Cyclical Wages in a Search-and-Bargaining Model with Large Firms *

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Abstract

This paper presents a complete general equilibrium model with flexible wages where the degree to which wages and productivity change when cyclical employment changes is roughly consistent with postwar U.S. data. Firms with market power are assumed to bargain simultaneously with many employees, each of whom finds himself matched with a firm only after a process of search. When employment increases as a result of reductions in market power, the marginal product of labor falls. This fall tempers the bargaining power of workers and thus dampens the increase in their real wages. The procyclical movement of wages is dampened further if the posting of vacancies is subject to increasing returns. JEL: E240, E370, J640

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When employment rises over the business cycle in the United States, real wages tend to rise somewhat as well. However, the size of these increases appears to be too modest to be consistent with a variety of models. This paper shows that it is possible to rationalize this modest elasticity of wages with respect to employment in a model with flexible wages. The model follows Mortensen and Pissarides (1994) in supposing that workers and firms must incur costs to find one another and that wages are set by bilateral bargaining. Rather than considering perfectly competitive firms that each employ one worker, the model considers large, imperfectly competitive firms. The existence of imperfectly competitive firms allows one to consider changes in market power as a source of business fluctuations, and it turns out that this helps to make real wages less procyclical. Large firms also tend to post multiple vacancies, so that the degree of returns to scale in the posting of vacancies affects their behavior. Letting these recruitment costs be subject to increasing returns also contributes to explaining why there are only small increases in real wages during economic expansions.

When economic expansions are induced by exogenous increases in the productivity of workers, the loss to a firm that loses a worker is larger during these expansions. This increases the strength of each worker's bargaining position and tends to raise real wages. By contrast, booms induced by reductions in the product market power of firms actually reduce the marginal product of labor as long as there are diminishing returns to labor. This tempers the loss experienced by a firm upon a worker's departure and thus reduces the bargaining power of workers. Wages are thus less procyclical.

The basic logic that reductions in market power that lead to increased employment are associated with a weaker bargaining position for workers is present in Rotemberg (1998) as well. That model, however, is static so that real wages actually decline when output increases. In the present paper, as in the Mortensen-Pissarides framework generally, there are two additional forces that tend to cause wages to rise with employment. The first is that jobs become easier to find in booms so that workers are less desperate for a job than they are in recessions. This strengthens the bargaining position of workers and leads them to obtain higher wages. This force is quantitatively important and motivates Hall and Milgrom

(2005) to study bargaining solutions for wages that are less sensitive to worker's alternative options. In this paper, by contrast, I use the Nash bargaining approach used in Mortensen and Pissarides (1994), so this force remains important.

The second force is that, in standard specifications of the costs of hiring workers, the increased labor market "tightness" in booms raises the cost of recruiting workers. When bargaining, workers realize that their employer would have to replace them if the workers were to depart. An increase in recruiting costs thus strengthens the bargaining position of workers and leads to higher real wages. The quantitative importance of this force depends on the size of the economies of scale in the posting of vacancies.

In the Mortensen and Pissarides model (1994) each firm hires just one worker and can post at most one vacancy. In Pissarides's (2000, chapter 3) extension of the model to large firms, however, each firm can post multiple vacancies. Pissarides (2000) assumes that each of these vacancies has the same cost, but it is easy to imagine that the technology of posting jobs is subject to economies of scale. For example, an advertisement for many employees might not cost much more than an advertisement for fewer. One of the contributions of this paper is to show that these economies of scale have profound implications. The reason is that they imply that the marginal recruitment cost in booms, when firms hire many workers, may not be significantly larger than in recessions, when firms hire fewer of them. This obviously reduces the extent to which real wages are procyclical.

The literature on the extent to which real wages are procyclical is voluminous. As shown in the Abraham and Haltiwanger (1995) survey, the results depend on how real wages are measured as well as on the sample period. Using aggregate data, the specification they report that leads to the most procyclical real wages has an elasticity of the real wage with respect to employment of under .3. Using individual data, estimates tend to be higher, and a finding of a unit elasticity is not uncommon. It is arguable, however, that neither the elasticity of aggregate wages nor the elasticity of individual wages with respect to employment corresponds to the wage elasticity implied by the model. The reason is that both individuals and firms differ in their characteristics, and the model I consider abstracts from these differences.

The closest observable analogue to the wage changes implied by the model may thus be the wage changes of individuals who do not change employer from one period to the next. Bils (1985) shows that these wages are much less procyclical than those of individuals who change jobs. His estimates suggest that a one percent increase in the unemployment rate reduces the wages of people who stay in their jobs by between .4 and .6 percent. Bils and McLaughlin (2001) show that people who stay in the same industry see their wage rise by about .2 percent when aggregate employment rises by one percent. This suggests that it would be desirable to have models that are consistent with an elasticity of the wage with respect to employment in the range .2 to .5. Given the uncertainty involved, it would also be attractive if small variations in the parameters could generate both somewhat higher and somewhat lower elasticities.

Supposing that employment fluctuations are due to changes in market power also helps to rationalize the relatively weak tendency of labor productivity to be procyclical. Shimer (2005a) and Mortensen and Nagypal (2005) show that rather substantial changes in technological opportunities are needed if one is to suppose that such changes account for the bulk of cyclical movements in U.S. labor markets. The reason is that, while improvements in technology raise labor demand, they raise real wages as well, so firms have only a moderate incentive to hire additional workers. Large increases in technological opportunities are thus needed to rationalize even moderate increases in employment. This implies that labor productivity rises substantially as well.

By contrast, reductions in market power that lead firms to hire additional workers do not necessarily lead to large increases in labor productivity. Indeed, one might imagine that the existence of diminishing returns to labor implies that labor productivity would actually have to fall when employment rises. However, as emphasized by Hall (1988), the increasing returns that tend to go hand in hand with market power can imply that productivity rises when the labor input is increased. In this paper, I thus choose the level of increasing returns in production to match the extent to which labor productivity tends to rise with employment.

As can be seen, for example, in Shimer (2005a) and Yashiv (2005), the literature on matching models in macroeconomics is extensive. This paper is most directly related to Shimer (2005a), whose main conclusion is that observed labor productivity movements are not large enough for matching models to rationalize movements in labor market variables. Another reason Shimer (2005a) provides an ideal point of reference for discussing the strengths and weaknesses of the approach presented here is that both models predict a strong negative correlation between vacancies and unemployment. In the detrended data he presents, this correlation is -.95, suggesting that a stable Beveridge curve is a highly desirable feature of a model that purports to explain labor markets.

The paper shares some common ground with Yashiv (2005), who also lets firms post multiple vacancies and allows shocks other than technology shocks to affect hiring. Yashiv (2005) considers the effects of changes in interest rates (which are modelled as affecting the discount rate) and of changes in separations. He finds, however, that the combination of these shocks generates a labor share (and thus a real wage) that is much more procyclical than in the data. His model's implied elasticity of the labor share with respect to employment exceeds 3, when this elasticity is actually slightly negative in U.S. data.

In highlighting disturbances to market power in a search-and-matching framework, the paper is related to Chéron and Langot (2000), Trigari (2004), Krause and Lubik (2003), and Walsh (2005). These papers consider firms with sticky prices whose ratio of price to marginal cost varies with monetary policy. Cheron and Langot (2000) show that the combination of sticky prices and the search-and-bargaining framework can simultaneously generate stable Phillips and Beveridge curves. At the same time, their model does generate real wages that are much more strongly related to employment than they are in their data.

Trigari (2004) and Walsh (2005) do not focus on the extent to which real wages are procyclical. Rather, they show that replacing competitive labor markets by a search-and-bargaining framework enhances the ability of sticky price models to explain the response of output, employment, and inflation to monetary disturbances. On the other hand, Krause and Lubik (2003) stress the unrealistic implications of their model concerning both the procyclical movements in real wages and the joint behavior of vacancies and unemployment.

One difference between their specification and the one considered here is that they suppose that the productivity of each job is independent of how many other employees the firm has hired. This means that increases in employment do not reduce the marginal product of labor of existing jobs and thus do not exert downward pressure on wages.

Rigid prices may well provide the most empirically plausible reason for cyclical fluctuations in market power. Nonetheless, this paper takes a more direct route and considers fluctuations in market power that are due to fluctuations in the elasticity of demand facing the typical firm. Such fluctuations are of interest in their own right, and a valuable recent analysis rationalizing them is provided in Ravn *et al.* (2004). It is thus of interest to learn whether changes in the elasticity of demand with empirically plausible characteristics can explain aggregate fluctuations. Even if they cannot, the analysis shows that some aspects of real wage behavior are independent of the underlying causes of fluctuations in firm market power.

The paper proceeds as follows. The next section lays out the dynamic equations of the model. Section 2 considers steady states. Section 3 focuses on how steady states change as either market power or technology changes. Looking at differences between steady states both provides clearer intuition (because the steady-state equations are particularly simple) and gives meaningful elasticities (because the economy converges to its steady state relatively quickly). This latter point is established numerically in Section 4, which analyzes the dynamic behavior of the model economy near its steady state. Section 5 concludes.

1 Model

Worker preferences and the matching of workers to firms are based on a discrete-time version of Mortensen and Pissarides (1994). A constant number of individuals $\bar{H}$ would like to work at the current wage w_t, but only H_t of them actually work. The rest, u_t, are unemployed so that

$$u_t = \bar{H} - H_t. \tag{1}$$

Those who are unemployed at t have a probability of having a job at $t+1$ equal to f_t, so this job-finding probability varies over time. Meanwhile, those who have a job at t have a probability s of being unemployed at $t+1$, where this separation probability is kept constant on the grounds that Shimer (2005b) and Hall (2005b) have argued that this is a good approximation to employment dynamics. This approximation simplifies the analysis considerably, and it seems worthwhile to know whether an economy that experiences only fluctuations in the finding rate can replicate some of the cyclical features of actual economies. In this approximation, the dynamics of unemployment are given by

$$u_{t+1} = s(\bar{H} - u_t) + (1 - f_t)u_t. \tag{2}$$

As in Pissarides (2000) and Shimer (2005a), the finding rate f_t is assumed to depend on the ratio of vacancies posted by firms v_t to unemployment u_t. For small fluctuations, this function can be approximated by a power function so that

$$f_t = \left(\frac{v_t}{u_t}\right)^{\eta}, \tag{3}$$

where η is a positive parameter.

