage norm, $\bar{w}_t = w_{t-1}$, where current wages are set according to a weighted average of the notional (Nash-bargained) wage and last periods wage. $\gamma = 1$ is our benchmark model, while $\gamma = 0$ indexes the case of fully backward-looking wage-setting. The simulation results are similar to the model with a fully rigid wage. If $\gamma = 0$ firms cannot adjust wages contemporaneously to productivity shocks (see Figure 7). Since they anticipate wage increases in the future, the present value of a job, its opportunity value relative to the Nash bargaining solution rises. Firms take advantage of this by increasing employment; the separation falls, as does job destruction. As before, unemployment and vacancies move in the opposite direction, and the Beveridge curve obtains ($corr(u_t, v_t) = -0.68$).

It becomes clear that key to the Beveridge curve is the comparative lack of contemporaneous adjustment in the real wage. Down-weighting the backward-looking part (higher γ) preserves the negative correlation for even large values of γ .²³ For small γ , the model does a reasonable job in replicating the salient volatilities, although compared to the perfectly rigid case, unemployment and vacancies have the same standard deviation. The crucial shortcoming of all model variations discussed so far is the lack of negative correlation between job creation and destruction. The reason is that firms almost exclusively adjust via the endogenous separation rate, while job creation does not play a quantitatively significant role.

The impulse responses for inflation are qualitatively similar to those with flexible wages. For money shocks, not shown here, inflation rises by about a third less, but returns to steady state after a little more than 6 quarters. While inflation responds slightly less, the output response is higher. There is no humped-shaped response of output. On the other hand, for technology shocks, inflation falls more on impact and output rises more. In both cases, there is some amplification, but essentially no additional persistence arising from real wage rigidity. For the simulations, no degree of wage rigidity brings the model closer to the observed positive correlation between output and inflation, nor the negative correlation between real wages and inflation.

²³At $\gamma = 1$ the Beveridge curve disappears, however.

7 Conclusion

The model analysis has generated two important insights: frictions in the labor market alone do not generate enough real wage rigidity. In a standard New Keynesian model, labor market frictions and endogenous job destruction have counterfactual implications for the real wage, unemployment, and vacancy dynamics over the cycle. As the impulse response analysis shows, real wages mainly move inversely with labor productivity, and vacancies and unemployment positively. The model thus fails to produce a Beveridge curve.

Introducing extraneous real wage rigidity removes most of the shortcomings on the labor market side of the model. A larger effective share of the surplus accruing to firms increases their incentive to open vacancies in response to expansionary shocks. The feedback to the demand side of the model is weak, since real wage rigidity does not necessarily imply rigidity in real marginal cost, which matter for the dynamics of inflation. The reason is that, with frictions, the relevant measure of marginal cost is a real *dynamic* marginal cost, that enters the Phillips curve trade-off. It represents the marginal contribution of an additional unit of labor to the present discounted value of profits. This is distinctly different from current real wages. Nevertheless, extreme wage rigidity somewhat reduces the cyclicity in this measure, and hence inflation. This shows that adding labor market frictions alone does not necessarily improve the performance of the New Keynesian model along the desired margins.

While wage rigidity does help generate a Beveridge curve and increase the volatility of labor market variables, a shortcoming remains. Job creation and destruction in our model remain positively correlated, at odds with the data. We believe that the main reason for this shortcoming lies in the excess sensitivity of job destruction to desired changes in employment. There are two factors at work. One is that job destruction is costless, while job creation is not. The other is that vacancy creation only leads to an inflow of new worker one period hence, while job destruction is instantaneous. A quick fix for this problem would be to assume away the endogeneity of job destruction, and set it constant. Some parts of the literature take this path. While this buys tractability it does not shed light on the underlying reasons for labor market flows. Some factor must be at work that makes job destruction a costly margin relative to job creation, either directly, in terms of firing costs,

or indirectly, by some form of heterogeneity. As an example for the latter, new and old jobs could be different, so that it is beneficial to increase employment by hiring new workers on new jobs, rather than keeping more of the unproductive, old job. Introducing heterogeneity potentially generates more sluggish employment adjustment and hence contribute to the persistence of output and inflation. We leave this to future research.

Appendix

A Calculating the real wage

Inserting the corresponding values, and using the job creation condition, yields

$$w_{it} + \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left[(1 - \rho_{it+1}) \int_{\tilde{a}_{it+1}}^{\bar{a}} W_{it+1} \frac{f(a_i)}{1 - F(\tilde{a}_{it+1})} da_i + \rho_{t+1} U_{t+1} \right] \quad (38)$$

$$-b - \beta E_t \left(\frac{\lambda_t}{\lambda_{t+1}} \right) \left[\theta_t q(\theta_t) (1 - \rho_{t+1}) \int_{\tilde{a}_{it+1}}^{\bar{a}} W_{it+1} \frac{f(a_i)}{1 - F(\tilde{a}_{it+1})} da_i + (1 - \theta_t q(\theta_t) (1 - \rho_{t+1})) U_{t+1} \right] \quad (39)$$

