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Productivity and unemployment over the business cycle

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ABSTRACT

The low correlation between cyclical unemployment and productivity over the post-war period hides a large sign switch in the mid-1980s: from significantly negative the correlation became significantly positive. Using a search model of unemployment with nominal rigidities and variable labor effort, I show that technology shocks can generate a positive unemployment-productivity correlation whereas non-technology shocks (i.e. aggregate demand shocks) tend to do the opposite. In this context, I identify two events that can quantitatively explain the increase in the correlation: (i) a sharp drop in the volatility of non-technology shocks in the mid-1980s, and (ii) a decline in the response of productivity to non-technology shocks, which from procyclical became acyclical in the last 25 years.

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1. Introduction

Since the seminal work of Mortensen and Pissarides (1994), a vast literature, including Mertz (1995), Andolfatto (1996) and Shimer (2005), has focused on labor productivity to explain movements in unemployment.[1] In a Mortensen–Pissarides search and matching model, shifts in labor demand are caused by changes in productivity, and productivity is seen as the central driving force of unemployment. An increase in productivity raises the surplus from a firm-worker match, leads firms to post more job vacancies and pulls down the unemployment rate. Given the major role played by productivity, there is surprisingly little empirical evidence on the impact of productivity changes on unemployment.

This paper presents a study of the relationship between productivity and the labor market in the US and refines a key stylized fact of the business cycle literature; the low correlation between total hours worked and productivity.[2] While the correlation between cyclical unemployment and the cyclical component of productivity is weak over the post-war period, this low correlation hides a large sign shift in the mid-1980s. From significantly negative, the correlation became significantly positive, while standard search models imply a negative correlation. This finding holds for different measures of productivity and different measures of labor input. In particular, the correlation between hours per worker and productivity followed a similar pattern and switched sign in the mid-1980s.

Such sign shifts could be the result of forces working in opposite directions. I estimate a VAR with unemployment and productivity and find that a positive technology shock, identified as the only disturbance with a permanent impact on labor productivity, increases unemployment temporarily and generates a positive unemployment-productivity correlation. In contrast, a positive non-technology shock (temporarily) increases productivity, decreases unemployment and generates a negative correlation.

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[1] See also, among others, den Haan et al. (2000), Hall (2005) and Gertler and Trigari (2009).

[2] This low correlation has attracted a lot of interest in the business cycle theory literature. See, for example, Benhabib et al. (1991), Christiano and Eichenbaum (1992), and Chang and Kim (2007).

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To provide a structural interpretation for these new facts, I present a New-Keynesian model with search unemployment, and interpret non-technology shocks as aggregate demand shocks. The model's ability to explain the data rests on three key elements: sticky prices, search and matching frictions, and variable hours and labor effort. Variable labor effort allows the model to generate procyclical endogenous movements in productivity. Following a positive aggregate demand shock, firms raise their labor input in order to satisfy demand. Since employment is subject to hiring frictions, firms must first rely on the intensive labor margin. Firms increase hours and effort, and thus measured labor productivity increases. However, relying too much on the intensive margin is costly because a worker's disutility of work is convex in hours and effort. To minimize labor costs, firms posts vacancies to hire more workers, and unemployment goes down. Following a positive technology shock, aggregate demand does not increase as much as productivity because prices are sticky. Being more productive, firms initially meet their demand by decreasing hours and effort since employment takes time to adjust. With shorter hours and lower effort, the value of a marginal worker goes down, firms post fewer vacancies, and unemployment increases.

Since technology and aggregate demand shocks generate opposite comovements in unemployment and productivity, a change in their relative importance could switch the sign of the unemployment-productivity correlation. The volatility of non-technology shocks identified with long-run restrictions displays a large drop in the early 1980s. I simulate the impact of such a drop and find that changes in shock volatilities can account for about 40% of the increase in the unemployment-productivity correlation. Some other force must be at work. One possibility is that, conditional on each shock, the relationship between unemployment and productivity has changed. Comparing empirical impulse responses before and after 1984, the cyclical response of productivity to non-technology shocks became small and non-significant in the post-1984 period. As a result, the negative correlation generated by non-technology shocks became less negative, and the unconditional correlation increased. In the model, a weaker procyclicality of productivity is the result of a more flexible labor market with lower hiring frictions and more elastic hours per worker, as firms rely less on the effort margin when the other margins—employment and hours per worker—become cheaper. I simulate this structural change alongside smaller aggregate demand shocks, and find that these two events can quantitatively explain the sign switch of the unemployment-productivity correlation in the mid-1980s, as well as the sign flip of the hours per worker-productivity correlation.