Each consumer at t has overall lifetime utility given by

$$E_t \sum_{j=0}^{\infty} \beta^j (C^i_{t+j} + \tilde{\lambda}\delta^i_{t+j}), \tag{4}$$

where C^i_τ is the consumption of individual i at τ, $\tilde{\lambda}$ is a parameter, and δ^i_τ is an indicator that equals one if the individual is unemployed at τ and zero otherwise. Letting w_t denote the wage at t in terms of time t goods, and supposing that individuals have access to a financial asset that has a real return r, individual i's asset holdings at the beginning of $t+1$ are

$$A^i_{t+1} = (1 + r)[A^i_t - C^i_t + w_t - T_t + \delta^i_t(\hat{\lambda} - w_t)],$$

where T_t and $\hat{\lambda}$ represent lump sum taxes and unemployment insurance payments at t, respectively. For individuals not to all prefer to consume zero at certain dates, $\beta(1+r)$ must be equal to one.

The linearity of the utility function (4) implies a constant real rate r as in Shimer (2005a). Since Andolfatto (1996), several researchers have considered search-and-bargaining models that let the real rate vary because consumers' utility functions have the constant relative risk aversion (CRRA) form. With differences in people's employment histories, the CRRA becomes more manageable if one supposes that perfect insurance against being unemployed is available, so that *ex ante* identical individuals all have the same consumption *ex post*. However, this insurance implies that people prefer being unemployed to working, which is somewhat in tension with supposing that individuals search for work and threaten their employers with departure in order to increase their wages.

If one postulates CRRA preferences with the property that period utility is separable in consumption and leisure, the level of consumption affects the amount of additional income that makes people indifferent between working and not working. When consumption rises, the marginal utility of income falls and reservation wages rise, which leads to more pro-cyclical wages. It may be possible to weaken this effect by removing the perfect-insurance assumption. This effect can also be eliminated by following den Haan *et al.* (2000) and supposing that, as in (4), period utility depends on a linear combination of consumption and leisure. Reservation wages are then constant. Thus, two benefits of (4) are the constancy of reservation wages and the tractability of the model, even in the absence of perfect insurance.

Given these preferences, let U_t^u denote the value to a worker of being unemployed at the beginning of t, while $(U_t^e + w_t)$ denotes the value of being employed. Letting $\lambda = \tilde{\lambda} + \hat{\lambda}$ be the flow benefit of being unemployed at t, U_t^u and U_t^e satisfy

$$\begin{aligned} U_t^u &= \lambda + E_t\beta\{f_t(U_{t+1}^e + w_{t+1}) + (1-f_t)U_{t+1}^u\} \qquad \text{and} \\ U_t^e &= E_t\beta\{(1-s)(U_{t+1}^e + w_{t+1}) + sU_{t+1}^u\}, \end{aligned}$$

where the operator E_t takes expectations conditional on information available at the beginning of period t. Taking the difference between the second and the first of these equations, and letting $\Delta_t \equiv U_t^e - U_t^u$,

$$\Delta_t = E_t\beta(1-s-f_t)(\Delta_{t+1} + w_{t+1}) - \lambda. \tag{5}$$

The behavior of firms depends on the cost of recruiting. Because I depart somewhat from standard assumptions concerning this cost, I discuss it in some detail before turning to other determinants of firm profitability. In the Pissarides (2000) analysis of large firms, vacancies are supposed to have a constant cost c, and all vacancies are equally likely to be filled. If total vacancies are v_t and the total number of people hired at t is $u_t f_t$, as in the analysis above, the probability that any one vacancy is filled is $u_t f_t / v_t$. For a large firm that can post many vacancies, the expected cost of recruiting a worker is then $cv_t / u_t f_t$.

In the case of large firms, however, it need not be the case that the cost of posting v^i vacancies is linear in v^i. Indeed, whether this cost is interpreted as the cost of advertising openings in an information source or as the cost of deciding how tasks need to be split up among workers to obtain the outcomes that the firm seeks, it is easy to imagine that this cost is subject to economies of scale.[1] For this reason, it is worth considering a more general recruiting cost, where the cost to an individual firm of posting v^i vacancies is given by $R(v^i)$, where

$$R(v^i) = c(v^i)^{\epsilon_c}.$$

The case of $\epsilon_c = 1$ then corresponds to the Pissarides (2000) analysis of large firms.[2]

Vacancies that are posted at t allow the firm to increase its employment at $t+1$ beyond $(1-s)H_t^i$, where H_t^i is its employment at t and where a fraction s of these employees depart. Following the analysis of Pissarides (2000), a firm that posts v_t^i vacancies can expect to

[1] Vacancies are often measured by the Conference Board help-wanted index. Interestingly, having this index increase by one percent may well increase the costs of the firms placing these adds by less than one percent. Abraham and Wachter (1987, p. 209) report that this index is obtained by counting the total monthly number of job advertisements placed in major newspapers. This total number rises when advertisers repeat their advertisements a larger number of times. Placing an advertisement x times does not generally cost x times the amount it costs to place an advertisement once. For example, the *Boston Globe*'s May 2005 rates indicate that the cost of placing an advertisement for four additional days within a week is zero once the advertisement runs for Sunday and two additional weekdays (the Sunday rate per agate line is \$25, the daily rates once an ad appears on Sunday is \$5, and the weekly rate is \$35). See http://bostonworks.boston.com/mediakit/ratecards/. This example indicates that even the marginal cost of placing an additional ad may fall when more ads are placed.

[2] Yashiv (2005) also considers costs that do not rise linearly with vacancies, though he only studies the case of diminishing returns to scale. While his functional form is not identical to mine, his model is analogous to supposing that $\epsilon_c > 1$, which implies that real wages are even more procyclical.

hire $v_t^i u_t f_t / v_t$ additional workers.[3] The analysis is simplified by supposing that firms have access to a technology where the posting of these vacancies ensures that exactly $v_t^i u_t f_t / v_t$ new employees are hired.[4] It follows that

$$H_{t+1}^i - (1-s)H_t^i = \frac{v_t^i u_t f_t}{v_t}. \tag{6}$$

Total hiring costs for this firm are thus $c(v_t(H_{t+1}^i - (1-s)H_t^i)/u_t f_t)^{\epsilon_c}$ so that the marginal cost of hiring an additional worker for $t+1$ is

$$\phi_t^i \equiv \frac{dR}{dH_{t+1}^i} = c\epsilon_c \left(\frac{v_t}{u_t f_t}\right)^{\epsilon_c} \left(H_{t+1}^i - (1-s)H_t^i\right)^{\epsilon_c - 1}. \tag{7}$$

At a symmetric equilibrium, each firm's total hiring equals $u_t f_t / N$, where N is the number of firms. Marginal hiring costs at such a symmetric equilibrium thus equal

$$\phi_t = \frac{c\epsilon_c N^{1-\epsilon_c} v_t^{\epsilon_c}}{u_t f_t}. \tag{8}$$

Since the elasticity of ϕ_t with respect to v_t equals ϵ_c, it falls when this parameter falls. By contrast, the elasticity of ϕ with respect to $(u_t f_t)$ remains minus one regardless of ϵ_c. A one-percent increase in uf always lowers by one percent the increase in vacancies that is needed to attract an additional worker, so it reduces the cost of these extra vacancies by about one percent. A one-percent increase in v, by contrast, has two effects. While it raises the amount by which vacancies must increase to attract an additional worker, it also raises the number of vacancies the firm must post to attract *its standard share* of the uf workers available for hire. With $\epsilon_c < 1$, this increase in the baseline level of vacancies reduces the percent by which costs rise when vacancies are increased to hire an additional worker.

The upshot of this discussion is that one cannot generally determine the size of changes in ϕ from changes in v and u, even if one has fitted a matching function to recover empirically

[3] This requires that firms be sufficiently small that the effect of their vacancies on the ratio uf/v can be neglected. In the case where the number of firms N is large, one obtains essentially identical formulas by neglecting the effect of changes in a firm's vacancies on total hiring and supposing instead that the total number of workers hired $(u_t f_t)$ distributes itself evenly over the total number of vacancies posted by firms.

[4] This requires that there be a slight negative correlation between the probability of success of the different vacancies that are posted by a particular firm. One advantage of this specification is that it ensures that all the symmetric firms in the model remain of the same size, since they all post the same number of vacancies in equilibrium.

the way that f responds to vacancies and unemployment. What remains possible is to use (2) to compute the unemployment rates induced by changes in f_t. Knowing these unemployment rates, one can use one's knowledge of f to obtain the necessary changes in vacancy rates. Increases in f tend to raise uf because the percentage decline in u is not as large as the percentage increase in f. So, f can only increase if v rises as well. The increase in uf exerts a negative influence on ϕ, while the influence of the increase in v is positive. With sufficiently low values of ϵ_c, however, this latter effect is small, so the overall effect on ϕ is ambiguous. In the extreme case where ϵ_c is close to zero, an increase in total hiring actually leads to a decline in the cost of obtaining an additional worker.

The timing of moves by firms and workers is the following. At the end of period t, firms are assumed to learn the productivity and market power conditions for $t + 1$. They then choose their capital, their price for that period, and the vacancies v_t^i they post at t. To simplify the analysis, the cost of posting these vacancies is paid at $t+1$, when the recruitment effort of the firm bears fruit. Each worker then bargains individually with the firm. Because this bargaining is efficient and λ is less than the marginal product of labor, all workers stay at the firm with which they are matched. The typical firm finds itself with K_t^i units of capital and H_t^i workers. Its output in period, Y_t^i is

$$Y_t^i = z_t(F(K_t^i, H_t^i) - \Phi), \tag{9}$$

where the function F is homogeneous of degree one in both arguments, z_t is an economy-wide indicator of productivity, and Φ is a fixed cost. This fixed cost can be set to zero when there is perfect competition among firms but needs to be positive to ensure that profits are zero if firms have market power.

This market power, in turn, is the result of imperfect substitutability of the goods produced by different firms. Thus, aggregate output y_t and consumption are aggregators of the output and consumption of individual goods. Supposing that the average price charged by all other firms at t is p_t, a firm that charges P_t^i finds itself with a demand

$$D_t^i = \frac{y_t}{N}\left(\frac{P_t^i}{p_t}\right)^{-\epsilon_{dt}}, \tag{10}$$

where ϵ_{dt} is the elasticity of demand, which is allowed to vary over time.

