Strategic Wage Bargaining, Labor Market Volatility, and Persistence

Matthias S. Hertweck

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Matthias S. Hertweck[†]

University of Konstanz & IfW

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Abstract

This paper modifies the standard Mortensen-Pissarides model in order to explain the cyclical behavior of vacancies and unemployment. The modifications include strategic wage bargaining and convex labor adjustment costs. We find that this setup replicates the cyclical behavior of both labor market variables remarkably well. First, we show that the model with strategic wage bargaining matches closely the volatility of vacancies and unemployment. Second, the introduction of convex labor adjustment costs makes both variables much more persistent. Third, our analysis indicates that these two modifications are complementary in generating labor market volatility *and* persistence.

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1 Introduction

The Mortensen-Pissarides job search and matching model[1] has become the standard theory of equilibrium unemployment. Moreover, starting with Merz (1995), Andolfatto (1996) and den Haan et al. (2000), several authors have shown that the inclusion of labor market frictions improves the propagation mechanism of standard real-business-cycle models considerably. Recently, however, the job matching model has come under criticism. Following the influential work of Shimer (2005), a large literature has emerged which has shown that the job matching model cannot replicate the cyclical behavior of its two central variables – vacancies and unemployment.

In particular, Shimer (2005) emphasizes that the job matching model generates insufficient volatility of vacancies and unemployment at the business cycle frequencies. Indeed, Shimer (2005) challenges not the job search and matching approach itself, but rather the commonly-used Nash (1953) bargaining assumption for wage determination. This approach postulates that the household and the firm divide the mutual surplus period-by-period according to a constant sharing parameter. This implies that the wage bill per worker is almost as elastic as the underlying productivity shock, giving firms only little incentive to adjust the stock of employment. For this reason, Shimer (2005) proposes to consider alternative bargaining assumptions that might deliver real wage rigidity. In a related article, Shimer (2004) provides evidence that real wage rigidity might amplify the volatility of vacancies and unemployment substantially.

Furthermore, Fujita (2004) demonstrates that vacancies in the job matching model are not sufficiently persistent. This artifact follows from firms' hiring behavior in the job matching model with linear vacancy posting costs. In response to a positive technology shock, firms anticipate the sharp and lasting rise in hiring costs and adjust employment instantaneously. Hence, vacancies spike on impact, but fall back half way only one period later. Contrary to this pattern, several authors[2] have found ample evidence that the impulse response function of vacancies displays a marked hump-shape, peaking with several quarters delay. Fujita & Ramey (2007) address this issue by introducing a sunk cost for the creation of new job positions. This modification improves the persistence of vacancies remarkably. Moreover, the impulse response function of vacancies shows a distinct hump-shape.

The main aim of this paper is to replicate the cyclical behavior of vacancies and unemployment along both dimensions – volatility *and* persistence. Therefore, we modify the standard job matching model in two ways. First, we adopt strategic wage bargaining as introduced into the literature by Hall & Milgrom (2008). In contrast to (static) Nash bargaining, strategic wage bargaining assumes that wages are determined by a Rubinstein (1982) game of alternating offers. This approach accounts for the dynamic and interactive character of wage negotiations. The main difference between Nash bargaining and strategic wage bargaining lies in the players' threat points. Under Nash bargaining, both players' threat points are determined by their respective outside alternative, i.e. the value of labor market search. Under strategic wage bargaining, however, the prospective mutual surplus gives both players strong incentives to hold-up the bargaining process until an agreement is reached. Thus, both players' threat points are determined by their respective value of bargaining. As argued by Hall & Milgrom (2008), the value of bargaining is much less sensitive to current labor market conditions than the outside alternative. In our benchmark model, strategic wage bargaining reduces the elasticity of the wage bill per worker by half. As a consequence, the elasticity of the net flow value of the marginal match rises enormously, providing firms much stronger incentives to hire new workers in economic upswings. In this way, strategic wage bargaining gives an endogenous explanation for the observed high degree of labor market volatility.

Second, we combine strategic wage bargaining with convex labor adjustment costs (Gertler & Trigari 2009). In contrast to linear vacancy posting costs, firms' hiring costs now are determined by the number

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[1] See Mortensen & Pissarides (1999) as well as Yashiv (2007) for comprehensive surveys.
[2] See Blanchard et al. (1989), Fujita (2004), Braun et al. (2009), as well as Ravn & Simonelli (2008), among others.

of vacancies that are *filled*, and not by the number of vacancies that are *posted.* Further, firms' hiring costs depend negatively on the current employment level. This implies that marginal matching costs are no longer a function of market tightness, but of the gross hiring rate. In contrast to market tightness, the gross hiring rate is much less elastic and much less persistent with respect to technology shocks. The altered behavior of marginal matching costs removes firms' incentives to adjust employment instantaneously. Instead, the convex shape of the labor adjustment cost function gives firms strong incentives to smooth their hiring activities. For this reason, the impulse response function of vacancies in our benchmark model shows a pronounced hump-shape, peaking several quarters after the shock. Consequently, the introduction of convex labor adjustment costs makes vacancies much more persistent, confirming the findings of Yashiv (2006).

Apart from that, we notice that strategic wage bargaining and convex labor adjustment costs are complementary in generating labor market volatility *and* persistence. This interesting result stems from the specification of the hiring cost function. Following Gertler & Trigari (2009), we assume that firms' hiring costs depend negatively on the employment level. Hence, convex labor adjustment costs open a second channel through which strategic wage bargaining amplifies labor market volatility. On the one hand, strategic wage bargaining enhances the volatility of employment by reducing the elasticity of wages. On the other hand, the larger the stock of employment, the lower are the firms' hiring costs. As a result, the introduction of convex labor adjustment costs generates not only more persistence, but also more volatility in the labor market.

Furthermore, we introduce the modified job matching model into a real model of the business cycle (Andolfatto 1996). This seems advantageous, given that this framework allows for a proper calibration of the factor income shares and small (accounting) profits (Hornstein et al. 2005). As demonstrated by Hagedorn & Manovskii (2008), profits have to be small in order to leverage a given productivity shock into large labor market fluctuations. In this context, Mortensen & Nagypál (2007) have shown that the impact of strategic wage bargaining on the volatility of vacancies and unemployment increases considerably once physical capital is considered.

Finally, we find that our setup gives rise to two distortionary effects. In the presence of convex labor adjustment costs, social optimality requires that the wage bill per worker is equal to the household's outside alternative. In contrast, we assume that (*i*) the wage bill per worker is independent of the fluctuations in household's outside alternative and (*ii*) firms' bargaining power is smaller than unity. This implies that firms' private gains from labor market search are generally smaller than their social contribution. Consequently, the dynamic behavior of the wage bill per worker is not socially optimal (Hosios 1990). For this reason, we compute the market solution to our setup, based on the model of Cheron & Langot (2004).

The remainder of this paper is organized as follows. Section 2 presents the model environment. Section 3 calibrates the model and evaluates its quantitative performance against U.S. data. Section 4 concludes.

2 The Model Environment

2.1 Labor Market Flows

The Mortensen-Pissarides job search and matching model presumes that search on the labor market is frictional. These frictions are represented by a Cobb-Douglas matching function. This function relates aggregate job matches m_t to the number of vacancies that are posted v_t and the search effort of the unemployed $e(1 - n_t)$:

$$m_t(v_t, (1 - n_t)) = \chi v_t^\alpha (e(1 - n_t))^{1-\alpha} \leq \min[v_t, (1 - n_t)], \tag{1}$$

where the effort $e > 0$ ("hours") per unemployed job searcher is taken to be constant. The ratio between vacancies and unemployed job searchers measures the tightness of the labor market. Moreover, we assume that the matching function is linearly homogeneous. Hence, the vacancy filling rate $q(\gamma_t)$ and the job finding rate $q(\gamma_t)\gamma_t$ depend solely on the value of market tightness γ_t:

$$q(\gamma_t) \quad \equiv \quad \frac{m_t}{v_t} = \chi e^{1-\alpha} \left(\frac{(1 - n_t)}{v_t} \right)^{1-\alpha}, \tag{2}$$

$$q(\gamma_t)\gamma_t \quad \equiv \quad \frac{m_t}{(1 - n_t)} = \chi e^{1-\alpha} \left(\frac{v_t}{(1 - n_t)} \right)^{\alpha}. \tag{3}$$

These ratios give the expected return on labor market search for firms and the unemployed, respectively. One can observe that the tighter the labor market, the longer the expected time to fill a vacancy, but the shorter the expected search for a job (and vice versa). However, households and firms do not internalize the effect of their search activities on the aggregate return rates. This behavior causes congestion externalities on both market sides.

We assume that new job matches m_t are formed at the end of each period. Simultaneously, a fraction of preexisting jobs is terminated. Consistent with the results of Shimer (2007), we assume the job destruction rate σ to be constant. Consequently, the law of motion for the aggregate employment level is given by:

$$n_{t+1} = (1 - \sigma)n_t + m_t. \tag{4}$$

2.2 The Problem of the Household

The representative household consists of a continuum of individuals who insure each other completely against idiosyncratic employment risk. The share of employed household members, n_t, works l_t "hours" per period on the job while the share $1 - n_t$ (the unemployed) searches e "hours" on the labor market. Both activities affect utility negatively as they reduce the amount of leisure. We assume the following per period utility function:

$$u^N(c_t^N, 1 - l_t) \quad = \quad \ln(c_t^N) + \phi_1 \frac{(1 - l_t)^{1-\eta}}{1 - \eta},$$

$$u^U(c_t^U, 1 - e) \quad = \quad \ln(c_t^U) + \phi_2 \frac{(1 - e)^{1-\eta}}{1 - \eta}.$$

The parameter $\phi_i, i = 1, 2$ captures the fact that the valuation of leisure depends on the employment status. Each employed household member earns the real wage rate w_t per hour l_t. Hence, $n_t w_t l_t$ constitutes the labor income of the representative household. In addition, households receive dividends remitted by firms π_t and rental income $r_t k_t$ from perfectly competitive capital markets. The state space of the household is given by the set $\Omega_t^H = \{k_t, n_t\}$. Thus, the maximization problem of the representative household can be formulated as:

$$\mathcal{W}(\Omega_t^H) \quad = \quad \max_{c_t^U, c_t^N, k_{t+1}} \left\{ n_t u^N(c_t^N, 1 - l_t) + (1 - n_t)u^U(c_t^U, 1 - e) + \right.$$

$$\left. \beta E_t \left[\mathcal{W} \left(\Omega_{t+1}^H \right) \right] \right\}, \tag{5}$$

s.t.

$$k_{t+1} \quad = \quad (1 - \delta + r_t)k_t + \pi_t + n_t w_t l_t - n_t c_t^N - (1 - n_t)c_t^U, \tag{6}$$

$$n_{t+1} \quad = \quad (1 - \sigma)n_t + q(\gamma_t)\gamma_t(1 - n_t). \tag{7}$$

Here, equation (6) is the budget constraint. Equation (7) is the law of motion for the household's employment share. Provided stochastic processes for $\{w_t, r_t, l_t, \pi_t, q(\gamma_t)\gamma_t \mid t \geq 0\}$ and a set of initial conditions $\{k_0, n_0\}$, the representative household chooses contingency plans $\{c_t^U, c_t^N, k_{t+1} \mid t \geq 0\}$ that maximize its expected discounted utility. These choices have to satisfy following first order conditions:

$$c_t^N : \lambda_t = u_1^N(c_t^N, 1 - l_t), \tag{8}$$

$$c_t^U : \lambda_t = u_1^U(c_t^U, 1 - e), \tag{9}$$

$$k_{t+1} : \lambda_t = \beta E_t[\lambda_{t+1}(1 - \delta + r_{t+1})]. \tag{10}$$

The first order conditions (8) and (9) show that perfect income insurance against idiosyncratic employment risk allocates the same consumption level to employed and unemployed workers. Equation (10) gives the familiar Euler equation for consumption.

