The Vanishing Procyclicality of Labor Productivity and the Great Moderation*

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Abstract

We document three changes in postwar U.S. macro 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 hypothesize a potential common source for those changes: a decline in labor market frictions. We develop a simple model with labor market frictions, variable effort, and wage rigidities to illustrate the mechanisms underlying our hypothesis, and to explore the latter's consistency with the observed decline in output volatility.

Keywords: labor hoarding, labor market frictions, wage rigidities, shot-run increasing returns to labor.

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1 Introduction

The evidence of a significant decline in the volatility of GDP and other major U.S. macroeconomic time series over the past two decades–the so called Great Moderation–has brought to light the evolving nature of the postwar U.S. business cycle. The present paper documents and discusses three aspects of that evolution:

(i) The correlation of labor productivity measures with output or labor input has declined, in some cases dramatically.[1]

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

(iii) The volatility or real wage measures has increased, both in relative and absolute terms.[3]

While each of these observations 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 those three developments may have a common source, namely, an increase in labor market flexibility, i.e. in the ease with which firms may adjust their labor force in response to various kinds of shocks. In order to illustrate the mechanism behind that hypothesized link we develop a stylized model of fluctuations with labor market

[1] As far as we know, Stiroh (2008) was the first to provide evidence of a decline in the labor productivity-hours correlation. Barnichon (2007) and Galí and Gambetti (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 of employment over the most recent U.S. recessions that is consistent with our finding.

[3] As far as we know, this finding has not been reported earlier.

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] A production function gives (log) output as a function of the previous variables, as well as a parameter a_t capturing the level of technology.

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

Implied (log) labor productivity is thus given by

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

The presence of labor market frictions (i.e. large costs of adjusting n_t), generates smaller fluctuations in employment, larger fluctuations in effort. As a result, the volatility of employment rises relative to that of output. Furthermore, labor productivity may become procyclical, even if technology shocks are not very important. Conversely, a reduction in labor market frictions would be expected to make labor productivity less procyclical (or even countercyclical) and to raise the volatility of employment (and hours) relative to output, in a way consistent with the empirical evidence, as reported below.

In addtion, and as recently 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

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

within that bargaining set is, in a sense, consistent with equilibrium. That feature makes room for rigid wages, which in turn may amplify the response of employment and output to supply shocks. Accordingly, a reduction in labor market frictions is likely to make wages more sensitive to those shocks, thus dampening the volatility of output and employment in response to those shocks. That feature may help explain the observed decline in the volatility of those two variables in the recent U.S. experience.[5]

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.

2 Changes in Postwar U.S. Economic Fluctuations: Three Observations

Next we document the three stylized facts that motivate our investigation, pertaining to the cyclical behavior of aggregate measures of labor productivity, labor input and wage measures. We use quarterly time series covering the period 1948:I-2007:IV and drawn from different sources (see below for a detailed description). To illustrate the changes experienced by the different statistics considered, we split the sample period into two subperiods, 1948:I-1983:IV ("pre-84") and 1984:I-2007:IV ("post-84"), with the choice of

[5]As argued in Blanchard and Galí (2007), an increase in the flexibility of wages may also help explain the lesser sensitivity of both GDP and inflation to the recent oil price shocks, relative to the 1970s.

break date motivated by the existing evidence on the timing of the Great Moderation.[6]

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. Some of the evidence makes use of output and hours in the nonfarm business sector from the BLS. We also use GDP as an economy-wide measure of output, with the corresponding labor input measures being either 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 based on the household 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 two alternative transformations in order to render the original time series stationary. Our first transformation uses a Band-Pass (BP) filter to remove the components of the log of the variable at hand corresponding to periodicities below 6 and above 32 quarters, with the resulting component interpreted as the one associated with business cycle frequencies.[7] The second transformation corresponds to the four-quarter difference (4D) of the log of each variable.[8]

[6]See, e.g. McConell an Pérez-Quirós (2000)

[7]See, e.g. Stock and Watson (1999).

[8]This is the transformation favored by Stock and Watson (2002) in their analysis of changes in output volatility.

2.1 The Vanishing Procyclicality of Labor Productivity

Table 1 reports the contemporaneous correlation between labor productivity and output, and labor productivity and labor input, for alternative measures and transformations (BP and 4D) of those variables. For each measure/tranformation we report the estimated correlation for each of the two subsample periods considered, as well as the difference between those estimates. In brackets we report the standard error for each estimate, computed.using the asymptotic distribution of the corresponding GMM estimator.[9] An asterisk denotes that the change in the estimated correlations across sample periods is significant at the 5 percent level.

2.1.1 Correlation with Output

Independently of the measure and detrending procedure use, the correlation of labor productivity with output in the pre-84 period is high and positive, with the point estimates ranging between 0.45 and 0.87 (all of them significant). 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 must have been a well established empirical fact, which could lend support to business cycle theories that assigned a central role to technology shocks as a source of fluctuations.