$$= \frac{\eta}{1 - \eta} \left(\epsilon_t A_t a_{it} - w_{it} + \beta E_t \left(\frac{\lambda_t}{\lambda_{t+1}} \right) \left[(1 - \rho_{t+1}) \int_{\tilde{a}_{it+1}}^{\bar{a}} J_{it+1} \frac{f(a_i)}{1 - F(\tilde{a}_{it+1})} da_i \right] \right) \quad (40)$$

$$w_{it} - b + \beta E_t \left(\frac{\lambda_t}{\lambda_{t+1}} \right) \left[\begin{aligned} &(1 - \rho_{t+1}) \int_{\tilde{a}_{it+1}}^{\bar{a}} W_{it+1} \frac{f(a_i)}{1 - F(\tilde{a}_{it+1})} da_i + \rho_{t+1} U_{t+1} \\ & - \theta_t q(\theta_t) (1 - \rho_{t+1}) \int_{\tilde{a}_{it+1}}^{\bar{a}} W_{it+1} \frac{f(a_i)}{1 - F(\tilde{a}_{it+1})} da_i \\ & - (1 - \theta_t q(\theta_t) (1 - \rho_{t+1})) U_{t+1} \end{aligned} \right] \quad (41)$$

$$= \frac{\eta}{1 - \eta} (\epsilon_t A_t a_{it} - w_{it}) + \frac{\eta}{1 - \eta} \frac{c^h}{q(\theta_t)} \quad (42)$$

One should note that from here, one arrives at the real wage expression in the text by recognizing that the term in the square brackets collapses to $1 - \theta_t q(\theta_t)$ times the expression for $c^h/q(\theta_t)$ derived in the text. The values of employment and unemployment can be substituted by virtue of the Nash bargaining assumption, $W - U = \frac{\eta}{1 - \eta} J$.

B (Linearized) Equation System

1. Euler equation:

$$\begin{aligned} y_t^{-\sigma} &= \beta R_t E_t \left[\frac{1}{\pi_{t+1}} y_{t+1}^{-\sigma} \right] \\ \sigma E_t \hat{y}_{t+1} &= \sigma \hat{y}_t + \hat{R}_t - E_t \hat{\pi}_{t+1} \end{aligned}$$

2. Real money demand:

$$\begin{aligned} m_t &= \chi \frac{R_t}{R_t - 1} y_t^\sigma \\ \hat{m}_t &= -\frac{1}{R - 1} \hat{R}_t + \sigma \hat{y}_t \end{aligned}$$

3. Number of unemployed and searching workers:

$$\begin{aligned} u_t &= 1 - n_t \\ u \hat{u}_t &= -n \hat{n}_t \end{aligned}$$

4. Labor market tightness:

$$\begin{aligned}\theta_t &= \frac{v_t}{u_t} \\ \hat{\theta}_t &= \hat{v}_t - \hat{u}_t\end{aligned}$$

5. Employment:

$$\begin{aligned}n_{t+1} &= (1 - \rho_{t+1}) \left(n_t + m v_t^{1-\xi} u_t^\xi \right) \\ \hat{n}_{t+1} + \frac{\rho}{1-\rho} \hat{\rho}_{t+1} &= (1 - \rho) \hat{n}_t + \rho(1 - \xi) \hat{v}_t + \rho \xi \hat{u}_t\end{aligned}$$

6. Separation rate:

$$\begin{aligned}\rho_t &= \rho^x + (1 - \rho^x) \rho_t^n \\ \hat{\rho}_t &= \frac{(1 - \rho^x) \rho^n}{\rho} \hat{\rho}_t^n\end{aligned}$$

7. Endogenous separation rate:

$$\begin{aligned}\rho_t^n &= F(\tilde{a}_t) \\ \hat{\rho}_t^n &= \frac{\partial F(\tilde{a})}{\partial \tilde{a}} \frac{\tilde{a}}{F(\tilde{a})} \hat{\tilde{a}}_t = \frac{\tilde{a} f(\tilde{a})}{F(\tilde{a})} \hat{\tilde{a}}_t\end{aligned}$$

8. Match destruction threshold:

$$\begin{aligned}\tilde{a}_t &= \left(1 - \frac{1}{\varepsilon_t}\right)^{-1} A_t^{-1} \left(b + \frac{c^h}{1-\eta} \left(\eta \theta_t - \frac{1}{m} \theta_t^\xi \right) \right) \\ \hat{\tilde{a}}_t &= -\frac{1}{\nu-1} \hat{\varepsilon}_t - \hat{A}_t + \frac{\frac{c^h}{1-\eta} \left(\eta \theta - \frac{\xi}{m} \theta^\xi \right)}{b + \frac{c^h}{1-\eta} \left(\eta \theta - \frac{1}{m} \theta^\xi \right)} \hat{\theta}_t\end{aligned}$$