2.3 The Problem of the Firm

Output is produced by firms that use capital k_t and labor hours $(n_t l_t)$ as input factors. The production function is taken to be Cobb-Douglas with constant returns to scale. This implies that the model has a representative firm. We assume that total factor productivity a_t is subject to an exogenous shock specified by the following autoregressive process:

$$\ln(a_t) = (1 - \rho)\ln(\bar{a}) + \rho \ln(a_{t-1}) + \epsilon_t, \text{ with } \epsilon_t \sim \mathcal{N}(0, \sigma_\epsilon^2) \text{ and } iid. \tag{11}$$

The specification of the firm's cost function follows Gertler & Trigari (2009). The firm incurs rental costs of capital $r_t k_t$, aggregate wage payments $n_t w_t l_t$, and labor adjustment costs ψ_t:

$$\psi(m_t, n_t) = \frac{\kappa}{2} \frac{m_t^2}{n_t} \tag{12}$$

In contrast to the standard specification, labor adjustment costs are determined by the squared number of new job matches m_t^2, the employment level n_t, and a constant scale parameter $\kappa/2$.[3] Consequently, firms' labor adjustment costs are determined by the number of vacancies that are *filled*, and not by the number of vacancies that are *posted*. In other words, vacancy posting *per se* is costless. In addition, notice that firms take the aggregate vacancy filling rate $q(\gamma_t)$ as given. Hence, from the perspective of the representative firm, the number of new job matches $m_t = q(\gamma_t)v_t$ is linear in vacancies.

Moreover, we assume that the representative firm is large in the sense that it has many workers, and that it is large enough to eliminate all uncertainty about n_{t+1}. This ensures that all firms in the model remain of the same size (Rotemberg 2008). However, the representative firm in our model is small in the sense that it is competitive. For this reason, the firm takes not only the aggregate vacancy filling rate, but also the wage bill per worker, $w_t l_t$, as given.[4] The state space of the firm is given by the set $\Omega_t^F =$

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[3]Several recent studies (Nilsen et al. 2007, King & Thomas 2006, Merz & Yashiv 2007) provide evidence for the empirical relevance of convex adjustment cost functions at the macro level.

[4]In words, the representative firm does not internalize the impact of its hiring activities on the expected wage bill per worker $(\partial w_{t+1} l_{t+1})/(\partial n_{t+1}) = 0$. Nevertheless, the firm anticipates the future wage bill per worker $w_{t+1} l_{t+1}$ correctly. See Section 2.5.1 for more information.

$\{n_t\}$. Thus, the representative firm's problem can be formulated as:

$$\mathcal{V}(\Omega_t^F) = \max_{k_t, v_t} \left\{ y_t - n_t w_t l_t - r_t k_t - \frac{\kappa}{2} \frac{m_t^2}{n_t} + \beta E_t \left[(\lambda_{t+1}/\lambda_t) \mathcal{V}(\Omega_{t+1}^F) \right] \right\}, \tag{13}$$

s.t.

$$y_t = a_t k_t^\theta (n_t l_t)^{(1-\theta)}, \tag{14}$$

$$n_{t+1} = (1-\sigma)n_t + q(\gamma_t)v_t. \tag{15}$$

Given stochastic processes for $\{a_t, w_t, r_t, l_t, q(\gamma_t) \mid t \geq 0\}$ and an initial condition for n_0, the representative firm chooses contingency plans $\{k_t, v_t, n_{t+1} \mid t \geq 0\}$ that maximize the expected present value of the dividend flow. The first order conditions are given as:

$$k_t : r_t = \theta \frac{y_t}{k_t}, \tag{16}$$

$$n_{t+1} : \kappa x_t = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \left((1-\theta) \frac{y_{t+1}}{n_{t+1}} - w_{t+1} l_{t+1} + \frac{\kappa}{2} x_{t+1}^2 + (1-\sigma)\kappa x_{t+1} \right) \right], \tag{17}$$

where the gross hiring rate m_t/n_t is denoted by x_t. Equation (16) shows the familiar relation between the real interest rate and the marginal product of capital under perfectly competitive capital markets. The hiring condition (17) states that the representative firm posts the optimal number of job vacancies v_t that equalizes expected marginal hiring costs κx_t (the left hand side) with the expected present value of the marginal match in the future (the right hand side). The expected present value of the marginal match depends on the marginal product per worker $(1-\theta)(y_{t+1}/n_{t+1})$, the expected wage bill per worker $w_{t+1} l_{t+1}$, expected savings on *adjustment* costs $(\kappa/2)x_{t+1}^2$, and expected savings on *hiring* costs $(1-\sigma)\kappa x_{t+1}$. Savings on *adjustment* costs capture the fact that each marginal match increases the stock of employment in the next period, irrespective of when the match is terminated. On the contrary, savings on *hiring* costs are only realized if the match survives the following period.

2.4 The Resource Constraint

The following equation gives the resource constraint of our economy. The resource constraint postulates that output is divided into consumption, gross investment and labor adjustment costs:

$$y_t = c_t + k_{t+1} - (1-\delta)k_t + \frac{\kappa}{2} \frac{m_t^2}{n_t}. \tag{18}$$

2.5 Wage Determination

2.5.1 The Bargaining Set

Frictions in the labor market create a prospective mutual surplus between firm-worker matches. This surplus equals the value added of the match compared to the payoff of both parties in the labor market. Following Pissarides (2000, chapter 3), we assume that the wage bill per worker $w_t l_t$ is determined for each match separately while wages in all other matches are taken as given. Hence, the relevant surplus share of the household and the firm, respectively, is determined by the marginal job match:

$$\mathcal{W}_2(\Omega_t^H) = \left\{ \lambda_t(w_t l_t + c_t^U - c_t^N) + (1-\sigma)\beta E_t \left[\mathcal{W}_2(\Omega_{t+1}^H) \right] \right\} - \\ \left\{ u^U(c_t^U, 1-e) - u^N(c_t^N, 1-l_t) + q(\gamma_t)\gamma_t \beta E_t \left[\mathcal{W}_2(\Omega_{t+1}^H) \right] \right\}, \tag{19}$$

$$\mathcal{V}_1(\Omega_t^F) = (1-\theta)F_{2,t} l_t - w_t l_t + \frac{\kappa}{2} x_t^2 + (1-\sigma)\beta E_t \left[(\lambda_{t+1}/\lambda_t) \mathcal{V}_1(\Omega_{t+1}^F) \right]. \tag{20}$$

The surplus share of the household $\mathcal{W}_2(\Omega_t^H)$ equals the difference between the value of employment and the value of unemployment.[5] The value of employment is made up of the sum of the wage bill per worker and household's expected present value of the match in the future. The value of unemployment, i.e. household's outside alternative, consists of the current utility gain from leisure and household's continuation payoff from labor market search. The surplus of the firm $\mathcal{V}_1(\Omega_t^F)$ is composed of (*i*) the marginal product per worker, (*ii*) the wage bill per worker, (*iii*) savings on *adjustment* costs, and (*iv*) the expected present value of the match in the future. A non-arbitrage condition ensures that the outside alternative of the firm (i.e. the ex-ante value of an unfilled vacancy) is zero. The sum of the marginal product per worker, i.e. the marginal product per "hour" $F_{2,t}$ times "hours worked" h_t, and savings on adjustment costs $(\kappa/2)x_t^2$ is defined as gross flow value of the marginal match. Given that the weight of the marginal match is small, both parties take the gross flow value of the marginal match as given during the bargaining process.

Thus, the mutual surplus S_t of the marginal firm-worker match (in units of the consumption good) is given as the sum of the two shares:

$$S_t = (\mathcal{W}_2(\Omega_t^H)/\lambda_t) + \mathcal{V}_1(\Omega_t^F). \tag{21}$$

The allocation of the mutual surplus between the household and the firm determines the wage bill per worker $w_t l_t$. In order to satisfy individual rationality, the equilibrium wage bill per worker has to make each party at least indifferent between accepting the contract and the forgone outside alternative of continued labor market search. We obtain the reservation wage bill (per worker) of the household and the firm, respectively, by setting the surplus share equal to zero. Equation (19) shows that the reservation wage bill of the household $(wl)_{min}$ is given by the value of unemployment *less* household's expected value of the match in the future:

$$(wl)_{min} = \frac{1}{\lambda_t}\Big\{ u(c_t^U, 1-e) - u(c_t^N, 1-l_t) + q(\gamma_t)\gamma_t \beta E_t\left[\mathcal{W}_2(\Omega_{t+1}^H)\right] -$$
$$(1-\sigma)\beta E_t\left[\mathcal{W}_2(\Omega_{t+1}^H)\right]\Big\}. \tag{22}$$

Analogously, the reservation wage bill of the firm $(wl)_{max}$ is defined as the gross flow value of the marginal match *plus* firm's expected present value of the marginal match in the future:[6]

$$(wl)_{max} = (1-\theta)F_{2,t}l_t + \frac{\kappa}{2}x_t^2 + (1-\sigma)\beta E_t\left[(\lambda_{t+1}/\lambda_t)\mathcal{V}_1(\Omega_{t+1}^F)\right]. \tag{23}$$

These two reservation wage bills constitute the lower and the upper bound of the bargaining set which contains all feasible wage bills (Malcomson 1999). In other words, the equilibrium value of the wage bill per worker is indeterminate. Therefore, we assume that wages are determined by an *ex-post* bargaining game between the household and the firm. In particular, we consider two alternative approaches – standard Nash (1953) bargaining and a Rubinstein (1982) game of alternating offers. In addition, the wage bill per worker is subject to continuous renegotiation whenever new information arrives. In our discrete-time model, this implies that new matches are formed at the end of each period. However, bargaining does not start until the beginning of the next period when the new state of technology can be observed.

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[5] With perfect insurance against unemployment, the level of consumption is independent of the employment status ($c_t^N = c_t^U$).

