The Vanishing Procyclicality of Labor Productivity*

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Abstract

We document three changes in postwar US macroeconomic dynamics: (*i*) the procyclicality of labor productivity has vanished, (*ii*) the relative volatility of employment has risen, and (*iii*) the relative (and absolute) volatility of the real wage has risen. We propose an explanation for all three changes that is based on a common source: a decline in labor market frictions. We develop a simple model with search frictions, variable effort, and endogenous wage rigidities to illustrate the mechanisms underlying our explanation. We show that the reduction in search frictions may also have contributed to the observed decline in output volatility.

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1 Introduction

The nature of business cycle fluctuations changes over time. There is a host of evidence for changes in the dynamics of postwar US macroeconomic time series (Blanchard and Watson (), Galí and Gambetti (2009), Hall (2007), McConell and Pérez-Quirós (2000), Stock and Watson (2002)). The present paper documents and discusses three aspects of these changes:

1. The correlation of labor productivity with output or labor input has declined, by some measures dramatically so.[1]

2. The volatility of labor input measures has increased (relative to that of output).[2]

3. The volatility of real wage measures has increased, both in relative and absolute terms.[3]

All three of the above observations point towards a change in labor market dynamics. While each may be of independent interest and have potentially useful implications for our understanding of macro fluctuations, our goal in the present paper is to explore their possible connection. In particular, we seek to investigate the hypothesis that all three changes may be driven by an increase in labor market flexibility, allowing firms to adjust their labor force more easily in response to various kinds of shocks. In order to illustrate the mechanism behind this explanation, we develop a stylized model of fluctuations with labor market frictions, and investigate how its predictions vary with the parameter that indexes the importance of such frictions.

The main intuition behind that mechanism is easy to describe. Suppose that firms have two margins for adjusting their effective labor input: (observed) employment and (unobserved) effort, which we respectively denote (in logs) by n_t and E_t.[4] Labor input (employment and effort) are transformed into output according to a standard production function,

$$y_t = (1-\alpha)(n_t + \psi\mathcal{E}_t) + a_t$$

[1] As far as we know, Stiroh (2009) was the first to provide evidence of a decline in the labor productivity-hours correlation. Barnichon (2008), Galí and Gambetti (2009), Gordon (2009) and Nucci and Riggi (2009), using different approaches, independently investigated the potential sources of that decline.

[2] To the best of our knowledge, Galí and Gambetti (2009) were the first to uncover that finding, but did not provide the kind of detailed statistical analysis found below. Independently, Hall (2007) offered some evidence on the size of the decline in employment in the most recent recessions that is consistent with our finding.

[3] As far as we know, this finding was not known previously, although it is reported in independent work by Gourio (2007) and Champagne and Kurmann (2009).

[4] To simplify the argument we assume for the time being that hours per worker are constant.

where a_t is log total factor productivity and α is a parameter measuring diminishing returns to labor.

Measured labor productivity, or output per person, is given by

$$y_t - n_t = -\alpha n_t + (1-\alpha)\psi e_t + a_t$$

Labor market frictions make it costly to adjust employment n_t. Endogenous effort e_t provides an alternative margin of adjustment of labor input and is not subject to those frictions (or to a lesser degree). Thus, the larger the search frictions, the less employment fluctuates and the more volatile fluctuations in effort. As a result, a reduction in search frictions decreases the volatility of effort and therefore increases the relative volatility of employment with respect to output. The increased volatility of n_t would make labor productivity less procyclical. In the presence of shocks other than shifts in technology, this effect may change the sign of the correlation of labor productivity with output and employment, so that productivity becomes acyclical or countercyclical, consistent with the evidence reported below.

In addition, as emphasized by Hall (2005), the presence of labor market frictions generates a non-degenerate bargaining set for the wage, i.e. a wedge between the firms' and workers' reservation wages. Any wage within that bargaining set is consistent with labor market equilibrium. That feature makes room for wage rigidities. We model wages as rigid within the bargaining set, adjusting only when approaching the bounds of the bargaining set. In this model, a reduction in labor market frictions endogenously makes wages more sensitive to shocks, increasing the volatility of fluctuations in wages. If the rigidity is extended to the wages of newly hired workers, then the increased flexibility of wages may dampen the volatility of output and employment in response to shocks.[5] That feature may help explain the observed decline in the volatility of those two variables in the recent US experience.[6]

The remainder of the paper is organized as follows. Section 2 documents the changes in the patterns of fluctuations in labor productivity, employment and wages. Section 3 develops the basic model. Section 4 describes the outcome of simulations of a calibrated version of the model, and discusses its consistency with the evidence.

[5] This is clearly true for technology shocks. As argued in Blanchard and Galí (2008), increased wage flexibility may also dampen the sensitivity of GDP and inflation to oil price shocks.

[6] A more flexible labor market does of course not make the economy completely immune to very large shocks like the recent financial crisis. If the labor market were as rigid as it was in the early 80s, the current recession might have been even substantially more severe.

2 Changes in Labor Market Dynamics

We document three stylized facts regarding postwar changes in US economic fluctuations that motivate our investigation. All three facts are about changes in the dynamics of the labor market and pertain to the cyclical behavior of labor productivity, labor input and wages. We use quarterly time series over the period 1948:1-2007:4 drawn from different sources (see below for a detailed description). To illustrate the changes in the different statistics considered, we split the sample period into two subperiods, pre-84 (1948:1-1983:4) and post-84 (1984:1-2007:4). The choice of the break date is motivated by existing evidence on the timing of the Great Moderation, the sharp drop in output volatility around 1984 (McConell and Pérez-Quirós (2000)).

Our evidence makes use of alternative measures of output and labor input. In all cases labor productivity is constructed as the ratio between the corresponding output and labor input measures. Most of the evidence uses output and hours in the private sector from the BLS productivity and cost program. We also use GDP as an economy-wide measure of output, with the corresponding labor input measures being total hours or employment. The time series for economy-wide hours is an unpublished series constructed by the BLS and used in Francis and Ramey (2008). The employment series is the usual one from the establishment survey. In all cases we normalize the output and labor input measures by the size of the civilian noninstitutional population (16 years and older).

We use three alternative transformations on the logarithms of all variables in order to render the original time series stationary. Our preferred transformation uses the bandpass (BP) filter to remove fluctuations with periodicities below 6 and above 32 quarters, as in Stock and Watson (1999). We also use the Hodrick-Prescott (HP) filter with a smoothing parameter of 1600, which is common in the business cycle literature, and the fourth difference (4D) of the original time series, which is the transformation favored by Stock and Watson (2002) in their analysis of changes in output volatility.[7]

2.1 The Vanishing Procyclicality of Labor Productivity

Figure 1 shows the fluctuations at business cycle frequencies in labor productivity in the US over the postwar period. It is clear from the graph that in the earlier part of the sample, productivity was significantly below trend in each recession. However, in the post-84 data, this is no longer the case. When we calculate the correlation of

[7]The data and Stata code used to calculate the statistics reported here are available at www.crei.cat/~vanrens/VPLP.

productivity with output or employment, as in Figure 2, it is clear that there is a sharp drop in the cyclicality of productivity around 1984. The correlation of productivity with output, which used to be strongly positive, fell to close to zero, and the correlation of productivity with employment, which was zero or slightly positive in the earlier period of the sample, became negative.

These findings are formalized in Table 1, which reports the contemporaneous correlation between labor productivity and output and employment, for alternative transformations and time periods. In each case, we report the estimated correlation for the pre and post-84 subsamples, as well as the difference between those estimates. The standard errors, reported in brackets, are computed using the delta method.[8]

2.1.1 Correlation with Output

Independently of the detrending procedure and time period, the correlation of output per hour with output in the pre-84 period is high and significantly positive, with the point estimate ranging between 0.69 and 0.86, depending on the filter and time period, and always strongly significantly positive. In other words, from the vantage point of the early 80s –the period when the seminal contributions to RBC theory were written– the procyclicality of labor productivity was a well established empirical fact, which lent support to business cycle theories that assigned a central role to technology shocks as a source of fluctuations.

In the post-84 period, however, that pattern changed considerably. The estimates of the productivity-output correlation dropped to values close to (and not significantly different from) zero. The difference with the corresponding pre-84 estimates is highly significant. Thus, on the basis of those estimates labor productivity has become an acyclical variable (with respect to output) over the past two decades.

When we use an employment-based measure of labor productivity, output per worker, the estimated correlations still drop significantly but remain (borderline) significantly greater than zero in the post-84 period. This should not be surprising given that hours per worker are highly procyclical in both subperiods and that their volatility relative to employment-based labor productivity has increased considerably.[9]

[8] We use least squares (GMM) to estimate the second moments (variances and and covariances) of each pair of variables, as well as the (asymptotic) variance-covariance matrix of this estimator. Then, we calculate the standard errors for the standard deviations, the relative standard deviations and the correlation coefficient using the delta method.

[9] Letting n and h denote employment and total hours respectively, a straightforward algebraic ma-

2.1.2 Correlation with Labor Input

The right-hand side panels in Table 1 display several estimates of the correlation between labor productivity and labor input. The estimates for the pre-84 period tend to be low, and in some cases insignificantly different from zero. Thus, labor productivity was largely acyclical with respect to hours in that subperiod. This near-zero correlation is consistent with the evidence reported in the early RBC literature, using data up to the mid 80s.[10]

As was the case when using output as the cyclical indicator, the estimated correlations between labor productivity and employment decline dramatically in the post-84 period. In fact these correlations become negative, regardless of the filter used or the precise time period considered and mostly significantly so, with the point estimates ranging from -0.36 to -0.60 for output per hour and from -0.03 to -0.38 for output per worker. The change with respect to the pre-84 period is always highly significant. In other words, labor productivity has become in the past two decades unambiguously countercyclical with respect to employment.

2.2 The Rising Relative Volatility of Labor Input

The left-hand panel of Table 2 displays the standard deviation of several measures of labor input in the pre and post-84 periods, as well as the ratio between the two. The variables considered include employment in the private sector, hours in the private sector (employment times hours per worker) and economy-wide hours. The decline in the volatility of hours since the mid 80s, like that of other major macro variables, is seen to be large and highly significant, with the ratio of standard deviations ranging between 0.49 and 0.73, and always significantly smaller than one.

A more interesting piece of evidence is the change in the *relative* volatility of labor input, measured as the ratio of the standard deviation of labor input to the standard deviation of output. These estimates are presented in the right-hand panel of Table 2. Without exception, all labor input measures have experienced an increase in their

nipulation yields the identity:

$$\rho(y-n,y) = \frac{\sigma_{y-h}}{\sigma_{y-n}}\rho(y-h,y) + \frac{\sigma_{h-n}}{\sigma_{y-n}}\rho(h-n,y)$$

Thus, even in the case of acyclical hours-based labor productivity, i.e. $\rho(y-h,y) \simeq 0$, we would expect $\rho(y-n,y)$ to remain positive if hours per worker are procyclical, i.e. $\rho(h-n,y) > 0$.

[10] Christiano and Eichenbaum (1992) used data up to 1983:4 (which coincides with the cut-off date for our first subperiod), but starting in 1955:4. Their estimates of the correlation between labor productivity and hours were -0.20 when using household data and 0.16 using establishment data.

relative volatility in the post versus pre-84 period. In other words, the decline in the variability of labor input has been less pronounced than that of output. The increase in the relative volatility of hours worked ranges from 28 to 54% in the private sector and from 7 to 44% in the total economy. The corresponding increase for employment is slightly smaller, ranging from 11 to 47% in the private sector, but is still statistically significant.

The previous evidence points to a rise in the elasticity of labor input with respect to output. Put differently, firms appear to have relied increasingly on labor input adjustments in order to meet their changes in output.

2.3 The Rising Volatility of Wages

Next we turn our attention to the volatility of (real) wages, both in absolute and relative terms. We consider four different wage measures. The first three are constructed as real compensation per hour. The first difference is in the measure of compensation, which comes either from the national income and product accounts (NIPA), as in the measure for the labor productivity and cost program (LPC) and the NIPA, or from the establishment survey (Current Employment Statistics, CES). The second difference is in the measure of hours, which refers to the private sector in the LPC and CES measures and to the total economy in the NIPA measure. The fourth measure is usual hourly earnings (or usual weekly earnings divided by usual weekly hours) from the Current Population Statistics (CPS), deflated using the CPI. For all measures, compensation or earnings are deflated using the compensation deflator from the LPC, but the results are robust to deflating with the output deflator or the consumer price index (CPI-U) as we show below.

