Efficiency Wage and Labor-Market Business Cycles: A New Keynesian Analysis

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Abstract

This paper examines the cyclical implications of real wage rigidity for labor market and inflation dynamics in a New Keynesian model under the Mortensen-Pissarides (1994) search frictions. Shapiro and Stiglitz's (1984) efficiency wage framework is incorporated into the otherwise ordinary Nash bargaining wage determination, thereby generating downward wage rigidity over business cycles. Key findings are: first, real wage rigidity induced by the efficiency wage scheme significantly amplifies the volatilities of labor market quantities and dampens real wage fluctuations. Thus, it can address Shimer's (2005) volatility puzzle and explain the observed weak cyclicality of real wages. Second, introducing downward wage rigidity can generate the asymmetric dynamics of inflation as well as labor market quantities observed in the data; the model exhibits a significantly left-skewed distribution for employment and vacancy but a highly right-skewed distribution for inflation along the business cycles.

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1. Introduction

This paper studies the cyclical implications of real wage rigidity for labor market and inflation dynamics in a New Keynesian model combined with the Mortensen-Pissarides (1994) labor market frictions. Studying the link between wage rigidities and business cycles is not new at all. There are two main lines of studies distinguished by the workhorse model used and the main objective of study.

The first is a pure real labor search model. Shimer (2005) argued that the standard equilibrium search model of unemployment explains much less than 10% of the observed volatility in the U.S. data given reasonable model specification and parameter values (the volatility puzzle). A principal reason for this lack of amplification, he argues, is that the wage, set as an outcome of Nash bargaining, responds so procyclically that it offsets almost all of the effects of productivity shocks. In a natural way, a number of studies have attempted to offer a solution to the volatility puzzle by introducing wage rigidity. For example, Hall (2005) shows that a fixed wage, justified by the social norm functioning as a focal point for the outcome of wage bargaining, can generate volatile fluctuations in unemployment and vacancies of an order of magnitude comparable to those in the data. Gertler and Trigari (2009) and Hall and Milgrom (2008) also introduced wage rigidity (from a staggered wage setting or as the outcome of a strategic bargaining game) and found that it can substantially amplify fluctuations in unemployment and vacancies. Costain and Reiter (2008) have assessed that sticky wages seem to be a potentially promising way of improving the model's fit, particularly in terms of the relative volatility of unemployment to output.

The second is a variant of the New Keynesian (NK) model. It is well recognized that the standard New Keynesian model cannot explain the observed inflation inertia and the persistent effects of monetary shocks unless there exists a sufficient degree of rigidity in real marginal cost. A most promising source is rigid real wage. Consequently, over the past few years, a growing number of studies (Christiano et al., 2005; Christoffel & Linzert, 2005, 2010; Trigari, 2006; Blanchard & Gali, 2007; Christoffel et al., 2009) have attempted to rectify the source and degree of inflation inertia by combining this wage rigidity into the New Keynesian model with or without labor market frictions. For example, Blanchard and Gali (2007) theoretically show how the presence of real wage rigidities in the standard NK model becomes a source of inflation inertia. Trigari (2006) shows that under an alternative bargaining framework, a direct channel from wages to inflation exists, so that the level of wages and their stickiness can play a crucial role for inflation dynamics.

In fact, wage rigidity has very important implications for explaining both inflation and labor market dynamics; rigid wages affect the incentive to post vacancies and create new jobs as well as the elasticity of marginal cost with respect to output change, thereby accounting for inflation inertia and the persistent effects of monetary shocks. Nonetheless, few studies investigate the cyclical implications of wage rigidity in the combined arrangement of those two afore-mentioned types of models. Moreover, most of those studies mentioned above have introduced wage rigidities in more of an ad hoc manner and therefore lack any proper micro-foundation. In most cases, rigid wages are embedded in a Calvo (1983) or Taylor (1980) type staggered manner. Sometimes, wages are perfectly fixed at a constant level, justified by the social norm or the outcome of strategic bargaining games. Another critical problem in those wage arrangements is that most of them are characterized as symmetric wage rigidities, so that they cannot reflect the observed downward rigidity in wage adjustment as documented in many previous empirical studies.[1] This leads to the counterfactual symmetry of business cycle fluctuations in the model economy.

Among only a few studies examining the cyclical implications of wage rigidity for both inflation and labor market dynamics, Krause and Lubik (2007) incorporate real wage rigidity (partial adjustment form) into a New Keynesian model with search and matching frictions. They found that introducing wage rigidity improves the behavior of the labor market, as the volatility of vacancies and employment is amplified and the Beveridge curve can be replicated, but it cannot explain inflation inertia and the persistent effects of monetary shocks. Faccini, Millard and Zanetti (2011) also obtain similar results. Nonetheless, in both studies, the wage rigidities are introduced in an ad hoc manner and are also a form of symmetric rigidity, since the authors pay little attention to how well the model can address the cyclical asymmetry observed in the data. In contrast, Abbritti and Fahr (2011) mainly focus on cyclical asymmetry. When they embed downward wage rigidity (asymmetric wage adjustment cost) into a NK model with search frictions, they find that the presence of downward rigidity strongly improves the fit of the model to the observed skewness of labor market quantities (negative) and wage or price inflation (positive). However, they do not attempt to resolve the volatility puzzle or explain inflation inertia, and their framework of downward wage rigidity is still not micro-founded.

We develop a variant of the New Keynesian framework in the Mortensen-Pissarides frictional labor market by incorporating the real wage rigidity based on the efficiency wage framework of Shapiro and Stiglitz (1984). As in the recent New Keynesian literature, the model economy is characterized by monopolistic competition and price rigidity, plus the frictional labor market. A new feature is that Shapiro and Stiglitz's efficiency wage framework is incorporated into the otherwise ordinary Nash bargaining wage determination featured in the standard labor matching model. Since firms have imperfect information about a worker's effort, they must pay wages satisfying a no-shirking condition (NSC), which places a lower bound on the worker's match surplus (downward wage rigidity). Thus, by dampening real wage fluctuations, this can possibly amplify fluctuations in vacancy postings and hiring as argued by Hall (2005) and Shimer (2005). Furthermore, the downwardness of wage rigidity may well explain the cyclical asymmetry in labor market and inflation dynamics; in recessions, the downward rigidity may force firms to pay workers a relatively larger share of the match surplus, making profits more procyclical than in booms. Thus, negative shocks are mainly absorbed through a stronger decline in vacancy postings and employment rather than through wage and price adjustment, while in booms real wages and inflation increase more flexibly, limiting the increase of vacancy postings and employment.

The key economic results of the model are summarized as follows. First, real wage rigidity induced by the efficiency wage scheme significantly amplifies the volatilities of labor market quantities and dampens real wage fluctuation. Thus, it can address the volatility puzzle and explain the observed weak cyclicality of real wages. Second, downward real wage rigidity can generate the asymmetric dynamics of inflation as well as labor quantities. Indeed, when we impose a strict (fixed) limit on downward wage adjustment, introducing the efficiency wage remarkably increases the degree of skewness, even beyond the level observed in the data. Therefore, the model can resolve the counterfactual symmetry in the standard business cycle model. Finally, however, the real wage rigidity does not add much in terms of inflation inertia and the persistence of the effects of monetary shocks, as documented by Krause and Lubik (2007). The wage rigidity dampens fluctuations in the real unit labor cost, a main component of a firm's marginal cost. However, its dampening effect is fully offset by more volatile variations in job posting costs, the other component of real marginal cost.

Our main contributions are two-fold. First, by incorporating moral hazard into an otherwise standard New Keynesian model with labor search frictions, we provide a rich micro-foundation for endogenous downward wage rigidity. Second, the model matches the data well in terms of the volatility in labor market fluctuations and, by virtue of introducing downward rigidity, the observed asymmetry in inflation as well as labor market variables.

Among the equilibrium labor search models, the paper closest to ours is Costain and Jansen (2010). By embedding Shapiro and Stiglitz's shirking model into the standard equilibrium search model, they endogenize the otherwise ad hoc wage rigidity. However, the difference between their paper and ours is that their model introduces endogenous separation and is purely real, abstracting from price and money. Moreover, it fails to amplify the cyclical fluctuations of labor market variables; rather, it worsens the volatility puzzle, not to mention that it cannot generate the cyclical asymmetry observed in the labor market data.

The remainder of the paper is organized as follows. To motivate the analysis, Section 2 presents some stylized business cycle facts, paying special attention to the volatility and asymmetry of labor market variables and inflation. Section 3 develops the model. Section 4 describes the calibration of the model and reports the main findings. Some supporting evidences will also be presented. Section 5 concludes.

2. Some Stylized Facts about Business Cycle Dynamics

To document some stylized facts about business cycles and compare them with model moments, we use real data from 1964Q1~2011Q4 obtained from various sources. The employment series (n) is total private employment from the Current Employment Survey (CES). For a fair comparison, the unemployment rate (u) is measured as the ratio of non-employment to the population over 16, since there exists no out-of-labor-force in the model. Vacancy (v) is measured by the Help-Wanted Advertising index compiled by the Conference Board. The inflation series (π) is quarterly growth rates of the GDP deflator (seasonally adjusted). The nominal interest rate (r) is measured by the effective federal funds rate. Real wages (w) are measured by (total private) average weekly earnings from the CES divided by the GDP deflator. The output series (y) is annualized real GDP in chained 2005 dollars compiled by the Bureau of Economic Analysis (BEA). The empirical counterpart of real consumption (c) in the model is measured as the sum of real private consumption expenditure and gross private domestic investment (both from the BEA), since there is no physical capital and investment in the model.

[Insert Table 1 Here.]

Table 1 summarizes some selected moments of major macroeconomic variables in the U.S. In the context of the motivation of this paper, two things are worth noting: higher volatilities of labor market quantities relative to output and prominent asymmetries in labor quantities and inflation. Employment and vacancy posting are highly procyclical, and the volatility of employment is almost comparable to that of output; the relative volatility is close to unity. Moreover, vacancy posting is much more volatile than output. Shimer (2005) focused on the standard equilibrium search model's inability to explain this striking volatility of employment and vacancy. Contrarily, real wage is only weakly procyclical, and its volatility is much lower than that of output, as is well documented in previous empirical studies. These observations motivate us to introduce real wage rigidity as an additional amplifying mechanism, as suggested by Hall (2005) and Gertler and Trigari (2009).