Firm i's real flow of profits at t, π_t^i is given by

$$\pi_t^i = (P_t^i/p_t)\min(Y_t^i, D_t^i) - w_t^i H_t^i - r_t K_t^i - R(v_{t-1}^i), \tag{11}$$

where w_t^i is the firm's real wage. Goods cannot be stored so the firm finds it in its interest to set $Y_t^i = D_t^i$ along the equilibrium path. Off the equilibrium path, worker departures do lower Y_t^i relative to D_t^i. Moreover, a firm that loses a worker at t and does not change its number of vacancies at the end of t can expect to end up with $(1-s)$ fewer workers at $t+1$. It follows that a firm that loses a worker must anticipate that it may have to increase its hiring at the end of t to make up for this loss. The departure of a worker thus leads to an expected flow of losses equal to

$$(P_t^i/p_t)z_t F_H(K_t^i, H_t^i) + E_t\beta(1-s)\phi_t^i - w_t^i, \tag{12}$$

where the first term represents the marginal product of labor (as in Pissarides (2000)), while the second term represents the additional expected recruiting costs. Note that the recruiting costs ϕ_t^i correspond to vacancies posted in period t. These recruitment costs are discounted because they are paid at $t+1$ and they are multiplied by $(1-s)$ to take account of the possibility that these recruitment costs would have been incurred anyway with probability s.[5]

As in Pissarides (2000), the wage is set through a generalization of Nash bargaining and maximizes a weighted geometric average of the gains of the two parties. Workers are assumed to bargain individually and simultaneously. One can think of each worker as bargaining with a separate representative of the firm. Thus, each worker and the representative that he bargains with assume at the time of bargaining that the firm will reach a set of agreements

[5]The probability of leaving the firm s is assumed to be identical with the worker's probability of becoming unemployed, as in Shimer (2005a). This is only a simplification because many workers move from one job to another, so the probability that a worker separates from a firm is higher than the probability that this worker separates from active employment. One attraction of incorporating both separation rates explicitly is that, even if the two rates are assumed to be constant, more workers would transition from job to job in booms. This would mean that vacancies are "more productive" in booms and could thereby further reduce the calibrated procyclicality of ϕ_t

with the other workers that leads these to remain employed. They also assume that the price has been set so that all the worker's output is sold if the works stays with the firm.

The perceived gain to the representative of the firm of keeping a worker is then given in (12), while the gain to the worker from employment is $\Delta_t + w_t$. The bargaining solution thus maximizes

$$\Big(\Delta_t + w_t^i\Big)^{\alpha}\Big((P_t^i/p_t)z_t F_H(K_t^i, H_t^i) + E_t\beta(1-s)\phi_t^i - w_t^i\Big)^{1-\alpha},$$

where α represents the bargaining strength of the workers. The solution of this maximization problem is

$$w_t^i + \Delta_t = \alpha[(P_t^i/p_t)z_t F_H(K_t^i, H_t^i) + E_t\beta(1-s)\phi_t^i + \Delta_t]. \tag{13}$$

At a symmetric equilibrium, all firms charge the same price and the marginal product of labor $z_t F_H(K_t^i, H_t^i)$ is equal to a common value that I label ρ_t so that this equation becomes

$$w_t = -\Delta_t + \alpha(\rho_t + E_t\beta(1-s)\phi_t + \Delta_t). \tag{14}$$

When firm i decides at the end of $t-1$ on vacancies as well as prices and capital for t, it maximizes

$$U_t^i = E_t \sum_{j=1}^{\infty} \beta^j \pi_{t+j}^i.$$

Given its choice of capital and labor, the optimal price is the one that ensures that the firm's output Y_t^i is equal to the firm's demand D_t^i. [6] Using this price as well as the wage given by (13), the firm's flow of profits at t is given by

$$\begin{aligned}\pi_t^i \;&=\; \left(\frac{y_t}{N}\right)^{1/\epsilon_{dt}}\Big(z_t F(K_t^i, H_t^i) - z_t\Phi\Big)^{1-1/\epsilon_{dt}} - r_t K_t^i - R\left(\frac{v_{t-1}(H_t^i - (1-s)H_{t-1}^i)}{u_{t-1}f_{t-1}}\right)\\ &\qquad -H_t^i\Big[\alpha((P_t^i/p_t)z_t F_H + E_t\beta(1-s)\phi_t^i) + (\alpha-1)\Delta_t\Big].\end{aligned}$$

[6]This requires that the firm have nothing to gain in the bargaining stage by having the capacity to produce more output than is demanded at the price that it has set. No such benefit exists if, as assumed above, wages are set under the supposition that all workers are indeed needed to produce the quantity demanded. This still raises the question of why the firm does not recruit some workers just so they can be ready to carry out the job of any worker who leaves. This possibility can be neglected if one assumes that vacancies attract workers only if they involve a specific task that is not already carried out by another worker. See Rotemberg (1998) for further discussion.

Since the path of Δ involves payoffs of workers outside the firm, the firm treats this path as exogenous. The firm's first-order condition with respect to H_t^i is thus

$$\frac{dU_t^i}{dH_t^i} = 0 = \left(1 - \frac{1}{\epsilon_{dt}}\right)\left(\frac{y_t/N}{z_t(F(K_t^i, H_t^i) - \Phi)}\right)^{1/\epsilon_{dt}} z_t F_H - w_t^i - \phi_{t-1}^i + E_t\beta(1-s)\phi_t^i + \\ \alpha H_t^i \left[\left(\frac{y_t/N}{z_t F(K_t^i, H_t^i) - z_t\Phi}\right)^{1/\epsilon_{dt}} \left(\frac{(z_t F_H)^2}{\epsilon_{dt}(z_t F(K_t^i, H_t^i) - z_t\Phi)} - z_t F_{HH}\right) - E_t\beta(1-s)\frac{d\phi_t^i}{dH_t^i}\right].$$

A positive value of $d\phi_t^i/dH_t^i$ discourages hiring, because it implies that increases in hiring raise wages at the bargaining stage. Using (7),

$$\frac{d\phi_t^i}{dH_t^i} = (1-s)(1-\epsilon_c)\frac{\phi_t^i}{H_{t+1}^i - (1-s)H_t^i},$$

which is indeed positive when $\epsilon_c < 1$. The reason is that extra hiring at t implies lower expected hiring at $t+1$ which raises marginal recruiting costs if $\epsilon_c < 1$.

Combining these equations, and noting that $z_t(F(K_t^i, H_t^i) - \Phi)$ equals y/N at a symmetric equilibrium, the first-order condition with respect to H_t^i at such an equilibrium becomes

$$\rho_t\left(1 - \frac{1 - \alpha\mu_t s_H}{\epsilon_{dt}} + \frac{\alpha s_K}{e}\right) = w_t + \phi_{t-1} - E_t\beta(1-s)\phi_t\left(1 - \frac{\alpha(1-s)(1-\epsilon_c)H_t}{u_t f_t}\right), \quad (15)$$

where $s_H \equiv HF_H/F$ and μ_t is the ratio of zF to output $(zF - \Phi)$. In deriving this equation, I made use of the homogeneity of F, which implies that $s_H = 1 - s_K$ and that $HF_{HH} = -KF_{HK} = -s_K F_H/e$, where e is the elasticity of substitution between capital and labor.

Because the firm's hiring costs are concave if $\epsilon_c < 1$, it is important to check that the firm satisfies its second-order condition for an optimum, at least along a path where all firms satisfy (15). Using (14) in the above expression for dU_t^i/dH_t^i, this derivative becomes

$$\begin{aligned}\frac{dU_t^i}{dH_t^i} &= \left(\frac{y_t/N}{z_t(F(K_t^i, H_t^i) - \Phi)}\right)^{1/\epsilon_{dt}}\left(1 - \alpha - \frac{1 - \alpha\mu_t s_{Ht}}{\epsilon_{dt}} + \alpha\frac{s_{Kt}}{e}\right) z_t F_H \\ &\quad + (1-\alpha)\Delta_t - \phi_{t-1}^i + E_t\beta(1-s)\left[(1-\alpha)\phi_t^i - \alpha H_t^i \frac{d\phi_t^i}{dH_t^i}\right].\end{aligned}$$

Assuming a constant elasticity of substitution e between capital and labor, the second derivative of firm welfare therefore equals

$$\frac{d^2U_t^i}{dH_t^{i2}} = -\left(\frac{y_t/N}{z_t(F(K_t^i, H_t^i) - \Phi)}\right)^{1/\epsilon_{dt}}\left(1 - \alpha - \frac{1 - \alpha\mu_t s_{Ht}}{\epsilon_{dt}} + \alpha\frac{s_{Kt}}{e}\right)\left[\frac{s_{Kt}}{e} + \frac{\mu_t s_{Ht}}{\epsilon_{dt}}\right]\frac{z_t F_H}{H_t^i}$$

$$+\left(\frac{y_t/N}{z_t(F(K_t^i,H_t^i)-\Phi)}\right)^{1/\epsilon_{dt}}\alpha s_{Ht}\left[\frac{\mu_t}{\epsilon_{dt}}\left(1-\mu_t s_{Ht}-\frac{s_{Kt}}{e}\right)+\frac{s_{Kt}}{e}\left(\frac{1}{e}-1\right)\right]\frac{z_t F_H}{H_t^i}$$
$$-\left\{\frac{d\phi_{t-1}^i}{dH_t^i}-E_t\beta(1-\alpha)(1-s)\frac{d\phi_t^i}{dH_t^i}\right\}-E_t\alpha\beta(1-s)\left\{\frac{d\phi_t^i}{dH_t^i}+H_t^i\frac{d^2\phi_t^i}{dH_t^{i2}}\right\}. \quad (16)$$

For e not too far from 1, the first two terms in this equation are negative, as is required for the second-order condition to hold.[7] The concavity of R makes the first term in curly brackets positive, which could potentially lead to violations of this condition. However, (7) also implies that $d^2\phi_t^i/dH_t^{i2}$ is positive when $\epsilon_c < 1$, so that the last term in curly brackets is positive as well; and this contributes to satisfying the second-order condition. Because this term is quantitatively important in the calculations reported below, a brief discussion seems worthwhile.

When $\epsilon_c < 1$, firms are somewhat discouraged from hiring workers at t, because doing so raises future hiring costs and thereby raises wages. The last terms in (16) show that this effect becomes even more important as firms increase their hiring. The reason is that recruiting costs rise faster with recruitment for low levels of hiring. As the firm increases its hiring and needs ever less future hiring, it thereby makes the derivative of recruiting costs with respect to hiring larger.