9. Inflation dynamics:

$$\begin{aligned}\varepsilon_t &= \nu \left(1 - \psi(\pi_t - \pi) \pi_t + \beta E_t \left(\frac{y_{t+1}}{y_t} \right)^{-\sigma} \psi(\pi_{t+1} - \pi) \pi_{t+1} \frac{y_{t+1}}{y_t} \right)^{-1} \\ \hat{\varepsilon}_t &= \varphi \pi^2 \hat{\pi}_t - \beta \varphi \pi^2 E_t \hat{\pi}_{t+1}\end{aligned}$$

10. Differential equation in labor market tightness ($X = (1 - \eta) \frac{\nu-1}{\nu} A H(\tilde{a}) - c \eta \theta - (1 - \eta) b + \frac{c}{m} \theta^\xi$):

$$\begin{aligned}\frac{c^h}{m} \theta_t^\xi &= \beta E_t \left(\frac{y_{t+1}}{y_t} \right)^{-\sigma} (1 - \rho_{t+1}) \times \\ &\times \left[(1 - \eta) \left(1 - \frac{1}{\varepsilon_{t+1}} \right) A_{t+1} H(\tilde{a}_{t+1}) - c^h \eta \theta_{t+1} - (1 - \eta) b + \frac{c^h}{m} \theta_{t+1}^\xi \right]\end{aligned}$$

$$\begin{aligned}\xi\widehat{\theta}_t - \sigma\widehat{y}_t &= \left(\frac{c^h\xi}{m}\theta^\xi - \eta c\theta \right) X^{-1}E_t\widehat{\theta}_{t+1} + \frac{(1-\eta)A\nu-1}{X}\frac{\partial H(\tilde{a})}{\partial \tilde{a}}\tilde{a}E_t\widehat{a}_{t+1} \\ &+ \frac{(1-\eta)AH(\tilde{a})\nu-1}{X}\frac{\nu-1}{\nu}E_t\widehat{A}_{t+1} + \frac{(1-\eta)AH(\tilde{a})}{\nu X}E_t\widehat{\varepsilon}_{t+1} \\ &- \frac{\rho}{1-\rho}E_t\widehat{\rho}_{t+1} - \sigma E_t\widehat{y}_{t+1}\end{aligned}$$

11. Job destruction rate:

$$\begin{aligned}jdr_t &= \rho_t - \rho_x \\ \widehat{jdr}_t &= \frac{\rho}{\rho - \rho_x}\widehat{\rho}_t\end{aligned}$$

12. Job creation rate:

$$\begin{aligned}jcr_t &= (1 - \rho_t)\frac{mv_{t-1}^{1-\xi}u_{t-1}^\xi}{n_{t-1}} - \rho_x, \\ \frac{\rho - \rho_x}{\rho}\widehat{jcr}_t + \frac{\rho}{1-\rho}\widehat{\rho}_t &= \widehat{n}_{t-1} + \xi\widehat{u}_{t-1} + (1 - \xi)\widehat{v}_{t-1}.\end{aligned}$$

13. Real wage:

$$w\widehat{w}_t = \eta c\theta\widehat{\theta}_t + \eta\frac{\nu-1}{\nu}AH(\tilde{a})\widehat{A}_t + \frac{\eta AH(\tilde{a})}{\nu}\widehat{\varepsilon}_t + \eta\frac{\nu-1}{\nu}A\frac{\partial H(\tilde{a})}{\partial \tilde{a}}\tilde{a}\widehat{a}_t$$

14. Aggregate income:

$$\begin{aligned}y_t &= n_t A_t H(\tilde{a}_t) - c^h v_t \\ \widehat{y}_t &= \frac{Q}{y} \left[\widehat{n}_t + \widehat{A}_t + \frac{\partial H(\tilde{a})}{\partial \tilde{a}} \frac{\tilde{a}}{H(\tilde{a})} \widehat{a}_t \right] - \frac{c^h v}{y} \widehat{v}_t\end{aligned}$$