[Insert Figure 1 Here.]

Second, as documented for major developed countries in Abbritti and Fahr (2011),[2] the asymmetries in the main macroeconomic variables over the business cycle appear to be a key structural feature of the U.S. economy; employment and vacancy posting are strongly negatively skewed, hence occasionally falling sharply and usually growing in a steady manner. Contrarily, the inflation rate of the GDP deflator is highly positively skewed. This positive skewness implies sharp rises on rare occasions and downward rigidity of price adjustment. Positive skewness is also the case for real wages, though its magnitude is much smaller.

To effectively visualize the cyclical distribution of the main variables, Figure 1 plots the kernel density estimates of employment (n), vacancy (v), and inflation (π) using a Gaussian kernel with optimal bandwidth. Consistent with Table 1, it exhibits a significantly left-skewed distribution for employment and vacancy but a highly right-skewed distribution for inflation with a long right tail. This observation motivates us to explore to what extent introducing downward wage rigidity can generate cyclical asymmetries similar to the ones observed in the data.

3. Model Economy

3.1. The Environment

There is a unit mass of identical households in the economy. Each member in a representative household can be either employed or unemployed. Firms in the production sector are monopolistically competitive, produce a differentiated good using labor as only input, and face a price adjustment cost à la Rotemberg (1982).

The labor market is characterized by a NK variant of Mortensen and Pissarides' (1994) matching model, and the Shapiro and Stiglitz efficiency wage framework (1984) is incorporated into the otherwise ordinary Nash bargaining process. As we will show later, this implies that, given the realized productivity shocks, when the Nash bargaining wage is above a minimum efficiency wage level, firms may pay the bargain wage; otherwise, firms should pay the efficiency wage in order to maintain incentive compatibility so that workers will not shirk. In equilibrium, no workers actually shirk because the incentive compatibility condition always holds.

The timing of events in the model economy is as follows:

1. Aggregate productivity shocks are realized and known by every agent.
2. Firms post vacancies and new matches occur accordingly.

3. Exogenous separation (quitting) or the firing of (detected) shirking workers occurs.
4. Firms and workers bargain with each other over contingent real wages.
5. Firms set the price of their products
6. Production takes place; that is, workers determine whether to shirk or not, and idiosyncratic productivity shocks are realized.
7. Produced consumer goods and government bonds are traded in the product and asset market, respectively.

Note that the realized idiosyncratic shocks are unverifiable between firms and workers; both agents only observe ex post total output, conditional on known aggregate productivity and technology.[3] Thus, there is no ex ante heterogeneity; every worker is treated equally in the bargaining and production process. We also assume that the level of unobserved effort and the idiosyncratic shocks are unverifiable by a third party, so the worker-firm relationship must be sustained by a bilateral incentive-compatible contract instead of by a contract enforceable by any third party, e.g., the court.

In addition to the assumption of unobservable effort, this ex ante homogeneity is essential in order to make workers' threat to shirk credible. For example, if both aggregate and idiosyncratic productivities are verifiable, given a firm's technology, firms can infer the level of effort that workers have exerted so that firms can punish any shirking worker. While in Shapiro and Stiglitz (1984) the information asymmetry is directly "assumed," here it is derived from the firm's lack of information about idiosyncratic productivity.

Another important implication of this ex ante homogeneity is that endogenous separation can be justifiably ruled out in the model. Since a production decision is based only on the ex ante "expected" surplus, as long as both the firm's expected net surplus and the worker's expected utilities are positive, the match is maintained. Thus, even if endogenous separation is allowed, it does not occur at all in any non-trivial equilibrium of the model. This absence of endogenous separation is one of the main differences from Costain and Jansen (2010).

3.2. Household

A representative household is made up of a continuum of members with a unit mass. As in Merz (1995) and Andolfatto (1996), household members fully pool their income and consumption. Under the assumption of perfect insurance, consumption is equalized across household members at a given period. This is equivalent to assuming the existence of one large household, of which each member intratemporally acts like a risk-neutral agent.

The household maximizes its expected lifetime utility,

$$E_0[\sum_{t=0}^{\infty}\beta^t(\frac{c_t^{1-\sigma}}{1-\sigma}-e_t)] \tag{1}$$

subject to the sequence of the real budget constraint,

$$c_t+\frac{b_t}{p_t}=\bar{w}_t n_t+w^u(1-n_t)+\frac{\Theta_t}{p_t}-\frac{\tau_t}{p_t}+R_{t-1}\frac{b_{t-1}}{p_t} \tag{2}$$

Here, e_t is the disutility from a worker's effort, b_t is a one-period nominal bond, $\bar{w}_t$ is an expected wage, n_t is a fraction of working household members, w^u is the value from non-market activity, Θ_t is the dividend from the profits of household-owned firms, τ_t is a lump-sum tax and R_t is the gross nominal interest rate. A worker may either choose to work, i.e., to incur the disutility from his efforts $e_t=\bar{e}\lambda_t$, or to shirk $e_t=0$, where λ_t denotes the marginal utility of consumption.

Note that due to the presence of perfect income sharing, an individual's budget constraint does not depend on his employment history and current status. The intertemporal optimality condition yields the standard Euler equation.

$$\frac{1}{c_t}=\beta R_t E_t(\frac{1}{c_{t+1}\pi_{t+1}}) \tag{3}$$

where $\pi_{t+1}=p_{t+1}/p_t$.

3.3. Firms

We assume a continuum of firms indexed by $i\in[0,1]$, each producing differentiated consumption goods. Each firm creates a continuum of jobs summing up to measure one, and the jobs are either vacant or filled by workers. Each job in a firm has access to a constant-returns production technology. The technology of a representative filled job j in firm i is characterized by $y_{it}^j=a_t x_{it}^j n_{it}^j e_{it}^j$, where n_{it}^j is the number of workers hired by job j of firm i, and a_t is an aggregate productivity shock, while x_{it}^j is an i.i.d idiosyncratic (job-specific) productivity shock. Each shock evolves according to:

$$\ln a_t = (1-\rho_a)\ln a + \rho_a \ln a_{t-1} + \varepsilon_t^a, \varepsilon_t^a : N(0,\sigma_a^2), \quad \ln x_{it}^j : N(0,\sigma_x^2)$$

Note that if the worker chooses to shirk, $e_{it}^j = \underline{e}$; otherwise, $e_{it}^j = e^*$. Here, we assume that $\underline{e} > 0$ is so low that no firms would let workers shirk in any non-trivial equilibrium. Thus, to avoid a trivial equilibrium where workers choose to shirk ($e_{it}^j = \underline{e}$), firms are supposed to pay at least above a certain level of the efficiency wage. In the symmetric equilibrium over jobs, by the law of large numbers, the technology of each job j can be aggregated into the whole firm i's technology

$$y_{it} = a_t n_{it} e_{it} \bar{x}, \quad \bar{x} = \int_0^\infty x dF(x) \tag{4}$$

where $F(x)$ is a cumulative distribution function of idiosyncratic productivity shock x.

Unemployed workers are matched with vacant jobs through a constant returns to scale matching technology $M(u_t, v_t) = \zeta u_t^\xi v_t^{1-\xi}$. Thus, the number of employed workers at time t in each firm i evolves according to:

$$n_{it} = (1-\rho)(n_{it-1} + v_{it} q(\theta_t)) \tag{5}$$

where $q(\theta_t)$ is the probability that an open vacancy is matched with a worker.

$$\theta_t \equiv v_t / u_t, \quad q(\theta_t) = \zeta \theta_t^{-\xi} \tag{5´}$$

Open vacancies are matched with the total pool of searching workers, which is given by the total labor force minus the number of employed workers in the previous period, $u_t = 1 - n_{t-1}$. The representative firm chooses $\{p_{it}, n_{it}, v_{it}\}_{t=0}^\infty$ to maximize the expected profit in real terms,

$$MaxE_0 \{\sum_{t=0}^\infty \beta^t \frac{\lambda_t}{\lambda_0} [\frac{p_{it}}{p_t} y_{it} - \bar{w}_t n_{it} - \kappa v_{it} - \frac{\varphi}{2}(\frac{p_{it}}{p_{it-1}} - 1)^2]\}$$

subject to the demand for each variety of consumption goods $y_{it} = (\frac{p_{it}}{p_t})^\eta y_t$, the firm's technology, equation (4), and the law of motion of employment, equation (5), taking as given the contingent wage schedule determined by the bargaining process, which will be described later.

From the optimal conditions, the following equations are derived (index i is dropped by symmetry);

$$\partial v_t: \ \mu_t = \frac{\kappa}{(1-\rho)q(\theta_t)} \tag{6}$$

$$\partial n_t: \ \frac{\kappa}{q(\theta_t)} = (1-\rho)(mc_t a_t \bar{x}_t e^* - \bar{w}_t) + E_t[\beta(\frac{c_{t+1}}{c_t})^{-1}(1-\rho)\frac{\kappa}{q(\theta_{t+1})}] \tag{7}$$

$$\partial p_t: \ \varphi(\pi_t - 1)\pi_t = y_t(1+\eta-\eta mc_t) + E_t[\beta\varphi(\frac{c_{t+1}}{c_t})^{-1}(\pi_{t+1}-1)\pi_{t+1}] \tag{8}$$

where real marginal cost mc_t is the Lagrange multiplier on the demand for each variety, and the marginal value of a worker to firms μ_t is the Lagrange multiplier on constraint (5), and $\bar{w}_t$ is the expected value of contingent wage satisfying $\bar{w}_t = \int_0^\infty w_t(x)dF(x)$. Equation (8) represents a Rotemberg-type variant of the New Keynesian Phillips curve.