It is worth comparing the first-order condition (15) to the corresponding condition in the more standard model (Pissarides 2000), where firms have one worker at most and where ϕ_t is simply the expected cost of recruiting a worker at t for $t+1$. Free entry then implies that the expected profit from spending these resources on recruiting equals zero or that

$$\phi_{t-1}=E_t\sum_{j=0}^{\infty}\beta^j(1-s)^j(\rho_{t+j}-w_{t+j}).$$

[7] The second-order condition is only a necessary condition for the first-order condition to be associated with a profit maximum; it does not guarantee that there do not exist other employment paths with even larger values of U^i. One might be particularly concerned that the firm would prefer to hire only occasionally and keep its hiring equal to zero at other times, as suggested by Kramarz and Michaud (2003). While this is both a realistic possibility and one that might be optimal if the model were treated as valid globally, I neglect it to maintain the simple representative-firm framework. One way to rule out this behavior even if it were implied by the equations spelled out in the text is to suppose that these equations are valid only locally and that, for example, in each period the firm loses some employees whose replacement is essential to keep production positive.

This implies that

$$\rho_t - w_t - \phi_{t-1} + E_t \beta (1 - s) \phi_t = 0. \tag{17}$$

Comparing (15) and (17), it is apparent that the coefficients on w_t and ϕ_{t-1} are the same. However, the coefficients on the marginal product of labor and on $E_t \beta \phi_t$ are different. The differences in these coefficients give insights into the changes introduced by my "large-firm" assumptions. First, supposing that the firm's demand curve is less than infinitely elastic lowers the attractiveness of hiring workers. This just represents the standard monopolistic distortion. This tendency to hire fewer than the efficient number of employees is tempered somewhat by Nash bargaining, because workers absorb in lower wages a fraction of the reduction in price that is induced by expanding output.

Interestingly, two differences between (15) and (17) remain even if one assumes that firms are perfectly competitive. The first is that, with $s_K > 0$ and $e < \infty$, a firm lowers its marginal product of labor by hiring additional workers (where this reduction in the marginal product of labor is larger when the elasticity of substitution e is smaller and when the share of capital is larger). This provides an inducement to "overhire."[8]

The second difference is that, with $\epsilon_c < 1$, marginal recruiting costs fall when the firm recruits more workers. A firm that increases its employment at t tends to increase its wage as a result of needing to recruit less heavily at $t + 1$. The firm thus faces a reduced incentive to hire workers at t. It should be apparent that the sum total of these effects on the path of employment (for given levels of ϕ_{t+j}) depends on the parameters that one chooses. It is important to stress, however, that these changes relative to the standard model need not by themselves have any important effect on the extent to which real wages are procyclical. This issue is discussed further below.

If the marginal product of labor ρ_t is exogenous, a symmetric equilibrium is a path for

[8]See Stole and Zwiebel (1996) for this effect in the context of a somewhat different bargaining model. Chapter 3 of Pissarides (2000) avoids this effect by supposing that the firm takes the wage as given when it decides how many employees to hire. This exogeneity is not entirely consistent with Nash bargaining, however. This "overhiring" force also affects firms' choice of capital, since a firm can just as easily lower the marginal product of labor by under-employing capital as by over-employing labor. Andolfatto (1996) neglects this effect on capital accumulation by ignoring the dependence of wages on the capital input.

u_t, v_t, f_t, ϕ_t, Δ_t and w_t that satisfies (2), (3), (5), (8), (14) and (15). If $\rho_t = z_t F_H(K_t, H_t)$, one must include this equation as well as (1) among the equilibrium conditions and must solve for the path of ρ_t, H_t, u_t, v_t, f_t, ϕ_t, Δ_t and w_t.

I analyze this model in several steps. First, in the next section, I compute its overall steady state.

2 Steady State

The steady-state implication of (5) is

$$\Delta[1-\beta(1-s-f)] = \beta(1-s-f)w - \lambda,$$

where the unsubscripted values of Δ, w, and f represent their steady-state values. The steady-state implication of (14) is

$$\Delta(1-\alpha) = -w + \alpha(\rho + \beta(1-s)\phi).$$

Together, these equations imply that

$$\Big[1-\alpha\beta(1-s-f)\Big]w = (1-\alpha)\lambda + \alpha\Big[1-\beta(1-s-f)\Big]\Big[\rho+\beta(1-s)\phi\Big]. \tag{18}$$

This equation can be interpreted as giving the "bargaining wage." This wage is a linear combination of the value of leisure, the marginal product of labor, and the cost of replacing the worker by recruiting a new one.

Since (2) implies that $uf = (\bar{H} - u)s$ in a steady state, it follows from the definition of unemployment (1) that total hiring uf in a steady state equals total separations sH. Using this in (15) gives the steady-state relation

$$\left\{1 - \frac{1-\alpha\mu s_H}{\epsilon_d} + \frac{\alpha s_K}{e}\right\}\rho = w + m_\phi \phi, \tag{19}$$

where $m_\phi \equiv 1 - \beta(1-s)[1-\alpha(1-s)(1-\epsilon_c)/s]$. This equation can be interpreted as a "hiring equation," where the firm equates the benefit of hiring an additional worker (which is related though not necessarily identical to the marginal product of labor) to its marginal cost (which includes a wage and a hiring cost component).

For a given "replacement rate" λ/w, the bargaining and hiring equations (18) and (19) are linear in w/ρ and ϕ/ρ. Thus, one can readily solve for these two ratios as a function of the parameters $m, s, f, \alpha, e, s_H, \mu, \epsilon_c$, ϵ_d, and λ/w. Once one has the ratios w/ρ and ϕ/ρ, one can use (16) to check whether the second-order condition holds for the representative firm at this steady state. It does so for all the parameters considered below.

I take the first four parameters from Shimer (2005a) so that, with a period length of one month, $\beta = .996$, $s = .034$, $f = .45$, $\eta = .28$, and $\alpha = .72$. In the baseline specification, the substitution of capital for labor e is equal to one, and $s_H = 2/3$, as if one could use factor shares to calibrate a Cobb-Douglas production function. I also consider an alternative specification where s_H remains equals to 2/3 but where the short-run elasticity of substitution of capital for labor is lower. With a putty-clay specification, this short-run elasticity would be zero. Given the intuitive attraction of this putty-clay idea, my alternate specification assumes $e = 1/3$.

An equally important production function parameter that needs to be calibrated is μ, the steady-state value of μ_t. In a symmetric equilibrium, (9) implies that

$$Y_t = z_t(F(K_t, H_t) - \Phi). \tag{20}$$

In a steady state with constant z, the parameter $\mu = zF/Y$ is related to the ratio of fixed costs over output Φ/Y by the relationship $\mu - 1 = \Phi/Y$. If z and K are constant and the log deviations of H_t around the steady state are relatively small, the percentage deviations of output and employment from their steady-state values satisfy

$$\tilde{Y}_t = \mu s_H \tilde{H}_t, \tag{21}$$

where a tilde represents a log deviation from a steady state.

This equation implies that, if z fails to vary cyclically, s_H is known, the cyclical value of employment is correctly measured, and the cyclical value of Y is subject to measurement error, one can estimate μ from a regression of $\tilde{Y}_t$ on $\tilde{H}_t$. Using BEA data of output, hours, and employment from the business sector, I ran such regressions by detrending the three variables, using the method outlined in Rotemberg (2003). Using quarterly data from 1950:1 to 2002:1, the coefficient of employment in the regression of output on employment was 1.11. If $s_H = 2/3$, this coefficient is consistent with (21) when $\mu = 1.7$. The advantage of this parameter value, which I treat as my baseline, is that it allows the model without technology shocks to account for the observed cyclical productivity movements in a simple manner.[9] Consistent with this relatively high degree of returns to scale, I assume firms have significant market power, and I set the elasticity of demand ϵ_d equal to two.

The replacement rate λ/w has been the subject of some discussion. Shimer (2005a) sets λ/ρ (which is very similar to λ/w for his parameters) equal to .4 on the basis that, on average, unemployment insurance in the United States typically pays workers somewhat less than four-tenths of their regular wage. Hagedorn and Manovskii (2005) have emphasized that λ/w ought to be higher than the fraction of wages covered by unemployment insurance because people also give up their utility from leisure when they work, and this utility flow should be included in λ.

For any value of λ/w below 1, workers prefer working to not working, so they are "involuntarily unemployed" whenever they do not have a job. Setting this ratio very close to 1, on the other hand, would be inconsistent with the observation that reported well-being falls substantially when workers become unemployed (see Di Tella *et al.* 2003). This leads Mortensen and Nagypal (2005) to criticize Hagedorn and Manovskii (2005) for using parameters such that $\lambda/w = .983$, which implies that workers gain only 1.7 percent of flow utility by going from unemployment to employment. Keeping in mind this criticism, while also taking into account the fact that low values of λ/w tend to make real wages too procyclical, my baseline simulations are computed under the assumption that $\lambda/w = .9$. For comparison,

[9] It is worth noting that the coefficient of total hours in a regression of output on total hours was only 1.07 and thus implies a μ of only about 1.6. This may be somewhat more appropriate because hours per worker are well known to be procyclical. Still, since the model ignores fluctuations in hours per worker, I keep $\mu = 1.7$.

I also consider $\lambda/w = .4$.

This leaves only one additional parameter to be calibrated, namely ϵ_c. As discussed above, it is standard in search models to suppose that $\epsilon_c = 1$. Kramarz and Michaud (2003) provide some evidence on this parameter. They use French firm-level data on hiring and on certain hiring expenditures, namely expenditures on job advertising and search-firm fees. They run regressions of the change in these expenditures on the change in hiring between 1992 and 1996 and include a quadratic term in their regressions. This term allows them to reject the hypothesis that hiring costs are linear in hiring. However, their estimated degree of returns to scale is small. Starting at the mean of their sample, a firm whose hiring was one percent larger experienced about a .97 percent increase in its hiring costs. The true value of ϵ_c could be lower, however, if the degree of economies of scale were larger in the component of hiring costs that involves the firm's own employees or output. Also, the cross-sectional variability of changes in hiring costs across firms might be driven by cross-sectional differences in the extent to which firms open new plants. New plants may have a different effect on hiring costs than do changes in the number of employees who are associated with a fixed capital stock, and it is the latter that are most relevant for the model.