For the post-84 period, however, that pattern has changed considerably, with the estimates of the labor productivity-output correlation dropping to

[9] We use GMM to estimate the standard deviations and covariances of each pair of variables, as well as their corresponding (asymptotic) standard errors. The standard error for the correlation is obtained by applying the delta method to its formula in terms of the standard deviations and covariances.

values close to (and not significantly different from) zero, when we use hours (NFB or total) to construct our labor productivity measure. The difference with the corresponding pre-84 estimates is highly significant. Thus, and on the basis of those estimates, labor productivity has become an acyclical variable (with respect to output) over the past two decades.

As reported in the third panel, when we use an employment-based measure of labor productivity, the estimated correlations remain significantly positive in the post-84 period. But this should not be surprising given that hours per worker are highly procyclical in both subperiods (its correlation with output is 0.82 and 0.77, respectively, using BP filtered data) and that their volatility relative to employment-based labor productivity has increased considerably (from 0.63 to 0.90).[10] Those considerations notwithstanding, our empirical analysis still can uncover a decline, relatively small but statistically significant. in the correlation between employment-based labor productivity and GDP.

2.1.2 Correlation with Labor Input

The right-hand panel of Table 1 displays several estimates of the correlation between labor productivity and labor input, using alternative measures and detrending methods. The estimates using hours-based labor productivity

[10] Letting l and n respectively denote employment and hours, a straightforward algebraic manipulation yields the identity:

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

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

measures for the pre-84 period are low, and in two cases, insignificantly different from zero. They range from 0.03 to 0.20, thus suggesting a largely acyclical labor productivity with respect to hours in that subperiod. That near-zero correlation is consistent with the evidence reported in the early RBC literature, using data up to the mid-1980s.[11]

As it was the case when using output as a reference variable, the estimated correlations between labor productivity and hours decline dramatically in the post-84 period. In fact they all become negative, their values tightly clustered around -0.5, and with the change between the two subperiods being highly significant. In other words, labor productivity has become in the past two decades unambiguously countercyclical with respect to hours.

Once again, when employment is used to construct the labor productivity variable, the latter displays a positive correlation with labor input (given by employment in that case) in both sample periods, due to the high procyclicality of hours per worker. Despite this "contamination," aggravated by the larger relative volatility of hours per worker in the more recent period, our estimates point to a decline in the correlation, though that decline is significant only when BP filtered data are used.

2.2 The Increase in the Relative Volatility of Labor Input

The left-hand panel of Table 2 displays the standard deviation of several labor input measures for the pre-84 and post-84 periods, as well as the ratio

[11] 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 labor productivity - hours correlation were -0.20 when using household data and 0.16 when using establishment data.

between the two. The variables considered include nonfarm business hours, economy-wide hours, and the two components of the latter, i.e. employment and hours per worker.

The decline in the volatility of hours since the mid-1980s, like that of other major macro variables, is seen to be large and highly significant, with the ratio of standard deviations ranging between 0.57 and 0.7. A less well known fact is that such a volatility decline has affected both employment and hours per worker, the two components of hours, in a roughly proportional way, with the ratio of standard deviations being close to 0.6 in both cases, independently of the transformation used.

A more interesting piece of evidence is given, in our opinion, by the change in the *relative* volatility, measured as the ratio to the standard deviation of output, of the abovementioned variables. The right-hand panel of Table 2 displays the relative volatility measures for the two sample periods considered, as well as their ratio. We note that, with no exception, all labor input measures have experienced an increase in their relative volatility in the post-84 period, relative to the pre-84 period. Combined with the previous evidence this implies that the decline in the variability of labor input has been far more muted than that of output. In the case of total hours (both nonfarm business and economy-wide), as well as hours per worker, the size of the increase in the ratio of standard deviations ranges between 30 and 50 percent. The corresponding increase for employment is somewhat smaller (16 or 36 percent, depending on the detrending method), but still statistically significant.

The previous evidence points to a rise in the elasticity of labor input with respect to output. Put it differently, firms appear to have relied increasingly on labor input adjustments in order to meet their changes in output. Furthermore, that larger elasticity seems to apply to both observable margins (i.e. adjustment in the number of workers as well as in hours per worker).

2.3 The Increase in Wage Volatility

Next we turn our attention to (real) wages, their variability, and how the latter has changed over time, both in absolute and relative terms. We focus on two alternative wage measures, both of which are constructed using compensation per hour in the nonfarm business sector (LXNFC) as a measure of the nominal wage. The latter variable is divided by the nonfarm business price deflator (LXNFI) to obtain a measure of the product wage, and by the consumer price index (PCU) to construct a time series for the consumption wage.