2.3.1 Average Wages

The left-hand panel of Table 3 displays the standard deviation for each wage measure for different detrending procedures. Our statistics uncover a surprising finding: despite the general decline in macro volatility associated with the Great Moderation, the volatility of wages may have *in*creased in absolute terms. The estimated increase the standard deviation is fairly large, between 9 and 86% and mostly significant for the HP and bandpass filtered NIPA-based wage measures (LPC for the private sector or the NIPA measure for the total economy). Using fourth differences, the increase is much smaller, no longer significant and for some periods there seems to have been a (small) decrease.

Using compensation per hour from the CES, however, there seems to be a large and highly significant reduction in wage volatility. One difference between the two measures is that the NIPA measure includes non-wage payments and, in particular, employee stock options. Mehran and Tracy (2001) have argued that since these options are recorded when they realize rather than when they are handed out to employees, the NIPA measure gives a misleading picture of the evolution and volatility of compensation in the 90s. However, using the CPS measure, presented in Table 4, which includes non-wage compensation but not stock options, we again observe a fairly large increase in the volatility of wages.[11] Given the short time series available for these data, it is remarkably that the increase in volatility is significant at the 10% level, except when using fourth differences, in which case wage volatility seems roughly constant.

Our finding that wage volatility increased or at least did not decrease around the time of the Great Moderation, although with a caveat, is consistent with the results in Champagne and Kurmann (2009), who also use the CPS to show that the increase in wage volatility is not driven by compositional changes in the labor force. To the best of our knowledge, this result was not previously known.[12]

An immediate implication of the previous finding, and the one that we want to emphasize here, is the possibly very large increase in the relative volatility of wages with respect to to output or labor input, as shown in the right-hand panels of Tables 3 and 4. The relative volatility of wages with respect to output more than doubled for the NIPA-based measures and for the CPS wage. This result is robust to the filtering procedure or precise time period used. We interpret this evidence as being consistent with a decline in the significance of real wage rigidities around 1984.[13]

[11] We use data from the CPS outgoing rotation groups. Since these data are available only from 1979 onwards, we compare the volatility over the 1980-1984 period (allowing for fourth differences) with that of the 1985-2005 period. For comparison, the first panel of Table 4 presents the volatility of the LPC wage for this period. The second panel presents comparable statistics from the CPS series. Because the CPS wage series is based on a fairly small cross-section of workers, there is substantial measurement error in these series. Therefore, the standard deviations of the HP filtered and, particularly, the fourth differenced data are biased upward, see Haefke, Sonntag, and van Rens (2008) for details. There is no reason however, why the ratio of the standard deviations before and after 1984 would be biased. In addition, the bandpass filtered data, which do not include the high frequencies induced by the measurement error, are not subject to this bias.

[12] Stock and Watson (2002) uncover breaks in the volatility of a long list of macro variables, but they do not provide evidence for any wage measure.

[13] Blanchard and Galí (2008) argue that a reduction in the rigidity of real wages is needed in order to account for the simultaneous decline in inflation and output volatility, in the face of oil price shocks of a similar magnitude.

2.3.2 Wages of Newly Hired Workers

On a labor market with search frictions, the average wage is not allocative, since the frictions drive a wedge between the reservation wages of firms and workers. Therefore, in order to assess the implications of increased wage flexibility for other labor market variables, we also consider the volatility of the wage of newly hired workers as suggested by Haefke, Sonntag, and van Rens (2008) and Pissarides (2007).

Table 4 present volatility statistics for the wage of new hires, constructed from the CPS as in Haefke, Sonntag, and van Rens (2008).[14] The first thing to notice is that the wage of newly hired workers is much more volatile than the average wage in the entire labor force. This is consistent with the results in Haefke, Sonntag, and van Rens (2008), who argue that, in the post-84 period, wages of newly hired workers are perfectly flexible, in the sense that they respond one-to-one to changes in labor productivity. Here, we focus on the change in the volatility of wages over time.

The absolute volatility of the wage of newly hired workers, unlike the average wage, decreased substantially and significantly between the pre and post-84 periods. As a result, the increase in the relative volatility with respect to output is much smaller for new hires, ranging between 3% and 69%, depending on whether we use the mean or median wage and on the filter used. Although the increase in the relative volatility of the wage of newly hired workers is much less pronounced, there is some evidence that wages fluctuated more between recessions and booms also for this group of workers. This finding is consistent with the evidence presented in Haefke, Sonntag, and van Rens (2008, section 3.4) and points towards a decrease in wage rigidity that may be important for employment fluctuations.

3 A Model of Fluctuations with Labor Market Frictions and Endogenous Effort

Having documented in some detail the changing patterns of labor productivity, labor input, and wages, we turn to possible explanations. More specifically, and as anticipated in the introduction, we explore the hypothesis that all three observed changes documented above may have, at least partly, been caused by the same institutional change: increasing flexibility of the labor market, modelled as a decline in search frictions.

[14] But unlike in that paper, we do not correct fluctuations in the CPS wage series for changes in the composition of the labor force by demographic characteristics, education level and experience for comparability with the other wage measures. Doing so however, makes very little difference for the conclusions presented here.

To formalize this explanation, we develop a model of fluctuations with labor market frictions. The crucial element in this model is an endogenous effort choice, which provides an intensive margin for labor adjustment that is not subject to the search frictions. Since the main purpose of the model is to illustrate the mechanisms, we keep the model as simple as possible in dimensions that are likely to be orthogonal to the factors emphasized by our analysis. Thus, we abstract from endogenous capital accumulation, trade in goods and assets with the rest of the world, and imperfections in the goods and financial markets. We also ignore any kind of monetary frictions, even though we recognize that these, in conjunction with changes in the conduct of monetary policy in the Volcker-Greenspan years, may have played an important role in accounting for the decline in macro volatility.[15]

3.1 Labor Market Frictions

The labor market is populated by a continuum of identical firms, with vacancies they are looking to fill, and a continuum of identical households, with unemployed members they wish to find jobs for. Labor market frictions are represented by the lack of a centralized market clearing mechanism that would instantaneously vacancies to unemployed workers. Instead, vacancies are filled and unemployed workers find only with certain probabilities, which are endogenous and depend on aggregate labor market conditions. As is standard in the macro labor literature, see e.g. Pissarides (1985), we model the matching technology as an aggregate matching function, which relates the total number of matches M_t to the number of vacancies V_t and the number of unemployed workers U_t,

$$M_t = BU_t^{\mu}V_t^{1-\mu} \tag{1}$$

where $\mu \in (0,1)$ is an elasticity parameter and $B > 0$ is a parameter determining the overall efficiency of the matching process and thus the degree of labor market frictions. An alternative way to describe the matching technology is by the probabilities that vacancies find unemployed workers q_t and the probability that unemployed workers find a job f_t, also called the job finding probability or the hiring rate,

$$q_t = \frac{M_t}{V_t} = B\theta_t^{-\mu} \equiv q(\theta_t) \tag{2}$$

$$f_t = \frac{M_t}{U_t} = B\theta_t^{1-\mu} \equiv f(\theta_t) \tag{3}$$

[15] See, e.g. Clarida, Galí, and Gertler (2000) for a discussion of the possible role of monetary policy in the Great Moderation.

where $\theta_t = V_t/U_t$ is labor market tightness.

Because matching is not instantaneous, employment N_t becomes a state variable of the model, which evolves according to the following law of motion,

$$N_t = (1-\delta)\, N_{t-1} + M_t = (1-\delta)\, N_{t-1} + q\,(\theta_t)\, V_t = (1-\delta)\, N_{t-1} + f\,(\theta_t)\, U_t \qquad (4)$$

where $\delta > 0$ is the separation rate, and

$$U_t = 1 - (1-\delta)\, N_{t-1} \qquad (5)$$

is the number of workers looking for a job in period t.[16]

3.2 Households

Households are infinitely-lived and consist of a continuum of identical members represented by the unit interval. The household is the relevant decision unit for choices about consumption and labor supply. Each household member's utility function is additively separable in consumption and leisure, and the household assigns equal consumption C_t to all members in order to share consumption risk within the household. Thus, the household's objective function is given by,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{Z_t C_t^{1-\eta}}{1-\eta} - bL_t \right] \qquad (6)$$

where $\beta \in (0,1)$ is the discount factor, $\eta \in [0,1]$ is the inverse of the intertemporal elasticity of substitution, $b > 0$ can be interpreted as a fixed cost of working and Z_t is a preference shock. The second term in the period utility function is disutility from effective labor supply L_t, which depends on the fraction N_t of household members that are employed, as well as on the amount of effort $\mathcal{E}_{it}$ exerted by each employed household

[16] We deviate from the search and matching literature in terms of the timing and instead follow Blanchard and Galí (2009), assuming that workers are immediately productive in the period they are hired (i.e. they contribute to employment in that period), and that separations happen before hiring, so that workers that loose their job may find a new job in the same period. These timing assumptions have the advantage that as labor market frictions decrease to zero, the model reduces to a model with a frictionless labor market, whereas with the more conventional timing, $N_t = (1-\delta)\, N_{t-1} + M_{t-1}$, employment is still be predetermined by one period even with an infinitely efficient matching technology. Notice that because of this timing, the fraction of workers that are looking for a job in a given period u_t does not equal the measured unemployment rate, which is given instead by the fraction of workers that are without job at the end of the period: $\tilde{U}_t = U_t - M_t = 1 - N_t$.

member i,

$$L_t = \int_0^{N_t} \left(1 + \frac{\mathcal{E}_{it}^{1+\phi}}{1+\phi}\right) di = \left(1 + \frac{\mathcal{E}_t^{1+\phi}}{1+\phi}\right) N_t \tag{7}$$

where the second equality imposes the equilibrium condition that all working household members exert the same level of effort, $\mathcal{E}_{it} = \mathcal{E}_t$ for all i. The elasticity parameter $\phi \geq 0$ determines the degree of increasing marginal disutility from exerting effort. For simplicity we assume a constant workweek, thus restricting the intensive margin of labor input adjustment to changes in effort.

The household maximizes its objective function above subject to the sequence of budget constraints,

$$C_t = \int_0^{N_t} W_{it} di + \Pi_t = W_t N_t \tag{8}$$

where Π_t represents firms' profits, which are paid out to households in the form of dividents, and W_{it} are wages accruing to employed household member i. In equilibrium, divident payments are zero and wages are the same for all employed workers, as imposed in the second equality.

We assume parameters such that, at equilibrium wages, the household would prefer all of its members to work and thus sends all its unemployed members to the labor market. Therefore, the labor supply choice is degenerate and employment evolves according to its law of motion (4) implied by the matching technology,

$$N_t = (1-\delta) N_{t-1} + f(\theta_t) U_t = f(\theta_t) + (1-\delta)(1 - f(\theta_t)) N_{t-1} \tag{9}$$

where the household takes the aggregate job finding probability $f(\theta_t)$ as given. Finally, the household takes into account the effect of its decisions on the level of effort exerted by its members.

3.3 Firms

Firms produce a homogenous consumption good using a production technology that uses labor and effort as inputs,

$$Y_t = A_t \left(\int_0^{N_t} \mathcal{E}_{it}^{\psi} di\right)^{1-\alpha} = A_t \left(\mathcal{E}_t^{\psi} N_t\right)^{1-\alpha} \tag{10}$$

where Y_t is output, $\mathcal{E}_{it}$ is effort exerted by worker i, $\alpha \in (0,1)$ is a parameter that measures diminishing returns to total labor input in production, $\psi \in [0,1]$ measures additional diminishing returns to effort, and A_t is a technology shock common to all firms. Since all firms are identical, we normalize the number of firms to the unit interval, so that Y_t and N_t denote output and employment of each firm as well as aggregate output and employment in the economy. The second equality imposes the equilibrium condition that all workers in a firm exert the same level of effort, $\mathcal{E}_{it} = \mathcal{E}_t$ for all i.