For purposes of illustration, I thus report results for $\epsilon_c = .2$ as well as for the conventional case where $\epsilon_c = 1$. The results are monotone in the values of this parameter, so these examples ought to be informative about the effect of this parameter more generally. For future reference, Table 1 reports those parameters for which I consider variants. Shimer's (2005a) specification sets the parameters very close to the values in the "Alternatives" row with the exception that the elasticity of substitution e plays no role because $s_H = 1$.[10]

Table 2 reports the steady-state values of w/ρ and ϕ/ρ for several combinations of parameter values. As can be seen in this table, there are substantial differences in wages and marginal recruiting costs relative to the marginal product of labor across these specifications. To gain intuition for these differences, it is worth starting with specification (6), which is

[10] The two minor differences are that ϵ_d is set to a large finite value rather than to infinity and that λ/w is set to .4 rather than having λ/ρ set to this value.

close to the one used in Shimer (2005a). Changing from this specification to (7), where $s_K = 1/3$ and $e = 1$, so that the production function takes the modified Cobb-Douglas form with plausible capital costs leads to a substantial increase in both w/ρ and ϕ/ρ. The reason is that the dependence of the marginal product of labor on the amount of labor hired now leads to "overhiring." This has the effect of lowering the marginal product of labor both relative to the real wage and relative to recruiting costs. More formally, an increase in s_K/e raises the left-hand side of (19) so that ρ must fall relative to a linear combination of w and ϕ. Since (18) requires the wage to be an unchanged linear combination of ρ and ϕ, the wage must rise relative to ρ while falling relative to ϕ (so that ϕ/ρ rises more than w/ρ).

Going from specification (7) to specification (5) involves increasing market power, which lowers the left-hand side of (19) and reduces overhiring. While this does indeed lower w/ρ and ϕ/ρ, the actual size of this effect is relatively modest. Raising λ/w from .4 to .9 (when going from specification (5) to (2) or from specification (3) to (1)) raises w/ρ for the simple reason that workers have access to a superior alternative. This increase in wages relative to the marginal product of labor implied by (18) requires that ϕ/ρ fall to satisfy (19). In other words, the increase in the wage reduces the attractiveness of obtaining a worker, so the marginal recruiting cost must fall relative to the marginal product of labor.

Lowering ϵ_c when going from specification (5) to specification (3) (or from specification (2) to (1)) reduces both w/ρ and ϕ/ρ. The reason is that the lower value of ϵ_c makes marginal hiring less attractive by lowering the right-hand side (19). This tends to raise the marginal product of labor relative to the wage. The result is that the baseline specification has almost the same w/ρ as the alternative. The higher value of ϵ_c and the lower value of λ/w in the latter tend to raise w/ρ, but this is offset by the effect of the higher value of s_K/e in the former. The main difference between the baseline and the alternative is that ϕ/ρ is much larger in the latter. The reason is that increases in ϵ_c have a particularly large positive effect on recruiting costs.

Lowering the elasticity of substitution from 1 to 1/3, as is done when going from specification (1) to specification (4) also raises the left-hand side of (19), so it leads to more hiring, higher w/ρ, and higher ϕ/ρ. However, it is interesting to note that these effects are relatively modest. As we shall see below, the modesty (or lack thereof) of the effect of parameter changes on these steady-state values is not perfectly mirrored in a modesty of the effects of these parameters on the extent to which the real wage is procyclical. I turn to this issue next.

Most analyses of fluctuations based on the models of Mortensen and Pissarides (1994) suppose that these fluctuations are caused by changes in technological opportunities while λ, the opportunity cost of working, stays constant. An alternative viewpoint is that these fluctuations are due to non-technological changes in labor demand. They result, in particular, from changes in the wedge between the amount that firms are willing to pay workers and the workers' marginal product. In models where firms have access to a competitive labor market, this wedge can be thought of as the markup of price over marginal cost (see Rotemberg and Woodford 1991). One could try to formalize an analogous measure for the model considered here. However, it seems more attractive to focus directly on one of the potential sources of non-technological change in labor demand. The simplest such source is a movement in the elasticity of demand facing the typical firm, and I focus on such fluctuations here. Following the lead of Mortensen and Pissarides (1994), I suppose that λ stays constant in the face of these fluctuations.

I consider two different approaches for calculating the model's implications regarding the effects of changes in z and ϵ_d on employment and wages. Both these methods rely on approximations near a steady state, so they both apply only when fluctuations in the driving variables are relatively small. In one method, I suppose that the variables in the model always obey the steady-state relations (18) and (19), and I consider approximations of these relations around a particular point. Since it is important that variables not depart too much from this point, it is convenient to suppose that this approximation is taken around the point that describes the equilibrium when the exogenous variables take on their mean values. Because of the supposition that these steady-state relations always hold, I label this the "stochastic steady-state" method for computing the behavior of the model.

An obvious alternative is to rely on the dynamic equilibrium relations, and approximate these around a steady state. This is the second method that I employ. It might seem that this second method is superior since the dynamic equations do not imply that the economy always obeys the steady-state equations (18) and (19). However, the first method has some benefits and I start with it.

3 Stochastic Steady States

Using U.S. data on unemployment duration, Shimer (2005a) and Hall (2005b) infer f_t from the likelihood that people who have been unemployed for less than one month in a particular survey month remain unemployed in subsequent surveys. Shimer's (2005a) resulting estimate of f_t averages .45, so that nearly half of the unemployed find jobs within a month. Since the coefficient of lagged unemployment in (2) equals $(1 - s - f_t)$, such a high finding rate implies that unemployment converges quickly towards the "steady state" implied by f_t. This stochastic steady state is given by

$$u_t = \frac{s}{f_t + s}\bar{H}, \tag{22}$$

so the implied unemployment rate equals $s/(f_t + s)$. Figure 1 shows the actual U.S. unemployment rate and this implied unemployment rate. The implied rate is computed using Shimer's (2005a) method for obtaining f_t and setting s equal to the average separation rate in this sample, where this separation rate is also computed using his method. The actual and implied unemployment rates have similar cyclical movements, though the implied rate is somewhat less variable than the actual rate.[11] While the fit is far from perfect, Figure 1 suggests that it would be worthwhile to know whether a model that can generate these implied movements in the unemployment rate is also consistent with weak procyclical movements in the real wage.

Because this is a model where convergence to the "stochastic steady state" appears to be rapid, the stochastic steady state may be a good approximation to the dynamic equilibrium

[11]The actual and implied series overlap considerably more if the implied series is given by $s_t/(s_t + f_t)$ so that it includes variations in the separation.

of the model. Indeed, the next section shows that the elasticity of wages with respect to employment is similar in this stochastic steady state to the corresponding elasticity in a dynamic equilibrium model. Aside from this similarity, the main virtue of analyzing stochastic steady states is their simplicity. All that is required to understand the behavior of the variables in the model are the two equations (18) and (19), so it is easy to gain intuition for the results. In particular, it becomes easy to understand what features of U.S. data lead a low ϵ^c to be necessary for the procyclical movements in real wages to be mild.

Using a tilde to denote logarithmic deviations around a mean outcome and unsubscripted variables to denote the mean outcome, equation (22) implies that

$$\tilde{u}_t = \frac{-f}{f+s}\tilde{f}_t. \tag{23}$$

Combined with (1), (22) also provides a simple connection between employment and $\tilde{f}$. This is

$$\tilde{H}_t = \frac{s}{f+s}\tilde{f}_t = \tilde{u}_t + \tilde{f}_t, \tag{24}$$

where the second equality follows from (23). Meanwhile, equation (8) implies that

$$\tilde{\phi}_t = \epsilon_c \tilde{v}_t - \tilde{u}_t - \tilde{f}_t = \epsilon_c \tilde{v}_t - \tilde{H}_t, \tag{25}$$

where the second equality follows from (24). U.S. data indicate that $\tilde{v}$ rises very substantially when cyclical employment $\tilde{H}$ rises. This tendency of help wanted advertisement to change dramatically whenever there is a small change in aggregate employment is visible Figure 2, which plots the logarithms of both help wanted advertisement and employment. To allow the two lines to be displayed with the same scale, the mean has been subtracted from both series. To gain a sense of the differences in variability that are involved, employment dropped by 2 percent from its peak in 1979:11 to its trough in 1982:12 while the index of help wanted advertisement dropped from a value of 100 in 1979:11 to a value of 51 in 1982:12. Using detrended monthly data, the regression coefficient of the logarithm of help wanted advertisements on total nonfarm employment is around 8.[12] With $\epsilon_c = 1$, equation (25) then

[12]This was done using monthly data from 1951.01 to 2005.05. Because the data are monthly, I modified

implies that $\tilde{\phi}$ rises by about 7 percent when employment rises by one percent. Equation (18) then requires the wage to increase sharply. With a lower value of ϵ_c this effect is muted and it is possible for $\tilde{\phi}$ not to rise at all.

The linearization of (3) is:

$$\tilde{f}_t = \eta(\tilde{v}_t - \tilde{u}_t). \tag{26}$$

Using (26) to substitute for $\tilde{v}_t$ in (25) and using (23) to substitute for $\tilde{u}_t$ in the resulting equation, $\tilde{\phi}_t$ becomes a function of $\tilde{f}_t$ only:

$$\tilde{\phi}_t = \left[\epsilon_c\left(\frac{1}{\eta} - \frac{f}{f+s}\right) - \frac{s}{f+s}\right]\tilde{f}_t. \tag{27}$$

The level of ϵ_c such that the marginal hiring cost is unaffected by the finding rate makes the expression in square brackets zero and thus satisfies

$$\epsilon_c = \frac{\eta s}{(1-\eta)f + s},$$

which equals .0266 for the calibrated values of the other parameters. For higher values of ϵ_c, $\tilde{\phi}$ is increasing in $\tilde{f}$.