Rearranging equation (7) delivers the following expression for the real marginal cost,

$$mc_t = \frac{\bar{w}_t}{a_t \bar{x}_t e^*} + \frac{\frac{\kappa}{(1-\rho)q(\theta_t)} - E_t[\beta(\frac{c_{t+1}}{c_t})^{-1}\frac{\kappa}{q(\theta_{t+1})}]}{a_t \bar{x}_t e^*} \tag{9}$$

As in Krause and Lubik (2007) and Krause et al. (2008), in a New Keynesian model with search frictions, the marginal cost of a firm consists of two components. The first is the unit labor cost, $\bar{w}_t / a_t \bar{x}_t e^*$, and the second is an additional term related to matching frictions, $\{\frac{\kappa}{(1-\rho)q(\theta_t)} - E_t[\beta(\frac{c_{t+1}}{c_t})^{-1}\frac{\kappa}{q(\theta_{t+1})}]\} / a_t \bar{x}_t e^*$, which reflects the expected change in hiring cost. Posting a vacancy is costly; hence, an operating match is valuable to the extent that it can reduce future search costs. Also, this expression reveals how both changes in wage schemes and fluctuations in labor market tightness can influence inflation dynamics by affecting the marginal cost.

The labor demand condition (7) will characterize the labor market equilibrium, once it is combined with the wage function, which will be derived in the next section.

3.4. Wage Bargaining

We consider a bilateral wage bargaining problem when firms face the incentive-compatibility constraint induced by workers' moral hazard. Since firms cannot perfectly observe or verify workers' effort level, the workers' threat to shirk is credible. Firms can detect a shirking worker only with a probability of $0 < d < 1$; once caught, the worker would be fired. To induce workers to exert effort, firms are supposed to pay at least the wage (the efficiency wage) that maintains the incentive compatibility (the no-shirking condition, NSC), which ensures that the workers' value of exerting effort exceeds the value of shirking. In sum, workers' wages are determined basically by a conventional Nash bargaining process, but this bargaining process is constrained by the incentive-compatibility consideration to avoid workers' shirking. As a result, the expected wage is characterized by the weighted average of two different wage schemes: the Nash bargaining wage and the efficiency wage.

Before going over the wage bargaining problem, we need to describe the contingent asset values for firms and workers. The asset value of non-shirking workers V_t^E is

$$V_t^E = w_t - \bar{e} + E_t\{\beta(\frac{c_{t+1}}{c_t})^{-1}[(1-\rho)\max(V_{t+1}^E, V_{t+1}^S) + \rho V_{t+1}^U]\} \tag{10}$$

The asset value of workers who are shirking V_t^S is

$$V_t^S = w_t + E_t\{\beta(\frac{c_{t+1}}{c_t})^{-1}[(1-\rho)(1-d)\max(V_{t+1}^E, V_{t+1}^S) + ((1-\rho)d + \rho)V_{t+1}^U]\} \tag{11}$$

Note that in a non-trivial equilibrium, the NSC is always satisfied so that $\max(V_t^E, V_t^S) = V_t^E$ holds for any t.

The asset value of the unemployed V_t^U is

$$V_t^U = w^u + E_t\{\beta(\frac{c_{t+1}}{c_t})^{-1}[p(\theta_{t+1})(1-\rho)V_{t+1}^E + (1 - p(\theta_{t+1})(1-\rho))V_{t+1}^U]\} \tag{12}$$

where $p(\theta_t)$ is the probability that workers find a job, $p(\theta_t) = \zeta\theta_t^{1-\xi}$.

By using equations (10) and (11), the NSC is derived as

$$V_t^E \geq V_t^S \;\Leftrightarrow\; E_t[\beta(\frac{c_{t+1}}{c_t})^{-1}(1-\rho)(V_{t+1}^E - V_{t+1}^U)] \geq \frac{\bar{e}}{d} \quad \text{(NSC)} \tag{13}$$

On the firm's side, the asset value of a filled job V_t^J is

$$V_t^J = mc_t a_t x_t e^* - w_t + E_t[\beta(\frac{c_{t+1}}{c_t})^{-1}(\rho V_{t+1}^V + (1-\rho)V_{t+1}^J)] \quad (14)$$

Under the free-entry condition for job openings, the asset value of an unfilled vacancy V_t^V is zero, $V_t^V = 0$. Substituting this into (14) and aggregating over jobs, we can confirm that equation (14) becomes equivalent to the condition (7), and therefore the asset value of an operating job V_t^J is expressed as $V_t^J = \mu_t = \dfrac{\kappa}{(1-\rho)q(\theta_t)}$.

For later use, we rewrite the net value of non-shirking workers. Subtracting equation (12) from (10), we have

$$V_t^E - V_t^U = w_t - w^u - \bar{e} + E_t[\beta(\frac{c_{t+1}}{c_t})^{-1}(1-\rho)(1-p(\theta_{t+1}))(V_{t+1}^E - V_{t+1}^U)] \quad (15)$$

With the value functions defined above, the wage bargaining problem that firms and workers face at every period can be expressed as follows:

$$Max_{w_t}(V_t^E - V_t^U)^b (V_t^J)^{1-b} \quad \text{subject to} \quad V_t^E \geq V_t^S \quad (16)$$

where $b \in [0,1]$ measures the relative bargaining power of workers.

By solving problem (16) with or without the binding constraint (NSC), we can derive each wage function for two different types of wage scheme: the efficiency wage and the Nash bargaining wage.

One thing to note is that to ensure that workers do not shirk, firms should commit themselves to guaranteeing a minimum wage level (the efficiency wage) for the next period, not for the current period. This is due to the forward-looking nature of the NSC of (13); the net surplus of the non-shirking worker relative to the shirking worker ($V_t^E - V_t^S$) depends on the net surplus of the non-shirking worker relative to the unemployed worker in the next period, ($V_{t+1}^E - V_{t+1}^U$). Thus, it is future wages that influence the worker's incentive to shirk now. Unless firms commit themselves to paying at least the efficiency wage in the next period, which corresponds to the minimum surplus level satisfying the NSC (13), workers have no incentive not to shirk in the current period.

Another related point is that at a given time period, the efficiency wage should play a dual role: fulfilling the minimum surplus that the firm committed to in the previous period and making another commitment for the surplus in the next period, so as to satisfy the NSC of the current period. As seen in (15), the net surplus of workers in the current period ($V_t^E - V_t^U$) depends on the expected net surplus of workers in the next period ($V_{t+1}^E - V_{t+1}^U$). Thus, given a minimum level of net surplus in the current period to which the firm committed in the previous period, for the current efficiency wage level to be uniquely determined, the net surplus of workers in the next period ($V_{t+1}^E - V_{t+1}^U$) should be simultaneously committed to the minimum level that satisfies the binding NSCs of both the previous and the current period. In this way, the efficiency wage level in the current period is simultaneously determined with the committed level of net surplus for the next period.

First, when the NSC is not binding in the current period, the equilibrium wage (the Nash bargaining wage) can be written as

$$w_t^{NB} = (1-b)(w^u + \bar{e}) + b\{mc_t a_t x_t e^* + E_t[\beta(\frac{c_{t+1}}{c_t})^{-1}(\frac{\kappa}{q(\theta_{t+1})} - \frac{1-b}{b}(1-\rho)(1-p(\theta_{t+1}))(V_{t+1}^E - V_{t+1}^U))]\} \quad (17)$$

by substituting $V_t^E - V_t^U = \frac{b}{1-b}V_t^J = \frac{b}{1-b}\frac{\kappa}{(1-\rho)q(\theta_t)}$ and (14) into (15).

Second, substituting each NSC condition (13) for time $t-1$ and t in its equality to (15), we can derive the wage function that satisfies the binding NSC of the previous period and is simultaneously consistent with the committed level of minimum future surplus just enough to induce workers' current effort (the efficiency wage):

$$w_t^E = w^u + \bar{e} + \{E_{t-1}[\frac{1}{\beta(\frac{c_t}{c_{t-1}})^{-1}(1-\rho)}] - E_t[1-p(\theta_{t+1})]\}\frac{\bar{e}}{d} \quad (18)$$

That is, the efficiency wage at period t denotes the minimum wage that fulfills the worker's net surplus for t committed to at $t-1$ and is also consistent with the level of minimum net surplus for $t+1$ committed to at time t.

Then, Lemma 1 will show that in order to satisfy the NSC, all that needs to be done is to ensure that the unconstrained Nash bargaining wage is not lower than the efficiency wage level.

Lemma 1. If and only if the NSC is binding (holds in equality) for both period $t-1$ and t, implying $E_i[\beta(\frac{c_{i+1}}{c_i})^{-1}(1-\rho)(V_{i+1}^E - V_{i+1}^U)] = \frac{\bar{e}}{d}$ for $i = t-1$ and t, then $w_t^{NB} = w_t^E$.

Proof: Under the Nash bargaining, equation (15) is expressed as

$$V_t^E - V_t^U = w_t^{NB} - w^u - \bar{e} + E_t[\beta(\frac{c_{t+1}}{c_t})^{-1}(1-\rho)(1-p(\theta_{t+1}))(V_{t+1}^E - V_{t+1}^U)] \tag{19}$$

From equation (15), the efficiency wage, the equilibrium wage when the NSC is binding for both period $t-1$ and t, is characterized as

$$w_t^E = w^u + \bar{e} + \{E_{t-1}[\frac{1}{\beta(\frac{c_t}{c_{t-1}})^{-1}(1-\rho)}] - E_t[1-p(\theta_{t+1})]\}\frac{\bar{e}}{d} \tag{20}$$

Subtracting equation (20) from (19) and substituting the NSCs (13) for period $t-1$ and t in their equality leads to $w_t^{NB} = w_t^E$.

By the definition of the efficiency wage w_t^E, it is trivial to show that if $w_t^{NB} = w_t^E$, then the NSCs for period $t-1$ and t are binding. ■

Lemma 2. If the wage functions (17) and (18) satisfy $w^{NB}(\tilde{x}_t) = w^E(\tilde{x}_t)$, for any $x_t > \tilde{x}_t$, $w^{NB}(x_t) > w^E(x_t)$ holds; by Lemma 1, this means that the NSC is not binding in the current period for any $x_t > \tilde{x}_t$.