[6] Note that firms treat hiring costs as sunk. Hence, a firm would generate negative profits if it accepted a wage bill per worker close to $(w_t l_t)_{max}$ (Hall & Milgrom 2008). However, this possibility is ruled out by our calibration.

2.5.2 The Optimal Wage Contract

For the standard job search and matching model (with linear vacancy posting costs), Hosios (1990) has established a necessary and sufficient condition under which both congestion externalities just offset one another.[7] As mentioned above, the congestion externalities arise from the fact that firms take the aggregate vacancy filling rate $q(\gamma_t)$ as given when deciding upon the optimal number of vacancies v_t. Thus, from the firm's perspective, the number of new job matches $m_t = q(\gamma_t)v_t$ is linear in vacancies. Accordingly, the firm's private gain of the marginal vacancy is given as:

$$\kappa = q(\gamma_t)\mathcal{V}_1(\Omega_{t+1}^F). \tag{24}$$

In contrast, the social planner solution accounts for the fact that new job matches are a concave function of vacancies (see equation 1). Hence, the social planner internalizes that the vacancy filling rate decreases in the number of posted vacancies. Therefore, the marginal vacancy yields following social benefit (see A.1):

$$\kappa = \alpha q(\gamma_t)S_{t+1}. \tag{25}$$

Social optimality requires that firms' private gains from search effort equals their social benefit. Consequently, firms' incentives to post vacancies are efficient if and only if

$$\mathcal{V}_1(\Omega_t^F) = \alpha S_t \tag{26}$$

holds. In words, the Hosios condition postulates that the private gain per match equals the share α of the mutual surplus S_t per match.

In contrast, if firms internalized the congestion effect on the aggregate vacancy filling rate correctly, social optimality would require firms to gain the entire mutual surplus per match, i.e.:

$$\mathcal{V}_1(\Omega_t^F) = S_t. \tag{27}$$

However, if firms gained the entire mutual surplus, even though they did not internalize the congestion effects, the private gains from the marginal vacancy would be larger than the social benefit. Thus, firms would have an incentive to "over-hire". In order to avoid the over-hiring effect, the Hosios condition requires that firms gain only the share α of the mutual surplus per match.

Under convex labor adjustment costs, on the contrary, firms' hiring costs depend on the number of vacancies that are filled $q(\gamma_t)v_t$, and not on the number of vacancies that are posted v_t. Consequently, the congestion externalities bias not only firms' private gains, but also – to the same extent – firms' hiring costs. This removes firms' incentives to over-hire, even if they gained the entire mutual surplus per match. Under these circumstances, the congestion externalities exactly offset each other if and only if the entire mutual surplus per match accrues to the firms (see A.2), i.e. if equation (27) holds.

2.5.3 Nash Bargaining

Nash bargaining has become the standard method for wage determination in job matching models. This approach postulates a number of axioms and derives a unique equilibrium sharing rule for the mutual surplus. In addition, Nash (1953) proves that exactly the same solution can be generated by a simultaneous one-shot game. This bargaining game presumes that both parties threaten each other to terminate the bargain unilaterally rather than to conclude an agreement. Subsequently, both parties reveal their demands simultaneously. If these demands are not compatible, the match is broken up

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[7]Merz (1995) has generalized the Hosios condition for dynamic models.

and both players gain only their respective outside alternative, i.e. they return to labor market search. However, given perfect information and rational players, Nash (1953) shows that both parties agree on following unique sharing rule:

$$w_t l_t = \arg\max_{w_t l_t} \left\{ \left(\mathcal{W}_2(\Omega_t^H)/\lambda_t \right)^{1-\xi} \left(\mathcal{V}_1(\Omega_t^F) \right)^{\xi} \right\}, \tag{28}$$

where the original version assumes symmetric bargaining power ($\xi = 1/2$). The generalized version, however, allows any value for ξ in the interval $(0,1]$.[8] Hence, the solution to our model is given by the wage bill per worker which maximizes the weighted product of both parties' surplus shares. This sharing rule allocates period-by-period a constant share of the mutual surplus to each of the two parties:

$$\xi \left(\mathcal{W}_2(\Omega_t^H)/\lambda_t \right) = (1-\xi)\mathcal{V}_1(\Omega_t^F). \tag{29}$$

Thus, in the case of linear vacancy posting costs, the Nash solution generates the socially optimal bargaining outcome if and only if firms' bargaining power ξ coincides with the matching elasticity of vacancies α. With convex labor adjustment costs, however, social optimality requires that the entire match surplus S_t accrues to the firms (i.e. $\xi = 1$). This implies that the wage bill per worker $w_t l_t$ is equal to the household's outside alternative. Nevertheless, we consider the general case $\xi \in (0,1]$ throughout our analysis.

The resulting wage bill per worker equals the weighted average of the gross flow value of the marginal match and household's outside alternative:

$$w_t l_t = (1-\xi)\left[(1-\theta)\frac{y_t}{n_t} + \frac{\kappa}{2}x_t^2 \right] + \xi \left[\frac{u_t^U - u_t^N}{\lambda_t} + \frac{(1-\xi)}{\xi}\frac{m_t \kappa x_t}{(1-n_t)} \right]. \tag{30}$$

Household's outside alternative depends on the flow value of unemployment, i.e. the current utility gain in leisure $(u^U - u_t^N)/\lambda_t$, and the continuation payoff from labor market search. The latter, in turn, depends on the current job finding rate $m_t/(1-n_t)$ times her adjusted share $(1-\xi)/\xi$ of the expected present value of a *prospective* future match κx_t. Consequently, household's outside alternative is very sensitive to current labor market conditions.

Notably, the expected present value of the *current* match (see equation 19 and equation 20) does not enter equation (30). This is due to the fact that the mutual surplus is always allocated according to the same sharing rule (28). Hence, both expressions widen the bargaining set proportionally, but have no impact on the bargaining outcome. We define the replacement rate b as the ratio between the flow value of unemployment and the gross flow value of the marginal match.

2.5.4 Strategic Wage Bargaining

Hall & Milgrom (2008) highlight that Nash bargaining abstracts from the dynamic and interactive character of wage negotiations. For that reason, they argue that wages in the job matching model should be determined by a Rubinstein (1982) game of alternating offers. In particular, Hall & Milgrom (2008) emphasize the crucial importance of the prospective mutual surplus. The mutual surplus gives both players strong incentives to conclude the bargaining successfully. Hence, neither party seriously considers breaking up the bargaining process completely. Given perfect information, this implies that threatening to terminate the bargaining process is not a credible option (Schelling 1960). Instead, both parties threaten each other to reject unfavorable demands. Since both parties are impatient, this strategy causes costly delays and gives them the incentive always to make acceptable demands. Consequently, once a firm-worker match has successfully been formed, it is the value of bargaining – and not the outside

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[8]Note that equation 30 and equation 31 are not defined for $\xi = 0$.

alternative – that determines the relevant surplus.

In their analysis, Hall & Milgrom (2008) focus on the limiting case in which the time interval between successive offers decreases to zero. Under these circumstances, they show that both parties agree on the equilibrium wage bill per worker instantaneously. This allows us to approximate the solution to the dynamic bargaining game by a corresponding static game (Binmore et al. 1986). The solution to this new game can be found by maximizing the weighted product of the two surplus shares – like in the standard Nash solution. However, the solution to this dynamic bargaining problem is inherently different from the Nash solution as the surplus of each party is no longer determined by the respective outside alternative, but by the losses associated with delays.

Following Hall & Milgrom (2008), we calibrate the dynamic bargaining model to the same steady state as the standard bargaining model. This simplifying assumption implies that the steady state value of bargaining coincides with the outside alternative.[9] Furthermore, Hall & Milgrom (2008) emphasize that the value of bargaining might depend less sensitively on *current* labor market conditions than the outside alternative. Thus, they take the value of bargaining to be time-invariant. For this reason, we replace all variables in equation (30) that derive from the outside alternative with their steady state values (denoted by an over line):

$$w_t l_t = (1 - \xi) \left[(1 - \theta) \frac{y_t}{n_t} + \frac{\kappa}{2} x_t^2 \right] + \xi \left[\frac{\bar{u}^U - \bar{u}^N}{\bar{\lambda}} + \frac{(1 - \xi)}{\xi} \frac{\bar{m} \kappa \bar{x}}{(1 - \bar{n})} \right]. \tag{31}$$

This sharing rule is equivalent to Nash bargaining with a constant outside alternative. Given that the outside alternative is typically pro-cyclical, the dynamic bargaining game generates a less elastic wage bill per worker than Nash bargaining. Consequently, the households' share of the surplus falls below $(1 - \xi)$ in economic upswings (and vice versa). Note that the wage bill per worker satisfies individual rationality as long as it remains within the bargaining set.

In summary, strategic wage bargaining gives rise to two distortionary effects. As discussed above, social optimality under convex labor adjustment costs requires that the wage bill per worker $w_t l_t$ is equal to the household's outside alternative. In contrast, we assume that (*i*) the wage bill per worker is independent of the fluctuations in household's outside alternative and (*ii*) firms' bargaining power ξ is generally smaller than unity, i.e. $\xi \in (0, 1]$. Hence, firms' private gains from search effort are generally smaller than their social contribution. In this case, the dynamic behavior of the wage bill per worker is not socially optimal (Hosios 1990).

2.6 Optimal Labor Effort

The model is closed with the condition for optimal labor effort l_t ("hours"). We assume that both parties have a joint interest to maximize the value of the mutual surplus S_t. Provided that the marginal product per "hour" $F_{2,t}$ is taken as given by both parties, the maximization problem of S_t with respect to l_t yields following condition:

$$(1 - \theta) \frac{y_t}{n_t l_t} = \frac{1}{\lambda_t} \frac{\phi_1}{(1 - l_t)^\eta}. \tag{32}$$

This condition determines how the wage bill per worker is split up into the real wage rate per "hour" w_t and "hours" per worker l_t.

2.7 Competitive Equilibrium

The competitive equilibrium is a set of allocations $\{c_t, k_{t+1}, v_t, n_{t+1}\}$ and prices $\{r_t, w_t\}$, such that:

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[9]Actually, if the value of bargaining coincided with the outside alternative, the respective player would be indifferent between delaying and terminating the bargain.

(**i**) employment relationships are governed by the matching function (1) and the law of motion of employment (4)

(**ii**) $\{c_t, k_{t+1}\}$ solves the household's problem (5) subject to the budget constraint (6) and the law of motion for its employment share (7)

(**iii**) total factor productivity follows the exogenous stochastic process (11)

(**iv**) $\{k_t, v_t\}$ solves the firm's problem (13) subject to the production technology (14) and the law of motion for its stock of employment (15)

(**v**) the resource constraint (18) holds and the perfectly competitive capital market clears

(**vi**) the wage bill per worker is determined either by Nash bargaining (30) or by strategic wage bargaining (31)

(**vii**) hours per worker maximize the mutual surplus (32)

(**viii**) an initial condition for the state space (k_0, n_0, z_0) is given

Consequently, the competitive equilibrium is defined by following conditions: (1), (4), (8), (9), (10), (11), (14), (16), (17), (18), either (30) or (31), and (32).