The left-hand panel of Table 3 displays the standard deviation for each wage measure and subperiod. Our statistics uncover a surprising finding: despite the general decline in macro volatility associated with the Great Moderation, the volatility of both the product and consumption wages appears to have increased in absolute terms. The estimated increase the standard deviation is large.and significant for the product wage, but more moderate and statistically insignificant for the consumption wage. We are not aware of any earlier reporting of this fact.[12]

An immediate implication of the previous finding, and the one that we want to emphasize here, is the *very large* increase in the volatility of wages'

[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.

relative to output or hours, as shown in the second and third panels of Table 3. In particular, we see how the relative volatility of the wage has more than doubled for all the measures and corresponding transformations considered (and has trebled in one case). We interpret that evidence as being consistent with the hypothesis of a decline over time in the significance of real wage rigidities.[13]

Table 4 helps reinforce the previous evidence, while focusing on the joint behavior of the wage product and labor productivity, and its changes over time. Labor productivity provides an interesting reference since a wide class of perfectly competitive models (including the standard RBC model) imply that it should move one-for-one with the wage in equilibrium. The evidence in Table 4 makes clear that the extent to which this is true, and the nature of the deviations from that benchmark, depend very much on the period one looks at. Thus, we see that in the pre-84 period the standard deviation of the product wage was approximately only 60 percent that of labor productivity, and its correlation with the latter variable was less than 0.5. In the post-84 period, by contrast, the standard deviations of the product wage is shown to be substantially (and significantly) larger than that of labor productivity. As a result, the ratio of relative standard deviations between those two variables has more than doubled across the two sample periods considered. Furthermore, as shown in the right hand panel of Table 4 the correlation between the product wage and labor productivity has increased significantly across sample periods, though it remains well below unity in the most recent

[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.

period.

Having documented with some detail the changing patterns of labor productivity, labor input, and wages, we next turn to possible explanations. More specifically, and as anticipated in the introduction, we explore the hypothesis that the observed changes documented above may have, at least partly, a single common explanation, namely, a decline in the significance of labor market frictions.

3 A Model of Economic Fluctuations with Labor Market Frictions

Next we develop a model of fluctuations with labor market frictions. Our aim is to illustrate the mechanisms through which changes in the importance of those frictions may provide a potential explanation for the observed changes in the properties of macro fluctuations discussed in the previous section. In order to focus on that goal we keep the model as simple as possible in dimensions that are likely to be orthogonal to the factors emphasized by our analysis. Thus, our model abstracts from endogenous capital accumulation, trade of goods and financial assets with the rest of the world, and imperfections in goods markets. We also ignore any kind of monetary frictions, even though we acknowledge that the latter, 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.[14]

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

3.1 Households

We assume an infinitely-lived representative household with a continuum of members represented by the unit interval. The household is the relevant decision unit, and has an objective function given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \; U(C_t, N_t, \{\mathcal{E}_{it}\}, Z_t)$$

where C_t denotes household consumption, $N_t \in [0,1]$ is the fraction of household members who are employed, $\mathcal{E}_{it}$ is the amount of effort put by household member $i \in [0,1]$, and Z_t is a preference shock. Parameter $\beta \in (0,1)$ is the usual discount factor. For simplicity we assume a constant workweek, thus restricting the intensive margin of labor input adjustment to changes in effort.

We specify the household's period utility to be given by:

$$U(C_t, N_t, \{\mathcal{E}_{it}\}, Z_t) \equiv Z_t \; \log C_t - \int_0^{N_t} \left(b + \frac{\mathcal{E}_{it}^{1+\varphi}}{1+\varphi} \right) \; di$$

where b can be interpreted as a fixed cost of working.

The objective function above is maximized subject to the sequence of budget constraints.

$$C_t = \int_0^{N_t} W_{it} \; di + \Pi_t$$

where W_{it} denotes the wage accruing to household member i, and Π_t represents firms' profits which are reverted to households in the form of dividends.[15]

[15] For simplicity we ignore the possibility of trade in financial securities, which would have no impact on equilibrium given our assumption of homogenous households.

Employment evolves over time according to the law of motion:

$$N_t = (1-\delta)\ N_{t-1} + x_t\ U_t$$

where δ is an exogenous separation rate, x_t denotes the job finding rate, and $U_t \equiv 1-(1-\delta)N_{t-1}$ represents the fraction of household members who are unemployed at the beginning of period t.

3.2 Firms

We assume a continuum of identical firms producing a homogenous consumption good. Technology is represented by the production function

$$Y_{jt} = A_t\ \left(\int_0^{N_{jt}} \mathcal{E}_{jit}^{\ \theta}\ di\right)^{1-\alpha}$$

where Y_{jt} is output and A_t is an exogenous, time-varying technology parameter common to all firms.

The firm's objective function is given by

$$E_0 \sum_{t=0}^{\infty} Q_{0,t}\ (Y_{jt} - W_{jt}N_{jt} - G_t H_{jt}) \tag{1}$$

where $W_{jt}N_{jt}$ represent labor compensation, H_{jt} denotes the number of hires, G_t is the (non-wage) cost per hire, which is taken as given by each individual firm. Finally, we define the relevant stochastic discount factor recursively as $Q_{0,t} \equiv Q_{0,1}Q_{1,2}...Q_{t-1,t}$, where $Q_{t,t+1} \equiv \beta\frac{C_t}{C_{t+1}}\frac{Z_{t+1}}{Z_t}$. Finally, the firm's employment evolve over time according to