Proof: First, we assume that given any realization of the aggregate productivity shock a_t within a proper domain, there exists the unique threshold level $\tilde{x}_t$ of the idiosyncratic productivity shock that satisfies $w^{NB}(\tilde{x}_t) = w^E(\tilde{x}_t)$, equalizing equations (17) and (18). Since the Nash bargaining wage function $w^{NB}(x_t)$, equation (17), is a strictly increasing function of the idiosyncratic productivity shock x_t while the efficiency wage function $w^E(x_t)$, equation (18), is not related to the idiosyncratic shock (it is affected only by aggregate conditions), for any $x_t > \tilde{x}_t$, $w^{NB}(x_t) > w^{NB}(\tilde{x}_t) = w^E(\tilde{x}_t) = w^E(x_t)$ holds. In other words, for any $x_t > \tilde{x}_t$, the Nash bargaining wage exceeds the efficiency wage level; thus, by Lemma 1, the NSC does not bind in the current period. ■

These lemmas imply that in order to induce workers to exert an appropriate amount of effort, firms have only to pay an ordinary Nash bargaining wage whenever it exceeds a committed level of the efficiency wage. Only when the level of the unconstrained Nash bargaining wage is lower than the efficiency wage (when the NSC is binding), firms are forced to pay a wage at least above the efficiency wage level.

Now, using the threshold idiosyncratic productivity $\tilde{x}_t$, we can characterize the total expected wage function on the firm's side. First, the solution of the condition $w^{NB}(\tilde{x}_t) = w^E(\tilde{x}_t)$ determines the threshold productivity $\tilde{x}_t$. By subtracting equation (18) from (17),

$$\begin{aligned} & b\{mc_t a_t \tilde{x}_t e^* - w^u - \bar{e} + E_t[\beta(\frac{c_{t+1}}{c_t})^{-1}(\frac{\kappa}{q(\theta_{t+1})} - \frac{1-b}{b}(1-\rho)(1-p(\theta_{t+1}))(V_{t+1}^E - V_{t+1}^U))]\} \\ & = \{E_{t-1}[\frac{1}{\beta(\frac{c_t}{c_{t-1}})^{-1}(1-\rho)}] - E_t[1-p(\theta_{t+1})]\}\frac{\bar{e}}{d} \end{aligned} \tag{21}$$

By Lemma 2, the type of wage function for a certain job depends on whether its realized idiosyncratic shock x_t is higher or lower than the threshold productivity $\tilde{x}_t$. Since each firm consists of a continuum of many ex-ante identical jobs, a firm's total wage payment depends on the distributional properties of the idiosyncratic shock x_t, which are characterized by the cumulative distribution function $F(x)$.

Let's define γ_t as the probability that the NSC is binding (so that firms are forced to pay at least the efficiency wage). By Lemmas 1 and 2, γ_t can be expressed as

$$\gamma_t = \Pr(w_t^{NB} \le w_t^E) = \Pr(x_t \le \tilde{x}_t) = F(\tilde{x}_t) \tag{22}$$

Among n_{it} workers employed by firm i, a fraction γ_t of jobs pay the efficiency wage, while a fraction $1-\gamma_t$ of jobs pay the Nash bargaining wage. Now, a firm's total expected wage can be written as

$$\bar{w}_t = \gamma_t E_t(w_t^E | x_t \le \tilde{x}_t) + (1-\gamma_t)E_t(w_t^{NB} | x_t > \tilde{x}_t) \tag{23}$$

As shown in equation (18), the efficiency wage level w_t^E is determined independently of the realized level of the idiosyncratic shock x_t. Thus, $E_t(w_t^E | x_t \le \tilde{x}_t) = E_t(w_t^E)$ holds. However, as seen in equation (17), the expected level of the Nash bargaining wage w_t^{NB} relies on the distribution of x_t conditional on $x_t > \tilde{x}_t$, which takes a truncated log-normal by the log-normality of x_t. Using the properties of a truncated log-normal distribution, the expected value of x_t, conditional on its being larger than the threshold level $\tilde{x}_t$, can be expressed as

$$E(x_t \,|x_t > \tilde{x}_t) = \exp(\frac{\sigma_x^2}{2})\frac{\Phi(\sigma_x - (\ln \tilde{x}_t / \sigma_x))}{\Phi(-(\ln \tilde{x}_t / \sigma_x))} \tag{23$'$}$$

where $\Phi(\cdot)$ is a cumulative distribution function of standard normal distribution.

Substituting this into equation (17), the conditional Nash bargaining wage $E_t(w_t^{NB} \,|x_t > \tilde{x}_t)$ can be written as

$$\begin{aligned} E_t(w_t^{NB} \,|x_t > \tilde{x}_t) &= (1-b)(w^u + \overline{e}) + b\{mc_t a_t e^* \exp(\frac{\sigma_x^2}{2})\frac{\Phi(\sigma_x - (\ln \tilde{x}_t / \sigma_x))}{\Phi(-(\ln \tilde{x}_t / \sigma_x))} \\ &+ E_t[\beta(\frac{c_{t+1}}{c_t})^{-1}(\frac{\kappa}{q(\theta_{t+1})} - \frac{1-b}{b}(1-\rho)(1-p(\theta_{t+1}))(V_{t+1}^E - V_{t+1}^U))]\} \end{aligned} \tag{23$''$}$$

Combining the total expected wage function (equation (23)) with the labor demand condition (7), we can characterize the labor market equilibrium condition as

$$\frac{\kappa}{q(\theta_t)} = (1-\rho)[mc_t a_t \overline{x}_t e^* - \gamma_t E_t(w_t^E) - (1-\gamma_t)E_t(w_t^{NB} \,|x_t > \tilde{x}_t)] + E_t[\beta(\frac{c_{t+1}}{c_t})^{-1}(1-\rho)\frac{\kappa}{q(\theta_{t+1})}] \tag{24}$$

3.5. Government and Monetary policy

The government levies a lump-sum tax τ_t and issues a nominal bond b_t, which pays a gross nominal interest rate R_t one period later, in order to finance the exogenous government spending g_t and satisfy the following budget constraint each period:

$$g_t + R_{t-1}\frac{b_{t-1}}{p_t} = \frac{\tau_t}{p_t} + \frac{b_t}{p_t}$$

The government expenditure g_t exogenously evolves through

$$\ln g_t = (1-\rho_g)\ln g + \rho_g \ln g_{t-1} + \varepsilon_t^g, \qquad \varepsilon_t^g \sim N(0, \sigma_g^2)$$

Monetary policy is described by the following Taylor rule:

$$\frac{R_t}{R^*} = [(\frac{\pi_t}{\pi^*})^{\gamma_\pi} (\frac{y_t}{y^*})^{\gamma_y}] m_t \tag{25}$$

where R^*, π^*, and y^* are the steady-state gross interest rate, the target inflation rate, and potential output. The monetary policy shock m_t evolves through

$$\ln m_t = \rho_m \ln m_{t-1} + \varepsilon_t^m, \qquad \varepsilon_t^m : N(0, \sigma_m^2)$$

3.6. Model Equilibrium

The resource constraint of the economy can be expressed as follows:

$$y_t = a_t n_t \bar{x}_t e^* = c_t + g_t + \kappa v_t + \frac{\varphi}{2}(\pi_t - 1)^2 \tag{26}$$

A decentralized equilibrium of the model economy is characterized by a sequence of allocation and prices $\{ c_t, n_t, v_t, \theta_t, \tilde{x}_t, \gamma_t, \pi_t, mc_t, R_t, \bar{w}_t, w_t^{NB}, w_t^E \}_{t=1}^{\infty}$ satisfying equations (3), (5), (5)´, (8), (17), (18), (21), (22), (23), (24), (25) and the resource constraint (26) for a given set of aggregate shock processes $\{ a_t, g_t, m_t \}_{t=0}^{\infty}$ and initial states n_0.

4. Quantitative Analysis

4.1. Calibration

Except for the efficiency wage arrangement, calibration of most parameters is mainly based on Faia (2008, 2009). The time period is measured in quarters, and I set the discount factor $\beta = 0.99$, so that the annual interest rate in the steady state is about 4%. We choose a standard value for the inverse of the intertemporal elasticity of consumption, $\sigma = 2$. The mark-up of prices over marginal cost is set equal to 20%, implying $\eta = -6$. The price adjustment cost parameter is set to $\varphi = 20$, following Faia (2009), who based her calibration on the observed sensitivity of inflation to marginal costs (see Lubik and Schorfheide (2004)).

The unemployment elasticity of matching, ξ, is set to 0.6, which is the median of the range of estimates that Pissarides and Petrongolo (2001) have reported. Following standard practice in the literature, we set the worker's bargaining power parameter b equal to ξ so that it can satisfy the Hosios (1990) condition. The steady-state worker finding rate, $q(\theta)$, is set to 0.7, following den Haan et al. (2000). The exogenous separation rate, ρ, is set to 0.1, consistent with Abowd and Zellner's (1985) measurement from 1972-1982 data (3.42% per month). Following Cooley and Quadrini (2004) and Faia (2009), the steady-state employment rate is set to $n = 0.6$, which corresponds to the average employment-population ratio in the U.S. during 1964Q1-2011Q4.[4] The steady-state vacancy ratio, v, can be obtained by solving equation (5) in the steady state. Given those calibrated values, the matching efficiency parameter, ζ, is obtained from the steady-state relationship, $\zeta = \rho n \theta^{\xi} / (\mathrm{v}(1\text{-}\rho))$. The value for the vacancy posting cost, κ, is obtained by solving the steady-state version of the labor market equilibrium condition (equation (7)) in the Nash bargaining model economy. The value of non-market utility, w^u, is set so as to generate the steady-state ratio, $w^u / \bar{w}$, of 0.6[5] in the Nash bargaining model economy, which corresponds to the average net replacement rates (2001-2010) for the households earning the average income in the U.S. (see OECD (2012)). For a fair comparison of the models, the same values of w^u and κ are calibrated to the efficiency wage economy.