3 Model Evaluation

3.1 Calibration

We calibrate the model so that one period corresponds to a month. This seems advantageous given that, in the U.S., the job finding rate is very high. When we simulate the model, we time-aggregate the artificial data to quarterly frequencies in order to make them comparable to the U.S. aggregate time series. Table 1 summarizes the parameter values of our model.

Using data on aggregate income shares, Cooley & Prescott (1995) calibrate the production elasticities of capital ($\theta = 0.40$) and labor ($1 - \theta = 0.60$). We adopt their conventional values, even though the production elasticity of labor is slightly larger than the average labor share in our job matching model (0.58, see table 2). In addition, we set the monthly depreciation rate δ to match an annual rate of 10% (Kydland & Prescott 1982).

β is chosen to be consistent with a quarterly real interest rate of 1 percent. Following Juster & Stafford (1991), we set the steady state working time of employed household members to $\bar{l} = 1/3$ of their discretionary time endowment. Moreover, Barron & Gilley (1981) estimate that the typical unemployed primarily engaged in random job search (approximately one half of the sample) spends between 8 and 9 hours per week to contact potential employers. This corresponds to about 25% of the average working time $\bar{l}$. For the given specification of preferences (Andolfatto 1996), the elasticity of intertemporal substitution in labor supply is given as: $\nu = \eta^{-1}((1/\bar{l}) - 1)$. Blundell & Macurdy (1999) provide robust evidence that the value of ν for annual hours of employed men is between 0.1 and 0.3. For *employed* women, Blundell et al. (1988) and Triest (1990) estimate values in the same range. However, Browning et al. (1999) observe that leisure is more substitutable over shorter intervals than longer ones. Using monthly data on employed men, MaCurdy (1983) finds significantly higher elasticities ($0.3 - 0.7$). Hence, we choose ν equal to 0.5, which implies setting $\eta = 4$.

We calibrate the monthly job separation rate to 3.5% (Shimer 2007). This value implies that the average job duration is 2 1/2 years. Furthermore, the steady state unemployment rate is set to 10 percent (Hall 2005b). This measure includes the officially unemployed job searchers and the pool of

marginally attached non-participants (Jones & Riddell 1999). Thus, our calibration implies that the average job finding rate, $q(\overline{\gamma})\overline{\gamma}$, is equal to 0.32 (see table 2), which is consistent with the results of Hall (2005b). The monthly vacancy filling rate is set to match the quarterly value $q(\overline{\gamma}) = 0.71$ estimated by van Ours & Ridder (1992).[10] Based on the fact that per-period labor adjustment costs "are not much more than one percent of per-period payroll cost" (Hamermesh & Pfann 1996, p. 1278), we calibrate aggregate labor adjustment costs $\overline{\psi}$ equal to 1% of aggregate output. This value implies that the average replacement ratio $\overline{b}$ is equal to 63%. This value is somewhat larger than the upper bound ($\overline{b} = 40\%$) estimated by Shimer (2005). However, Shimer (2005) interprets b entirely as an unemployment benefit. In our model b includes also utility costs of working, e.g. leisure value of unemployment or the value of home production (Hagedorn & Manovskii 2008). Unfortunately, empirical evidence on the size of the leisure value of unemployment is scarce (Holmlund 1998). According to Costain & Reiter (2008), the upper bound of the utility costs of working is equal to 75%. Hence, our value seems reasonable.[11]

We calibrate the matching elasticity of unemployment to $\alpha = 0.5$. This value is within the plausible range $(0.5 - 0.7)$ proposed by Petrongolo & Pissarides (2001). In addition, we assume symmetrically distributed bargaining power, i.e. $\xi = 0.5$ (Svejnar 1986). Thus, as mentioned above, our model gives rise to two distortionary effects. On the one hand, we assume that the wage bill per worker is independent of the fluctuations in the household's outside alternative. On the other hand, firms' bargaining power ξ is strictly smaller than unity.[12] Consequently, their private gains from search effort are generally smaller than their social contribution (Hosios 1990). Nevertheless, we set $\alpha = \xi$ in order to facilitate comparison with the existing literature.

We calibrate the law of motion for the technology shock by setting the monthly autocorrelation coefficient ρ equal to 0.9830 and the standard deviation σ_ϵ equal to 0.0044. The monthly autocorrelation coefficient is chosen to match the conventionally used quarterly value of 0.95 (Cooley & Prescott 1995). Furthermore, we set the standard deviation of the monthly process so that the volatility of the time-aggregated Solow residual is in accordance with a standard-calibrated quarterly real business cycle model (Cooley & Prescott 1995).[13]

Notice that our calibration ensures that the reservation value of the firm $(\overline{wl})_{max}$ is larger than the reservation value of the household $(\overline{wl})_{min}$.

3.2 Results

This section examines the quantitative performance of the modified job matching model. We analyze how the chosen wage determination mechanism and the costs of labor adjustment, respectively, affect the dynamics of the model in response to technology shocks. Moreover, we highlight the interactions between both modifications.

We evaluate the model generated time series against quarterly U.S. data from 1964:1 to 2004:3. Most of the time series are from the Federal Reserve Bank of St. Louis (FRED®). In addition, we use the expanded unemployment series from Hall (2005b). From this data we construct a set of time series which corresponds to the variables in our model (see table 3 and table 4). We log and detrend all series using the Hodrick & Prescott (1997) filter assuming a smoothing parameter of 1600.

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[10] According to (Shimer 2005), the model allows the normalization of the vacancy filling rate. Nevertheless, we choose a meaningful value.

[11] In the model with linear vacancy posting costs, $\overline{\psi} = 0.01$ implies that the average replacement ratio is equal to 81%. This value is slightly larger than the upper bound ($\overline{b} = 75\%$) suggested by Costain & Reiter (2008), but still below the estimate $\overline{b} = 94\%$ of Hagedorn & Manovskii (2008). The choice for $\overline{b}$ is crucial, because a larger b decreases the surplus. Consequently, the higher the value of $\overline{b}$, the easier it is to leverage a given shock into labor market fluctuations.

[12] The social planner's problem is documented in A.1.

[13] Cooley & Prescott (1995) estimate the quarterly parameters ($\rho = 0.95, \sigma_\epsilon = 0.007$) assuming that the labor income share equals $1 - \theta$. In labor search models, this assumption holds only as an approximation.

Table 5 reports the well-known business cycle statistics of the U.S. labor market. In particular, we focus on the cyclical behavior of vacancies v and unemployment $1-n$. The data reveal that both variables are highly volatile and very persistent. In addition, vacancies are clearly pro-cyclical whereas unemployment is strongly counter-cyclical. Consequently, vacancies and unemployment are almost perfectly negatively correlated ($\rho_{VU} = -0.96$). Due to the strong persistence of both variables, we observe that the negative correlation between vacancies and unemployment remains also at leads and lags (Fujita 2004). Hence, the dynamic correlation structure between vacancies and unemployment follows a pronounced U-shape (see table 6 and figure 3). This pattern is known as the "dynamic Beveridge curve".[14] Furthermore, we observe that the wage bill per worker wl and output per worker y/n are only weakly correlated (see table 7).

We log-linearize the model around the non-stochastic steady state and solve for the recursive law of motion using the "Toolkit" from Uhlig (1998).[15] Corresponding to the U.S. data sample period, we simulate the model to 432 "monthly" data points. Subsequently, we transform the artificial data as described above and compute the statistics over 10.000 simulations.

3.2.1 Comparative Impulse Response Analysis

We now inspect the model's impulse responses to a one percent shock in total factor productivity. In particular, we explore the role of the chosen wage determination mechanism and the costs of labor adjustment, as well as the interactions between them. Figure 1 compares the impulse responses of the strategic bargaining model with convex labor adjustment costs (henceforth called the "benchmark model", denoted by a solid line), the Nash bargaining model with convex labor adjustment costs (henceforth called the "NB model", denoted by a dashed line), and the and the strategic wage bargaining model with linear vacancy posting costs (henceforth called the "LC model", denoted by a dotted line). The graphs depict the evolution of the relevant variables over 96 months (32 quarters).

The Benchmark Model The hiring condition (17) reveals that the pattern of cyclical employment adjustment is governed by two main determinants: First, the net flow value of the marginal match captures cyclical variations in the return to additional employment. Second, the structure of labor adjustment costs determines how fast and at what cost firms adjust employment over the business cycle. In the following, we focus on the impact of these two factors.

In response to a one percent technology shock, we observe that the gross flow value of the marginal match rises by about one percent. The elasticity of the wage bill per worker, in contrast, is significantly lower. This follows directly from strategic wage bargaining (see equation 31). Accordingly, the elasticity of the wage bill per worker is given by the elasticity of the gross flow value of the marginal match times the household's bargaining power $(1-\xi)$. As a result, the costs per worker increase much less than the gains. This generates an increase of about 17 percent in the net flow value of the marginal match, giving firms strong incentives to amplify employment adjustment over the business cycle.

In the case of convex labor adjustment costs, firms choose the optimal number of vacancies v_t such that expected marginal matching costs κx_t are equal to the expected present value of the marginal match. Due to the convex shape of ψ_t, new job matches m_t are much less elastic than the net flow value of the marginal match. Furthermore, the convex shape of ψ_t gives firms strong incentives to smooth hiring activities over several periods. For this reason, new job matches rise on impact by somewhat more than 4 percent and then remain well above their steady state value for the entire observation period. This continuous inflow of new job matches leads to a pronounced hump-shape in the impulse response

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[14]See, inter alia, Fujita & Ramey (2006) and the references therein.

[15]The above calibration ensures a unique and stable equilibrium.

function of employment, which peaks about 2 1/2 years after the shock. Consequently, the impulse response function of unemployment follows a distinct U-shape.

Moreover, the strong reaction in employment feeds back to the expected marginal matching costs. Given that employment is a state variable, the impulse response function of expected marginal hiring costs increases on impact by exactly the same amount as new job matches. In the following periods, however, the long-lasting increase in employment dampens marginal hiring costs. Hence, the impulse response function of marginal hiring costs converges relatively quickly to its steady state value. This pattern reinforces gradual and long-lasting hiring activities and, thus, might explain the remarkable slow convergence of new job matches.