$$N_{jt} = (1-\delta)\ N_{j,t-1} + H_{jt}$$

3.3 Labor Market Frictions

In our model labor market frictions are represented by the lack of a centralized labor market. When a worker separates from a firm he joinf the pool of the unemployed. An unemployed person cannot bid down the wage until he gets a job offer. Instead he has to wait for a firm to employ his services at a wage that is bargained ex-post. In that bargaining the worker's market power arises from the fact that the firm would have to incur a hiring cost G_t to replace him. That hiring cost, which is taken as given by the firm, is determined by

$$G_t = \Gamma A_t \; x_t^{\eta}$$

where

$$x_t \equiv \frac{H_t}{U_t} \in [0,1]$$

is an index of labor market tightness, with $H_t \equiv \int H_{jt} \; dj$ denoting aggregate hires. Note that from the viewpoint of the household x_t represents the probability that each unemployed member finds a job in period t, i.e. the job finding rate.

3.4 The Firm-Worker Relationship

We assume that, once a worker is employed by a firm, his individual effort is determined efficiently, by equating its marginal product to its marginal disutility (expressed in terms of consumption). Formally, the following equality must be satisfied for all workers and firms:

$$\frac{C_t}{Z_t} \; \mathcal{E}_{jit}^{\varphi} = (1-\alpha)\theta \; \frac{Y_{jt}}{N_{jt}\mathcal{E}_{jt}^{\theta}} \; \mathcal{E}_{jit}^{-(1-\theta)}$$

Given that in equilibrium all workers will supply the same effort:

$$\mathcal{E}_{jt}^{1+\varphi} = (1-\alpha)\theta \ \frac{Y_{jt}}{N_{jt}} \ \frac{Z_t}{C_t} \tag{2}$$

which can be combined with the production function to yield the following equilibrium effort schedule for firm j

$$\mathcal{E}_{jt} = \left((1-\alpha)\theta \ A_t N_{jt}^{-\alpha} \ \frac{Z_t}{C_t} \right)^{\frac{1}{1-\theta(1-\alpha)+\varphi}} \tag{3}$$

When considering whether to hire a new worker, the firm needs to take into account the impact of that decision on its workers' level of effort, as given by (3). Thus, the marginal product of a new hire is given by

$$\begin{aligned} \frac{dY_{jt}}{dN_{jt}} &= \frac{\partial Y_{jt}}{\partial N_{jt}} + \frac{\partial Y_{jt}}{\partial \mathcal{E}_{jt}} \frac{\partial \mathcal{E}_{jt}}{\partial N_{jt}} \\ &= (1-\Theta) \ \frac{Y_{jt}}{N_{jt}} \end{aligned}$$

where $1-\Theta = (1-\alpha)\left(1 - \frac{\alpha\theta}{1-\theta(1-\alpha)+\varphi}\right)$.

Maximization of the firm's value implies the following optimality condition:

$$G_t + W_{jt} = (1-\Theta) \ \frac{Y_{jt}}{N_{jt}} + (1-\delta) \ E_t\{Q_{t,t+1} \ G_{t+1}\} \tag{4}$$

i.e. the firm will hire up to the point where the cost of employing a new worker (hiring cost plus wage) equals the worker's marginal product plus the savings in hiring costs resulting from having to hire $1-\delta$ fewer workers in the following period.

Once a firm and a worker have been matched they bargain over the wage, taking their outside option into account. The firm's surplus, S_t^F, associated with a given employment relationship is given by the cost of replacing the worker, i.e. the hiring cost G_t. Equivalently, iterating (4) forward, it is given by $E_t \sum_{k=0}^{\infty} Q_{t,t+k}\ (1-\delta)^k\ ((1-\Theta)\ (Y_{j,t+k}/N_{j,t+k}) - W_{j,t+k})$, the expected sum of discounted profits generated by the new hire.

Let V_t^N and V_t^U denote the marginal value (expressed in terms of the consumption good) accruing to the household, generated by an employed and an unemployed member, respectively. Note that in the symmetric equilibrium we must have

$$\begin{aligned} V_t^N &= W_t - \frac{C_t}{Z_t}\ b - \frac{(1-\alpha)\theta}{1+\varphi}\ \frac{Y_t}{N_t} \\ &\quad + E_t\{Q_{t,t+1}\ [(1-\delta(1-x_{t+1}))\ V_{t+1}^N + \delta(1-x_{t+1})\ V_{t+1}^U]\} \end{aligned}$$

$$V_t^U = E_t\{Q_{t,t+1}[(1-x_{t+1})\ V_{t+1}^N + x_{t+1}\ V_{t+1}^U]\}$$

where we have used (2) to substitute for the effort level when deriving the expression for V_t^N.