As for the parameters characterizing the efficiency wage scheme, we set the shirking detection probability d to 0.05 and normalize the inputted effort level e^* to 1. Given this normalization, we obtained the disutility (in consumption units) from exerting effort, $\bar{e}$, by solving the steady-state version of condition (21).

Following the main RBC literature, the innovation process for the aggregate productivity shock a_t is calibrated such that its standard deviation is set to $\sigma_a = 0.007$ and its persistence to $\rho_a = 0.95$. The standard deviation and the persistence of the innovation to government expenditure shocks are set such that $\sigma_g = 0.0075$ and $\rho_g = 0.9$, based on the empirical evidence for the U.S. in Perotti (2004). As in Thomas (2011), the standard deviation of the innovation to monetary policy shocks, σ_m, is calibrated to match the standard deviation of real output in the model economy (the Nash bargaining economy) to the data. The standard deviation of the (logged) idiosyncratic shock, σ_x, is set to 0.13 following Walsh (2005), who based his calibration on the relative volatility of job destruction to output in the U.S. data. This value is consistent with those in den Haan et al. (2000) and Krause and Lubik (2007), who use 0.10 and 0.12, respectively.

We consider the monetary policy rule which is a standard Taylor rule with a higher weight on inflation, $\gamma_\pi = 3$ and $\gamma_y = 0.5/4$ (divided by four to redefine the annual GDP gap on a quarterly basis), the same as the strict inflation targeting rule in Faia (2009); by doing so, we can almost match the standard deviation of the nominal interest rate in the model economy (the Nash bargaining economy) to the data.

We numerically compute the impulse response and implement the dynamic simulation by solving first- and second-order approximations to the optimal policy function around a non-stochastic steady state, based on the perturbation method of Schmitt-Grohe and Uribe (2004).

4.2. Impulse Response

From now on, we present the distinguished features of our benchmark efficiency wage model, compared with the standard Nash bargaining NK model. To begin with, the impulse responses of each model will be evaluated; first, we compare the impulse responses of our benchmark model with those of the standard Nash bargaining model. Then, the consequences of fixing the efficiency wage are discussed.

Our model's behavior in response to aggregate productivity and monetary policy shocks documents two results: first, the real wage rigidity induced by the efficiency wage scheme significantly amplifies the volatilities of labor market quantities and dampens real wage fluctuations. Second, this friction does not add much in explaining inflation inertia and the persistence of the effects of monetary shocks.

[Insert Figure 2 Here.]

Consider first the effects of a 1% increase in aggregate productivity. The impulse responses of selected variables are depicted in Figure 2. In the face of a positive productivity shock, vacancy and employment rise and the unemployment rate falls; thus, labor market tightness markedly goes up. Compared with the standard Nash bargaining model, introducing the efficiency wage scheme makes wage responses more muted and thus amplifies fluctuations in vacancies, unemployment, and market tightness, as pointed out by Shimer (2005) and Hall (2005). Note that this amplification is robust regardless of Hagedorn and Manovskii's (2008) argument that only the extremely high ratio of non-market utility to the steady-state wage level, e.g., $w^u / \bar{w} \approx 0.977$, can explain the observed high volatility of unemployment and vacancies. This is because the value of non-market utility, w^u, is set so as to generate the steady-state ratio, $w^u / \bar{w}$, of 0.6 in our model economy (the Nash bargaining economy).[6]

In the Nash bargaining economy, in response to a productivity shock, inflation falls only slightly and output markedly goes up while the disinflation persists. This is also the case in the efficiency wage model, but a minor difference is that upon the impact of shocks, inflation temporarily rises. This is mainly because an amplified increase in job posting and hiring costs fully offsets a decrease in real unit labor costs induced by the positive productivity shock (see equation (9)). Owing to this offsetting effect, inflation reaches its trough a bit later than in the standard Nash bargaining model, which results in a more lagged response of output. However, the persistence of inflation itself is hardly affected by introducing the efficiency wage scheme.

[Insert Figure 3 Here.]

Consider next the effects of a 1% increase in the monetary policy rate. The impulse responses of selected variables are depicted in Figure 3. In the face of a recessionary monetary policy shock, vacancy and employment fall and the unemployment rate rises; thus, labor market tightness markedly goes down. As in the responses to aggregate productivity shocks, the efficiency wage scheme also amplifies fluctuations in vacancies, unemployment, and market tightness, as it dampens wage responses. Nonetheless, a more dampened wage (a main component of the real marginal cost) does not lead to inflation inertia because more volatile movements of market tightness make job posting and hiring costs (the other component of the real marginal cost) vary more, offsetting the dampening effect of rigid wages (see equation (9)). This offsetting mechanism echoes the findings of Krause and Lubik (2007). Due to this mechanism, the efficiency wage scheme does not make any significant difference in terms of inflation inertia.

One thing to note is that upon the impact of a recessionary monetary shock, output temporarily rises in the model. This is mainly because given a more sluggish adjustment of labor input resulting from search frictions,[7] the combined effect of a declining price and a strict inflation-targeting monetary rule fully offsets an initial decrease in real demand. However, after a small initial increase, output soon falls below its steady-state level and then slowly recovers.

To see the implications of wage rigidity more clearly, we construct an economy where the efficiency wage is not time-varying as in equation (18), but fixed at its steady-state constant level $\bar{w}^E$. In other words, the wage equation (23) can be rewritten as,

$$\bar{w}_t = \gamma_t \bar{w}^E + (1-\gamma_t) E_t(w_t^{NB} \mid x_t > \tilde{x}_t) \tag{27}$$

where $\tilde{x}_t$ and γ_t satisfy $w^{NB}(\tilde{x}_t) = \bar{w}^E$ and $\gamma_t = \Pr(w_t^{NB} \le \bar{w}^E) = \Pr(x_t \le \tilde{x}_t)$ (see equations

(21) and (22)).

Under a fixed efficiency wage, the impulse responses of selected variables are depicted in Figures 4 and 5. We can confirm the former baseline results in a more significant manner. Fixing the efficiency wage generates an extremely higher magnitude of amplification in employment and vacancies, and its dampening effect on real wage becomes more striking. The higher amplification of market tightness, by affecting job posting and hiring costs, makes the responses of inflation more volatile, but there are no significant changes in terms of the persistence of the responses.

[Insert Figure 4 and Figure 5 Here.]

To sum up, the real wage rigidity based on the efficiency wage framework amplifies the volatilities of employment and vacancies by dampening wage fluctuations, as indicated by Shimer (2005) and Hall (2005). However, it is hardly helpful in explaining inflation inertia, confirming the argument of Krause and Lubik (2007).

4.3. Moment Analysis

In this section, business cycle statistics from the data are compared with the corresponding statistics from the simulated model. Moment comparison reveals two main results: first, it evidently confirms the former result that the efficiency wage scheme significantly amplifies the volatilities of labor market quantities and dampens real wage fluctuations. Second, and more important, downward real wage rigidity arising from the incentive consideration can generate the asymmetric behavior of inflation as well as labor market quantities along the business cycle, and the generated asymmetry has an order of magnitude comparable to that observed in the data.

Consider first the volatilities of the main variables in the model. The simulated moments of selected variables are summarized in Table 2. This table confirms the results of the impulse response analysis above. The efficiency wage scheme makes the volatility of unemployment and market tightness more than double while reducing that of real wages to about 75% of that in the standard Nash bargaining model. This amplification also carries over to the relative volatilities against output. This tendency becomes more striking in the fixed efficiency wage model; the fixed efficiency wage makes the volatility of unemployment and market tightness more than three times as high as in the standard model while reducing that of real wages to about 50% of that in the standard Nash bargaining model. However, amplification is not enough, since the baseline efficiency wage model still generates smaller (absolute and relative) volatilities in employment and vacancies than observed in the data. Only when the efficiency wage is fixed are those volatilities comparable to the data. Meanwhile, introducing the efficiency wage does not significantly affect inflation volatility.

[Insert Table 2 Here.]

Now, we turn to the cyclicality and persistence of the main variables in the model. Considering first the correlation of the main variables with real output in Table 3, the standard Nash bargaining model usually generates the same direction of correlation as in the data, except for inflation and the nominal interest rate. Unlike the flexible wage version of Krause and Lubik (2007) and Costain and Jansen (2010), our model, assuming exogenous separation, exhibits a Beveridge curve relation, implying a negative correlation between unemployment and vacancies. In addition, there are two things to note: first, incorporating wage rigidity through the efficiency wage scheme makes the real wage become more acyclical over the business cycle, while it exhibits strong pro-cyclicality in the standard Nash bargaining model. We can see that the efficiency wage model significantly reduces the correlation coefficient of the real wage with output, making it comparable to the data, particularly in the case of the fixed efficiency wage. Second, all the models exhibit a negative correlation between output and inflation and between output and the nominal interest rate, contrary to the data in which both inflation and the nominal interest rate seem to be almost acyclical.[8] This is due to the dominating effect of productivity shocks over monetary shocks, and this dominance is closely related to the model's inability to generate inflation inertia and the persistent effects of monetary shocks, a main shortcoming of the standard New Keynesian model. However, as the real wage becomes more rigid, the counter-cyclicality of inflation and the nominal interest rate in the model also becomes gradually weaker.

[Insert Table 3 Here.]

As for the persistence, the standard Nash bargaining model usually generates persistence of comparable magnitude to that in the data, except for inflation. As for inflation, the model generates even higher persistence than observed in the data. However, considering the highly stylized aspect of the model, this is likely to be just an artifact arising from the fact that the very high persistence of the shocks themselves directly carries over to the whole model. Introducing the efficiency wage does not change much about the autocorrelation structure of the main variables. Rather, when the efficiency wage is fixed, most variables become a bit less persistent. This is due to the significant amplifications in labor market volatility resulting from the wage rigidity introduced.