15. Law of motion for real money balances:

$$\widehat{m}_t = \widehat{m}_{t-1} + \widehat{\phi}_t - \widehat{\pi}_t$$

16. Growth rate of (nominal) money supply:

$$\widehat{\phi}_t = \rho_m \widehat{\phi}_{t-1} + \epsilon_{m,t}$$

17. Productivity shock:

$$\widehat{A}_t = \rho_A \widehat{A}_{t-1} + \epsilon_{A,t}$$

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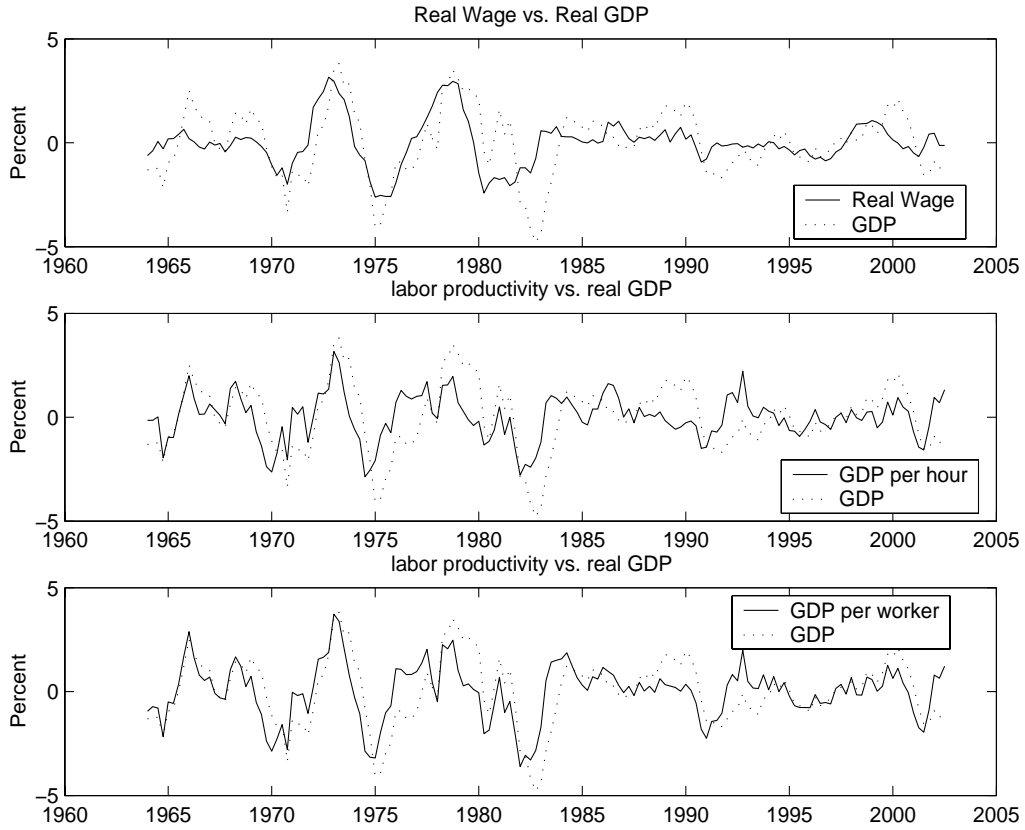


Figure 1: Real Wages and Labor Productivity over the Business Cycle

Notes: The table reports summary statistics for selected aggregate variables over the period 1964:1 to 2002:3. All series have been logged and detrended using an HP-filter.