Finally, we analyze the impulse response function of vacancies. As mentioned above, we assume that firms' hiring costs depend on the number of vacancies that are *filled*, and not on the number of vacancies that are *posted.* Therefore, firms always post the number of vacancies that is necessary to obtain the optimal number of new job matches. According to the aggregate matching function (see equation 1), the number of new job matches is given by the current level of unemployment and the number of vacancies that are posted. In response to a positive technology shock, firms face the following scenario: On the one hand, firms have to maintain a continuous inflow of new job matches. On the other hand, the impulse response function of unemployment decreases sharply over more than 2 1/2 years. This leads to a strong fall in the vacancy filling rate. The lower the vacancy filling rate, the more vacancies have to be posted in order to obtain the optimal number of new matches. For this reason, the impulse response function of vacancies increases on impact by about 10 percent. In the following periods, vacancies continue to rise and reach a maximum of 18 percent increase with 2 1/2 years delay. In words, the impulse response of vacancies follows a marked hump-shape. This pattern is found to be consistent with the data.[16]

The Impact of Strategic Wage Bargaining We now discuss the impulse responses of the "NB model". Under Nash bargaining, the elasticity of the wage bill per worker is not only determined by the gross flow value of the marginal match, but also by the household's outside alternative. Given that household's outside alternative is clearly pro-cyclical, we note that the elasticity of the wage bill per worker increases substantially. Hence, the wage bill per worker is nearly as elastic as the gross flow value of the marginal match. As a result, the costs per worker increase almost as much as the gains. This implies that the elasticity of the net flow value of the marginal match decreases enormously. Additionally, due to the hump-shape in the household's outside alternative, the net flow value of the marginal match is less persistent than in the benchmark model. This illustrates that Nash bargaining gives firms much less incentives to hire new workers than strategic wage bargaining.

In fact, we observe that firms' hiring activities decline dramatically. On impact, new job matches rise only by less than one percent and then fall back quickly to their steady state value. Thus, the impulse response of employment is substantially smaller. For the same reason, the U-shaped response of unemployment is much weaker. Moreover, due to the mild response of employment, the feedback effect from employment on lower expected marginal matching costs is almost not present.

The modest increase in matches, in conjunction with the weak reduction in unemployment, implies that the vacancy filling rate reduces only slightly. Consequently, vacancies rise on impact only by somewhat more than one percent, continue to increase slightly for about 3 quarters, and then return slow and monotone to their steady state value. For this reason, vacancies are much less elastic than in the benchmark model. Furthermore, we observe that the hump-shaped dynamics of the impulse response functions are less distinct.

We conclude that strategic wage bargaining amplifies the elasticity of employment, unemployment and vacancies enormously. Apart from that, the hump-shaped (U-shaped) response of vacancies (unem-

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[16]See Footnote 2 and the references therein.

ployment) is more distinct under Nash bargaining.

The Impact of Convex Labor Adjustment Costs   We now examine the impact of convex labor adjustment costs on the dynamic behavior of the labor market. Therefore, we compare the impulse responses of the benchmark model with the impulse responses of the "LC model". In both cases under consideration, the wage bill per worker is determined by strategic wage bargaining. We observe that the instantaneous elasticities of the gross flow value of the marginal match, household's outside alternative, and the wage bill per worker, respectively, are very similar. In contrast, the relative response of the net flow value of the marginal match in the LC model is significantly larger than in the benchmark model.[17] Consequently, one should expect that the LC model generates larger employment fluctuations.

On impact, the elasticity of new job matches in the LC model is about three times larger than in the benchmark model. In the following periods, however, firms' hiring activities decrease sharply. As a result, the impulse response function of employment peaks already after about 9 months. This is due to the modified hiring mechanism. Given linear vacancy posting costs, firms post vacancies in order to equalize expected marginal hiring costs $\kappa/q(\gamma_t)$ and the expected present value of the marginal match. In contrast to the benchmark model, expected marginal hiring costs in the LC model depend on the inverse vacancy filling rate $1/q(\gamma_t)$ and not on the gross hiring rate x_t. In response to the technology shock, the inverse vacancy filling rate increases by about 13 percent and then remains persistently well above its steady state value over the whole observation period. This behavior differs substantially from the rather moderate and temporary increase of the gross hiring rate in the benchmark model.

Since firms are forward looking, they anticipate the future fall in unemployment when deciding upon the optimal number of vacancies. The future fall in unemployment tightens the labor market and, thus, *raises* the expected marginal matching costs in the future. For this reason, firms post vacancies instantaneously as long as the number of unemployed job searchers is still high. This pattern makes it impossible for the LC model to generate a hump-shaped impulse response function of vacancies. Instead, vacancies spike on impact and fall back half way only one period later. This behavior is in sharp contrast to the empirical evidence.

In the benchmark model, however, the mechanism works in the other direction. Firms' expected marginal hiring costs depend on the gross hiring rate x_t. This implies that a high level of employment (i.e. a low level of unemployment) *lowers* expected marginal costs. In comparison to the inverse vacancy filling rate, the gross hiring rate is much less elastic *and* much less persistent. This removes firms' incentive to adjust employment instantaneously. On the contrary, it gives firms strong incentives to smooth hiring over a long period. Hence, the overall employment impact in the LC model is substantially lower than in the benchmark model.

The Interactions between Strategic Wage Bargaining and Convex Labor Adjustment Costs
So far, we have found that (*i*) strategic wage bargaining amplifies labor market fluctuations and (*ii*) convex labor adjustment costs account for hump-shaped impulse response functions. Indeed, beyond understanding how both modifications work in isolation, it is important to explore their interactions.

As discussed above, the impact of current labor market conditions on expected marginal matching costs depends crucially on the specification of firms' hiring costs. In the LC model, a tight labor market *raises* expected marginal matching costs. In the benchmark model, in contrast, a high level of employment *lowers* expected marginal matching costs. Consequently, strategic wage bargaining amplifies the elasticity of labor market variables through two channels. On the one hand, strategic wage bargaining dampens the cyclical fluctuations in the wage bill per worker. This stimulates firms' hiring activities. On the

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[17]Note that the absolute value of the net flow value of the marginal match in the benchmark model is about twice as large than in the LC model (see footnote 11).

other hand, the higher the stock of employment, the lower the costs of labor adjustment. Thus, the introduction of convex labor adjustment costs increases not only labor market persistence, but also its cyclical fluctuations.

Furthermore, we observe that labor market variables in the benchmark model are even somewhat more persistent than in the NB model. This is due to the fact that strategic wage bargaining removes the impact of the hump-shaped outside alternative. Hence, the net flow value of the marginal match is more persistent, translating into more persistent labor market fluctuations. In summary, we note that strategic wage bargaining and convex labor adjustment costs are complementary in generating elastic *and* persistent labor market responses.

Robustness of the Hump-Shaped Vacancy Responses   In the following, we examine whether the hump-shaped impulse response function of vacancies in the benchmark model is robust with respect to the two distortionary effects – strategic wage bargaining and the value of firms' bargaining power.

As shown in a previous paragraph, vacancies in the NB model are much less elastic than in the benchmark model. In addition, the hump-shape is flattened considerably.

Therefore, we evaluate the benchmark model with firms' bargaining power set to unity. On impact, vacancies rise by about 15 percent. This increase is about one and a half times higher than in the case of symmetrically distributed bargaining power. Moreover, vacancies display a marked hump-shape, albeit the hump is slightly weaker than in the benchmark model.

However, social optimality under convex labor adjustment costs requires that the wage bill per worker equals household's outside alternative. This condition is only satisfied if we assume Nash bargaining *and* if we set firms' bargaining power equal to unity. We now observe that vacancies increase on impact by about 7 percent, reach a maximum with about 3 quarters delay, and then return relatively quickly to their steady state value. These results indicate that the combination of both distortionary effects dampens the hump to some degree. Nevertheless, the hump-shaped pattern of vacancies is a robust result of our benchmark model.

3.2.2   Simulation Results

This section evaluates the benchmark model against U.S. data. Thereby, our analysis focuses on the cyclical behavior of vacancies and unemployment (table 5). In particular, we examine the model in terms of its capability to generate sufficient volatility *and* persistence in both variables.

The Benchmark Model   Strategic wage bargaining makes the wage bill per worker independent of fluctuations in household's outside alternative. Hence, the wage bill per worker (wl) is significantly less volatile than output per worker (y/n), giving firms strong incentives to expand their hiring activities in economic upswings. Thus, the benchmark model replicates closely the cyclical volatility of vacancies (v), unemployment ($1-n$) and market tightness (γ). This result is in line with the insight in Hall & Milgrom (2008): Strategic wage bargaining generates endogenous real wage rigidity. This increases the volatility of the net flow value of the marginal match. As a result, labor market variables become more volatile.

Furthermore, we note that vacancies, unemployment and market tightness are highly persistent. This can be ascribed to the modified hiring condition which alters the qualitative pattern of firms' hiring behavior. Consequently, the benchmark model generates hump-shaped responses in unemployment *and* vacancies. For the same reason, the benchmark model is capable to replicate the U-shaped pattern of the dynamic Beveridge curve (see table 6 and figure 3). Consistent with the data, the negative relation between model generated vacancies and unemployment remains for more than 4 quarters.

Apart from that, the benchmark model accounts for the fact that unemployment and market tightness lag the cycle by one quarter. This indicates that the combination of strategic wage bargaining and

convex labor adjustment costs enhances the model's ability to propagate technology shocks in the labor market. On the other hand, the benchmark model cannot match the cyclical co-movement of two other variables – output per worker and the wage bill per worker. In the data, the contemporaneous correlation between output and output per worker is close to unity. The wage bill per worker, in contrast, shows a much weaker contemporaneous correlation with output. Table 7 displays that both variables are only moderately positively correlated. In the model, however, we observe that output per worker and the wage bill per worker are perfectly correlated.

Indeed, the almost perfect correlation between output per worker and the wage bill per worker is generated essentially by construction. Equation (31) shows that variations in the wage bill per worker are closely related to changes in output per worker. Since this paper is motivated by the cyclical behavior of vacancies and unemployment, we allow only for total factor productivity shocks. Yet, we conjecture that adding a shock to the value of bargaining may help to bring the co-movement of labor market variables closer to the data.

The Impact of Strategic Wage Bargaining   In the NB model, both parties receive period-by-period a constant share of the mutual surplus. For this reason, the wage bill per worker is almost as volatile as output per worker, giving firms little incentive to adjust employment over the business cycle. This contrasts sharply with the data. Consequently, the cyclical fluctuations of vacancies and unemployment are insufficiently small. The same applies to market tightness, confirming the conclusion reached by Shimer (2005).

On the other hand, the Nash bargaining assumption does not alter the *qualitative* pattern of employment adjustment. The model generated time series of vacancies and unemployment remain almost as persistent as in the benchmark model. As a result, the dynamic Beveridge curve maintains the U-shaped pattern. Even though, we note that the negative relation between vacancies and unemployment remains now only for somewhat more than 3 quarters (instead of more than 4 quarters in the benchmark model). This might be due to the fact that Nash bargaining reduces not only the volatility, but also the persistence of the net flow value of the marginal match.