The log-linearization of the bargaining equation (18) yields

$$\begin{aligned}\Big[1 - \alpha\beta(1-s-f)\Big]\frac{w}{\rho}\tilde{w}_t &= \alpha[1-\beta(1-s-f)]\Big[\tilde{\rho}_t + \beta(1-s)\frac{\phi}{\rho}\tilde{\phi}_t\Big] \\ &\quad + \alpha\beta f\left(1 + \beta(1-s)\frac{\phi}{\rho} - \frac{w}{\rho}\right)\tilde{f}_t. \end{aligned} \tag{28}$$

Using the definition $\rho_t = z_t F_H$, the deviation in the marginal product of labor $\tilde{\rho}$ is given by

$$\tilde{\rho}_t = \tilde{z}_t - \frac{s_K}{e}\tilde{H}_t. \tag{29}$$

By using (29) to substitute for $\tilde{\rho}_t$ in (28) and using (27) to substitute for $\tilde{\phi}_t$ in (28) and then finally using (24) to replace $\tilde{f}_t$ by $\tilde{H}_t$, one obtains an equation relating $\tilde{w}_t$ to $\tilde{H}_t$ and $\tilde{z}_t$.

the parameters of Rotemberg (2003) so that the objective function involves the covariance between the cycle at t and the cycle 64 months hence, while the constraint is that the cycle at t be uncorrelated with the difference between the current trend and the average of the trends at $t+20$ and $t-20$.

If there are no changes in technological opportunities so that $\tilde{z}_t = 0$, this equation gives the elasticity of the wage with respect to employment.

Lest this argument seem too mechanical, it is worth understanding the economic logic that allows one to compute this key elasticity using just the bargaining steady-state relation. Suppose that a change in the elasticity of demand leads to an increase in the job-finding rate. Steady-state considerations allow one to pin down by how much this increases employment, and thus the extent to which the marginal product of labor falls if z is unchanged. The wage also depends on how much the marginal recruiting cost is affected, and this depends not only on the finding rate and on unemployment (which is determined by the finding rate) but also on the level of vacancies. However, if one knows how the finding rate depends on vacancies and unemployment, one also knows the level of vacancies that is consistent with the given combination of the unemployment and finding rates. This vacancy rate can then be used along with the unemployment and finding rates to compute the marginal hiring cost ϕ. In bargaining, the wage depends only on the marginal product of labor, the finding rate, and hiring costs. Since all three of these determinants of wages can be derived from the finding rate (or the level of employment), one can compute how the wage is related to employment from this equation alone. Interestingly, this calculation does not depend on the original impulse that leads firms to hire labor, as long as this impulse affects ρ only through its effect on employment.

Table 3's first column with results displays these elasticities for some selected parameter values. For the baseline case, this elasticity is around .4, which is close to the microeconomic evidence on the wages of people who keep their jobs. The table also shows that changes in the parameters towards those employed in Shimer (2005a) increase this elasticity to the point that it becomes too large relative to the empirical evidence.

Raising ϵ_c so that it equals one implies that recruiting costs rise substantially with employment, so the elasticity of the wage increases to 4.5. With $\epsilon_c = .2$, by contrast, these recruiting costs rise less. Even if ϵ_c is lowered to the value of .0266 where marginal recruiting costs are independent of employment, the wage still rises even though the marginal product of labor falls. The reason is that an increase in employment is also associated with a higher finding rate for jobs and this improves the bargaining position of workers.

This explains why λ/w has such a powerful effect on this elasticity. When $\lambda/w = .4$, workers vastly prefer employment to unemployment. Workers are thus in a very weak bargaining position when the finding rate is low, so they accept low real wages. An increase in the finding rate has a big effect on the bargaining position of the workers (since they now have less to lose from not forming a bond with a particular employer), so the bargained wage rises substantially. By contrast, when $\lambda/w = .9$ the bargaining position of workers is not so different in the boom and the bust, so real wages are less procyclical.

Specification (4) is interesting because it shows that the real wage becomes nearly acyclical when the changes in labor demand are due to ϵ_d and the elasticity of substitution between capital and labor is lowered to 1/3. The reason this elasticity has such a powerful effect is that it governs the extent to which the marginal product of labor falls when employment rises. With a lower value for e, the marginal product of labor falls more and this keeps the rise in the real wage small. When labor demand is driven by technology shocks, lowering the elasticity of substitution of capital for labor does not have this effect, because firms are not led to hire workers that reduce the marginal product of labor.

To compute the changes in ϵ_d that give rise to changes in employment when z is constant, or to compute the effect of changes in z, one must also use equation (19). When e is not equal to one, the labor and capital shares (HF_H/F and KF_K/F) depend on the level of employment and it is worth recording this dependence before approximating (19) as a whole. In particular

$$d\left(\frac{KF_K}{F}\right) = \frac{KF_K}{F}\left(\frac{HF_{HK}}{F_K} - \frac{HF_H}{F}\right)\frac{dH}{H} = s_K s_H \left(\frac{1}{e} - 1\right)\frac{dH}{H}.$$

Since $KF_K + HF_H = F$, the derivative of HF_H/F has the same magnitude and the opposite sign. As a result, the log-linear approximation of (19) around the mean outcome is

$$\begin{aligned} \frac{w}{\rho}\tilde{w}_t + \frac{m_\phi \phi}{\rho}\tilde{\phi}_t &= \left\{1 - \frac{1-\alpha\mu s_H}{\epsilon_d} + \frac{\alpha s_K}{e}\right\}\tilde{\rho}_t \\ &\quad + \alpha s_K s_H \left(\frac{1}{e} - \frac{\mu}{\epsilon_d}\right)\left(\frac{1}{e} - 1\right)\tilde{H}_t + \frac{1-\alpha\mu s_H}{\epsilon_d}\tilde{\epsilon}_{dt}. \end{aligned} \tag{30}$$

In the case of constant z, equation (30) can be used to compute the extent to which the elasticity of demand must change for any given change in employment. To carry out this computation, one uses (29), (25), and (26) to substitute for $\tilde{\rho}_t$, $\tilde{\phi}_t$, and $\tilde{f}_t$, respectively, as well as (28) to substitute for the the wage $\tilde{w}_t$. The resulting response of $\tilde{\epsilon}_d$ to changes in employment is displayed in the second results column of Table 3.

The first thing to note about these percentage increases in the elasticity of demand that are needed to increase employment by one percent is that they are large. They are, in particular, much larger than the changes in demand elasticity that are needed to vary labor demand by the same amount if firms have access to a competitive labor market. Recall that such a firm sets its price equal to $\epsilon_d/(\epsilon_d - 1)$ times marginal cost, which is in turn equal to the wage divided by the marginal product of labor. Thus, for the typical firm,

$$\frac{\epsilon_d}{\epsilon_d - 1} w = zF_H.$$

The linearization of this equation near a particular outcome yields

$$\tilde{\epsilon}_{dt} = (\epsilon_d - 1)(\tilde{w}_t + \frac{s_K}{e}\tilde{H}_t - \tilde{z}_t). \tag{31}$$

This implies that, with the baseline values of ϵ_d and s_k/e, a one-percent increase in employment that is accompanied by a .4-percent increase in the wage requires less than a .75-percent increase in the elasticity of demand. By contrast, in the baseline case, a one-percent increase in employment together with the implied .4-percent increase in the wage requires more than a 17-percent increase in the elasticity of demand. One reason for this large difference is that bargaining implies that workers' wages fall when the firm's price falls as it increases output. This makes the firm less sensitive to its elasticity of demand.

Table 3 also shows that the size of the increase in the elasticity of demand that is needed to raise employment by one percent is larger when $\epsilon_c = 1$ or when $\lambda/w = .4$. As discussed above, both of these modifications imply that wages rise more with employment. The increases in labor demand that are needed to rationalize a given increase in employment are larger, so ϵ_d must rise by more. In addition, when $\epsilon_c = 1$, ϕ rises with the level of employment. These higher recruiting costs act as an additional brake on hiring so that ϵ_d must rise even more.

When $\epsilon_c = 1$, the elasticity of demand must rise by 47 percent to increase employment by one percent, and this seems excessive. However, it is important to keep in mind that the elasticity of demand is mainly a modelling device to capture the effect of changes in product market distortions that could be due to other causes. Still, these changes appear more plausible when the model implies only that the elasticity of demand must rise by 6 percent for each percent increase in employment.

As the analysis above suggests, it is possible to reduce the required increase in the elasticity of demand further by lowering α. However, this reduction in the bargaining power of workers is not a panacea; it tends to increase the elasticity of the wage with respect to employment. The reason is that a lower α implies that wages are less affected by the marginal product of labor (which falls in booms) and more affected by the the "net benefit from being unemployed" $(-\Delta)$. This net benefit rises in booms because unemployed workers expect to find jobs sooner. Linking wages more closely to $(-\Delta)$ thus implies that they are more procyclical.

The log-linearized equations (28) and (30) can also be used to study the effect of technology shocks or, as Shimer (2005a) has framed the question, the size of the technological changes that are needed to rationalize employment movements. To see this, follow Shimer (2005a) and suppose that the elasticity of demand is constant. Then, after substituting for $\tilde{\phi}$, $\tilde{\rho}$, and $\tilde{f}$, these two equations have three unknowns $\tilde{H}$, $\tilde{w}$, and $\tilde{z}$. They can thus be solved for the $\tilde{z}$ and $\tilde{w}$ as a function of the log deviation of employment.

The resulting elasticities of the wage and z with respect to employment are displayed in the last two columns of Table 3. One implication of the model that I have discussed already is that real wages are more procyclical when employment is driven by changes in z than when it is driven by changes in ϵ_d, and the table shows that this difference is quantitatively important. The elasticity of the wage with respect to employment is always at least twice as large in the former case.

Using Shimer's parameters in specification (6), productivity must rise by 30 percent to induce a one-percent increase in employment. This is just another way of phrasing Shimer's

(2005a) central result that productivity does not fluctuate sufficiently to justify the observed fluctuations in the job-finding rate.[13]

Interestingly, the table shows that the baseline parameters for this study produce smaller, and more appealing, required changes in productivity. That an increase in λ/ρ (like the one that causes the difference between specification (5) and specification (2)) helps to reduce this elasticity was shown already by Hagedorn and Manovskii (2005). As suggested earlier, a higher value of λ/ρ makes recessions less costly for unemployed workers, so their wages do not fall as much. This reduces the extent to which labor costs rise in booms, so productivity need not increase as much to rationalize a given increase in employment.

Reducing the value of ϵ_c (as when going from specification (5) to specification (3) or from specification (2) to specification (1)) also reduces the elasticity of z with respect to employment considerably. When ϕ increases with employment (because $\epsilon_c > .02666$), there are two effects that require higher increases in z. First, the higher value of ϕ leads workers to obtain higher wages because it is more costly to replace them. Second, the higher value of ϕ acts directly as a reason to keep hiring low. Both of these must be offset by larger increases in productivity for the firm to increase its employment in the first place.