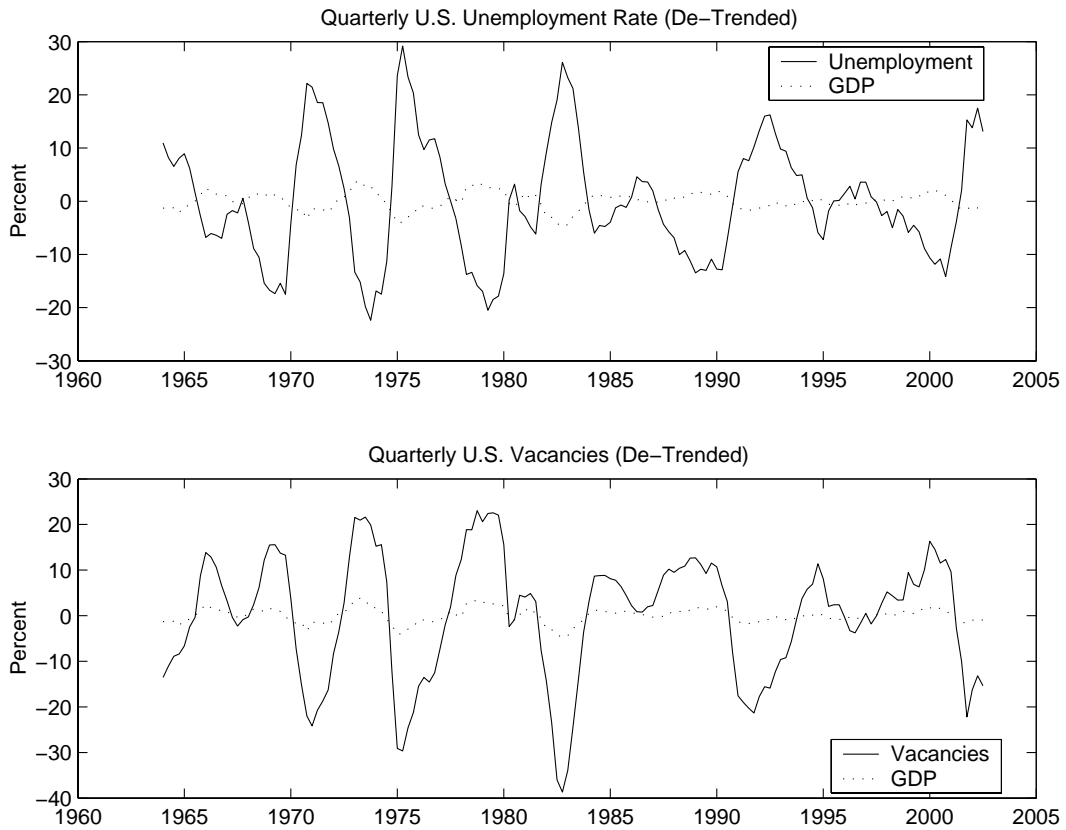


Figure 2: Vacancies and Unemployment

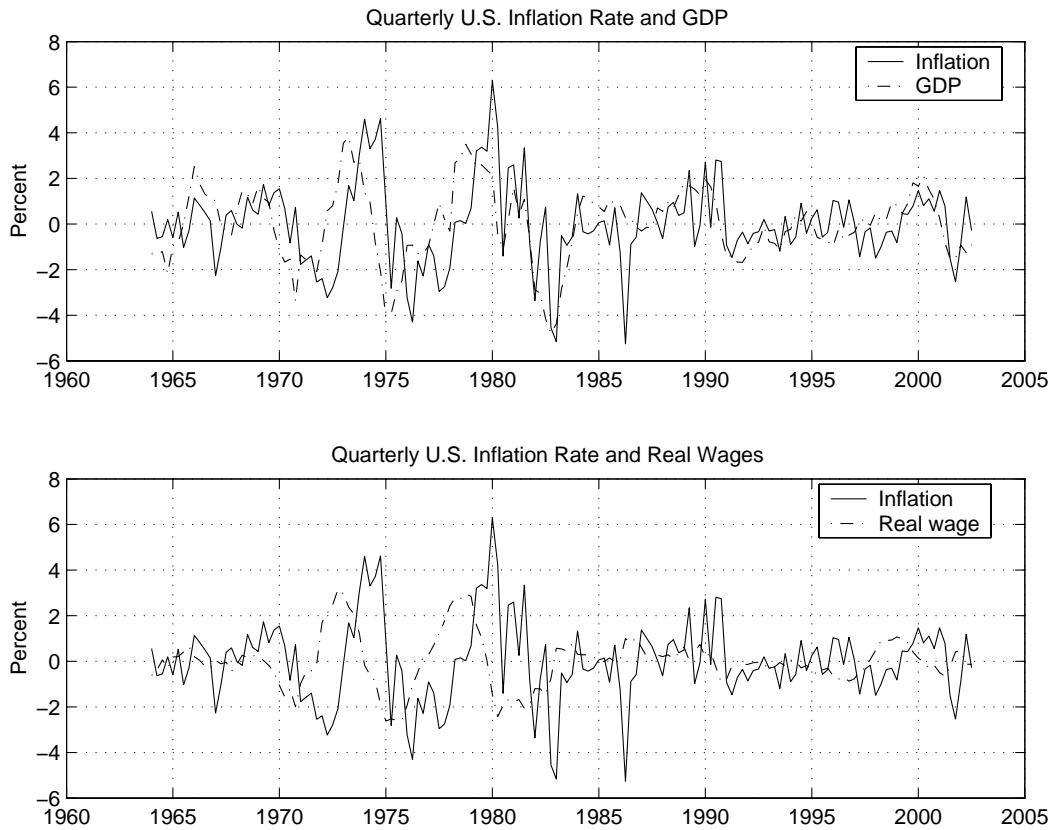


Figure 3: Inflation and Macroeconomic Aggregates

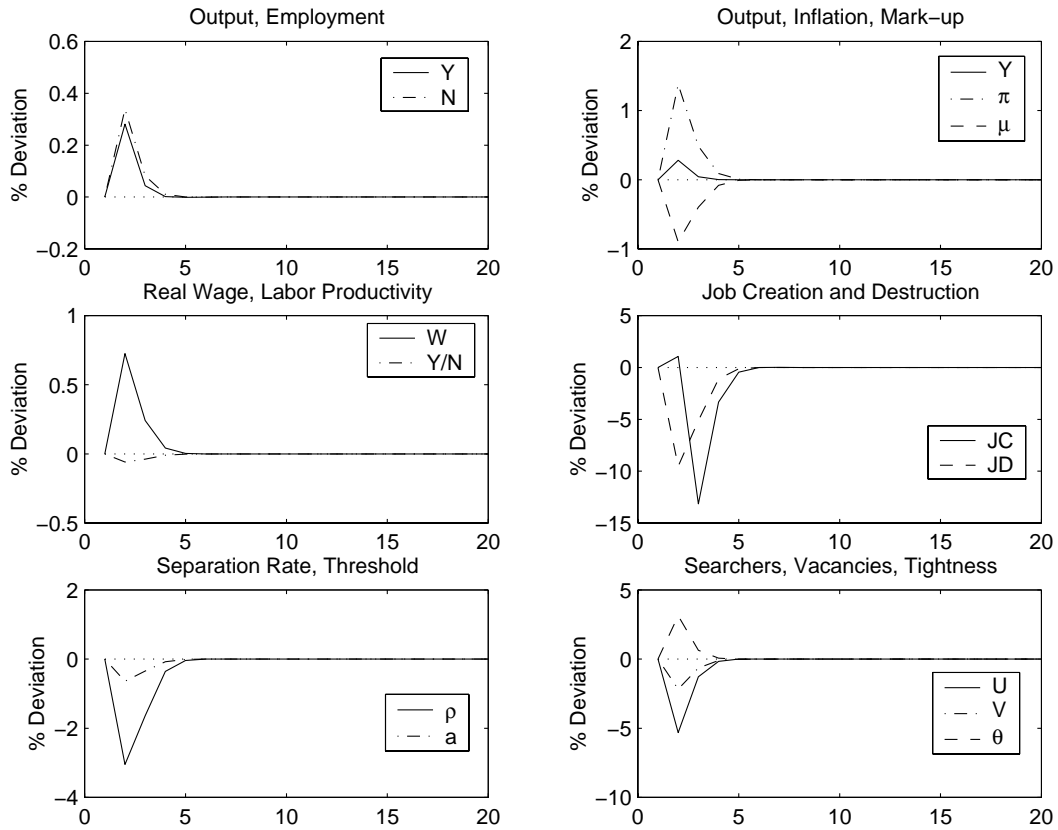