The Impact of Convex Labor Adjustment Costs   Due to strategic wage bargaining, we observe that the wage bill per worker is about half as volatile as output per worker, giving firms strong incentives to amplify hiring activities. This result holds independently of the hiring cost function. In the LC model, however, we observe that vacancies spike on impact and fall back very quickly. Consequently, the cumulative inflow of new job matches in the LC model is much weaker than in the benchmark model, inducing less volatility in employment, unemployment and market tightness.

For the same reason, all labor market variables are not sufficiently persisitent. This pattern can be ascribed to the modified hiring condition. Given linear vacancy posting costs, firms anticipate the fall in the vacancy filling ratio and, hence, adjust employment instantaneously. On the contrary, convex labor adjustment costs give firms strong incentives to smooth their hiring activities over several periods. This causes the continuous inflow of new job matches in the benchmark model, generating highly persistent labor market variables. Thus, as pointed out by Yashiv (2006), convex labor adjustment costs improve the performance of the job search and matching model considerably.

In particular, the first order autocorrelation of vacancies in the LC model is much weaker than in the benchmark model. This follows directly from the counter-factual shape of the impulse response function under linear vacancy posting costs. Moreover, the shape of the dynamic Beveridge curve is biased. Despite the strong negative contemporaneous correlation, the cross-correlation between unemployment and leaded vacancies is close to zero beyond 2 quarters. In other words, the LC model predicts rather a J-shaped relationship, echoing the findings of Fujita (2004).

The Interactions between Strategic Wage Bargaining and Convex Labor Adjustment Costs
We summarize that (*i*) strategic wage bargaining amplifies the volatility of the labor market and (*ii*) convex labor adjustment costs improve labor market persistence. Therefore, we conclude that only the combination of both features generates sufficient volatility and persistence in the labor market.

Furthermore, the results presented above indicate that strategic wage bargaining and convex labor adjustment costs are complementary in generating volatility and persistence. This interesting result stems from the specification of the hiring cost function. Following Gertler & Trigari (2009), firms' hiring costs now depend negatively on the employment level. Hence, large labor market fluctuations dampen the cyclical variations of firm's hiring costs. For this reason, strategic wage bargaining amplifies the volatility of labor market variables through two channels. On the one hand, strategic wage bargaining amplifies firms' hiring activities in economic upswings. On the other hand, the higher the stock of employment, the lower the costs of labor adjustment. Consequently, the introduction of convex labor adjustment costs enhances the cyclical volatility of unemployment and market tightness. The volatility of vacancies, however, remains virtually unchanged.

In addition, strategic wage bargaining removes the impact of the hump-shaped outside alternative on the wage bill per worker. Thus, strategic wage bargaining induces not only more labor market volatility, but also more labor market persistence.

The complementarity between strategic wage bargaining and convex labor adjustment costs is also illustrated by the dynamic Beveridge curve. Only if we combine both features, the negative relation between vacancies and unemployment remains for more than 4 quarters. Clearly, the impact of convex labor adjustment costs seems to be more important in this respect.

Business Cycle Analysis   The last section has shown that the benchmark model replicates the cyclical behavior of the labor market remarkably well. In the following, we analyze the business cycle properties of the benchmark model more comprehensively. The main features of the US business cycle are well-known (Cooley & Prescott 1995): The fluctuations of output y and total hours nl are nearly equal, while consumption c fluctuates less and investment i fluctuates more. Employment n is almost as volatile as output, indicating that fluctuations in total hours are generated for the most part by the extensive margin. This conjecture is confirmed by the relatively tiny fluctuations in hours per worker l. In addition, also labor productivity $y/(nl)$ and the real wage rate w fluctuate considerably less than output. All these variables are pro-cyclical, albeit labor productivity and real wages show clearly less pro-cyclical variations than the other variables.

Table 8 compares the business cycle statistics of the benchmark model with the data. In total, the benchmark model captures properly the cyclical behavior of consumption, investment and employment. In particular, the benchmark model works well along the extensive margin of cyclical employment adjustment. Beyond matching the standard business cycle facts, the benchmark model accounts additionally for the low and positive correlation between employment and the wage bill per worker found in U.S. data (see table 9).

Furthermore, the data reveal that the empirical correlation between total hours and the real wage rate is essentially zero. This pattern is often referred to as the "Dunlop-Tarshis observation".[18] However, we observe that the benchmark model cannot match this stylized fact as closely as the other features of the U.S. business cycle. Nevertheless, the benchmark model performs much better than the alternative model specifications. The failure to match the Dunlop-Tarshis observation indicates that the model cannot replicate the cyclical co-movement of hours per worker.[19] In the data, hours per worker are pro-cyclical.

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[18]See, inter alia, Christiano & Eichenbaum (1992) and the references therein.
[19]Note that we observe hours per worker in the data. In the model, however, l_t might capture rather (unobservable) labor effort.

In the model, the contemporaneous correlation between output and hours per worker is close to zero. This artifact follows from the interactions between strategic wage bargaining and convex labor adjustment costs. As described above, the combination of both modifications induces larger employment fluctuations than the other model specifications. This leads to larger output fluctuations, implying a strong income effect. On the other hand, the combination of strategic wage bargaining and convex labor adjustment leads to a fast decline in labor productivity. This implies that the intertemporal substitution effect is relatively weak. Consequently, workers grant more value to leisure and, thus, make less (additional) labor effort in economic upswings.

Apart from that, the counter-factual behavior of hours per worker biases also the cyclical properties of some other variables, like the real wage rate. Given that the real wage rate is defined as the wage bill per worker over hours per worker, the real wage rate has to account for almost the whole pro-cyclicality of the individual wage bill. As a result, the model generated real wage rate is highly pro-cyclical – in stark contrast to the data. Furthermore, labor productivity is too pro-cyclical and total hours are too less volatile.

For the same reason, we observe that the benchmark model cannot fully account for the relatively high volatility of the aggregate wage bill. In addition, the aggregate wage bill is too pro-cyclical. Hence, the benchmark model generates too much volatility in the labor share and underestimates its lead. Yet, the benchmark model still improves the dynamic behavior of the labor share slightly compared to previous studies (Andolfatto 1996).

Moreover, we note that output volatility is slightly lower than in the data. This may be due to the somewhat understated volatility in total hours and investment. However, it is likely to increase output volatility by allowing for variable capital utilization (Burnside & Eichenbaum 1996).

Finally, we analyze the cyclical behavior of the wage bill per worker, relative to the cyclical behavior of the bargaining set. As explained above, the wage bill per worker satisfies individual rationality only if it lies in the bargaining set. For this purpose, figure 4 reports the evolution of the reservation value of the firm (upper graph), the wage bill per worker (middle graph) and the reservation value of the household (lower graph) over 12000 simulated periods. We highlight the steady state value of household's reservation value as well as its 95% confidence interval. The graphs show that the wage bill per worker is always in the bargaining set during any period in this long simulation. Moreover, the upper confidence bound of household's reservation value is far below the graph of the wage bill per worker. Consequently, all employment formations are efficient (Hall 2005a). In other words, the critique of Barro (1977) does not apply here.

4   Conclusion

This paper modifies the standard Mortensen-Pissarides job matching model in order to explain the cyclical behavior of vacancies and unemployment. The modifications include convex labor adjustment costs and strategic wage bargaining as introduced into the literature by Hall & Milgrom (2008). The main contribution of our paper is to improve the cyclical behavior of vacancies and unemployment along two dimensions – volatility and persistence.

First, we show that strategic wage bargaining increases the volatility of both variables enormously. This is due to the fact that strategic wage bargaining makes the wage bill per worker independent of the fluctuations in household's outside alternative. As a result, the elasticity of firms' costs per worker is reduced by half. Hence, firms have much stronger incentives to hire new workers in economic upswings.

Second, the introduction of convex labor adjustment costs leads to more persistent labor market responses. In particular, the impulse response function of vacancies shows a marked hump-shape, peaking with several quarters delay. This can be attributed to the firms' altered optimization problem. In contrast

to the case of linear vacancy posting costs, firms' hiring costs now depend on the number of vacancies that are *filled*, and not on the number of vacancies that are *posted.* Thus, marginal hiring costs under convex labor adjustment costs are less volatile and less persistent than under linear vacancy posting costs, giving firms strong incentives to smooth their hiring activities.

Moreover, we observe that strategic wage bargaining and convex labor adjustment costs are complementary in generating labor market volatility *and* persistence. This interesting result stems from the specification of the hiring cost function. Following Gertler & Trigari (2009), we assume that firms' hiring costs depend negatively on the employment level. For this reason, strategic wage bargaining amplifies the elasticity of labor market variables through two channels. On the one hand, strategic wage bargaining enhances employment volatility. On the other hand, large labor market fluctuations dampen the cyclical variations of firms' hiring costs. Consequently, the introduction of convex labor adjustment costs induces not only more persistence, but also more volatility in the labor market.

Apart from that, we find that our model gives rise to two distortionary effects. Given convex labor adjustment costs, social optimality requires that the wage bill per worker is equal to the household's outside alternative. In contrast, we assume that (i) the wage bill per worker is independent of the fluctuations in household's outside alternative and (ii) firms' bargaining power ξ is strictly smaller than unity. Therefore, firms' private gains from search effort are generally smaller than their social contribution. In this case, the dynamic behavior of the wage bill per worker is not socially optimal (Hosios 1990).

It would be interesting to extend our analysis toward endogenizing the value of bargaining. To our knowledge, the only paper that attempts to address this issue is by Knabe (2009). The study of such questions, however, is beyond the scope of this paper.