Firms choose the number of vacancies to post in order to maximize the expected discounted value of profits,

$$E_0 \sum_{t=0}^{\infty} Q_{0,t} \left[Y_t - W_t N_t - g V_t \right] \tag{11}$$

taking as given aggregate labor market conditions $q(\theta_t)$ and subject to the law of motion for employment (4) implied by the matching technology,

$$N_t = (1 - \delta) N_{t-1} + q(\theta_t) V_t \tag{12}$$

where $g > 0$ represents the costs (in terms of output) of posting a vacancy and $Q_{0,t}$ is the stochastic discount factor for future profits. The stochastic discount factor is defined recursively as $Q_{0,t} \equiv Q_{0,1} Q_{1,2} ... Q_{t-1,t}$, where

$$Q_{t,t+1} \equiv \beta \frac{Z_{t+1}}{Z_t} \left(\frac{C_t}{C_{t+1}} \right)^{\eta} \tag{13}$$

measures the marginal rate of substitution between two subsequent periods. Like the household, the firm takes into account the effect of its decisions on the level of effort exerted by its workers.

3.4 Effort Choice and Job Creation

When an unemployed worker and a vacancy meet, the household and the firm jointly decide on a level of effort that the worker will put on the job and over a wage. If they agree, a match is formed and starts producing. In equilibrium, the effort level of all workers is set efficiently, maximizing the total surplus generated by each match.[17] This efficient effort level, in each period and for each worker, equates the cost of exerting more effort, higher disutility to the household, to the benefit, higher production and therefore profits for the firm.

Consider a worker i, who is a member of household h and is employed in firm j. The marginal disutility to the household from that worker exerting more effort $MDU(\mathcal{E}_{it})$,

[17] Suppose not. Then, household and firm could agree on a different effort level that increases total match surplus, and a modified surplus sharing rule (wage) that would make both parties better off.

expressed in terms of consumption, is obtained from equation (7) for total effective labor supply:

$$MDU\left(\mathcal{E}_{it}\right) = \frac{bC_{ht}^{\eta}}{Z_t}\frac{\partial L_{ht}}{\partial \mathcal{E}_{it}} = \frac{bC_{ht}^{\eta}\mathcal{E}_{it}^{\phi}}{Z_t}di \tag{14}$$

The marginal product of that additional effort to the firm $MP\left(\mathcal{E}_{it}\right)$, is found from production function (10):

$$MP\left(\mathcal{E}_{it}\right) = \frac{\partial Y_{jt}}{\partial \mathcal{E}_{it}} = \left(1-\alpha\right)\psi A_t \left(\int_0^{N_{jt}} \mathcal{E}_{vt}^{\psi} dv\right)^{-\alpha} \mathcal{E}_{it}^{-(1-\psi)} di \tag{15}$$

In equilibrium, $MDU\left(\mathcal{E}_{it}\right) = MP\left(\mathcal{E}_{it}\right)$ for all i and, because all firms and all households are identical, also $C_{ht} = C_t$ and $N_{jt} = N_t$. Therefore, it must be that all workers exert the same level of effort in equilibrium, $\mathcal{E}_{it} = \mathcal{E}_t$ for all i. Imposing this property, we obtain the following equilibrium condition for effort,

$$\mathcal{E}_t = \left[\left(1-\alpha\right)\psi\frac{Z_t}{bC_t^{\eta}}A_t N_t^{-\alpha}\right]^{\frac{1}{1+\phi-(1-\alpha)\psi}} \tag{16}$$

or, using production function (10) to simplify:

$$\mathcal{E}_t^{1+\phi} = \psi\frac{Z_t}{bC_t^{\eta}}\frac{\left(1-\alpha\right)Y_t}{N_t} \tag{17}$$

When considering whether to post a vacancy, firms take into account the impact of the resulting increase in employment on the effort level exerted by their workers. Thus, the marginal product of a new hire is given by,[18]

$$\frac{dY_{jt}}{dN_{jt}} = \frac{\partial Y_{jt}}{\partial N_{jt}} + \frac{\partial Y_{jt}}{\partial \mathcal{E}_{jt}}\frac{\partial \mathcal{E}_{jt}}{\partial N_{jt}} = \left(1-\Psi_F\right)\frac{\left(1-\alpha\right)Y_t}{N_t} \tag{18}$$

where $\Psi_F = \frac{\alpha\psi}{1+\phi-(1-\alpha)\psi}$ measures the additional (negative) effect from a new hire on output that comes from the endogenous response of the effort level in the firm.

Maximizing the expected net present value of profits (11), where output is given by production function (10) and the stochastic discount factor by (13), subject to the law

[18] With a slight abuse of notation, $\mathcal{E}_{jt}$ denotes the effort level exerted by all workers (from different households) in a particular firm j. Firm j considers employing N_{jt} workers, given that all other firms employ the equilibrium number of workers N_t. Because there are infinitely many firms, firm j's decision to employ $N_{jt} \neq N_t$ workers does not affect the fraction of household h's members that are employed, so that by the assumption of perfect risk-sharing within the household, the consumption of workers in firm j, $C_{ht} = C_t$, is not affected. Therefore, the relation between effort and employment that the firm faces if all other firms (and all households) play equilibrium strategies, is given by equation (16), keeping C_t fixed. See appendix A for details on the derivation of equation (18).

of motion for employment implied by the matching technology (12) and the equilibrium condition for effort (17), gives rise to the following first order condition,

$$g = q\left(\theta_t\right) S_t^F \tag{19}$$

where S_t^F is the marginal value to the firm of having an additional worker in period t, which is given by,

$$\begin{aligned} S_t^F &= \left(1-\Psi_F\right) \frac{\left(1-\alpha\right) Y_t}{N_t} - W_t + \left(1-\delta\right) E_t \left[Q_{t,t+1} S_{t+1}^F\right] & (20) \\ &= E_t \sum_{s=0}^{\infty} \left(1-\delta\right)^s Q_{t,t+s} \left[\left(1-\Psi_F\right) \frac{\left(1-\alpha\right) Y_{t+s}}{N_{t+s}} - W_{t+s}\right] & (21) \end{aligned}$$

where the second equality follows from iterating forward (and defining $Q_{t,t} = 1$). This is a job creation equation, which states that the expected value of vacancy posting costs before a vacancy is filled, $g/q\left(\theta_t\right)$, must equal the expected net present value of profits (additional output minus the wage) of the filled job, S_t^F. We think of this equation as determining the number of vacancies V_t that are posted in equilibrium, and therefore aggregate labor market tightness θ_t.

3.5 The Bargaining Set

Because of labor market frictions, matches generate a strictly positive surplus. The reason is that neither households nor firms have an immediate alternative to the jobs or workers they are currently matched with and their only outside option is to enter the labor market and engage in a costly search process. In order to share the total match surplus, households and firms bargain over the wage. These negotations are limited only by the outside option of each party. The lower bound of the bargaining set is given by the reservation wage of the household, the wage offer at which the household is indifferent between accepting the offer and searching for another vacancy. Similarly, the upper bound of the bargaining set is the reservation wage of the firm, the wage offer that makes the firm indifferent between accepting the offer and searching for an unemployed worker. Within these bounds, any wage is consistent with equilibrium, see Hall (2005). Clearly, the bounds of the bargaining set are endogenous variables, which we now derive before introducing an equilibrium selection rule for the wage within the bargaining set.

The part of the match surplus that accrues to the firm S_t^F, as a function of the wage, is given by equation (20). In order to derive a similar expression for the household's part of the surplus S_t^H, we must first calculate the marginal disutility to the household of having one additional employed member, taking into account the endogenous response of effort. This marginal disutility of employment, expressed in terms of consumption, is given by,[19]

$$\frac{bC_t^\eta}{Z_t}\frac{dL_{ht}}{dN_{ht}} = \frac{bC_t^\eta}{Z_t}\left[1 + \frac{\Psi_H}{\psi}\mathcal{E}_t^{1+\phi}\right] = \frac{bC_t^\eta}{Z_t} + \Psi_H \frac{(1-\alpha)\,Y_t}{N_t} \tag{22}$$

where the second equality follows from substituting equation (17), and where $\Psi_H = \frac{\psi}{1+\phi}\frac{(1-\eta)(1+\phi)+\psi}{1+\phi+\psi}$ captures the effect on utility of one more employed member in the household through the endogenous response of effort. Using this expression, we can take a derivative of the household's objective function (6) with respect to N_t and divide by the marginal utility of consumption, to obtain the following expression for S_t^H.

$$S_t^H = W_t - \frac{bC_t^\eta}{Z_t} - \Psi_H \frac{(1-\alpha)\,Y_t}{N_t} + (1-\delta)\,E_t\left[Q_{t,t+1}\,(1-f(\theta_{t+1}))\,S_{t+1}^H\right] \tag{23}$$

The value to the household of having one more employed worker, equals the wage minus the disutility expressed in terms of consumption, plus the expected value of still having that worker next period, which is discounted by the probability that the worker is still employed next period.

The upper bound of the bargaining set W_t^{UB} is the highest wage such that $S_t^F \geq 0$, whereas the lower bound W_t^{LB} is the lowest wage such that $S_t^H \geq 0$. Using equations (20) and (23), we get $S_t^F = W_t^{UB} - W_t$ and $S_t^H = W_t - W_t^{LB}$. Substituting back into equations (19), (20) and (23), we can explicitly write the equilibrium of the model in terms of the wage and the bounds of the bargaining set.

$$g = q(\theta_t)\left(W_t^{UB} - W_t\right) \tag{24}$$

$$W_t^{UB} = (1-\Psi_F)\frac{(1-\alpha)\,Y_t}{N_t} + (1-\delta)\,E_t\left[Q_{t,t+1}\left(W_{t+1}^{UB} - W_{t+1}\right)\right] \tag{25}$$

$$W_t^{LB} = \frac{bC_t^\eta}{Z_t} + \Psi_H \frac{(1-\alpha)\,Y_t}{N_t} + (1-\delta)\,E_t\left[Q_{t,t+1}\,(1-f(\theta_{t+1}))\left(W_{t+1}^{LB} - W_{t+1}\right)\right] \tag{26}$$

Everything else equal, the more rigid is the wage in response to technology or preference shocks that shift the bounds of the bargaining set, the more volatile is labor market tightness θ_t in response to those shocks. We now turn to various possibilities for how wages are determined within the bargaining set.

[19] The derivation of this expression is similar to that of equation (18), see appendix A for details.

3.6 Wage Determination

One possible criterion for wage determination that we can think of as flexible wages in a model with a frictional labor market, is period-by-period (generalized) Nash bargaining. Nash bargaining assumes that the wage is set such that the total surplus from the match is split in a fixed proportion between household and firm. It is straightforward to see that in our framework, this assumption implies that the wage is a weighted average of the lower and upper bounds of the bargaining set. Let ξ denote the fraction of total match surplus that accrues to workers, $S_t^H = \xi \left(S_t^H + S_t^F\right) = \xi \left(W_t^{UB} - W_t^{LB}\right)$. Then,

$$W_t^* = \xi W_t^{UB} + (1-\xi) W_t^{LB} \tag{27}$$

where W_t^* denotes the Nash bargained wage. The parameter ξ is often referred to as workers' bargaining power.

Shimer (2005) and Hall (2005), among others, have argued that period-by-period Nash bargaining generates too volatile a wage in equilibrium, relative to what is observed in the data. As discussed below, in our model period-by-period Nash bargaining leads to fluctuations in the (log) wage of the same amplitude as labor productivity, and perfectly correlated with the latter. This is at odds with the data, where wages are about half as volatile as labor productivity in the pre-84 period, with the correlation between the two variables much smaller than one. Both the relative volatility of wages and their correlation with labor productivity increases significantly in the post-84 period. This motivates the introduction of a wage setting mechanism that departs from period-by-period Nash bargaining,

$$W_t = r_t W_{t-1} + (1-r_t) W_t^* \tag{28}$$

where r_t measures the degree of wage rigidity, which is endogenous.