Figure 4: Impulse Response Functions to a Unit Monetary Shock

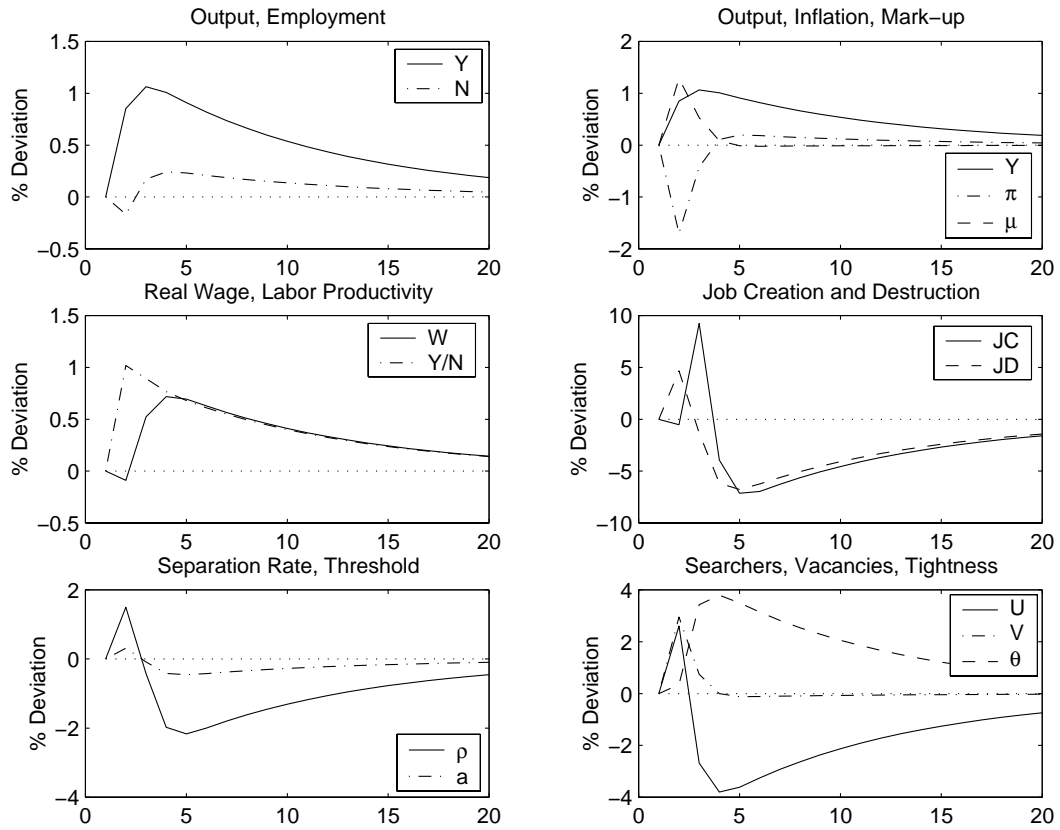


Figure 5: Impulse Response Functions to a Unit Productivity Shock

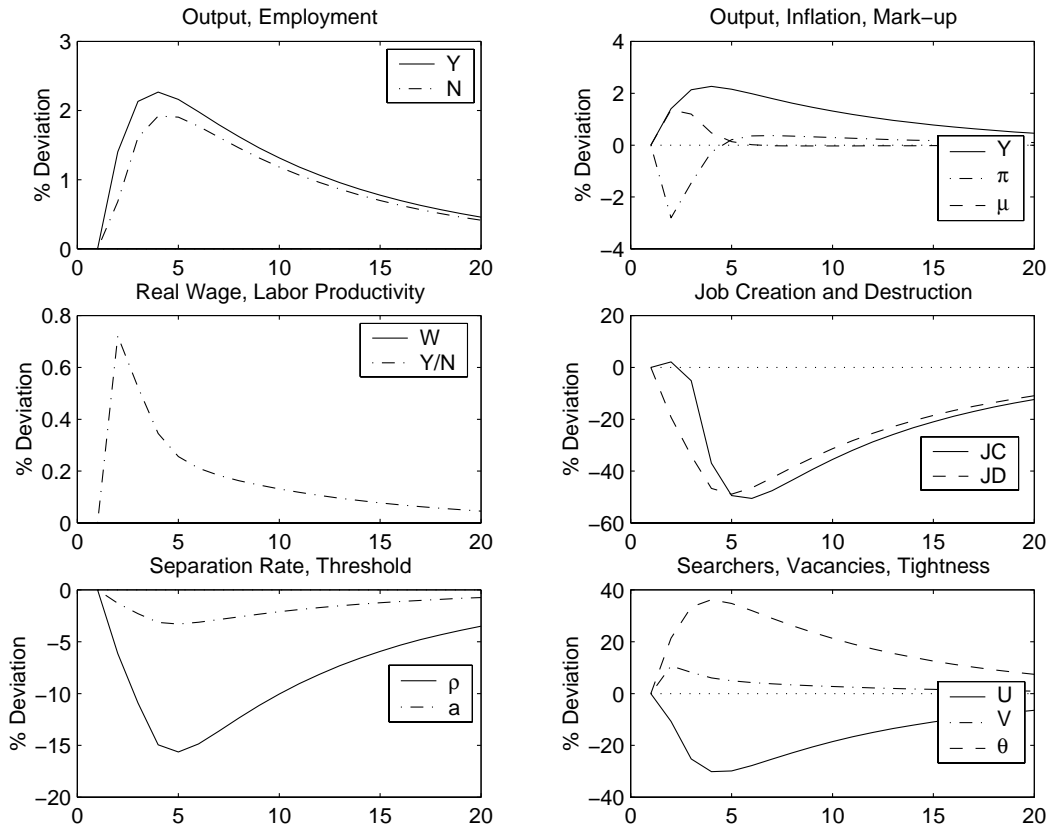