Now, let's turn to the implications of the efficiency wage for cyclical asymmetry by analyzing the third moments of the simulated data. As in Table 1, the U.S. data indicate that most of the main quantity variables (such as employment, vacancy, and real output) exhibit significant negative skewness, whereas most of the price variables (such as the nominal interest rate, inflation, and real wage) exhibit positive skewness, implying that in recessions employment and vacancies decrease more strongly than they increase in booms, whereas in booms wages and prices increase more strongly than they decrease in recessions.

[Insert Table 4 Here.]

Table 4 summarizes the skewness of the simulated series in the model. As shown in the second column of Table 4, the asymmetry observed in the data cannot be captured by the standard Nash bargaining model. The skewness estimates of most of the simulated variables are basically zero, and the estimates for unemployment and output are even of opposite signs to those for their empirical counterparts. Meanwhile, by introducing the efficiency wage scheme accounting for downward wage rigidity, the model (the third column) is not only able to exhibit the correct direction of skewness but is also able to match the degree of skewness of both the main price and the quantity variables well, especially labor market quantities and inflation. Following a shock that requires cuts in wages and discourages job creation, the downward rigidity arising from the efficiency motivation makes wages adjust more sluggishly—leading to more sluggish decreases in inflation—which further reduces the incentive for opening vacancies. In contrast, a relatively stronger increase in real wages—leading to faster increases in inflation—in booms implies that more of the additional surplus is attributed to workers, which significantly attenuates the incentive to post new jobs. This consequent negative skewness of vacancies is directly transmitted to employment. The opposite skewness of unemployment highlights the strong link between unemployment and vacancies through the Beveridge curve. Considering that labor constitutes the only input to production in the model, it is natural that the negative skewness of employment should prevail in shaping the adjustment of output and consumption. However, the asymmetry in output and consumption is less prominent, reflecting the buffering effect of consumption smoothing. In the case of the fixed efficiency wage, this asymmetry becomes more prominent even beyond the level observed in the data, indicating that the real-world labor market lies at some mid-point between the flexible efficiency wage model and the fixed efficiency wage model.

One thing to note is that even though the real wage rigidity is the only source of asymmetry in the model, the real wage itself does not exhibit strong asymmetry as observed in the data. This is because in recessions, downward wage rigidity amplifies the downward adjustments of vacancies and employment; consequently, this amplification puts a much stronger downward pressure on the flexible efficiency wage that otherwise functions as a strict lower limit to downward wage adjustments. This point can be confirmed by comparing the skewness of real wages between the baseline efficiency wage model (the second column) and the fixed efficiency wage model (the third column). We can see that fixing the efficiency wage to a constant level remarkably increases the degree of positive skewness, even beyond the level observed in the data. This indicates that in reality there may exist other sources that hinder the flexible adjustment of the efficiency wage level: e.g., legal minimum wage, implicit contracts between firms and workers, or explicit guidelines forced by collective bargaining.

[Insert Figure 6 Here.]

To visualize the cyclical distribution of vacancies, unemployment, and inflation, Figure 6 plots the kernel density estimates of the vacancy/unemployment ratio (θ) and inflation (π) using a Gaussian kernel with optimal bandwidth. Contrary to the data, the Nash bargaining economy generates almost symmetric distributions for both variables, whereas the efficiency wage model exhibits a more left-skewed distribution for the vacancy/unemployment ratio and a more right-skewed distribution for inflation, so that both distributions become a bit closer to the data distribution. Fixing the efficiency wage brings this asymmetry to an extreme, even beyond the level observed in the data. This also indicates that the real-world economy may be located somewhere between the baseline efficiency wage model and the fixed efficiency wage model.

4.4. Cross-Industry Evidence

In order to examine the empirical validity of our model's prediction, we implement a cross-industry analysis; we regress the skewness or volatility of sectoral hours worked and employment on a proxy variable reflecting sectoral differences in the intensity of the efficiency consideration in determining wages. As the proxy, we calculate the log difference between sectoral wage per hour and average productivity of labor (measured as sectoral real output per hour) and use its time series mean as our explanatory variable. The intuition is this: in the sector where a worker's input of effort is more critical, the higher the minimum wage level needs to be in order to induce the effort (higher efficiency wage), and consequently the gap between the realized wage level and labor productivity widens. To control for sectoral heterogeneity, we include the skewness (or volatility) of sectoral real output, $skewness(y)$ (or $SD(y)$), in each cross-industry regression.

We obtain 4-digit SIC industry data from the NBER-CES manufacturing data set, documented by Bartelsman et al. (2000). The data set includes the sectoral data of 459 manufacturing industries[9] for 1958-2005. The main trended variables—such as sectoral hours worked, employment, and real output—are detrended by log differencing. We also regress employment, instead of hours worked, so that we can distinguish between the relative contributions of the intensive and the extensive margin, respectively.

[Insert Table 5 Here.]

Table 5 summarizes the results of the cross-industry regressions. Consistent with the prediction of our model, in the sector where the efficiency consideration is more critical to its wage determination, consequently leading to a higher wage level relative to average labor productivity, both hours worked and employment exhibit more significantly negative skewness and higher volatility.[10] Note that this is the case even when we control for sectoral heterogeneity by including the skewness or volatility of sectoral output in each regression. Since the result for hours worked is almost the same as that for employment, we can infer that cyclical asymmetry and amplification induced by the efficiency consideration take effect mainly along the extensive margin of labor, not the intensive margin. In this respect, it is an innocuous assumption that there exists only one margin of labor adjustment, the extensive margin, in our model. In sum, the empirical evidence from the cross-industry data supports our model's prediction: the existence of the efficiency wage scheme and the direction of its effect.

5. Concluding Remarks

This paper develops a variant of the New Keynesian model with the Mortensen-Pissarides search frictions by incorporating downward real wage rigidity based on the efficiency wage framework of Shapiro and Stiglitz (1984). When we examine the cyclical implications of the wage rigidity induced by the efficiency wage scheme for labor market and inflation dynamics, we find that real wage rigidity significantly amplifies the volatilities of labor market quantities and dampens real wage fluctuations. Thus, it can address Shimer's (2005) volatility puzzle and explain the observed weak cyclicality of real wage dynamics. Second, introducing downward wage rigidity can generate the asymmetric dynamics of inflation as well as labor quantities observed in the data. Therefore, the model can resolve the counterfactual symmetry commonly featured in the standard New Keynesian and equilibrium search model. However, the real wage rigidity under search frictions does not add much in terms of inflation inertia and the persistence of the effects of monetary shocks, as documented by Krause and Lubik (2007).

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Table 1. Data moments

U.S. data (Quarterly)	Data moments				
	Standard Deviation (%)	Relative SD to y	Correlation. with y	Autocorrelation	Skewness
n	2.4	0.969	0.832	0.968	-0.325
u	2.9	1.172	-0.819	0.972	0.202

$v/u(=\theta)$	21.2	8.505	0.772	0.955	-0.507
v	18.8	7.557	0.745	0.952	-0.534
π	0.4	0.144	0.188	0.659	0.970
r	0.5	0.218	0.216	0.899	0.954
w	1.7	0.674	0.554	0.960	0.567
y	2.5	1.000	1.000	0.941	-0.536
c	3.5	1.396	0.936	0.956	-0.407

Note: The sample period for the data is 1964Q1~2011Q4. All data series are detrended using an HP filter with a smoothing parameter of 10^5. For details on the data, see Section 2.

Table 2. Simulated moments: standard deviation

SD(%) (rel. SD to y)	U.S. data	Model		
		Nash bargaining	Efficiency wage	Fixed efficiency wage
n	2.4 (0.969)	0.8(0.319)	1.7(0.565)	2.6(0.707)

u	2.9 (1.172)	1.1(0.478)	2.5(0.845)	3.8(1.051)
θ	21.2(8.505)	5.5(2.240)	11.5(3.864)	18.7(5.197)
v	18.8(7.557)	4.5(1.841)	9.3(3.131)	15.7(4.394)
π	0.4 (0.144)	0.3(0.104)	0.3(0.098)	0.5(0.155)
r	0.5 (0.218)	0.5(0.199)	0.6(0.204)	1.4(0.410)
w	1.7 (0.674)	1.8(0.742)	1.4(0.482)	0.9(0.285)
y	2.5 (1.000)	2.5(1.000)	3.0(1.000)	3.5(1.000)
c	3.5 (1.396)	3.3(1.351)	4.0(1.347)	4.8(1.344)

Note: The sample period for the data is 1964Q1~2011Q4. All data series are detrended using an HP filter with a smoothing parameter of 10^5. Numbers in parentheses are the ratios of the standard deviation of each variable to that of output. Statistics for the model economies are computed by simulating the model 500 times for 200 periods. The statistics are averaged over the 500 simulations.

Table 3. Simulated moments: correlation with output and autocorrelation

Correlation with y (Autocorrelation)	U.S. data	Model		
		Nash bargaining	Efficiency wage	Fixed efficiency wage
n	0.832(0.968)	0.955(0.990)	0.967(0.992)	0.972(0.983)

u	-0.819(0.972)	-0.905(0.990)	-0.930(0.992)	-0.967(0.984)
θ	0.772(0.955)	0.993(0.938)	0.991(0.959)	0.864(0.893)
v	0.745(0.952)	0.973(0.909)	0.973(0.938)	0.792(0.848)
π	0.188(0.659)	-0.896(0.964)	-0.789(0.949)	-0.522(0.740)
r	0.216(0.899)	-0.782(0.964)	-0.544(0.904)	-0.290(0.676)
w	0.554(0.960)	0.975(0.911)	0.867(0.879)	0.686(0.860)
y	1.000(0.941)	1.000(0.957)	1.000(0.972)	1.000(0.980)
c	0.936(0.956)	0.986(0.955)	0.990(0.971)	0.993(0.978)

Note: Numbers in parentheses are the first-order autocorrelation coefficients of each variable.