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A Computations

A.1 Social Planner Solution with Convex Labor Adjustment Costs

The set $\Omega_t = \{k_t, n_t\}$ denotes the state space of the social planner.

$$
\begin{aligned}
\mathcal{U}(\Omega_t) \quad = \quad & \max_{c_t, l_t, k_{t+1}, n_{t+1}, v_t} \\
& \left\{ \ln(c_t) + n_t \phi_1 \frac{(1-l_t)^{1-\eta}}{1-\eta} + (1-n_t)\phi_2 \frac{(1-e)^{1-\eta}}{1-\eta} + \right. \\
& \left. \beta E_t[\mathcal{U}(\Omega_{t+1})] \right\},
\end{aligned}
\tag{33}
$$

s.t.

$$
k_{t+1} \quad = \quad F(k_t, n_t l_t) + (1-\delta)k_t - \frac{\kappa}{2} x_t^2 n_t - c_t, \tag{34}
$$

$$
n_{t+1} \quad = \quad (1-\sigma)n_t + m_t. \tag{35}
$$

The first order conditions are given as:

$$
c_t : \lambda_t \quad = \quad 1/c_t, \tag{36}
$$

$$
l_t : \lambda_t F_2(k_t, n_t l_t) \quad = \quad \phi_1(1-l_t)^{-\eta}, \tag{37}
$$

$$
k_{t+1} : \lambda_t \quad = \quad \beta E_t\left[\mathcal{U}_1(\Omega_{t+1})\right], \tag{38}
$$

$$
n_{t+1} : \mu_t \quad = \quad \beta E_t\left[\mathcal{U}_2(\Omega_{t+1})\right], \tag{39}
$$

$$
v_t : \mu_t \quad = \quad \lambda_t \kappa x_t. \tag{40}
$$

The envelope conditions are given as:

$$
\mathcal{U}_1(\Omega_t) \quad = \quad \lambda_t[F_1(k_t, n_t l_t) + 1 - \delta], \tag{41}
$$

$$
\begin{aligned}
\mathcal{U}_2(\Omega_t) \quad = \quad & \phi_1 \frac{(1-l_t)^{1-\eta}}{1-\eta} - \phi_2 \frac{(1-e)^{1-\eta}}{1-\eta} + \\
& \lambda_t F_2(k_t, n_t l_t) l_t + \mu_t \left[1 - \sigma - (1-\alpha)\frac{m_t}{1-n_t}\right].
\end{aligned}
\tag{42}
$$

Consequently, the social planner solution is defined by following conditions:

$$
\lambda_t \quad = \quad \beta E_t \lambda_{t+1}[F_1(k_{t+1}, n_{t+1} l_{t+1}) + 1 - \delta], \tag{43}
$$

$$
\lambda_t F_2(k_t, n_t l_t) \quad = \quad \phi_1(1-l_t)^{-\eta}, \tag{44}
$$

$$
\mu_t \quad = \quad \lambda_t \kappa x_t, \tag{45}
$$

$$
\begin{aligned}
\mu_t \quad = \quad & \beta E_t \left[\phi_1 \frac{(1-l_{t+1})^{1-\eta}}{1-\eta} - \phi_2 \frac{(1-e)^{1-\eta}}{1-\eta} + \right. \\
& \lambda_{t+1} F_2(k_{t+1}, n_{t+1} l_{t+1}) l_{t+1} + \\
& \left. \mu_{t+1}\left[1 - \sigma - (1-\alpha)\frac{m_{t+1}}{1-n_{t+1}}\right] \right],
\end{aligned}
\tag{46}
$$

$$
k_{t+1} \quad = \quad F(k_t, n_t l_t) + (1-\delta)k_t - \frac{\kappa}{2}\frac{m_t^2}{n_t} - c_t, \tag{47}
$$

$$
n_{t+1} \quad = \quad (1-\sigma)n_t + m_t. \tag{48}
$$

A.2 The Market Solution is generally not Socially Optimal

The surplus S_t (in utility units) equals the social benefit the marginal match:

$$\lambda_t S_t = \mathcal{U}_2(\Omega_t). \tag{49}$$

We substitute this result into the first order condition (39):

$$\mu_t = \beta E_t[\lambda_{t+1} S_{t+1}]. \tag{50}$$

The Nash sharing rule (28) implies that the firm gains the share ξ of the surplus:

$$\mathcal{V}_1(\Omega_t^F) = \xi S_t. \tag{51}$$

Hence:

$$\mu_t = \beta \xi^{-1} E_t \left[\lambda_{t+1} \mathcal{V}_1(\Omega_{t+1}^F) \right]. \tag{52}$$

Recall the first order condition of the firm (17):

$$\kappa x_t = \beta E_t \left[(\lambda_{t+1}/\lambda_t) \mathcal{V}_1(\Omega_{t+1}^F) \right] \tag{53}$$

Substituting (52) into (53) yields:

$$\kappa x_t = \beta \mu_t \xi E_t \left[(\lambda_{t+1}/\lambda_t) \beta^{-1} \lambda_{t+1}^{-1} \right] \tag{54}$$

Hence:

$$\kappa x_t \lambda_t = \mu_t \xi \tag{55}$$

Instead, the first order condition of the social planner (40) postulates:

$$\lambda_t \kappa x_t = \mu_t. \tag{56}$$

Hence, the market solution is socially optimal, if and only if $\xi = 1$ holds.

B Tables

Table 1: The Monthly Parameterization of the Model

Description	Variable	Value	Source
Technology			
production elasticity of capital	θ	0.40	Cooley & Prescott (1995)
depreciation rate	δ	0.0083	Kydland & Prescott (1982)
Preferences			
discount factor	β	0.9967	Kydland & Prescott (1982)
working time per worker	$\bar{l}$	1/3	Juster & Stafford (1991)
effort per job seeker	e	1/12	Barron & Gilley (1981)
individual labor supply elasticity	ν	0.5	MaCurdy (1983)
Labor Market			
job destruction rate	σ	0.035	Shimer (2007)
unemployment rate	$1 - \bar{n}$	0.10	Hall (2005b)
vacancy filling rate	$q(\bar{\gamma})$	0.3381	van Ours & Ridder (1992)
adjustment costs/ output ratio	$\bar{\psi}$	0.01	Hamermesh & Pfann (1996)
matching elasticity of vacancies	α	0.5	Petrongolo & Pissarides (2001)
firm's bargaining power	ξ	0.5	Svejnar (1986)
Technology Shock			
1st order autocorrelation	ρ	0.9830	Cooley & Prescott (1995)
standard deviation	σ_ϵ	0.004395	Cooley & Prescott (1995)

Table 2: Implied Steady State Values

Description	Variable	Value	Description	Variable	Value
job finding rate	$q(\bar{\gamma})\bar{\gamma}$	0.3150	vacancies	$\bar{v}$	0.0932
matches	$\bar{m}$	0.0315	gross hiring rate	$\bar{x}$	0.0350
hiring costs parameter	κ	18.1406	matching efficiency	χ	1.1305
real interest rate	$\bar{r}$	0.0034	capital	$\bar{k}$	34.2200
investment	$\delta\bar{k}$	0.2852	consumption	$\bar{c}$	0.7048
aggregate wage bill/labor share	$\overline{nwl}$	0.5881	wage bill per worker	$\overline{wl}$	0.6534
production function parameter	ζ	0.5012	real wage	$\bar{w}$	1.9603
household's reservation value	$(\overline{wl})_{min}$	0.0164	firm's reservation value	$(\overline{wl})_{max}$	1.2905
leisure parameter empl.	ϕ_1	0.5605	leisure parameter unempl.	ϕ_2	0.0504
leisure exponent	η	4	replacement ratio	$\bar{b}$	0.6331

Table 3: Raw Data Series

Key	Raw Series	Frequency	Database	Series ID
[1]	Labor Force	monthly	St. Louis Fed: FRED®	CLF16OV
[2]	Unemployment	monthly	http://www.stanford.edu/ ~rehall/MA-7-13-05.xls	JF rate calcs (G195:G626)
[3]	Vacancies	monthly	St. Louis Fed: FRED®	HELPWANT
[4]	Hours per Worker	monthly	St. Louis Fed: FRED®	AWHNONAG
[5]	Total Hours	monthly	St. Louis Fed: FRED®	AWHI
[6]	Real Wage	quarterly	St. Louis Fed: FRED®	COMPRNFB
[7]	Durable Goods	quarterly	St. Louis Fed: FRED®	PCDGCC96
[8]	Nondurable Goods	quarterly	St. Louis Fed: FRED®	PCNDGC96
[9]	Services	quarterly	St. Louis Fed: FRED®	PCESVC96
[10]	Investment	quarterly	St. Louis Fed: FRED®	GPDIC96

Table 4: Constructed Data Series

Key	Constructed Series	Variable	Construction
(1)	Consumption	c	$= ([8] + [9])/[1]$
(2)	Investment	i	$= ([7] + [10])/[1]$
(3)	Output	y	$= (1) + (2)$
(4)	Employment	n	$= ([1] - [2])/[1]$
(5)	Unemployment	$1 - n$	$= [2]/[1]$
(6)	Vacancies	v	$= [3]/[1]$
(7)	Market Tightness	$v/(1-n)$	$= (6)/(5)$
(8)	Hours per Worker	l	$= [4]$
(9)	Total Hours	$n \cdot l$	$= [5]$
(10)	Real Wage	w	$= [6]$
(11)	Aggregate Wage Bill	$w \cdot n \cdot l$	$= (9) \cdot (10)$
(12)	Labor's Share	$(w \cdot n \cdot l)/y$	$= (11)/(3)$
(13)	Labor Productivity	$y/(n \cdot l)$	$= (3)/(9)$
(14)	Output per Worker	y/n	$= (3)/(4)$
(15)	Individual Wage Bill	$w \cdot l$	$= (10) \cdot (8)$

Table 5: Simulation Results. This table shows the results of the model simulations. For each variable, we report the relative standard deviation (σ_X/σ_Y), the first order autocorrelation ($\rho_{X_T,X_{T+1}}$), the phase shift relative to output (in parenthesis), and the contemporaneous correlation with output (ρ_{XY}).

	v	$1-n$	γ	y/n	wl
U.S. Business Cycle Facts					
σ_X/σ_Y	7.35	6.31	13.51	0.57	0.60
$\rho_{X_T,X_{T+1}}$	0.92	0.89	0.91	0.76	0.85
ρ_{XY}	(+1) 0.86	(+1) -0.80	(+1) 0.84	(-3) 0.53	(-1) 0.55
Strategic Wage Bargaining with Convex Labor Adjustment Costs					
σ_X/σ_Y	9.84	7.08	16.24	0.63	0.37
$\rho_{X_T,T+1}$	0.87	0.93	0.91	0.68	0.68
ρ_{XY}	(0) 0.99	(+1) -0.90	(+1) 0.94	(-1) 0.62	(-1) 0.62
Nash Bargaining with Convex Labor Adjustment Costs					
σ_X/σ_Y	1.42	1.00	2.30	0.92	0.88
$\rho_{X_T,T+1}$	0.83	0.91	0.89	0.76	0.77
ρ_{XY}	(0) 0.99	(+1) -0.88	(0) 0.93	(0) 1.00	(0) 1.00
Strategic Wage Bargaining with Linear Vacancy Posting Costs					
σ_X/σ_Y	10.01	6.19	14.82	0.42	0.22
$\rho_{X_T,T+1}$	0.60	0.83	0.76	0.57	0.57
ρ_{XY}	(0) 0.88	(0) -0.99	(0) 0.98	(-1) 0.85	(-1) 0.85

Table 6: The Dynamic Beveridge Curve. The table shows the correlation coefficients between unemployment u_t and vacancies v_{t+k}, lagged respectively leaded by k quarters.

U.S. Data	-0.15	-0.35	-0.57	-0.77	-0.91	-0.96	-0.86	-0.67	-0.45	-0.20	0.02
B'mark Model	-0.30	-0.50	-0.69	-0.86	-0.96	-0.94	-0.76	-0.54	-0.32	-0.13	0.04
NB Model	-0.22	-0.41	-0.62	-0.82	-0.95	-0.93	-0.71	-0.46	-0.23	-0.04	0.11
LC Model	-0.07	-0.22	-0.40	-0.62	-0.84	-0.90	-0.51	-0.22	-0.05	0.06	0.14
	-5	-4	-3	-2	-1	0	1	2	3	4	5

Table 7: The Dynamic Cross-Correlation Pattern. The table shows the correlation coefficients between the wage bill per worker $w_t l_t$ and output per worker y_{t+k}/n_{t+k}, lagged respectively leaded by k quarters.