Thus, the surplus accruing to the household from an existing employment relation, $S_t^H \equiv V_t^N - V_t^U$, is given by

$$S_t^H = W_t - \frac{C_t}{Z_t}\ b - \frac{(1-\alpha)\theta}{1+\varphi}\ \frac{Y_t}{N_t} + (1-\delta)\ E_t\{Q_{t,t+1}(1-x_{t+1})\ S_{t+1}^H\} \quad (5)$$

We can now define the wage bargaining set as.the range of wages consistent with an efficient employment relationship, i.e. one such that $S_t^H \geq 0$ and $S_t^F \geq 0$. The lower and upper bounds of the bargaining set correspond, respectively, to the reservation wage for household and firms, and are given by

$$W_t^L = \frac{C_t}{Z_t}\, b + \frac{(1-\alpha)\theta}{1+\varphi}\, \frac{Y_t}{N_t} - (1-\delta)\ E_t\{Q_{t,t+1}(1-x_{t+1})\ S_{t+1}^H\} \tag{6}$$

$$W_t^U = (1-\Theta)\ \frac{Y_t}{N_t} + (1-\delta)\ E_t\{Q_{t,t+1}\ G_{t+1}\} \tag{7}$$

Thus, and following Hall (2005), any wage process that satisfies

$$W_t \in [W_t^L,\ W_t^U]$$

for all t is consistent with equilibrium.

Nash barganing provides one possible criterion for wage determination that satisfies the above efficiency condition. It assumes that the wage is adjusted period by period so that the total surplus from an employment relationship is split between the firm and the worker according to the proportionality rule

$$\xi\ S_t^H = (1-\xi)\ S_t^F$$

where ξ denotes the share of the surplus allocated to the firm, which is a measure of the latter's bargaining power. Using (4) through (7) above we obtain the following expression for the wage:

$$\begin{aligned} W_t &= \xi\ W_t^L + (1-\xi)\ W_t^U \\ &= \xi\left(\frac{C_t}{Z_t}\, b + \frac{(1-\alpha)\theta}{1+\varphi}\, \frac{Y_t}{N_t}\right) + (1-\xi)(1-\Theta)\ \frac{Y_t}{N_t} \\ &\quad +(1-\delta)(1-\xi)\ E_t\{Q_{t,t+1}\ x_{t+1}\ G_{t+1}\} \end{aligned} \tag{8}$$

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 evidence shown in Table 4 where, in particular, the wage is shown to be roughly half as volatile as labor productivity in the early sample period, while displaying a far from perfect correlation with the latter variable. Both the relative volatility and the correlation of the wage (vs. labor productivity) increase significantly in the post-84 period. This motivates the introduction of a wage setting mechanism that departs from period-by-period Nash bargaining. In what follows, and for the purposes of illustrating the role of wage rigidity, we make the extreme assumption of a constant wage when labor market frictions are present. In particular, we assume that the wage is fixed at the steady state level for the Nash wage, i.e.

$$W_t = \xi \; W^L + (1 - \xi) \; W^U \tag{9}$$

for all t. In that case we need to guarantee that the fixed wage remains within the bargaining set when the latter shifts around in response to shocks. This will be the case if the following conditions are met: (i) ξ is not too close to zero or one (i.e. if the relative bargaining power of workers and firms is not too uneven), (ii) the shocks are not too large, and (iii) the size of the bargaining set is sufficiently large. It is easy to show that condition (iii) is intimately related to the size of labor market frictions. More specifically, we note that

$$\begin{aligned} \Delta &\equiv W^U - W^L \\ &= \frac{1}{\xi}\,(W^U - W) \\ &= \frac{1}{\xi}\,G \end{aligned}$$

i.e. the average size of the bargaining set is proportional to the steady state hiring cost. Thus, the larger is the latter the easier it will be for any given smooth path for the wage to be consistent with equilibrium.

3.5 Equilibrium

Next we list the conditions that characterize the equilibrium of our model economy, and which we obtain by combining the optimality conditions derived above (after invoking symmetry) with the relevant market clearing conditions.

$$Y_t = A_t\ (N_t\ \mathcal{E}_t^{\theta})^{1-\alpha} \tag{10}$$

$$\mathcal{E}_t^{1+\varphi} = (1-\alpha)\theta\ \frac{Y_t}{N_t}\ \frac{Z_t}{C_t} \tag{11}$$

$$N_t = (1-\delta)\ N_{t-1} + H_t$$

$$x_t = \frac{H_t}{1-(1-\delta)N_{t-1}}$$

$$G_t = \Gamma A_t\ x_t^{\eta}$$

$$Y_t = C_t + G_t\ H_t$$

$$G_t = (1-\Theta)\ \frac{Y_t}{N_t} - W_t + (1-\delta)\ E_t\{Q_{t,t+1}\ G_{t+1}\}$$

$$Q_{t,t+1} = \beta \frac{C_t}{C_{t+1}} \frac{Z_{t+1}}{Z_t}$$

given any wage process $\{W_t\}$ satisfying $W_t \in [W_t^L, W_t^U]$ for all t, where the bounds W_t^L and W_t^U are defined by (6) and (7) above, and where the logs of the two driving forces $a_t \equiv A_t$ and $z_t = \log Z_t$ follow stationary $AR(1)$ processes

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

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

where $\{\varepsilon_t^a\}$ and $\{\varepsilon_t^z\}$ are independent white noise processes with variances given by σ_a^2 and σ_z^2 respectively.