In order to analyze the role of wage rigity while maintaining a convex model that we can solve using perturbation methods, we assume $\xi = \frac{1}{2}$ and posit the following reduced-form equation for wage rigidity,

$$r_t = \bar{r}\left(1 - \left(\frac{W_t - W_t^*}{\frac{1}{2}\left(W_t^{UB} - W_t^{LB}\right)}\right)^{2\rho}\right) \tag{29}$$

where $\rho \in \mathbb{N}_0^+$. This wage rule captures the idea that the wage is more likely to adjust when it is closer to the bounds of the bargaining set. The parameter ρ captures the degree of non-linearity in this relation. For $\rho = 0$, $r_t = 0$ and $W_t = W_t^*$, i.e. wages are flexible. For $\rho \in \mathbb{N}^+$, the degree of wage rigidity is endogenous, with wages being perfectly flexible at the upper or lower bound of the bargaining set and most rigid at the Nash-bargained wage W_t^*. As ρ becomes larger, wages are rigid in a larger part of the bargaining set. The limiting case for $\rho \to \infty$ and $\bar{r} = 1$ captures the case where the wage is fixed within the bargaining set but adjusts when it has to in order to avoid inefficient match destruction as in the working paper version of Hall (2005). We consider a flexible wage regime with $\rho = 0$ and regime with endogenous wage rigidity, $\rho \in \mathbb{N}^+$ and $\bar{r} = 1$.

The crucial insight for our purposes is that with this type of wage rule, the degree of wage rigidity depends endogenously on the size of the search frictions. If search frictions decrease, the width of the bargaining set decreases as well, so that there is less room for wage rigidity. Notice also that this type of wage rigidity can never lead to inefficient match destruction.

3.7 Equilibrium

We conclude the description of the model by listing the conditions that characterize the equilibrium. Vacancy posting decisions by firms are summarized by the job creation equation (24).

$$g = q(\theta_t)\left(W_t^{UB} - W_t\right) \tag{30}$$

The equilibrium level of effort is determined by efficiency condition (17),

$$\mathcal{E}_t^{1+\phi} = \psi \frac{Z_t}{bC_t^\eta} \frac{(1-\alpha)Y_t}{N_t} \tag{31}$$

and wage negotations are described by equations (28) and (29) for the equilibrium selection rule, and stochastic difference equations for the upper and lower bounds of the bargaining set (25) and (26).

$$W_t = r_t W_{t-1} + (1-r_t)\tfrac{1}{2}\left(W_t^{UB} + W_t^{LB}\right) \tag{32}$$

$$r_t = \bar{r}\left(1 - \left(\frac{W_t - \frac{1}{2}\left(W_t^{UB} + W_t^{LB}\right)}{\frac{1}{2}\left(W_t^{UB} - W_t^{LB}\right)}\right)^{2\rho}\right) \tag{33}$$

$$W_t^{UB} = (1-\Psi_F)\frac{(1-\alpha)Y_t}{N_t} + (1-\delta)E_t\left[Q_{t,t+1}\left(W_{t+1}^{UB} - W_{t+1}\right)\right] \tag{34}$$

$$W_t^{LB} = \frac{bC_t^\eta}{Z_t} + \Psi_H \frac{(1-\alpha)Y_t}{N_t} + (1-\delta)E_t\left[Q_{t,t+1}(1-f(\theta_{t+1}))\left(W_{t+1}^{LB} - W_{t+1}\right)\right] \tag{35}$$

Employment evolves according to its law of motion (9).

$$N_t = f(\theta_t) + (1-\delta)(1-f(\theta_t)) N_{t-1} \tag{36}$$

Finally, goods market clearing requires that consumption equals output minus vacancy posting costs, where the aggregate number of vacancies equals $V_t = \theta_t [1-(1-\delta) N_{t-1}]$, see equation (5).

$$C_t = Y_t - gV_t = Y_t - g\theta_t [1-(1-\delta) N_{t-1}] \tag{37}$$

The job finding and worker finding probabilities are defined from the matching technology, equations (2) and (3), output as in production function (10), and the stochastic discount factor as the marginal rate of intertemporal substitution (13).

$$q(\theta_t) = B\theta_t^{-\mu} \text{ and } f(\theta_t) = B\theta_t^{1-\mu} \tag{38}$$

$$Y_t = A_t \left(\mathcal{E}_t^{\psi} N_t\right)^{1-\alpha} \tag{39}$$

$$Q_{t,t+1} = \beta \frac{Z_{t+1}}{Z_t} \left(\frac{C_t}{C_{t+1}}\right)^{\eta} \tag{40}$$

and the parameters $\Psi_F = \frac{\alpha\psi}{1+\phi-(1-\alpha)\psi}$ and $\Psi_H = \frac{\psi}{1+\phi} \frac{(1-\eta)(1+\phi)+\psi}{1+\phi+\psi}$ are functions of the structural parameters. In total, we have 8 equations in the endogenous variables θ_t, $\mathcal{E}_t$, W_t, r_t, W_t^{UB}, W_t^{LB}, N_t and C_t, or 12 equations including the definitions for q_t, f_t, Y_t and $Q_{t,t+1}$.

Without an endogenous effort choice ($\psi = 0$ so that effort is not useful in production, $\Psi_F = \Psi_H = 0$, and $\mathcal{E}_t = 0$ for all t in equilibrium), and with flexible wages ($\bar{r} = 0$ so that $r_t = 0$ for all t), the model reduces to a standard search model. With linear utility over consumption ($\eta = 0$) and constant returns to labor ($\alpha = 0$), the model is a stochastic, discrete time version of the model in Pissarides (1985), similar to e.g. Hagedorn and Manovskii (2008) (except for the timing, see footnote 16 on page 11). With logarithmic utility over consumption ($\eta = 1$), the model reduces to that in Blanchard and Galí (2009) with flexible prices and wages.[20] However, unlike in these models, fluctuations in our

[20] To see this equivalence, replace $f(\theta_t)[1-(1-\delta)N_{t-1}] = H_t$, $g/q(\theta_t) = G_t$ and $f(\theta_t) = x_t$ and notice that $S_t^F + S_t^W = G_t/\xi$ by the job creation equation. Furthermore, the definition of the matching function implies,

$$G_t = \frac{g}{q(\theta_t)} = \frac{g}{B}\theta_t^{\mu} = \frac{g}{B}\left(\frac{f(\theta_t)}{B}\right)^{\frac{\mu}{1-\mu}} = gB^{-\frac{1}{1-\mu}} x_t^{\frac{\mu}{1-\mu}} = A_t \tilde{B}_t x_t^{\eta}$$

where $\tilde{B}_t = gB^{-\frac{1}{1-\mu}}/A_t$ and $\eta = \mu/(1-\mu)$.

model are driven by technology shocks as well as non-technology shocks or preference shocks, which could also be interpreted as shocks to the unemployment benefit and the discount factor.

The two driving forces of fluctuations, log total factor productivity $a_t \equiv \log A_t$ and log preferences over consumption $z_t \equiv \log Z_t$ follow stationary $AR(1)$ processes,

$$a_t = \rho_a a_{t-1} + \varepsilon_t^a \tag{41}$$

$$z_t = \rho_z z_{t-1} + \varepsilon_t^z \tag{42}$$

where ε_t^a and ε_t^z are independent white noise processes with variances given by σ_a^2 and σ_z^2 respectively.

We now proceed to use this model to analyze the possible role of labor market frictions in generating the observed changes in the cyclical patterns of output, labor input, productivity, and wages. For this analysis, all three non-standard elements: multiple shocks, endogenous effort and endogenous wage rigidity, are important.

4 The Increasing Flexibility of the Labor Market

This section provides an analysis of our model economy's equilibrium under alternative assumptions regarding the size of labor market frictions and wage determination. We start by looking at a version of the model with a frictionless labor market. This model provides a useful benchmark that we can solve for in closed form. Then, we introduce frictions and rely on numerical methods to simulate the model for different calibrations of the parameters.

4.1 The Frictionless Case

Consider the limiting case of an economy without labor market frictions ($B \to \infty$ or equivalently $g = 0$). The first thing to note is that in this case the width of the bargaining set collapses to zero, and the job creation equation (30) and the wage block of the model, equations (32), (33), (34) and (35), imply

$$W_t = W_t^{UB} = W_t^{LB} = (1 - \Psi_F)\frac{(1-\alpha)\,Y_t}{N_t} = \frac{bC_t^\eta}{Z_t} + \Psi_H \frac{(1-\alpha)\,Y_t}{N_t} \tag{43}$$

for all t. Furthermore, employment becomes a choice variable and its law of motion (36) is dropped from the system, and the aggregate resource constraint (37) reduces to

$C_t = Y_t$, which combined with (43) yields

$$N_t = (1-\alpha)(1-\Psi_F-\Psi_H)\frac{Z_t}{b}Y_t^{1-\eta} \tag{44}$$

Substituting into the equilibrium condition for effort (31), we obtain

$$\mathcal{E}_t^{1+\phi} = \frac{\psi}{1-\Psi_F-\Psi_H} \tag{45}$$

implying an effort level that is invariant to fluctuations in the model's driving forces. Since effort has stronger diminishing returns in production and stronger increasing marginal disutility than employment, this intensive margin of adjustment is never used if the extensive margin is not subject to frictions.

Combining equations (44) and (45) with the production function (39), we can derive closed-form expressions for equilibrium employment, output, wages and labor productivity. Using lower-case letters to denote the natural logarithms of the original variables, ignoring constant terms and normalizing the variance of the shocks,[21] we get:

$$n_t = (1-\eta)\,a_t + z_t \tag{46}$$

$$y_t = a_t + (1-\alpha)\,z_t \tag{47}$$

$$w_t = y_t - n_t = \eta a_t - \alpha z_t \tag{48}$$

A useful benchmark is the model with logarithmic utility over consumption ($\eta = 1$). In this case, employment fluctuates in proportion to the preference shifter z_t but does not respond to technology shocks.[22]

From the previous equations, it is straightforward to calculate the model's implications for the second moments of interest. In particular we have

$$cov\,(y_t - n_t, y_t) = \eta var\,(a_t) - \alpha\,(1-\alpha)\,var\,(z_t) \tag{49}$$

$$cov\,(y_t - n_t, n_t) = \eta\,(1-\eta)\,var\,(a_t) - \alpha var\,(z_t) \tag{50}$$

In the absence of labor market frictions, labor productivity is unambiguously countercyclical in response to preference shocks. The intuition for this result is that output

[21] If the original shocks are $\tilde{a}_t$ and $\tilde{z}_t$, then we define $a_t = \Omega\tilde{a}_t$ and $z_t = \Omega\tilde{z}_t$, where $\Omega = 1/\left[1-(1-\alpha)(1-\eta)\right]$.

[22] This result is an implication of the logarithmic or 'balanced growth' preferences over consumption in combination with the absence of capital or any other intertemporal smoothing technology, and is similar to the 'neutrality result' in Shimer (2009).

responds to preference shocks only through employment, and this response is less than proportional because of diminishing returns in labor input ($\alpha > 0$). Since productivity is unambiguously procyclical in response to technology shocks, the unconditional correlations depend on the relative variances of the shocks and the model parameters. For a wide range of parameter values, e.g. with logarthmic utility over consumption ($\eta = 1$), productivity is procyclical with respect to output but countercyclical with respect to employment.

The relative volatility of employment and wages with respect to output are given by the following expressions:

$$\frac{var\left(n_t\right)}{var\left(y_t\right)} = \frac{\left(1-\eta\right)^2 var\left(a_t\right) + var\left(z_t\right)}{var\left(a_t\right) + \left(1-\alpha\right)^2 var\left(z_t\right)} \tag{51}$$

$$\frac{var\left(w_t\right)}{var\left(y_t\right)} = \frac{\eta^2 var\left(a_t\right) + \alpha^2 var\left(z_t\right)}{var\left(a_t\right) + \left(1-\alpha\right)^2 var\left(z_t\right)} \tag{52}$$

The size of the relative volatility measures above depends again on the relative importance of the shocks, as well as on the size of α, the parameter determining the degree of diminishing returns to labor.