Reducing the elasticity of substitution between capital and labor also reduces the extent to which productivity must rise, though it turns out that this effect is quantitatively significant only when ϵ_c is low.[14] The source of this effect is the following. When $e < 1$, KF_K/F rises with employment. As we saw earlier, the extent to which firms wish to overhire rises with this share. Increases in employment thus reduce the profitability of additional hiring

[13]Shimer (2005a) shows that "net productivity" must rise by about one percent for each one-percent increase in the ratio of vacancies to unemployment. The reason this implies that productivity must rise by about 30 percent for each percent increase in employment can be seen as follows. A one-percent increase in "net productivity" corresponds to about a .6 percent increase in productivity itself given a λ/ρ ratio of .4. At the same time, $\eta = .28$ implies that a one-percent increase in v/u raises the job finding rate by .28 percent. A one-percent increase in the job-finding rate thus requires a 1/.28-percent increase in v/u and a .6/.28 (≈ 2) percent increase in productivity. Equation (24) implies that the finding rate must rise by about 15 percent for each one-percent increase in employment, so a one-percent increase in employment does indeed require a 30-percent increase in productivity.

[14]Indeed, using the alternative parameters AA, with $s_h = 2/3$ and $e = 1/3$, actually raises the elasticity of z with respect to employment to 32.

less than would otherwise be the case. This implies that productivity need not rise as much to induce the firm to carry out this extra hiring.

This raises the question of whether the parameters in (1) solve the puzzle raised by Shimer (2005a). Table 3 indicates that these parameters still require productivity to be substantially more procyclical than it is in U.S. data. Since $\mu = 1.7$ implies that labor productivity must rise by .13 percent as a direct result of the increase in employment, what is needed is about a 2.7-percent increase in labor productivity every time employment increases by one percent. This does not seem to be easy to reconcile with the relatively low covariance between labor productivity and employment (which I took earlier to imply that productivity rises by only .13 percent for each one-percent increase in employment). However, the question of whether low values of e and ϵ_c are sufficient for economic fluctuations to be due solely to technological disturbances deserves further study.

4 Approximate Equilibria near a Steady State

In this section, I consider dynamic simulations of the full model around a steady state. The model consists of equations (1), (2), (3), (5), (7), (14), and (15) and an equation specifying how ρ_t depends on H_t. In the case where $e = 1$, this equation takes the Cobb-Douglas form $\rho_t = z_t \bar{\rho} H^{s_H}$, whereas it takes the CES form when $e = 1/3$. This gives 7 equations in H_t, u_t, v_t, f_t, ϕ_t, Δ_t, w_t, ϵ_{dt}, and z_t. These equations have just one state variable, namely, the lagged value of u. They can be solved for the effects of technology by treating z_t as exogenous and fixing ϵ_{dt}, or for the effects of variable market power by fixing z_t and treating ϵ_{dt} as exogenous. Equivalently, I consider the stochastic processes for either z_t or ϵ_{dt} that are needed to rationalize a set of plausible stochastic processes for the log of H_t, h_t.

The stochastic processes I consider for h_t are based on the behavior of detrended employment in the business sector. Using data from 1950:1 to 2002:1, a regression of (quarterly) detrended employment on its own lag yields a coefficient of .941, while a regression on two lags gives a coefficient of 1.55 on the first lag and -.64 on the second. This AR(2) specification fits better in that the second coefficient is highly statistically significant and in that the Durbin-Watson statistic rises from .78 to 1.99 when two lags are included instead of one. Still, it is standard in analyzing Mortensen-Pissarides models to study AR(1) processes, and for this reason I consider two specifications that differ in the order of the autocorrelation that describes h_t.

I continue to suppose that a period lasts one month (so that the steady-state finding rate remains .45, for example) and the two specifications are:

$$h_t = .98 h_{t-1} + \nu_t^1 \tag{32}$$

$$h_t = 1.76 h_{t-1} - .78 h_{t-2} + \nu_t^2. \tag{33}$$

The first of these is simply the monthly analogue of the AR(1) model estimated with quarterly data, so its coefficient is the cubic root of the estimated coefficient discussed above. The second is more loosely based on the quarterly AR(2) specification. The two models do have in common that the peak response of employment to a shock in quarter t occurs in quarter $t+2$.[15]

This model is simulated using DYNARE, which uses a method of approximating the behavior of the model near a steady state that is close to Collard and Juillard (2001). Because these calculations involve a second-order approximation, the variance of the shocks ν^1 and ν^2 affect the results. I choose these variances so the standard deviation of h is approximately .02, the standard deviation of cyclical log employment in the U.S. business sector.

One simple way of presenting the resulting simulations is to consider regressions of wages, z, and ϵ_d on employment with simulated data. These can readily be computed from the impulse-response functions, and the results of these theoretical regressions are presented in Table 4.

The elasticities of the wage and z look quite similar to those of Table 3, though the

[15] In the monthly model, a shock that raises the average level of employment by one percent in the initial quarter raises it by 1.82 percent two quarters after this shock first has an impact. In the estimated quarterly model, this figure equals 1.74, which is somewhat lower. On the other hand, the estimated quarterly model's response after three quarters equals 1.57, which is somewhat higher than the 1.61 percent response implied by the monthly model. Thus, while the responses are similar in both cases, they are not identical.

required responses of ϵ_d are even larger. One obvious question that arises at this point is why the numerical implications of this fully dynamic model are so similar to those of its steady-state counterpart. The reason is that, with a high value of f_t, neither the future nor the past exert as strong influence on the model's current predictions. It has already been noted that the coefficient of lagged unemployment in (2) is $(1 - s - f_t)$, which is small when f is high. Moreover, $(1 - s - f_t)$ is also the coefficient of future Δ in (5). Thus, a high value of f also implies that Δ is mostly affected by developments in the very near future.

The remaining dynamic equilibrium condition is (15) and this too is consistent with employment and wages being near their steady state as long as there is not much difference between current and future hiring costs. Since (8) implies that hiring costs depend only on contemporaneous variables, slow-moving changes in employment like those implied by (32) and (33) are consistent with having the other variables in the model near the "steady-state" values that correspond to the current level of employment. This explains also why the statistics in Table 4 are not affected very strongly by whether one seeks to rationalize AR(1) or AR(2) stochastic processes for employment. Table 4 also shows that, as before, lowering the elasticity of substitution between capital and labor reduces the extent to which real wages are procyclical when employment fluctuations are due to changes in ϵ_d. While not reported in the table, the theoretical regression coefficients reported here also seem robust to plausible changes in the standard deviations of the νs.

One advantage of computing these approximations near a steady state is that they allow one to look at impulse responses. One can then see the pattern of movements in either z or ϵ_d that is needed to justify the stochastic processes for h. The changes in z and ϵ_d, together with the responses of log employment and the log real wage, are depicted for the more interesting AR(2) case in Figures 3 and 4.

Like the response of employment itself, the required responses of z and ϵ_d in the AR(2) case are hump shaped. However, while employment rises immediately (and then keeps rising for some time), both z and ϵ_d are required to fall somewhat on impact. Only later do z and ϵ_d rise, with their peak increases actually coming somewhat after the peak changes in employment. These results emerge because the baseline parameter values imply that the marginal cost of adding employees rises disproportionately as employment reaches its peak (when future employment declines). The relevant combination of current and expected future adjustment costs does not rise as rapidly when increases in employment are followed by further increases. As a result, the prospect of a future increase in labor demand (because of future increases in either z or ϵ_d) leads firms to increase their hiring immediately. The actual initial increase in employment is not quite as large, so the model requires that there be an opposing force that discourages initial employment.

The initial fall in ϵ_d that is required is equal to only about a quarter of the eventual peak rise in ϵ_d. By contrast, the initial fall in z_t is nearly half as large in absolute value as the ultimate increase in this productivity indicator. The underlying reason for this larger response is that bargaining between workers and firms leads wages to fall when z falls. Small reductions in z, which are accompanied by reductions in w in equilibrium, are therefore not sufficient to discourage hiring by the requisite amount. To track the actual increase in initial employment, z (and the real wage) must fall significantly.

5 Conclusions

This paper has shown that, in the context of matching models, variations in market power have some advantages relative to variations in technology shocks for explaining the relatively weak procyclical movements in productivity and real wages. While variations in market power emerge as an attractive source of aggregate fluctuations in employment, the particular source of these variations considered here does not. In particular, the variations in the elasticity of demand that are needed to explain employment fluctuations are too large. While this paper has not considered sticky prices explicitly, the findings suggest that it may be easier to rationalize the needed market-power fluctuations in such a setting. If prices were relatively constant, market power would fluctuate because firms would face changes in marginal cost as they varied their output to meet demand.

This paper has focused on matching the regression coefficients implied by the model (which are simply the correlation multiplied by the appropriate ratio of standard deviations) to those that one finds in actual data. The more usual approach (see for example Shimer (2005a)) is to try to match ratios of standard deviations in the model and in the data. Models with a single shock tend to imply correlations near one, so the model-generated regression coefficients are close to the ratio of standard deviations. In the data, however, many correlations — particularly those involving real wages — are smaller than one, and so the approach followed here is not identical to one that focuses on ratios of standard deviations.

In particular, matching the regression coefficient of wages on employment in a single-shock model leads to a real wage that is less variable than observed aggregate wages. Not surprisingly, obtaining a model that matches a single labor-market statistic still leaves one far from having a complete model of labor-market dynamics. A more complete model would incorporate multiple shocks. The regression coefficient of wages on employment would then equal the weighted average of the regression coefficients from models that have only one of the included shocks, with the weights being related to the extent to which the individual shocks contribute to fluctuations in employment.

It is thus possible in principle to have a small overall regression coefficient of wages on employment that results from some shocks that lead to large positive responses of wages to employment and other shocks that lead to large falls in wages when employment rises. Two studies focusing on the responses of real wages to exogenous monetary and fiscal disturbances both find small procyclical wages, however.[16] This suggests that a mechanism that induces small procyclical real-wage movements such as the one presented here, may well play a role also in a more complete model with multiple shocks.

[16]See Christiano, Eichenbaum, and Evans (2005) for responses to monetary policy and Rotemberg and Woodford (1992) for responses to shocks to military purchases.