As mentioned above we consider two alternative wage-setting rules: (i) period-by-period Nash bargaining (henceforth referred to as "flexible wage" regime), as described by

$$W_t = \xi \ W_t^L + (1 - \xi) \ W_t^U$$

and (ii) a "rigid wage" regime where the wage given by the stady state Nash wage:

$$W_t = \xi \ W^L + (1 - \xi) \ W^U$$

Next we use the above 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.

4 Changing Cyclical Patterns: The Role of Labor Market Frictions

This section provides an analysis of our model economy's equilibrium under alternative assumptions regarding the size of labor market frictions and the setting of wages. We start by looking at a frictionless version of the model without frictions, which provides a useful benchmark and for which an analytical solution exists. When we introduce frictions we rely instead on a log-linearized version of the model, focusing on the simulations of a calibrated version of the model under two alternative wage rules: flexible and rigid.

4.1 The Frictionless Case

We consider the limiting case of an economy with no hiring costs ($\Gamma = 0$) thus implying $G_t = 0$, for all t. In that case Nash bargaining requires that $S_t^H = S_t^F = 0$ for all t, which can be shown to imply

$$W_t = (1 - \Theta)\ \frac{Y_t}{N_t} = \frac{C_t}{Z_t}\ b + \frac{(1-\alpha)\theta}{1+\varphi}\ \frac{Y_t}{N_t} \tag{12}$$

for all t. On the other hand the goods market clearing condition now simplifies to

$$Y_t = C_t$$

for all t, which combined with (12) yields:

$$N_t = \frac{1-\Phi}{b}\ Z_t$$

where $\Phi \equiv \Theta + \frac{(1-\alpha)\theta}{1+\varphi}$, i.e. employment varies in proportion to the preference shifter Z_t but is invariant to technology shocks. Using (11), together with the above relation we obtain

$$\mathcal{E}_t^{1+\varphi} = \frac{(1-\alpha)\theta b}{1-\Phi}$$

thus implying an effort level that is invariant to fluctuations in the model's driving forces. While the latter property is undoubtedly the result of some of the special assumptions made on preferences and technology, it provides a useful benchmark for our purposes.

Letting lower case letters denote the natural logarithms of the original variables and ignoring constants terms we can derive the following closed form expressions for equilibrium employment, output, the wage, and labor productivity:

$$n_t = z_t$$

$$y_t = (1 - \alpha)\ z_t + a_t$$

$$w_t = y_t - n_t = -\alpha\ z_t + a_t$$

Using the previous equations we can easily determine the model's implications for the second moments of interest. In particular we have

$$cov(y_t - n_t, y_t) = -\alpha(1 - \alpha)\ var(z_t) + var(a_t)$$

$$cov(y_t - n_t, n_t) = -\alpha\ var(z_t)$$

Thus we see that, in the absence of labor market frictions, labor productivity is unambiguously countercyclical with respect to employment. On the other hand, and due to the fact that preference and technology shocks generate comovements of different sign between labor productivity and output, the sign of the unconditional covariance between those variable depends on the relative importance of the two types of shocks.

Furthermore, the volatility of output and that of employment and the wage relative to output are given by the following expressions:

$$var(y_t) = (1 - \alpha)^2 var(z_t) + var(a_t)$$

$$\frac{var(n_t)}{var(y_t)} = \frac{var(z_t)}{(1-\alpha)^2 var(z_t) + var(a_t)}$$

$$\frac{var(w_t)}{var(y_t)} = \frac{\alpha^2 \; var(z_t) + var(a_t)}{(1-\alpha)^2 var(z_t) + var(a_t)}$$

Thus, we see that 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 decreasing returns to labor. Below we use some of these formulas to calibrate the variance of the driving forces.

Having characterized the equilibrium of a version of the model with no frictions, and determined the corresponding expressions for the second moments that were the focus of our empirical analysis, we now turn to the analysis of a version of the model with frictions. Our objective is to in. Since an analytical solution does not exist when frictions are present we need to rely on simulations of a calibrated version of the model. We briefly discuss our calibration strategy in the next subsection.

4.2 Calibration

Our calibration corresponds to a quarterly frequency, in consonance with our evidence. Many of the model's parameters can be easily calibrated to values that are standard in the literature. The fact that we have little guidance for others is not so important given that our goal here is just to illustrate some qualitative changes in the patterns of fluctuations that may result from changes in the importance of labor market frictions.

Our baseline calibration is as follows. We set the discount factor β equal to 0.99, a standard value in the literature. The elasticity of the marginal disutility of effort, φ, is set to unity. We assume $\alpha = 1/3$. We assume that the hiring cost function is quadratic with respect to labor market tightness, i.e. $\eta = 2$. Parameter Γ is set at a value such that hiring costs represent 0.1 percent of output in the steady state. We assume equal bargaining power and set $\xi = 0.5$. The separation rate δ and the disutility of employment b are set in oder to match a job finding rate x equal to 0.7 and an unemployment rate of 5.5% in the steady state, in a way consistent with the observed average values for those variables in the postwar period.