4.2 Preview of the Results

We can contrast the predictions of the frictionless model above, with the opposite extreme case of infinitely large labor market frictions ($B = 0$). In this case, no vacancies will be posted, so that by the aggregate resource constraint (37) $C_t = Y_t$, as in the frictionless case. For simplicity, also assume that the separation rate equals zero, $\delta = 0$, so that employment is fixed at full employment, $N_t = 1$. In this case, combining the production function (39) with the equilibrium condition for effort (31), and taking logarithms, ignoring constant terms and normalizing the variance of the shocks,[23] we get:

$$e_t = \left(1-\eta\right) a_t + z_t \tag{53}$$

$$y_t = y_t - n_t = \left(1+\phi\right) a_t + \left(1-\alpha\right) \psi z_t \tag{54}$$

Since employment is fixed, effort is now procyclical in response to both types of shocks, as all of the adjustment of labor input occurs on the intensive margin. With infinitely large labor market frictions, labor productivity is perfectly (positively) correlated with output. The correlation between productivity and employment, as well as the relative volatility

[23] In this case, the normalization factor is $1/\left[1+\phi-\left(1-\alpha\right)\left(1-\eta\right)\psi\right]$.

of employment with respect to output equal zero. Finally, since the bargaining set is now infinitely wide, wages may be arbitrarily rigid, depending on the model parameters, so that the relative volatility of wages is also arbitrarily close to zero.

Comparing these predictions with those of the frictionless model in the previous subsection, it is clear that by moving from a completely rigid to a completely flexible labor market:

1. Labor productivity becomes less procyclical with respect to output.
2. Labor productivity goes from acyclical to countercyclical with respect to employment, depending on parameter values (a sufficient condition is logarithmic utility over consumption).
3. The relative volatility of employment increases.
4. The relative volatility of wages increases.

All four of these predictions are consistent with the data, as we documented in section 2. We are not arguing, of course, that the US labor market went from completely rigid to completely flexible. Rather, the argument so far is meant to illustrate that if the reduction in labor market frictions was large enough, it can qualitatively explain the patterns we observe in the data. To answer the question whether we can also quantitatively match those patterns for reasonable parameter values, we now turn to a numerical analysis of the full model.

4.3 Calibration

We simulate data at quarterly frequency and calibrate accordingly. The calibration is summarized in Table 6. Many of the model's parameters can be easily calibrated to values that are standard in the literature. We set the discount factor β equal to 0.99. For the curvature of the production function, we assume $\alpha = 1/3$ to match the capital share in GDP, and for the elasticity of the matching function we use the 'best practice' value of $\mu = 2/3$ as advocated by Mortensen and Nagypal (2007).

The cost parameter g is set such that hiring costs represent 0.1 percent of output in the steady state. We then set the fixed costs of working b and the separation rate δ to match the steady state (quarterly) job finding rate of 70% and unemployment rate of

5.5%. The implied replacement ratio is 0.68, well in line with the value advocated by Mortensen and Nagypal (2007).[24]

For the remaining parameters of the model, we have very little guidance from previous literature. However, since we are mostly interesting to illustrate the qualitative changes in the business cycle moments that the model can generate, we calibrate these parameters to some of the second moments. The testable prediction here is not whether the model can quantitatively match some or most of the second moments, but whether it can qualitatively generate *all* observed changes, changing *only* the search frictions.

For the model's driving forces, we assume high persistence in both shocks, setting $\rho_a = 0.97$ to match the first-order autocorrelation in Solow residuals, and $\rho_z = 0.9$. Given those values, we calibrate σ_a^2 and σ_z^2 so that the frictionless version of the calibrated model matches the volatility of BP-filtered output and hours in the post-84 period (using data for the private sector from the LPC). This requires setting $\sigma_z^2 = (1-\rho_z^2)var(n_t)$ and $\sigma_a^2 = (1-\rho_a^2)(var(y_t) - (1-\alpha)^2 var(n_t))$. By using this calibration strategy, we are implicitly assuming that the frictionless model is a good description of fluctuations in the post-84 period. Finally, for the curvature of the utility and production function in effort, we assume $\phi = 1$ (quadratic utility) and $\psi = 0.235$ to match the increase in the relative volatility in employment when we reduce search frictions to zero.

4.4 Simulation Results

We now simulate the calibrated model in order to calculate the second moments of interest. We start with the model with flexible wages and show that a reduction in labor market frictions matches the data on the cyclicality of labor productivity and the relative volatility of labor input. Then we consider endogenous wage rigidity and show that the model can also match an increase in the relative volatility of wages, and -if endogenous wage rigidities are strong enough- can also generate a reduction in output volatility.

4.4.1 Flexible Wages

The model with flexible wages is close to log-linear and a first-order approximation captures well the dynamics generated by the model. Therefore, we start by log-linearizing the equilibrium conditions, solving the linearized model and simulating it for $51,000$

[24] In fact, if we set the separation rate δ to its postwar average, the fixed costs of working b to match the replacement ratio of 0.7 and use the vacancy posting costs g to match the steady state unemployment rate, we get very similar values.

periods, discarding the first $1,000$ observations so as to eliminate any effect of the initial conditions. The results of this exercise are reported in the first panel of Table 7. The model with labor market frictions is taken to describe the pre-84 period, whereas we think of the post-84 labor market as close to frictionless. Notice that for the frictionless model both the standard deviation of output $\sigma(y)$ and the relative standard deviation of labor input, $\sigma(n)/\sigma(y)$, are calibrated to match the post-84 data.

The correlation of labor productivity with output is strongly procyclical in the model with a frictional labor market, and falls to close to zero for the frictionless model. The correlation of productivity with employment also falls, from around zero in the frictional labor market to a negative value in the frictionless model. Both observations are consistent with the evidence. The reason for the decline in the procyclicality of productivity, is the increase in the relative volatility of employment, a result that is consistent with the data as well.

Two elements in the model are crucial for these results. First, the effort choice provides an intensive margin of adjustment for labor input. As search frictions fall, it becomes optimal to adjust labor more through employment and less through effort. Thus, the volatility of employment increases more than that of output. Second, fluctuations in the model are driven by two types of shocks: technology shocks and preference shocks or labor supply shocks. In a one-shock model, the correlations between all variables would be close to either 1 or -1.[25] More importantly, if fluctuations were driven only by technology shocks then productivity could never be countercyclical, since employment would only fluctuate because of changes in labor demand, and the direct effect of technology on productivity would always prevail over the indirect effect of employment. It is important to stress, however, that our results are *not* driven by changes in the relative importance of both shocks, which we keep constant, but by the reduction in search frictions, which changes the response of the economy conditional on each shock.

The model also predicts a decrease in the relative volatility of wages and an increase in the volatility of output. As argued in section 2.3, the first prediction is arguably not consistent with the data. The second one clearly is in contradiction with the well-documented reduction in output volatility, the so called Great Moderation. The decrease in the relative volatility of wages is driven by the fact that the wage is approximately proportional to the marginal product of labor.[26] Since the marginal product of labor

[25] This is exactly true in a static, linear model. Our model is close to (log)linear and the version without capital and with flexible wages has only one state variable (employment), which has very fast transition dynamics.

[26] In a labor market with search frictions, the wage is not equal to marginal product of labor, but as long as b is not too large, they are still proportional since workers and firms share the match surplus

is proportional to output, but inversely proportional to employment, an increase in the relative volatility of employment must necessarily also decrease the relative volatility of wages. The increase in the volatility of output simply stems from the fact that search frictions act like adjustment costs in employment. Reducing those costs amplifies fluctuations in employment and therefore in output as well. In the next subsection we show that endogneous wage rigidities can easily reverse the predictions of the model for wages and possibly also bring the prediction for output volatility closer to the evidence.

4.4.2 Endogenous Wage Rigidity

We now turn to the model with endogenous wage rigidity, discussed in section 3.5. This model is intrinsically non-linear: if we log-linearize the wage rule in equations (28) and (29), it reduces to a partial adjustment rule with constant wage rigidity. Thus, we use a second-order approximation of the policy functions. As an accuracy check, Figure 3 shows that a second-order approximation captures well the non-linear wage rule for $\rho = 1$, but for $\rho = 2$ or larger, a higher-order approximation is needed. We simulate the second-order approximation of the model $2,000$ periods, again discarding the first $1,000$ observations to eliminate the effect of the initial conditions. The second panel of Table 7 presents the results for a second-order approximation of the flexible wage model. Comparing these results to those in the first panel of the table confirms that the flexible wage model, unlike the model with endogenous wage rigidity, is close to linear.

The third panel of Table 7 presents the simulated second moments for the model with endogenous wage rigidity and $\rho = 1$. Comparing these moments to those for the flexible wage model, we see that the previously described predictions of the model for the cyclicality of labor productivity and the relative volatility of employment remain virtually unchanged. The reason is that the fact that wages adjust when they get close to the bounds of the bargaining set mitigates the allocative effect of wage rigidity.

The prediction of the model for the relative volatility of wages, however, is reversed. The reduction in search frictions now increases the volatility of wages. To understand the mechanism behind this result, it is useful to consider the extreme case of endogenous wage rigidity ($\rho \to \infty$), in which wages are completely fixed within the bargaining set, but adjust when they hit the bounds of the bargaining set. If search frictions are high enough, so that the bargaining set is very wide, wages never adjust and their volatility is zero. On the other extreme, on a frictionless labor market, the bargaining set reduces to a point and wages behave as if they were flexible. Of course this effect is counteracted

in equal proportions.

by the fact that the bounds of the bargaining set themselves are less volatile when search frictions are lower. However, for our calibration of the parameters, the first effect dominates, as illustrated in Figure 4.

The increase in output volatility in response to the reduction in search frictions is less pronounced for the model with endogenous wage rigidity than for the model with flexible wages. The reason is that increased wage flexibility dampens fluctuations in output in response to technology shocks.[27] If we increase the degree of wage rigidity within the bargaining set by setting $\rho = 2$ as in the last panel in the Table, it is even possible to generate a reduction in the unconditional variance of output. This result is consistent with a possible role of a decline in labor market frictions as a source of the Great Moderation. However, for this high degree wage rigidity, the second-order approximation does not capture well the non-linearity in the wage rule, see Figure 3. Thus, whereas we find this last result intuitively compelling, it is speculative in the sense that it is not clear whether it may be important quantitatively.

5 Concluding Remarks

In this paper, we documented three changes in labor market dynamics over the post-war period in the US: the strong procyclicality of labor productivity has vanished, the volatility of employment has increased with respect to output, and the volatility of wages has increased relative to output and possibly even in absolute terms. We presented a model to argue that a more flexible labor market, modelled as a reduction in search frictions, could explain all three facts. In addition, we showed that the reduction in search frictions may also have contributed to the reduction in output volatility, which happened around the same time.

If it is true that the US labor market become more flexible in the mid 80s, then what institutional change was responsible for it? It is tempting to attribute the lower search frictions to improvements in recruitment technologies, particularly web-based job search. However, that development, while potentially important, happened much later.[28] Major changes on the US labor market in the mid 80s include the introduction of wrongful discharge laws in many states (Autor, Kerr, and Kugler (2007)), the increase in temporary help services (Estevão and Lach (1999)) and the decline of unionization (Farber and Western (2002)). The introduction of the wrongful discharge legislation

[27] In reponse to preference shocks, which affect labor supply rather than labor demand, the reverse is true. However, the effect of technology shocks dominates that of preference shocks in our calibration.

[28] The largest and one of the first internet recruitment providers, monster.com, started in 1994.

constitutes an increase in employment protection, which would increase rather than decrease frictions in our simple model. The increased share of temporary help workers (workers employed by a temporary help agency rather than directly by the employer where they work) is often seen as a response to increased employment protection and happened very gradually, see Figure 5, whereas the changes we document seem to have happened relatively suddenly around 1984.

In terms of timing, the decline in union power lines up very well with our story. Farber and Western (2002) document a sharp decline in the number of certification elections in the early 80s, see Figure 6, and interpret this as evidence for an "unfavourable political climate which raises the costs of unionization", induced by the Reagan's policies and in particular his handling of the air-traffic controllers' strike in 1981. A logical next step for future research would be to write down a model with unions and endogenize the reduction in labor market frictions.