Table 4. Simulated moments: skewness

Skewness	U.S. data	Model		
		Nash bargaining	Efficiency wage	Fixed efficiency wage

n	-0.325	-0.037	-0.269	-0.963
u	0.202	-0.001	0.190	0.865
θ	-0.507	-0.031	-0.261	-1.166
v	-0.534	-0.043	-0.288	-1.259
π	0.970	0.032	0.173	0.964
r	0.954	0.083	0.322	0.649
w	0.567	0.004	0.022	1.514
y	-0.536	0.004	-0.079	-0.486
c	-0.407	-0.037	-0.116	-0.512

Table 5. Cross-industry regressions

Regressors	Dependent variables			
	Sectoral Hours worked		Sectoral Employment	
	Skewness	SD	Skewness	SD
Avg($\ln(W / APL)$)	-0.167**	0.011**	-0.161*	0.011**

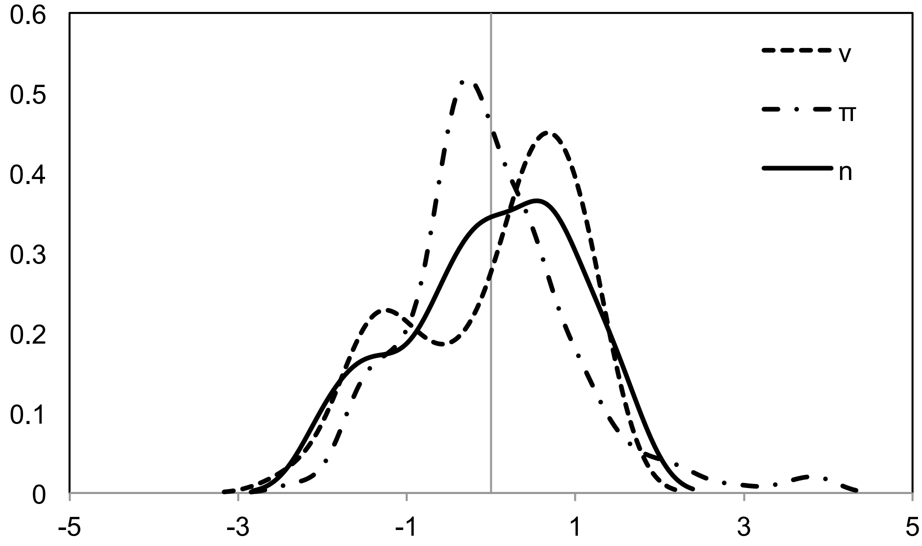
	(-2.61)	(4.47)	(-2.38)	(5.01)
Skewness(y)	0.653**		0.687**	
	(11.82)		(12.03)	
SD(y)		0.548**		0.542**
		(22.13)		(22.90)
R^2	0.458	0.712	0.462	0.721
Prob > F	0.000	0.000	0.000	0.000

Note: Numbers in parentheses are t values based on the Huber–White heteroscedasticity robust estimator of sample variances.

* denotes that the coefficient is statistically significant at the 5% level.

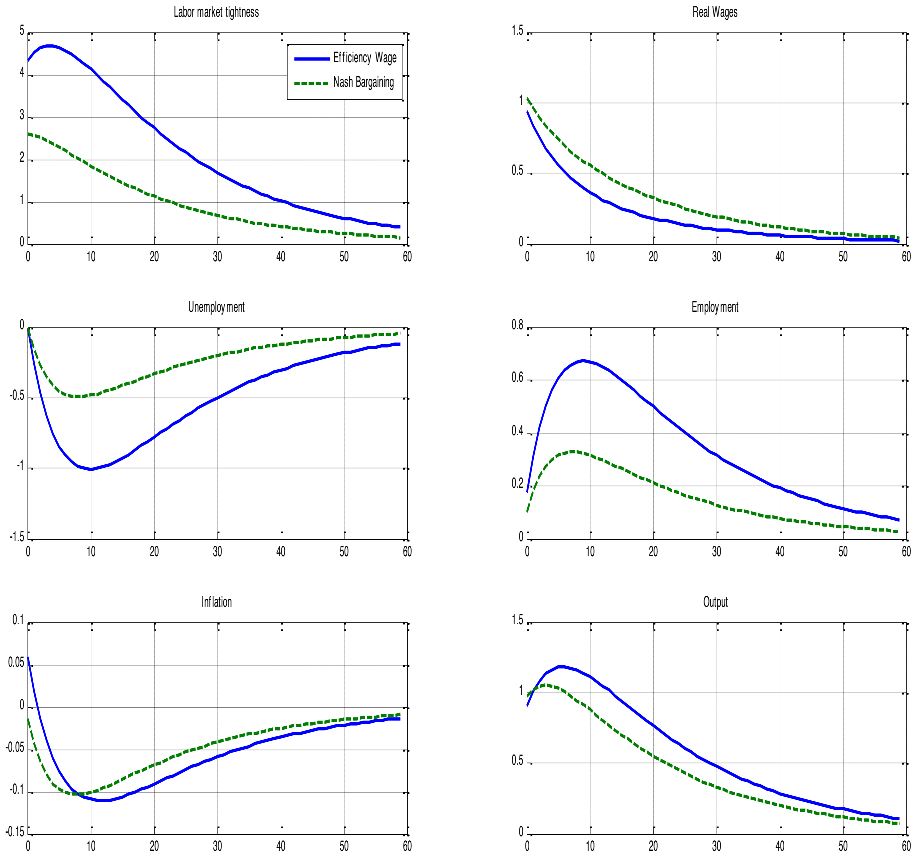
** denotes that the coefficient is statistically significant at the 1% level.

Figure 1. Kernel density estimates (Gaussian kernel) for employment, vacancy, and inflation



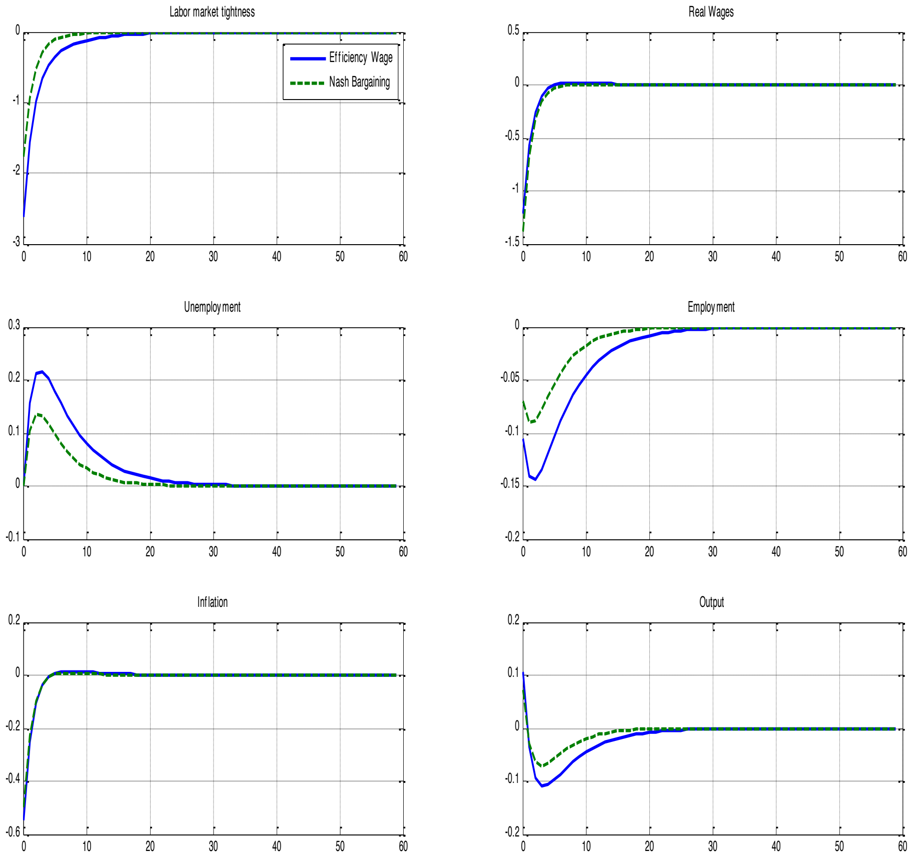
Note: The sample period for the data is 1964Q1~2011Q4. All data series are detrended using an HP filter with a smoothing parameter of 10^5. For proper scaling, all the series are standardized before estimating kernel density. Thus, the measurement unit on the x-axis is one standard deviation of each corresponding variable.

Figure 2. Impulse responses of selected variables to aggregate productivity shocks



Note: The solid line and the dashed line denote the impulse responses of the benchmark efficiency wage model and the Nash bargaining model, respectively. They depict the responses to a 1% increase in aggregate productivity. The time period is measured in quarters, and all the responses except that of inflation (measured in percentage points) are measured in percentages.

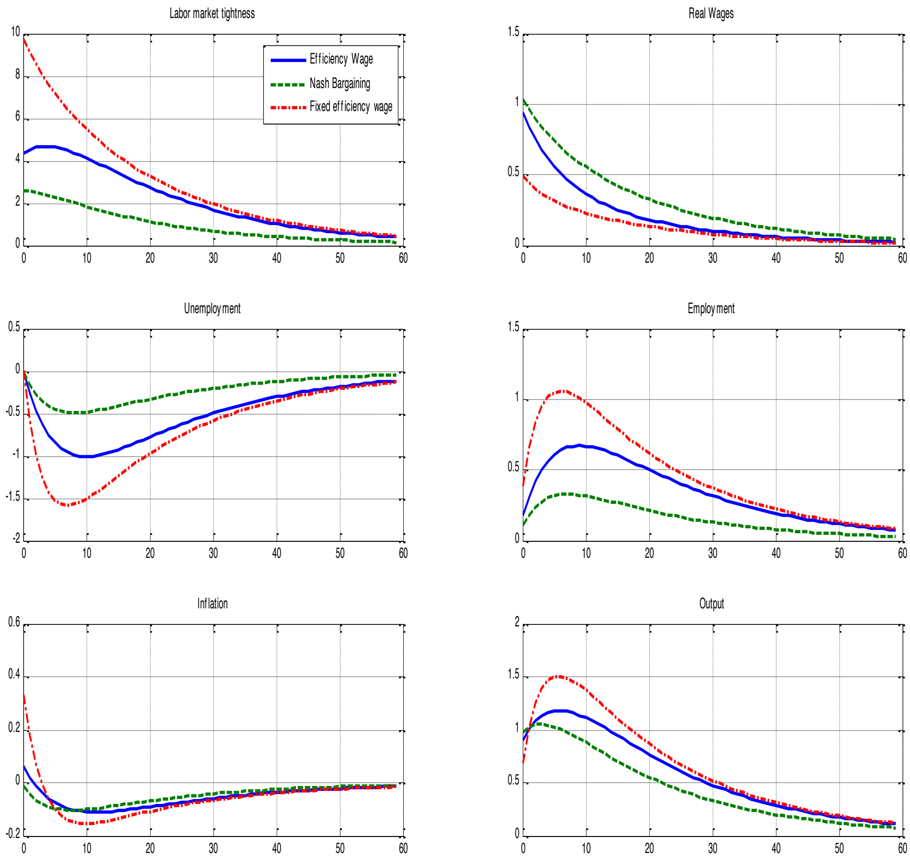
Figure 3. Impulse responses of selected variables to monetary policy shocks



Note: The solid line and the dashed line denote the impulse responses of the benchmark efficiency wage model and the Nash bargaining model, respectively. They depict the responses to a 1%p increase in the monetary policy rate. The time period is measured in quarters, and all the responses except that of inflation (measured in percentage points) are measured in percentages.