Figure 6: Impulse Response Function to a Productivity Shock under Wage Rigidity

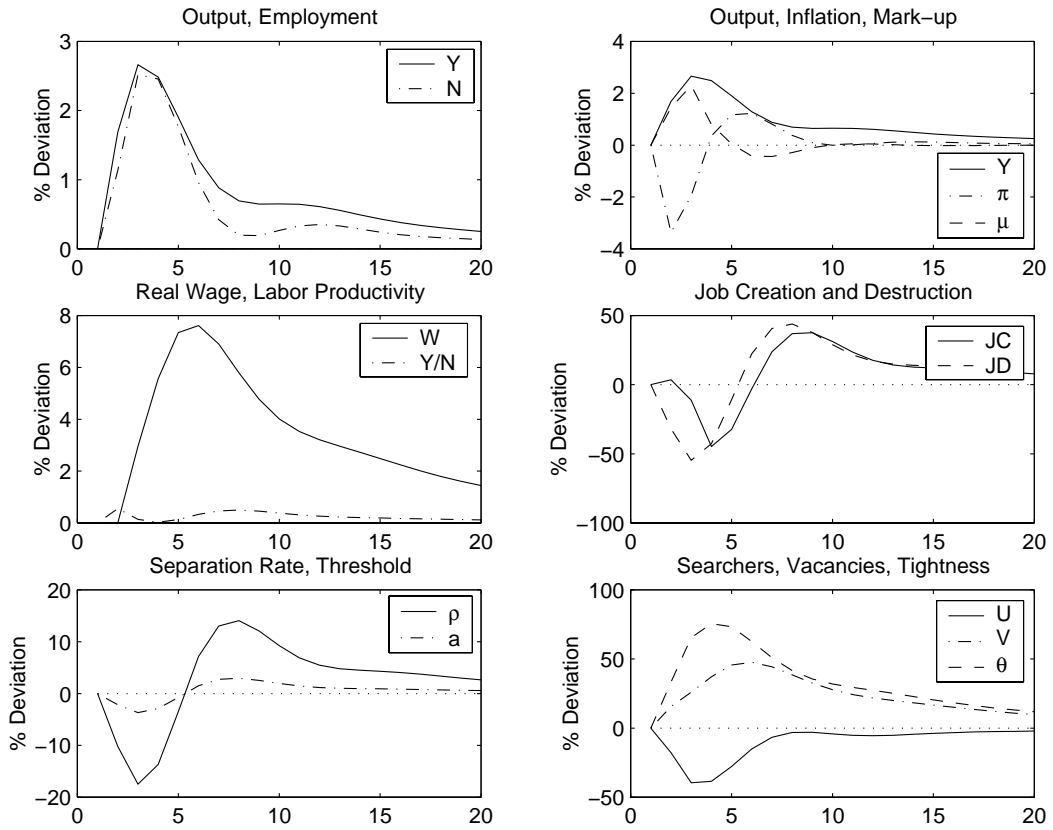


Figure 7: Impulse Response Functions to a Productivity Shock under Lagged Wage Norm