A Derivation of equations (18) and (22)

This appendix derives the marginal product of employment to the firm, equation (18), and the marginal disutility from employment, expressed in consumption terms, to the household, equation (22), if effort adjusts endogenously. From equations (10) and (7), it is straightforward differentation to decompose the total effect of employment on output and total effective labor supply into a direct effect and an effect through the endogenous response of effort.

$$\frac{dY_{jt}}{dN_{jt}} = \frac{\partial Y_{jt}}{\partial N_{jt}} + \frac{\partial Y_{jt}}{\partial \mathcal{E}_{jt}}\frac{\partial \mathcal{E}_{jt}}{\partial N_{jt}} = \frac{(1-\alpha)\,Y_{jt}}{N_{jt}}\left(1+\psi\frac{N_{jt}}{\mathcal{E}_{jt}}\frac{\partial \mathcal{E}_{jt}}{\partial N_{jt}}\right) \tag{55}$$

$$\frac{dL_{ht}}{dN_{ht}} = \frac{\partial L_{ht}}{\partial N_{ht}} + \frac{\partial L_{ht}}{\partial \mathcal{E}_{ht}}\frac{\partial \mathcal{E}_{ht}}{\partial N_{ht}} = 1+\frac{\mathcal{E}_{ht}^{1+\phi}}{1+\phi}\left(1+(1+\phi)\,\frac{N_{ht}}{\mathcal{E}_{ht}}\frac{\partial \mathcal{E}_{ht}}{\partial N_{ht}}\right) \tag{56}$$

Here, $\mathcal{E}_{jt}$ denotes the effort of all workers i that are employed in firm j and $\mathcal{E}_{ht}$ the effort of all workers that are members of household h.

To find the response of effort to changes in employment that firm and household face, we use the condition that the marginal disutility from effort of a given worker i (expressed in consumption terms) from equation (14), in equilibrium must equal the marginal productivity of that worker to the firm from equation (15).

$$\mathcal{E}_{it}^{1+\phi-\psi} = (1-\alpha)\,\psi\frac{Z_t}{bC_{ht}^{\eta}}A_t\left(\int_0^{N_{jt}}\mathcal{E}_{i't}^{\psi}di'\right)^{-\alpha} \tag{57}$$

First, suppose firm j considers employing N_{jt} workers, given that all other firms employ the equilibrium number of workers N_t. Because there are infinitely many firms, firm j's decision to employ $N_{jt} \neq N_t$ workers does not affect the fraction of household h's members that are employed, so that by the assumption of perfect risk-sharing within the household, the consumption of workers in firm j is not affected, $C_{ht} = C_t$. Substituting this, as well as the condition that all workers in firm j exert the same amount of effort, $\mathcal{E}_{it} = \mathcal{E}_{jt}$ for all $i \in [0, N_{jt}]$, the effort condition becomes,

$$\mathcal{E}_{jt}^{1+\phi-\psi} = (1-\alpha)\,\psi \frac{Z_t}{bC_t^{\eta}} A_t \left(\mathcal{E}_{jt}^{\psi} N_{jt}\right)^{-\alpha} \tag{58}$$

so that the elasticity of effort in a given firm j with respect to employment in that firm, is given by

$$\frac{N_{jt}}{\mathcal{E}_{jt}} \frac{\partial \mathcal{E}_{jt}}{\partial N_{jt}} = -\frac{\alpha}{1+\phi-(1-\alpha)\,\psi} \tag{59}$$

Substituting this elasticity into equation (55) above, gives expression (18) in the text.

Next, suppose household h considers having N_{ht} employed workers, given that all other households have N_t employed workers. Because there are infinitely many households, household's h's decision to have a fraction of $N_{ht} \neq N_t$ of its members employed, does not affect the level of employment in any firm $N_{jt} = N_t$. Furthermore, although the effort level of worker i may change because of household h's decision, effort of all other workers in firm j, who are members of different households, is unaffected, $\mathcal{E}_{it} = \mathcal{E}_{ht}$ and $\mathcal{E}_{i't} = \mathcal{E}_t$ for $i' \neq i$. Thus, the effort condition becomes,

$$\mathcal{E}_{ht}^{1+\phi-\psi} = (1-\alpha)\,\psi \frac{Z_t}{bC_{ht}^{\eta}} A_t \left(\mathcal{E}_t^{\psi} N_t\right)^{-\alpha} \tag{60}$$

and the elasticity of effort exerted by members of household h with respect to employment in that household, using equation (8), is given by,

$$\frac{N_{ht}}{\mathcal{E}_{ht}} \frac{\partial \mathcal{E}_{ht}}{\partial N_{ht}} = \frac{C_{ht}}{\mathcal{E}_{ht}} \frac{\partial \mathcal{E}_{ht}}{\partial C_{ht}} \cdot \frac{N_{ht}}{C_{ht}} \frac{\partial C_{ht}}{\partial N_{ht}} = -\frac{\eta}{1+\phi+\psi} \frac{W_{ht} N_{ht}}{C_{ht}} = -\frac{\eta}{1+\phi+\psi} \tag{61}$$

Substituting this elasticity into equation (56) above, gives expression (22) in the text.

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Table 1. The Vanishing Procyclicality of Labor Productivity

Output per hour

		Correlation with Output			Correlation with Empl.			Correlation with Hours		
		Pre-84	Post-84	Change	Pre-84	Post-84	Change	Pre-84	Post-84	Change
1949 - 2007	BP	0.60	0.25	-0.35	0.09	-0.47	-0.56	0.19	-0.40	-0.59
		[0.06]	[0.07]	[0.09]	[0.09]	[0.07]	[0.12]	[0.09]	[0.07]	[0.11]
	HP	0.61	0.04	-0.57	0.07	-0.60	-0.67	0.17	-0.56	-0.73
		[0.05]	[0.09]	[0.10]	[0.08]	[0.06]	[0.10]	[0.08]	[0.07]	[0.10]
	4D	0.62	0.18	-0.44	-0.03	-0.53	-0.51	0.09	-0.54	-0.62
		[0.05]	[0.09]	[0.10]	[0.08]	[0.08]	[0.11]	[0.07]	[0.08]	[0.11]
1965 - 2004	BP	0.65	0.29	-0.36	0.16	-0.44	-0.60	0.28	-0.36	-0.63
		[0.07]	[0.07]	[0.10]	[0.13]	[0.08]	[0.15]	[0.12]	[0.08]	[0.15]
	HP	0.64	0.04	-0.60	0.11	-0.59	-0.70	0.23	-0.54	-0.77
		[0.06]	[0.09]	[0.11]	[0.10]	[0.07]	[0.12]	[0.10]	[0.07]	[0.12]
	4D	0.62	0.12	-0.50	-0.01	-0.56	-0.55	0.11	-0.54	-0.65
		[0.07]	[0.09]	[0.12]	[0.10]	[0.08]	[0.13]	[0.10]	[0.09]	[0.13]
1975 - 1994	BP	0.78	0.34	-0.45	0.52	-0.39	-0.92	0.61	-0.36	-0.98
		[0.05]	[0.09]	[0.11]	[0.09]	[0.11]	[0.15]	[0.08]	[0.11]	[0.13]
	HP	0.66	-0.01	-0.68	0.26	-0.65	-0.91	0.39	-0.60	-0.99
		[0.08]	[0.14]	[0.17]	[0.13]	[0.08]	[0.15]	[0.12]	[0.09]	[0.15]
	4D	0.54	0.20	-0.33	-0.03	-0.51	-0.48	0.08	-0.52	-0.60
		[0.11]	[0.11]	[0.16]	[0.14]	[0.14]	[0.20]	[0.14]	[0.14]	[0.20]

Output per worker

		Correlation with Output			Correlation with Empl.			Correlation with Hours		
		Pre-84	Post-84	Change	Pre-84	Post-84	Change	Pre-84	Post-84	Change
1949 - 2007	BP	0.78	0.60	-0.18	0.31	-0.15	-0.47	0.44	0.01	-0.43
		[0.04]	[0.05]	[0.06]	[0.08]	[0.10]	[0.13]	[0.07]	[0.10]	[0.12]
	HP	0.77	0.40	-0.37	0.25	-0.32	-0.57	0.40	-0.18	-0.58
		[0.03]	[0.08]	[0.09]	[0.07]	[0.09]	[0.11]	[0.07]	[0.10]	[0.12]
	4D	0.76	0.46	-0.30	0.13	-0.33	-0.46	0.30	-0.21	-0.51
		[0.03]	[0.09]	[0.09]	[0.08]	[0.11]	[0.14]	[0.07]	[0.12]	[0.14]
1965 - 2004	BP	0.78	0.63	-0.15	0.33	-0.13	-0.46	0.47	0.06	-0.41
		[0.05]	[0.05]	[0.07]	[0.11]	[0.10]	[0.15]	[0.10]	[0.10]	[0.14]
	HP	0.76	0.41	-0.35	0.25	-0.31	-0.55	0.41	-0.15	-0.56
		[0.04]	[0.08]	[0.09]	[0.09]	[0.09]	[0.13]	[0.08]	[0.11]	[0.14]
	4D	0.75	0.43	-0.31	0.12	-0.33	-0.45	0.30	-0.20	-0.50
		[0.04]	[0.09]	[0.10]	[0.10]	[0.12]	[0.15]	[0.09]	[0.12]	[0.15]
1975 - 1994	BP	0.86	0.70	-0.16	0.62	-0.03	-0.65	0.73	0.10	-0.63
		[0.03]	[0.05]	[0.06]	[0.07]	[0.16]	[0.18]	[0.06]	[0.15]	[0.16]
	HP	0.74	0.36	-0.38	0.35	-0.38	-0.73	0.50	-0.22	-0.72
		[0.06]	[0.13]	[0.15]	[0.11]	[0.12]	[0.16]	[0.10]	[0.15]	[0.17]
	4D	0.69	0.49	-0.19	0.13	-0.30	-0.43	0.28	-0.18	-0.46
		[0.08]	[0.12]	[0.14]	[0.13]	[0.19]	[0.23]	[0.12]	[0.19]	[0.23]

Standard errors in brackets are calculated from the variance-covariance matrix of the second moments using the delta method. Data for the private sector are from the BLS labor productivity and cost program (LPC) and refer to the private sector.

Table 2. The Rising Volatility of Labor Input

Employment (private sector)

		Std. Dev.			Relative Std. Dev.		
		Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
1949 - 2007	BP	1.57	0.91	0.58	0.66	0.81	1.23
		[0.08]	[0.05]	[0.04]	[0.03]	[0.05]	[0.09]
	HP	1.62	1.16	0.72	0.66	0.97	1.47
		[0.08]	[0.07]	[0.06]	[0.03]	[0.06]	[0.12]
	4D	2.44	1.54	0.63	0.66	0.94	1.43
		[0.13]	[0.12]	[0.06]	[0.03]	[0.08]	[0.15]
1975 - 1994	BP	1.71	0.83	0.49	0.65	0.71	1.11
		[0.13]	[0.07]	[0.06]	[0.04]	[0.06]	[0.11]
	HP	2.10	1.27	0.60	0.71	1.01	1.41
		[0.15]	[0.11]	[0.07]	[0.05]	[0.10]	[0.17]
	4D	2.94	1.60	0.54	0.73	0.91	1.24
		[0.20]	[0.13]	[0.06]	[0.06]	[0.12]	[0.20]

Hours (private sector)

		Std. Dev.			Relative Std. Dev.		
		Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
1949 - 2007	BP	1.93	1.18	0.61	0.81	1.06	1.30
		[0.09]	[0.06]	[0.04]	[0.03]	[0.05]	[0.08]
	HP	1.96	1.44	0.73	0.80	1.20	1.50
		[0.10]	[0.08]	[0.05]	[0.03]	[0.07]	[0.10]
	4D	2.94	1.92	0.65	0.79	1.17	1.48
		[0.15]	[0.13]	[0.06]	[0.04]	[0.09]	[0.13]
1975 - 1994	BP	2.08	1.18	0.57	0.79	1.01	1.28
		[0.15]	[0.09]	[0.06]	[0.03]	[0.07]	[0.10]
	HP	2.40	1.58	0.66	0.81	1.25	1.54
		[0.19]	[0.13]	[0.08]	[0.04]	[0.11]	[0.15]
	4D	3.39	2.01	0.59	0.85	1.15	1.36
		[0.27]	[0.15]	[0.07]	[0.06]	[0.14]	[0.20]

Hours (total economy)

		Std. Dev.			Relative Std. Dev.		
		Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
1949 - 2007	BP	1.68	0.85	0.51	0.71	0.76	1.07
		[0.08]	[0.04]	[0.04]	[0.03]	[0.04]	[0.07]
	HP	1.71	1.06	0.62	0.70	0.89	1.27
		[0.09]	[0.07]	[0.05]	[0.03]	[0.05]	[0.09]
	4D	2.56	1.47	0.57	0.69	0.89	1.30
		[0.14]	[0.10]	[0.05]	[0.03]	[0.07]	[0.11]
1975 - 1994	BP	1.63	0.94	0.58	0.62	0.81	1.31
		[0.11]	[0.06]	[0.06]	[0.03]	[0.06]	[0.11]
	HP	1.98	1.22	0.61	0.67	0.97	1.44
		[0.15]	[0.10]	[0.07]	[0.03]	[0.09]	[0.15]
	4D	2.67	1.54	0.58	0.67	0.88	1.32
		[0.20]	[0.11]	[0.06]	[0.05]	[0.11]	[0.19]

Standard errors in brackets are calculated from the variance-covariance matrix of the second moments using the delta method. Data for the private sector are from the BLS labor productivity and cost program (LPC) and refer to the private sector. Hours (total economy) is an unpublished series for economy-wide hours constructed by the BLS and used in Francis and Ramey (2008).