Regarding the model's two driving forces, we assume a high persistence for both of them, thus setting $\rho_a = \rho_z = 0.9$. Given those values, we calibrate σ_a^2 and σ_z^2 so that the frictionless version (i.e. assuming $\Gamma = 0$) of our calibrated model (analyzed in the previous subsection) matches the volatility of BP-filtered output and hours in the post-84 period (using nonfarm business data). This requires that $\sigma_z^2 = (1 - \rho_z^2)\ var(n_t)$ and $\sigma_a^2 = (1 - \rho_a^2)$ $(var(y_t) - (1 - \alpha)^2 var(n_t))$. Note that by using that calibration strategy we are implicitly thinking of the frictionless model as the one characterizing the macro fluctuations of the post-84 period.

4.3 Simulations

Table 5 reports comovement and volatility statistics for three versions of our calibrated model: the frictionless model, the model with frictions and flexible wages, and the model with frictions and rigid wages. Note that for the frictionless case, and given our calibration strategy, both the standard deviation of output $\sigma(y)$ and the relative standard deviation of labor input, $\sigma(n)/\sigma(y)$, match the post-84 data exactly. Interestingly, however, the implied correlation of labor productivity with output is close to zero (0.11), whereas the corresponding correlation with respect to labor input is negative (-0.53) in that case, in a way consistent with the evidence for the post-84 period. The same is true for the relative volatility of the wage, which is shown to be 0.72 in the calibrated frictionless model, and around 0.85 ($s.e.= 0.10$) in the data (as seen in Table 3). The second and third rows display the corresponding statistics conditional on technology and preference shocks, respectively, thus making clear the role of each type of shock in generating the unconditional second moments.

What are the consequences of introducing labor market frictions on the previous statistics? As the second panel of Table 4 illustrates, the introduction of frictions, in the form of hiring costs, has several implications, even when we maintain the assumption of flexible wages (period-by-period Nash bargaining in our case). Importantly, and as a look at Table 5 makes clear, the changes brought about by the introduction of hiring costs in that case can be traced to changes in the economy's response to preference shocks. The reason is simple: in our model, employment is invariant to technology shocks in the absence of frictions, thus the latter do not have any influence on the economy's response to technology shocks when they are introduced.

We see that an immediate consequence of the introduction of hiring costs is the reduction in the volatility of output and, more than proportionally, in the volatility of employment. While the latter is consistent with our proposed interpretation of the U.S. evidence, the former is clearly not, being in conflict with the larger volatility observed in the pre-84 period. The same is true regarding the model's predictions on wage volatility, which increases relative to output as a result of the introduction of frictions.

On the other hand, labor market frictions affect the cyclical behavior of labor productivity in a direction consistent with our interpretation of the evidence: they generate a significant increase in the correlation of labor productivity with output (from a value close to zero to a high positive value) and labor productivity with labor input (from a large negative value to one close to zero). Note, however, that those changes in labor productivity comovements are not driven by variations in the underlying conditional correlations, but instead they are the result of the change in the relative importance of the two shocks, with preference shocks having a smaller weight as a source of fluctuations in the presence of frictions. The absence of a significant change in the correlations conditional on the non-technology shocks is, on the other hand, at odds with the evidence reported in Galí and Gambetti (2008).

The third panel of Table 5 reports the statistics corresponding to a version of the model with hiring costs and real wage rigidities. The introduction of the latter has two key effects on second moments. First, there is a reversal in the sign of the correlations of labor productivity with output and labor input conditional on preference shocks, which become positive. The reason is that the rigid wage dampens the response of employment, since wages do not react now to the reduction in the household's enhanced willingness to work. The increase in employment results exclusively from the higher marginal product of labor induced by the greater effort triggered by the preference shock. Thus, firms use variations in effort to a much greater extent than variations in employment. As a result, the correlation of labor productivity with both output and labor input changes sign and attains a value close to one.

Secondly, the presence of a rigid wage breaks the invariance of employment to technology shocks. This leads to an amplification of the economy's response to those shocks, with the conditional volatility of output nearly doubling. The latter effect more than offsets the decline in output volatility conditional on preference shocks, bringing the unconditional volatility to a level higher than in the frictionless model. That result is consistent with our interpretation of the possible role of a decline in labor market frictions as a source of the Great Moderation.