Table 1: U.S. Business Cycle Statistics

	Y	π	W	N	$\frac{Y}{N}$	U	V	θ
Standard Deviation								
	1.62	1.11	0.69	0.81	0.83	6.90	8.27	14.96
First Order Autocorrelation								
	0.87	0.56	0.91	0.94	0.79	0.91	0.92	0.92
Cross-Correlations								
	Y	π	W	N	$\frac{Y}{N}$	U	V	θ
Y	1	0.39	0.57	0.82	0.69	0.87	0.92	0.91
π	-	1	-0.19	0.60	-0.09	-0.53	0.46	0.50
W	-	-	1	0.27	0.66	-0.42	0.51	0.47
N	-	-	-	1	0.16	-0.93	0.88	0.91
$\frac{Y}{N}$	-	-	-	-	1	-0.34	0.49	0.43
U	-	-	-	-	-	1	-0.95	-0.98
V	-	-	-	-	-	-	1	0.99
θ	-	-	-	-	-	-	-	1

Table 2: Conditional Standard Deviations

	Y	π	W	N	$\frac{Y}{N}$	U	V	θ
U.S. Data	1.62	1.11	0.69	0.81	0.83	6.90	1.94	14.96
Benchmark Model: $\varphi = 10$								
Technology	1.57	0.74	0.68	0.24	0.82	3.72	1.24	3.53
Money	0.18	5.14	2.69	1.23	0.24	19.21	7.95	11.28
Both	1.62	0.94	0.74	0.27	0.82	4.28	1.53	3.73
High Price Rigidity: $\varphi = 185$								
Technology	1.14	0.42	1.82	0.69	1.29	10.81	2.70	8.39
Money	0.61	0.80	3.62	1.32	0.31	20.64	3.57	17.08
Both	1.25	0.54	2.39	0.89	1.16	13.91	2.98	11.16

Notes: The table reports summary statistics for selected aggregate variables. All series have been logged and detrended using an HP-filter.

Table 3: Conditional Correlations

Benchmark Cross-Correlations								
	Y	π	W	N	$\frac{Y}{N}$	U	V	θ
Y	1	-0.09	0.86	0.72	0.97	-0.72	0.21	0.91
π	-	1	0.43	0.61	-0.31	-0.61	-0.99	0.30
W	-	-	1	0.97	0.71	-0.97	-0.31	0.99
N	-	-	-	1	0.54	-1.00	-0.51	0.93
Y/N	-	-	-	-	1	-0.54	0.43	0.80
U	-	-	-	-	-	1	0.51	-0.93
V	-	-	-	-	-	-	1	-0.18
θ	-	-	-	-	-	-	-	1

Benchmark First Order Autocorrelations								
	Y	π	W	N	$\frac{Y}{N}$	U	V	θ
	0.92	0.28	0.82	0.65	0.87	0.65	0.25	0.85

Notes: The table reports summary statistics for selected aggregate variables All series have been logged and detrended using an HP-filter.

Table 4: Selected Second Moments for Alternative Models

	Standard Deviations							
	Y	π	W	N	$\frac{Y}{N}$	U	V	θ
Constant Wage Norm: $\gamma = 0$	3.51	0.62	0.00	0.86	0.18	13.43	3.08	16.01
Lagged Wage Norm: $\gamma = 0$	3.04	0.95	3.49	0.88	0.24	13.88	22.98	34.04
Lagged Wage Norm: $\gamma = 0.5$	1.67	0.92	1.24	0.32	0.76	5.04	5.27	9.36
	Cross Correlations							
	$\rho_{Y,\pi}$	$\rho_{Y,W}$	$\rho_{Y,\frac{Y}{N}}$	$\rho_{\pi,W}$	$\rho_{\pi,U}$	$\rho_{U,W}$	$\rho_{U,V}$	$\rho_{W,\frac{Y}{N}}$
Constant Wage Norm: $\gamma = 0$	-0.12	-	0.79	-	-0.01	-	-0.79	-
Lagged Wage Norm: $\gamma = 0$	-0.20	0.73	0.54	0.34	0.17	-0.62	-0.68	0.71
Lagged Wage Norm: $\gamma = 0.5$	-0.10	0.85	0.96	0.30	-0.41	-0.78	-0.63	0.78