Table 3. The Rising Volatility of Wages

Wage (LPC, private sector)

		Std. Dev.			Relative Std. Dev.		
		Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
1949 - 2007	BP	0.71	0.99	1.38	0.30	0.88	2.93
		[0.05]	[0.06]	[0.12]	[0.02]	[0.07]	[0.31]
	HP	0.85	1.03	1.21	0.35	0.86	2.48
		[0.06]	[0.06]	[0.11]	[0.03]	[0.08]	[0.29]
	4D	1.72	1.61	0.93	0.46	0.98	2.11
		[0.12]	[0.11]	[0.09]	[0.04]	[0.12]	[0.32]
1965 - 2004	BP	0.73	1.03	1.42	0.29	0.89	3.09
		[0.07]	[0.06]	[0.16]	[0.02]	[0.08]	[0.35]
	HP	0.80	1.07	1.35	0.31	0.86	2.80
		[0.06]	[0.07]	[0.14]	[0.03]	[0.08]	[0.37]
	4D	1.43	1.64	1.15	0.40	0.96	2.39
		[0.10]	[0.12]	[0.11]	[0.03]	[0.13]	[0.38]
1975 - 1994	BP	0.65	1.22	1.86	0.25	1.04	4.22
		[0.07]	[0.08]	[0.24]	[0.02]	[0.13]	[0.67]
	HP	0.76	1.12	1.46	0.26	0.89	3.43
		[0.08]	[0.09]	[0.18]	[0.03]	[0.10]	[0.60]
	4D	1.42	1.75	1.24	0.35	1.00	2.82
		[0.11]	[0.17]	[0.15]	[0.04]	[0.21]	[0.68]

Wage (NIPA, total economy)

		Std. Dev.			Relative Std. Dev.		
		Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
1949 - 2007	BP	0.78	0.86	1.10	0.33	0.76	2.32
		[0.05]	[0.05]	[0.10]	[0.02]	[0.07]	[0.24]
	HP	0.84	0.95	1.14	0.34	0.80	2.33
		[0.05]	[0.08]	[0.11]	[0.02]	[0.09]	[0.30]
	4D	1.85	1.57	0.85	0.50	0.95	1.92
		[0.10]	[0.10]	[0.07]	[0.03]	[0.12]	[0.26]
1965 - 2004	BP	0.84	0.91	1.09	0.33	0.78	2.36
		[0.08]	[0.05]	[0.12]	[0.02]	[0.07]	[0.27]
	HP	0.86	0.99	1.14	0.33	0.79	2.37
		[0.08]	[0.08]	[0.14]	[0.03]	[0.09]	[0.35]
	4D	1.67	1.59	0.95	0.47	0.92	1.98
		[0.11]	[0.11]	[0.09]	[0.04]	[0.12]	[0.30]
1975 - 1994	BP	0.78	1.08	1.39	0.29	0.93	3.15
		[0.10]	[0.07]	[0.20]	[0.03]	[0.11]	[0.52]
	HP	0.81	1.09	1.34	0.28	0.86	3.14
		[0.08]	[0.13]	[0.20]	[0.03]	[0.14]	[0.62]
	4D	1.68	1.86	1.11	0.42	1.06	2.53
		[0.14]	[0.17]	[0.14]	[0.05]	[0.21]	[0.58]

continued on next page ...

Wage (CES, private sector)

		Std. Dev.			Relative Std. Dev.		
		Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
1965 - 2004	BP	1.38	0.40	0.29	0.54	0.34	0.63
		[0.12]	[0.02]	[0.03]	[0.04]	[0.03]	[0.07]
	HP	1.27	0.46	0.36	0.49	0.37	0.75
		[0.11]	[0.03]	[0.04]	[0.05]	[0.04]	[0.10]
	4D	1.85	0.97	0.52	0.52	0.56	1.08
		[0.14]	[0.08]	[0.06]	[0.05]	[0.06]	[0.16]
1975 - 1994	BP	1.32	0.36	0.27	0.50	0.30	0.61
		[0.15]	[0.04]	[0.04]	[0.05]	[0.04]	[0.11]
	HP	1.21	0.35	0.29	0.41	0.27	0.67
		[0.14]	[0.05]	[0.05]	[0.05]	[0.04]	[0.13]
	4D	1.63	0.82	0.50	0.41	0.47	1.14
		[0.19]	[0.10]	[0.08]	[0.05]	[0.07]	[0.23]

Wage (LPC, private sector, output deflator)

		Std. Dev.			Relative Std. Dev.		
		Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
1949 - 2007	BP	0.67	0.95	1.42	0.28	0.85	3.02
		[0.04]	[0.07]	[0.13]	[0.02]	[0.08]	[0.34]
	HP	0.82	1.06	1.30	0.33	0.89	2.65
		[0.06]	[0.07]	[0.12]	[0.03]	[0.08]	[0.32]
	4D	1.48	1.65	1.11	0.40	1.00	2.51
		[0.11]	[0.11]	[0.11]	[0.04]	[0.13]	[0.39]
1975 - 1994	BP	0.62	1.22	1.97	0.23	1.04	4.47
		[0.08]	[0.10]	[0.29]	[0.03]	[0.14]	[0.80]
	HP	0.70	1.10	1.57	0.24	0.88	3.68
		[0.09]	[0.10]	[0.23]	[0.04]	[0.11]	[0.70]
	4D	1.26	1.69	1.34	0.32	0.96	3.05
		[0.09]	[0.18]	[0.17]	[0.04]	[0.21]	[0.74]

Wage (LPC, private sector, CPI deflator)

		Std. Dev.			Relative Std. Dev.		
		Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
1949 - 2007	BP	0.83	0.99	1.20	0.35	0.89	2.54
		[0.05]	[0.06]	[0.10]	[0.02]	[0.08]	[0.27]
	HP	0.96	1.04	1.08	0.39	0.87	2.21
		[0.06]	[0.06]	[0.09]	[0.03]	[0.08]	[0.26]
	4D	1.93	1.70	0.88	0.52	1.04	1.99
		[0.13]	[0.12]	[0.08]	[0.04]	[0.13]	[0.30]
1975 - 1994	BP	1.00	1.19	1.19	0.38	1.02	2.68
		[0.09]	[0.09]	[0.13]	[0.04]	[0.13]	[0.44]
	HP	1.16	1.14	0.98	0.39	0.90	2.30
		[0.09]	[0.09]	[0.11]	[0.05]	[0.11]	[0.40]
	4D	2.01	1.94	0.96	0.50	1.10	2.20
		[0.24]	[0.19]	[0.15]	[0.07]	[0.23]	[0.56]

Standard errors in brackets are calculated from the variance-covariance matrix of the second moments using the delta method. Wages are calculated as real compensation per hour. Compensation and hours data for the private sector are from the BLS labor productivity and cost program. Compensation data for NIPA compensation are combined with an unpublished economy-wide series for hours constructed by the BLS and used in Francis and Ramey (2008). Compensation from the establishment survey or Current Employment Statistics (CES) exclude non-wage payments.

Table 4. The Rising Volatility of Wages: Newly Hired Workers

Wage (LPC, private sector)

		Std. Dev.			Relative Std. Dev.		
		Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
1980 - 2005	BP	0.46	1.01	2.20	0.18	0.88	4.78
		[0.06]	[0.06]	[0.29]	[0.04]	[0.08]	[1.01]
	HP	0.59	1.05	1.78	0.20	0.86	4.22
		[0.08]	[0.07]	[0.27]	[0.05]	[0.08]	[1.09]
	4D	1.71	1.63	0.95	0.37	0.97	2.62
		[0.13]	[0.11]	[0.10]	[0.05]	[0.13]	[0.50]

Wage (CPS, total economy)

		Std. Dev.			Relative Std. Dev.		
		Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
Median	BP	0.54	0.93	1.73	0.22	0.81	3.77
		[0.08]	[0.08]	[0.28]	[0.03]	[0.08]	[0.60]
	HP	0.78	1.14	1.46	0.27	0.93	3.46
		[0.14]	[0.10]	[0.28]	[0.06]	[0.10]	[0.84]
	4D	1.59	1.75	1.10	0.35	1.04	3.02
		[0.28]	[0.12]	[0.21]	[0.07]	[0.08]	[0.65]
Mean	BP	0.49	0.54	1.10	0.20	0.47	2.39
		[0.05]	[0.03]	[0.13]	[0.04]	[0.04]	[0.48]
	HP	0.66	0.83	1.27	0.23	0.68	3.02
		[0.11]	[0.06]	[0.24]	[0.05]	[0.07]	[0.78]
	4D	1.48	1.27	0.86	0.32	0.76	2.36
		[0.14]	[0.11]	[0.11]	[0.05]	[0.09]	[0.46]

Wage newly hired workers (CPS, total economy)

		Std. Dev.			Relative Std. Dev.		
		Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
Median	BP	1.96	1.09	0.56	0.79	0.95	1.21
		[0.25]	[0.08]	[0.08]	[0.09]	[0.10]	[0.19]
	HP	5.08	2.94	0.58	1.75	2.40	1.37
		[0.73]	[0.24]	[0.10]	[0.35]	[0.25]	[0.31]
	4D	5.67	3.40	0.60	1.23	2.02	1.65
		[0.63]	[0.27]	[0.08]	[0.18]	[0.25]	[0.31]
Mean	BP	1.42	0.67	0.47	0.57	0.58	1.03
		[0.16]	[0.05]	[0.07]	[0.08]	[0.05]	[0.17]
	HP	3.54	2.31	0.65	1.22	1.88	1.54
		[0.47]	[0.18]	[0.10]	[0.25]	[0.18]	[0.35]
	4D	4.49	2.77	0.62	0.97	1.65	1.69
		[0.60]	[0.26]	[0.10]	[0.17]	[0.24]	[0.38]

Standard errors in brackets are calculated from the variance-covariance matrix of the second moments using the delta method. CPS wage data are earnings per hour from the outgoing rotation groups, which limits the period for which quarterly data are available to after 1980. Wage series are constructed as in Haefke, Sonntag, and van Rens (2008) but are not corrected for composition bias for comparability with other data sources. However, keeping the composition of the labor force contant in terms of education, experience and demographic characteristics makes very little differerence for the results presented here.