[to be completed]

5 Conclusions

[to be written]

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Table 1. Cyclical Behavior of Labor Productivity

	Correlation with Output			*Correlation with Labor Input*		
	Pre-84	Post-84	Change	Pre-84	Post-84	Change
Nonfarm Business						
BP	0.61 (0.04)	−0.01 (0.09)	−0.62* (0.10)	0.18 (0.07)	−0.53 (0.07)	−0.72* (0.10)
4D	0.66 (0.05)	0.07 (0.09)	−0.58* (0.10)	0.20 (0.07)	−0.49 (0.09)	−0.69* (0.11)
Total (hours)						
BP	0.45 (0.06)	0.03 (0.08)	−0.42* (0.11)	0.03 (0.08)	−0.51 (0.07)	−0.54* (0.11)
4D	0.57 (0.06)	0.11 (0.08)	−0.46* (0.10)	0.05 (0.08)	−0.46 (0.08)	−0.51* (0.11)
Total (employment)						
BP	0.84 (0.02)	0.74 (0.04)	−0.10* (0.04)	0.41 (0.07)	0.18 (0.09)	−0.22* (0.11)
4D	0.87 (0.02)	0.72 (0.04)	−0.14* (0.04)	0.32 (0.07)	0.20 (0.10)	−0.12 (0.12)

Note: standard errors in brackets. An asterisks indicates significant change across periods at a 5% level (one-sided test).

Table 2. Labor Input Volatility						
	Absolute			*Relative to Output*		
	Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
Hours (NFB)						
BP	2.07 (0.10)	1.35 (0.08)	0.65* (0.05)	0.80 (0.03)	1.18 (0.06)	1.46* (0.09)
4D	3.07 (0.18)	2.17 (0.16)	0.70* (0.06)	0.76 (0.03)	1.14 (0.07)	1.50* (0.11)
Hours (Total)						
BP	1.78 (0.09)	1.02 (0.06)	0.57* (0.04)	0.89 (0.03)	1.16 (0.06)	1.30* (0.08)
4D	2.62 (0.17)	1.69 (0.11)	0.64* (0.06)	0.82 (0.04)	1.12 (0.06)	1.36* (0.10)
Employment						
BP	1.17 (0.06)	0.60 (0.04)	0.51* (0.04)	0.58 (0.03)	0.68 (0.04)	1.16* (0.08)
4D	1.66 (0.09)	1.06 (0.09)	0.64* (0.06)	0.52 (0.03)	0.71 (0.03)	1.36* (0.10)
Hours per worker						
BP	0.73 (0.06)	0.49 (0.03)	0.64* (0.06)	0.38 (0.03)	0.56 (0.03)	1.45* (0.13)
4D	1.32 (0.12)	0.83 (0.05)	0.62* (0.06)	0.41 (0.03)	0.55 (0.05)	1.33* (0.16)

Note: standard errors in brackets. An asterisk indicates significant change across periods at a 5% level (one-sided test).

Table 3. Wage Volatility

	Absolute			*Relative to Output*			*Relative to Hours*		
	Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio	Pre-84	Post-84	Ratio
P-Wage									
BP	0.70	0.99	1.40*	0.27	0.86	3.15*	0.34	0.73	2.15*
	(0.07)	(0.06)	(0.16)	(0.02)	(0.08)	(0.40)	(0.03)	(0.05)	(0.25)
4D	1.24	1.60	1.29*	0.31	0.85	2.74*	0.40	0.73	1.82*
	(0.09)	(0.11)	(0.03)	(0.02)	(0.11)	(0.42)	(0.03)	(0.08)	(0.25)
C-Wage									
BP	0.89	0.98	1.10	0.34	0.85	2.47*	0.43	0.72	1.68*
	(0.05)	(0.06)	(0.09)	(0.03)	(0.08)	(0.29)	(0.03)	(0.06)	(0.18)
4D	1.71	1.64	0.95	0.42	0.86	2.03*	0.56	0.75	1.35*
	(0.11)	(0.10)	(0.09)	(0.03)	(0.11)	(0.30)	(0.05)	(0.08)	(0.18)

Note: standard errors in brackets. An asterisk indicates significant change across periods at a 5% level (one-sided test).

Table 4. The Product Wage and Labor Productivity						
	Relative Volatility			*Correlation*		
	Pre-84	Post-84	Ratio	Pre-84	Post-84	Change
BP	0.59 (0.06)	1.40 (0.10)	2.35* (0.28)	0.42 (0.07)	0.62 (0.06)	0.20* (0.09)
4D	0.60 (0.05)	1.31 (0.11)	2.17* (0.25)	0.48 (0.07)	0.62 (0.05)	0.14* (0.08)

Note: standard errors in brackets. An asterisk indicates significant change across periods at a 5% level (one-sided test).

Table 5. Model Simulations

	No Frictions			*Frictions (0.1%)*			*Wage rigidity*		
	Both	Tech	Pref	Both	Tech.	Pref	Both	Tech	Pref
$corr(y-n,y)$	0.11	1.0	-1.0	0.84	1.0	-0.98	0.97	0.97	0.98
$corr(y-n,n)$	-0.53	0.0	-1.0	-0.10	0.0	-0.98	0.96	0.96	0.96
$\frac{\sigma(n)}{\sigma(y)}$	**1.18**	0.0	1.5	0.54	0.0	1.16	0.80	0.81	0.79
$\frac{\sigma(w)}{\sigma(y)}$	0.72	1.0	0.5	0.92	1.0	0.46	0.0	0.0	0.0
$\sigma(y)$	**1.15**	0.70	0.90	0.78	0.70	0.37	1.35	1.33	0.20