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Table 1
Variable Parameters

	s_h	ϵ_c	λ/w	ϵ_d	μ	e
Baseline (BB)	2/3	.2	.9	2	1.7	1
Alternative (AA)	1	1	.4	10,000	1	1/3

Table 2
Steady-State Values

Specification	Parameters	w/ρ	ϕ/ρ
(1)	Baseline (BB)	0.94	0.01
(2)	BB with $\epsilon_c = 1$	1.14	0.24
(3)	BB with $\lambda/w = .4$	0.69	0.03
(4)	BB with $e = 1/3$	0.96	0.04
(5)	BB with $\epsilon_c = 1$ and $\lambda/w = .4$	1.12	0.69
(6)	Alternative (AA)	0.98	0.47
(7)	AA with $s_H = 2/3$ and $e = 1$	1.21	0.82

Table 3
Elasticities with Respect to Employment at Stochastic Steady State

Spec.	Parameters	Variable ϵ_d		Variable z	
		Elasticity of w	Elasticity of ϵ_d	Elasticity of w	Elasticity of z
(1)	Baseline (BB)	0.44	17.27	2.60	3.64
(2)	BB with $\epsilon_c = 1$	4.54	47.06	9.39	9.93
(3)	BB with $\lambda/w = .4$	3.38	45.48	11.06	9.60
(4)	BB with $e = 1/3$	0.16	43.08	3.07	5.04
(5)	BB with $\epsilon_c = 1$ and $\lambda/w = .4$	15.35	148.47	30.87	31.33
(6)	Alternative (AA)	-	-	29.92	30.04
(7)	AA with $s_H = 2/3$ and $e = 1$	-	-	31.25	31.72

Table 4
Elasticities with Respect to Employment near Steady State

Spec.	Parameters	Variable ϵ_d		Variable z	
		Elasticity of w	Elasticity of ϵ_d	Elasticity of w	Elasticity of z
(1)	Baseline (BB) AR(2)	.41	41.3	2.54	3.68
(2)	Baseline (BB) AR(1)	.41	50.8	2.72	3.88
(3)	BB with $\epsilon_c = 1$, AR(2)	5.37	40.9	11.5	10.7
(4)	BB with $\epsilon_c = 1$, AR(1)	5.22	41.4	11.7	11.0
(5)	BB with $e = 1/3$, AR(2)	.13	125.1	3.05	5.20
(6)	BB with $e = 1/3$, AR(1)	.13	129.9	3.32	5.48

Figure 1: Actual and Implied Unemployment Rates in the U.S.

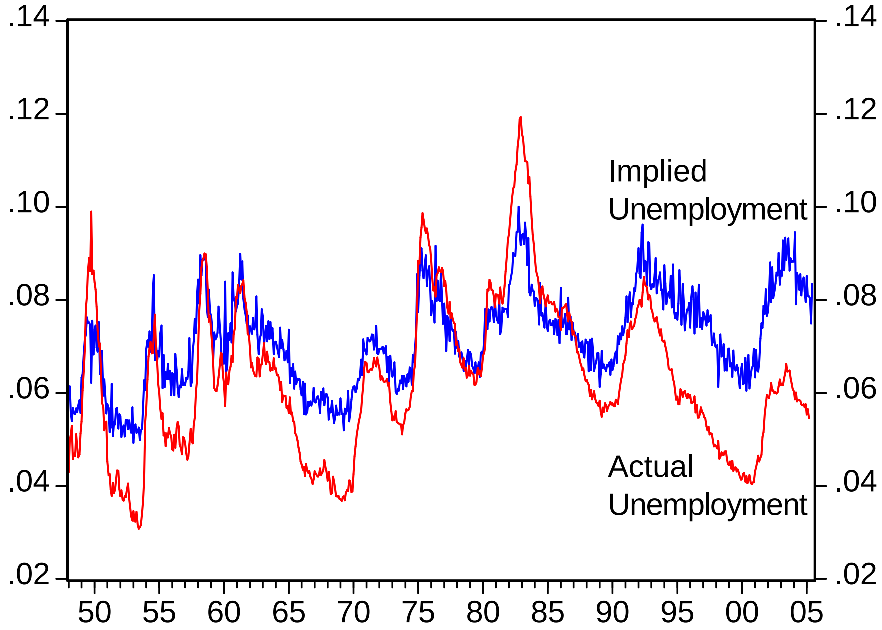

Figure 2: Logarithms of Help Wanted Advertisement and Employment

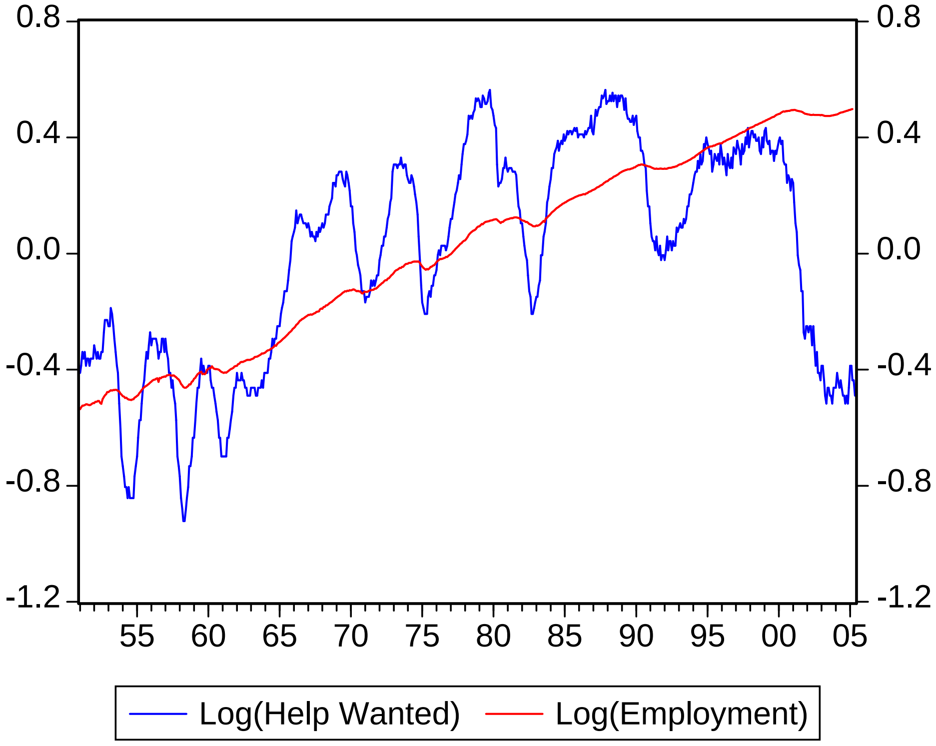

Figure 3: Technology changes, Baseline parameters - AR(2) employment

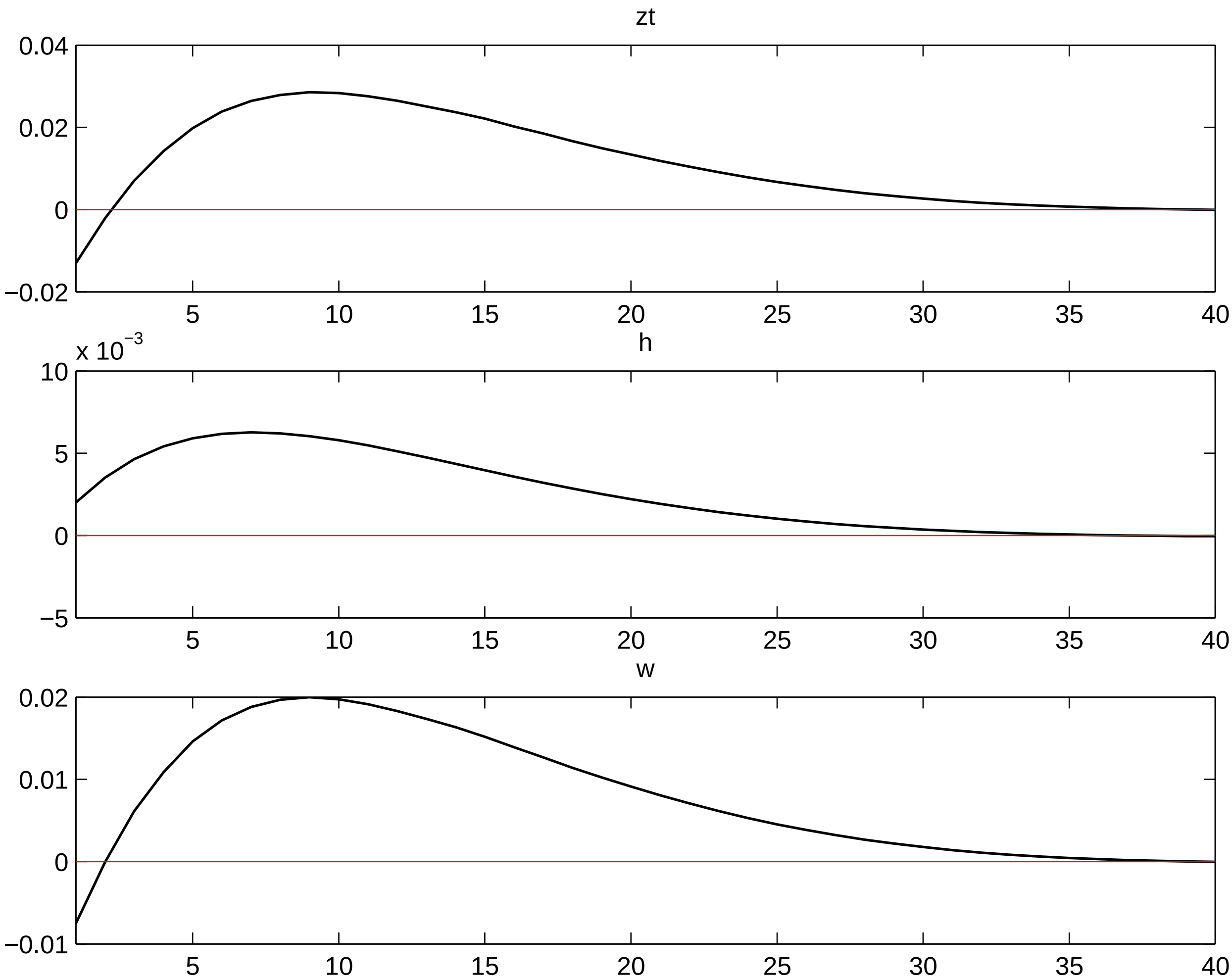

Figure 4: Demand elasticity changes, Baseline parameters - AR(2) employment