Figure 4. Impulse responses of selected variables to aggregate productivity shocks

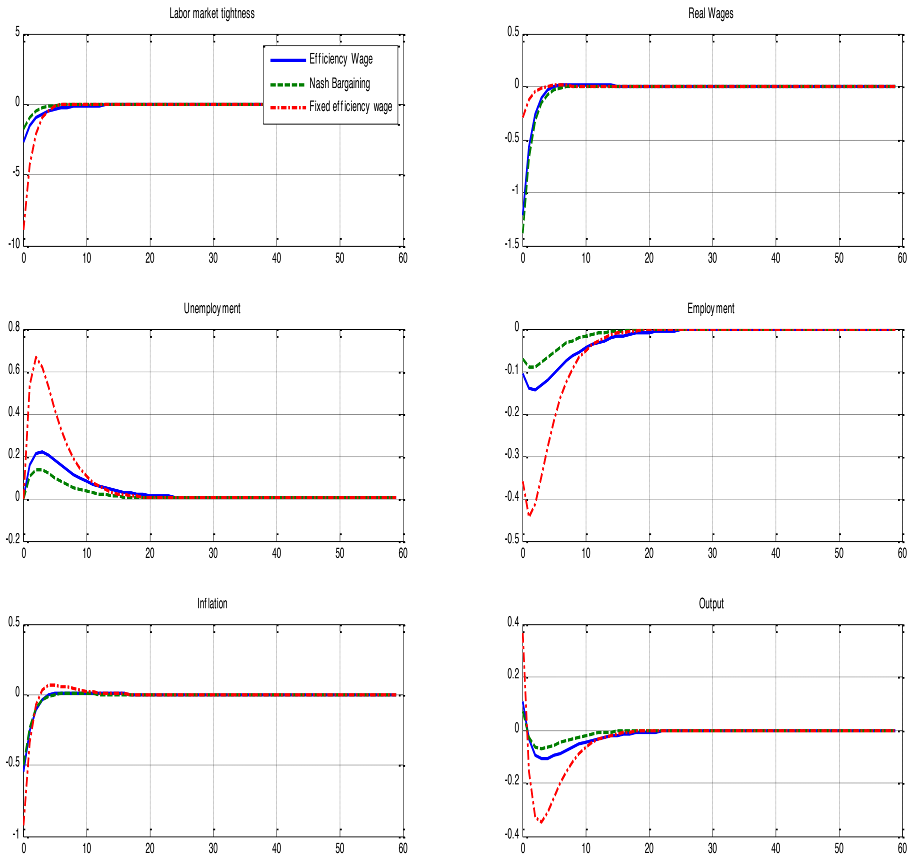
(fixed efficiency wage)



Note: The solid line and the dashed line denote the impulse responses of the benchmark efficiency wage model and the Nash bargaining model, respectively. The red dash-dot line denotes the responses of the fixed efficiency wage model. They depict the responses to a 1% increase in aggregate productivity.

Figure 5. Impulse responses of selected variables to monetary policy shocks

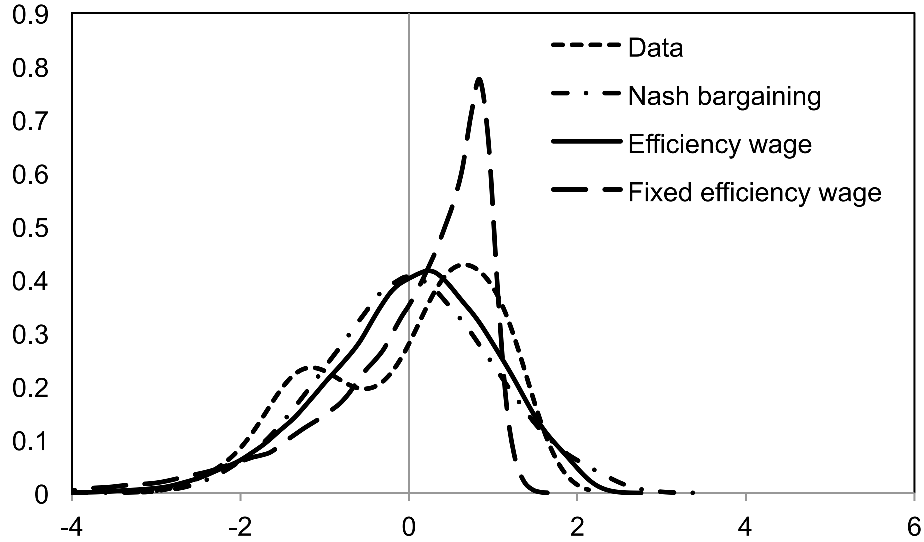
(fixed efficiency wage)



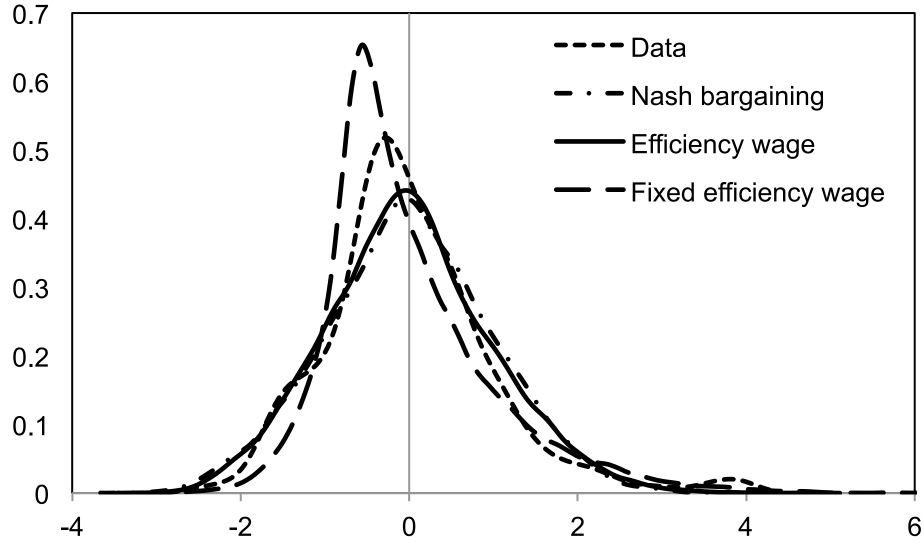
Note: The solid line and the dashed line denote the impulse responses of the benchmark efficiency wage model and the Nash bargaining model, respectively. The red dash-dot line denotes the responses of the fixed efficiency wage model. They depict the responses to a 1%p increase in the monetary policy rate.

Figure 6. Kernel density estimates (Gaussian kernel) for vacancy/unemployment ratio and inflation

Vacancy/unemployment ratio



Inflation



Note: The sample period for the data is 1964Q1~2011Q4. All data series are detrended using an HP filter with a smoothing parameter of 10^5. For proper scaling, all the series are standardized before estimating kernel density. Thus, the measurement unit on the x-axis is one standard deviation of each corresponding variable.

Endnotes

1 For example, see Dickens et al. (2007) for the detailed results of a related international survey.

2 Many other studies have documented similar cyclical asymmetry; see, for example, Neftci (1984), Sichel (1993), McKay and Reis (2008), and Barnichon (2012).

3 In contrast to firms, observing their own effort level, workers can infer the realized idiosyncratic shock in an ex post manner.

4 Changing the steady-state employment rate does not affect the qualitative nature of our model results.

5 Note that this level of the steady-state ratio lies between the two extremes among previous related studies: Shimer's (2005), $w^{\mu} / \bar{w} \,\mathrm{B}\, 0.4$, and Hagedorn and Manovskii's (2008), $w^{\mu} / \bar{w} \,\mathrm{B}\, 0.977$.

6 In fact, the ratio of non-market utility to the steady-state wage level in the efficiency wage economy, $w^{\mu} / \bar{w} \,\mathrm{B}\, 0.566$, is lower than the calibrated value $w^{\mu} / \bar{w} = 0.6$ for the standard Nash bargaining economy. This is because the introduction of downward wage rigidity eventually raises the steady-state level of real wages.

7 Note also that our model does not allow for endogenous separation.

8 Krause and Lubik (2007) also report a negative correlation between output and inflation, although its magnitude is small.

9 We exclude eight industries from our analysis because their data are missing for some recent periods due to the revision of the SIC system in 1997 and 2002. Thus, we employ the data of a total of 451 industries for our analysis.

10 Note that there is no significant relation between the intensity of efficiency consideration and the skewness (and volatility) of sectoral wages per hour (not reported). This is consistent with the fact that the real wage itself does not exhibit any significant asymmetry in our benchmark model, even though the real wage rigidity is the only source of asymmetry in the model.