Table 5. Additional Business Cycle Statistics

Volatility output and productivity (1949-2007)

		Std. Dev.			Relative Std. Dev.		
		Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
Output	BP	2.37	1.12	0.47			
		[0.13]	[0.06]	[0.04]			
	HP	2.45	1.20	0.49			
		[0.13]	[0.07]	[0.04]			
	4D	3.72	1.64	0.44			
		[0.18]	[0.16]	[0.05]			
/worker	BP	1.36	0.81	0.60	0.57	0.72	1.26
		[0.08]	[0.05]	[0.05]	[0.03]	[0.06]	[0.12]
	HP	1.48	0.85	0.58	0.60	0.71	1.18
		[0.08]	[0.06]	[0.05]	[0.03]	[0.06]	[0.12]
	4D	2.50	1.26	0.51	0.67	0.77	1.15
		[0.14]	[0.08]	[0.04]	[0.03]	[0.07]	[0.13]
/hour	BP	1.06	0.75	0.71	0.45	0.67	1.51
		[0.06]	[0.06]	[0.07]	[0.03]	[0.07]	[0.18]
	HP	1.17	0.85	0.72	0.48	0.71	1.48
		[0.07]	[0.06]	[0.07]	[0.03]	[0.07]	[0.18]
	4D	2.04	1.32	0.64	0.55	0.80	1.46
		[0.13]	[0.08]	[0.06]	[0.03]	[0.09]	[0.19]

Correlations (1949-2007)

		Correlation with Output			Correlation with Empl.			Correlation with Hours		
		Pre-84	Post-84	Change	Pre-84	Post-84	Change	Pre-84	Post-84	Change
Employment	BP	0.84	0.70	-0.14						
		[0.02]	[0.05]	[0.06]						
	HP	0.81	0.74	-0.07						
		[0.03]	[0.04]	[0.05]						
	4D	0.75	0.69	-0.06						
		[0.03]	[0.05]	[0.06]						
Hours	BP	0.90	0.79	-0.11						
		[0.02]	[0.04]	[0.04]						
	HP	0.88	0.81	-0.07						
		[0.02]	[0.03]	[0.04]						
	4D	0.84	0.74	-0.10						
		[0.02]	[0.05]	[0.05]						
Wage	BP	0.40	0.28	-0.12	0.20	-0.11	-0.31	0.22	-0.09	-0.31
		[0.08]	[0.09]	[0.12]	[0.09]	[0.09]	[0.13]	[0.09]	[0.10]	[0.14]
	HP	0.37	-0.01	-0.38	0.23	-0.31	-0.54	0.21	-0.31	-0.52
		[0.08]	[0.10]	[0.12]	[0.09]	[0.10]	[0.14]	[0.09]	[0.10]	[0.14]
	4D	0.30	0.11	-0.20	-0.02	-0.29	-0.27	0.01	-0.36	-0.36
		[0.07]	[0.07]	[0.10]	[0.07]	[0.08]	[0.11]	[0.07]	[0.08]	[0.11]

Standard errors in brackets are calculated from the variance-covariance matrix of the second moments using the delta method. See tables 1, 2 and 3 for data sources.

Table 6. Model Calibration

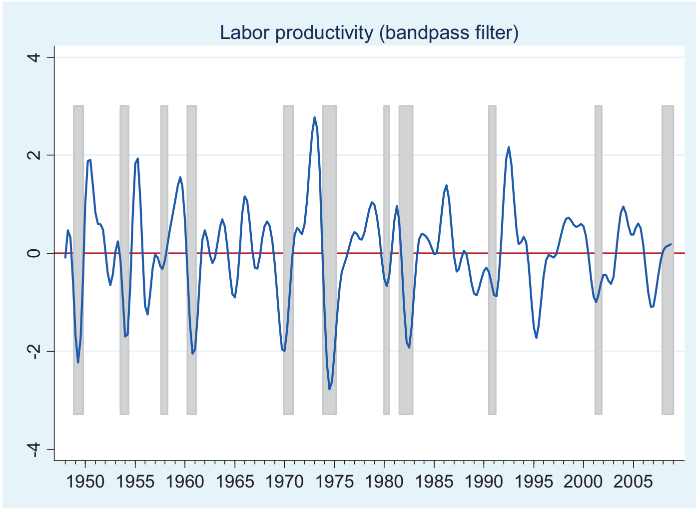
	Parameter	Target
Utility:	$\beta = 0.99$, $u(c) = \log c$	quarterly data
Production:	$f(N) = N^{1-\alpha}$, $\alpha = 1/3$	capital share
Matching:	$\mu = 2/3$	Mortensen and Nagypal (2007)
Wage setting:	$\xi = 1/2$	symmetry
Search frictions:	vacancy posting costs	0.1% output
Worker flows:	$b = 0.54$, $\delta = 0.10$	$f(\bar{\theta}) = 70\%$, $\bar{u} = 13\%$ (repl. ratio = 0.68)
Shocks:	$\rho_z = 0.9$, $\sigma_z = 0.6$ $\rho_A = 0.97$, $\sigma_A = 0.17$	$\mathrm{sd}(n)/\mathrm{sd}(y)$ $\mathrm{sd}(y)$
Effort:	$\phi = 1 \Rightarrow b + \frac{1}{2}\mathcal{E}_t^2$, $\psi = 0.235$	$\Delta\mathrm{sd}(n)/\mathrm{sd}(y)$

Table 7. Model Simulations

	correlation productivity		relative std.dev.		std.dev.
	with output	with empl	empl n_t	wage w_t	output y_t
Benchmark model					
Frictions	0.82	−0.09	0.57	0.90	0.78
Frictionless	0.08	−0.55	1.19	0.73	1.14
2nd order approx					
Frictions	0.8	0.0	0.6	0.9	0.7
Frictionless	0.0	−0.6	1.3	0.7	1.1
Rigid wages ($\rho = 1$)					
Frictions	0.7	0.1	0.7	0.6	1.0
Frictionless	0.0	−0.6	1.3	0.7	1.1
Rigid wages ($\rho = 2$)					
Frictions	0.8	0.8	0.8	0.1	1.2
Frictionless	0.0	−0.6	1.3	0.7	1.1

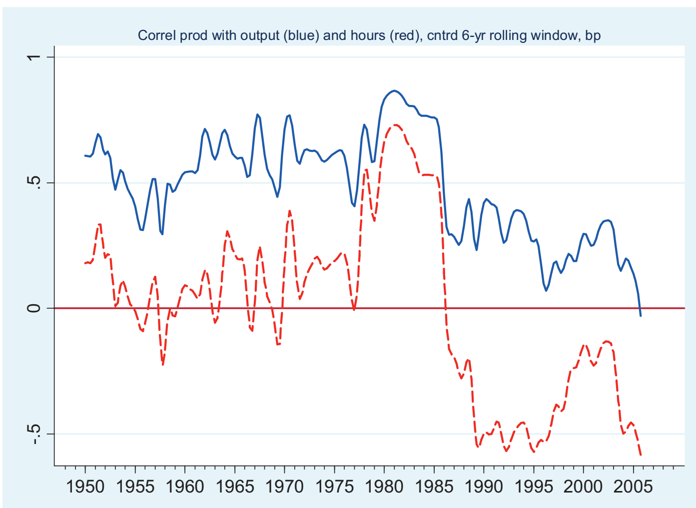
Moments for the benchmark model are based on 50,000 simulated quarters, for the other models on 1,000 quarters.

Figure 1. The Vanishing Procyclicality of Labor Productivity



Output per hour in the US private sector. Shaded areas are NBER recessions.

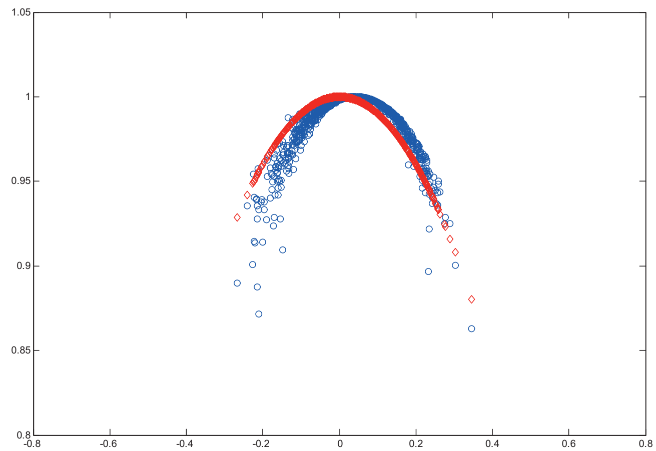
Figure 2. The Vanishing Procyclicality of Labor Productivity: Rolling Correlations



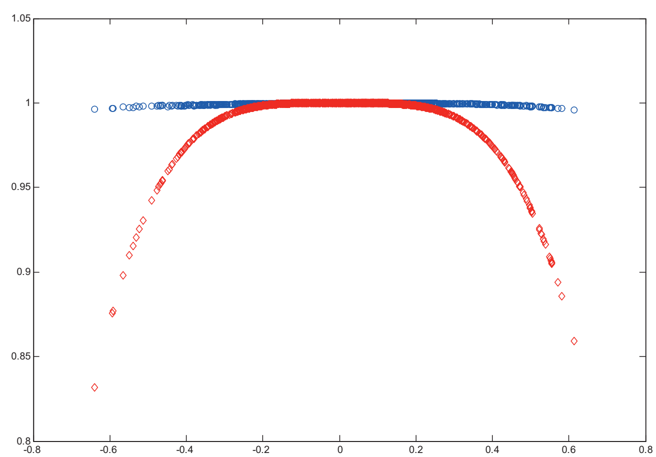
Correlations are calculated in a centered 6-year rolling window of quarterly bandpass-filtered data.

Figure 3. Endogenous Wage Rigidity: Wage Rule

$\rho = 1$ (quadratic)



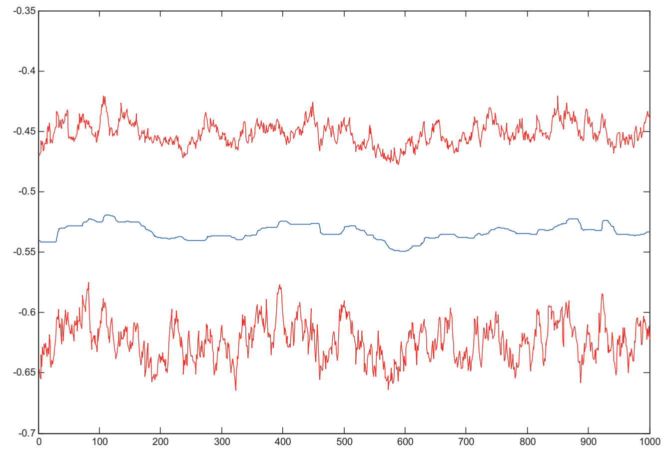
$\rho = 2$ (quartic)



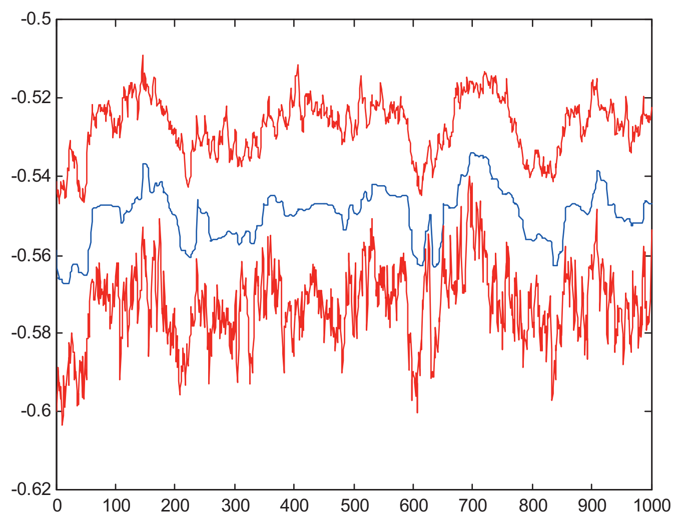
Wage rigidity r_t as a function of the relative distance of the wage from the center of the bargaining set $(W_t - W_t^*) / \frac{1}{2}\left(W_t^{UB} - W_t^{LB}\right)$, see equation (29). The red diamonds represent the theoretical non-linear relation. The blue circles are simulated data from a second-order approximation of the model.

Figure 4. Endogenous Wage Rigity: Simulated Wage Data

Large frictions



Small frictions

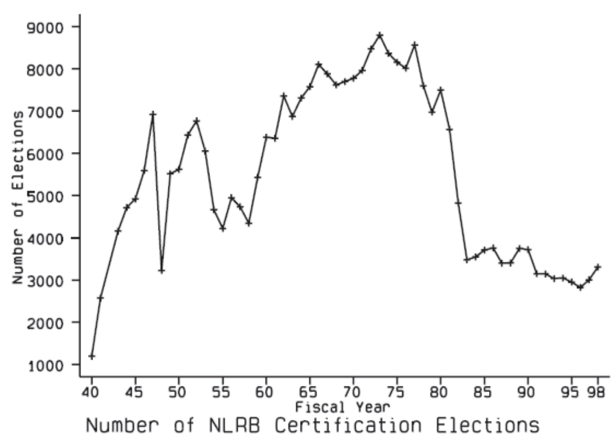


Simulated wage paths for the model with large frictions and small frictions. In this calibration, the wage is more volatile if frictions are smaller.

Figure 5. The Rise of Temporary Help Services

Source: Estevão and Lach (1999)

Figure 6. The Decline of Unions



Source: Farber and Western (2002)