U.S. Data	0.30	0.38	0.45	0.47	0.47	0.43	0.31	0.12	-0.04	-0.21	-0.31
B'mark Model	-0.17	-0.07	0.09	0.33	0.68	1.00	0.68	0.33	0.09	-0.06	-0.16
	-5	-4	-3	-2	-1	0	1	2	3	4	5

Table 8: Business Cycle Statistics. For each variable, the table reports the relative standard deviation (σ_X/σ_Y), the first order autocorrelation ($\rho_{X_T,X_{T+1}}$), the phase shift relative to output (in parenthesis), and the contemporaneous correlation with output (ρ_{XY}).

	c	i	nl	n	l	w	$y/(nl)$	nwl	$(nwl)/y$
				U.S. Business Cycle Facts					
				$\sigma_Y = 1.77$					
σ_X/σ_Y	0.42	3.30	1.04	0.85	0.23	0.53	0.69	1.21	0.74
$\rho_{X_T,X_{T+1}}$	0.74	0.84	0.91	0.89	0.74	0.82	0.82	0.91	0.82
ρ_{XY}	(0) 0.81	(0) 0.97	(+1) 0.77	(+1) 0.82	(0) 0.78	(-1) 0.27	(-4) 0.28	(+1) 0.79	(-5) -0.07
				Benchmark Model					
				$\sigma_Y = 1.32$					
σ_X/σ_Y	0.42	2.37	0.68	0.79	0.17	0.26	0.63	0.86	0.26
$\rho_{X_T,X_{T+1}}$	0.81	0.87	0.93	0.93	0.83	0.69	0.67	0.90	0.68
ρ_{XY}	(0) 0.97	(0) 0.99	(+1) 0.88	(+1) 0.90	(+4) -0.03	(0) 0.88	(0) 0.78	(0) 0.97	(-1) -0.63

Table 9: The Dunlop-Tarshis observation. The table reports the correlation coefficients between employment n_t and the wage bill per worker $w_t l_t$ as well as the correlation coefficients between total hours $n_t l_t$ and the real wage rate w_t, respectively.

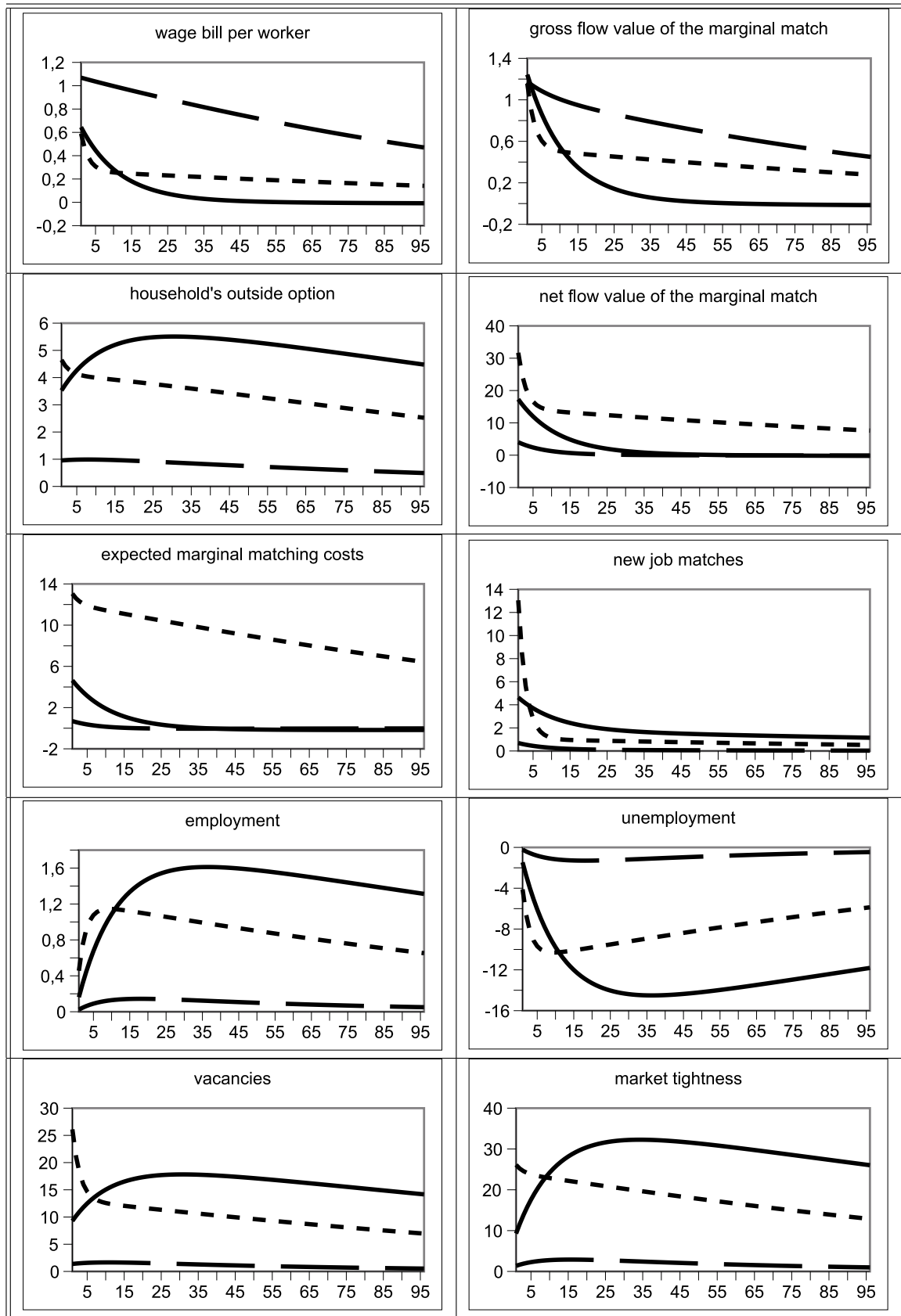|	U.S. Data	B'mark Model	NB Model	LC Model
$\rho(n_t, w_t l_t)$	0.36	0.22	0.87	0.87
$\rho(n_t l_t, w_t)$	0.08	0.55	0.98	0.88

C   Figures

Figure 1: Impulse Response Functions. The graphs depict the evolution of the benchmark model (solid line), the NB model (dashed line), and the LC model (dotted line) over 96 months (32 quarters).

Figure 2: Robust Hump-Shaped Vacancy Dynamics. The solid line represents the benchmark model. The dashed line represents the NB model. The dot-dashed line represents the benchmark model with firms' bargaining power equal to unity. The dot-dot-dashed line represents the NB model with firms' bargaining power equal to unity.
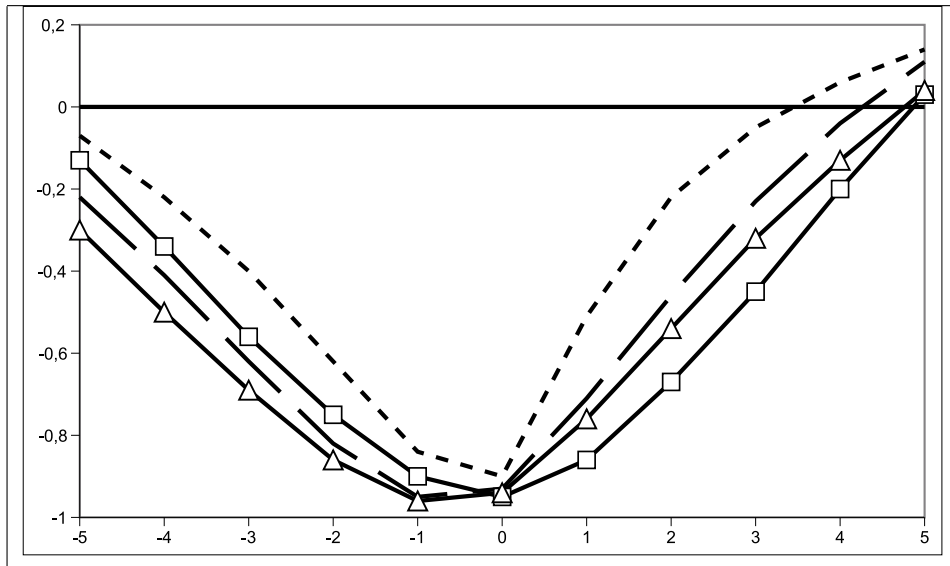

Figure 3: The Dynamic Beveridge Curve (graphical representation of table 6). The solid line with square shaped markers represents U.S. data. The solid line with triangle-shaped markers represents the benchmark model. The dashed line represents the NB model. The dotted line represents the LC model.
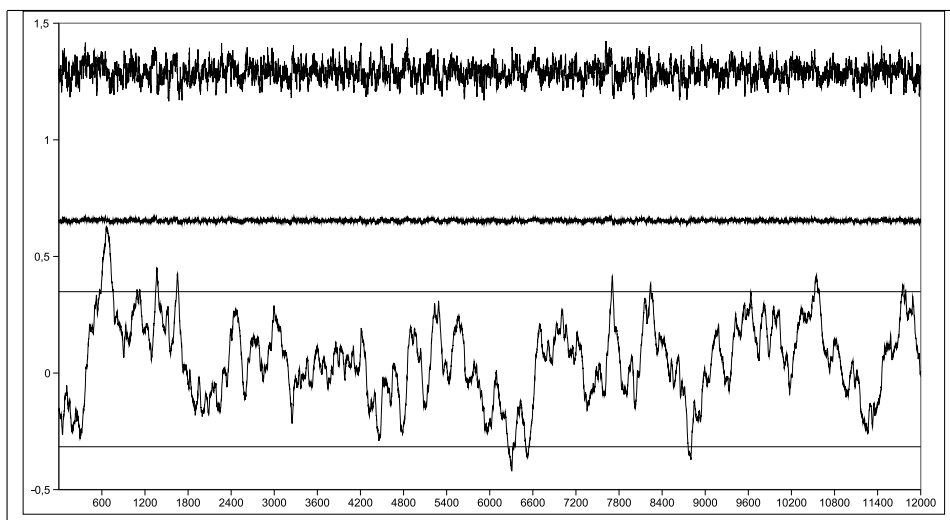

Figure 4: The Bargaining Set. The graphs depict the evolution of the reservation value of the firm (upper graph), the wage bill per worker (middle graph) and the reservation value of the worker (lower graph) over 12000 simulated periods. In addition, we highlight the 95% confidence interval of the worker's reservation value.