There is little empirical work on the relationship between unemployment and productivity or between hours per worker and productivity, but the low correlation between total hours and productivity has long been recognized. Gali (1999) and Basu et al. (2004) spawned a large literature on the negative effect of technology shocks on total hours worked.[3] In a recent empirical paper, Gali and Gambetti (2009) generalized Gali's (1999) approach by estimating a structural VAR with time varying coefficients. Despite a different empirical approach and a focus on total hours instead of unemployment and hours per worker, our findings are complementary. In particular, they report a decline in the correlation between total hours and productivity during the 1980s. However, without a structural model, they do not study the reasons behind this decline. Moreover, they document a shrinking contribution of non-technology shocks to output volatility after 1984, in line with my finding that non-technology shocks were smaller after the mid-1980s.[4]

Gali (1999) offered a New-Keynesian explanation for the negative impact of positive technology shocks on total hours, and the present model invokes a similar mechanism to explain the positive response of unemployment. While other mechanisms could generate an increase in unemployment in the case of fully flexible prices (Wang and Wen, 2010; Holly and Petrella, 2008; Chang et al., 2009), the present mechanism can also account for the sign shift in the unemployment-productivity correlation. Krause and Lubik (2007) and Thomas (2009) introduced equilibrium unemployment in a New-Keynesian framework by modeling firms facing both hiring frictions and nominal frictions, and the present model follows a similar approach.[5]

The remainder of the paper is organized as follows: Section 2 studies the relationship between productivity and the labor market; Sections 3 describes the model and its properties; Section 4 confronts the model with the data; and Section 5 offers some concluding remarks.

2. Empirical evidence

This section studies the relationship between productivity and the labor market.[6] It first looks at raw statistics and document a robust change in the sign of the unemployment-productivity correlation in the mid-1980s. Such a sign switch could be the result of forces working in opposite directions. Using a bivariate VAR with long-run restrictions, I find that technology shocks generate a positive unemployment-productivity correlation whereas non-technology shocks do the opposite. In this context, two (mutually non-exclusive) developments could generate a large increase in the unemployment-productivity correlation: (i) a decline in the relative size of non-technology shocks versus technology

[3] See, among others, Christiano et al. (2003), Francis and Ramey (2004), Chang and Hong (2006), Fernald (2005), and Holly and Petrella (2008).

[4] However, their empirical approach cannot identify whether this "shrinking contribution of non-technology shocks" is due to smaller shocks or to a weaker transmission mechanism of these shocks.

[5] See also Kuester (2007), Sveen and Weinke (2008) and Blanchard and Gali (2010). For an alternative approach to combine nominal rigidities with search frictions, see Walsh (2004) and Trigari (2009).

[6] Details related to the data and the estimation methods appear in Appendices A1 and A2.

Table 1
Correlations between labor productivity and labor input measures.

	1984–2008	Pre-1984	Post-1984
$\rho_{U,Y/H}$	−0.10	−0.24**	0.44**
	(0.09)	(0.10)	(0.16)
$\rho_{V,Y/H}$	0.17	0.34**	−0.31**
	(0.11)	(0.13)	(0.15)
$\rho_{E,Y/H}$	−0.06	0.09	−0.57**
	(0.09)	(0.10)	(0.17)
ρHpW,Y/H	0.31**	0.50**	−0.25*
	(0.10)	(0.11)	(0.12)

Note: The four rows report the correlations between output per hour and respectively unemployment, vacancies, employment and hours per worker. All series start in 1948 except for vacancies which starts in 1951. All series are detrended with an HP-filter with smoothing parameter 1600. Standard-errors are shown in parentheses. Significance is indicated by one asterisk (10-percent level) or two asterisks (5-percent level).

shocks, and (ii) a structural change that modified the conditional correlation generated by each shock. This section explores these two possibilities successively.

2.1. Raw statistics

Cyclical unemployment and the cyclical component of labor productivity (i.e., output per hour) are weakly correlated over the post-war period. As Table 1 shows, their correlation is not significant and only slightly negative (−0.10) over 1948–2008, a result in line with the well documented low correlation between total hours and productivity (see e.g. Chang and Kim, 2007). Other labor market indicators such as employment, vacancy posting and hours per worker also display a low correlation with productivity. However, looking at unemployment and productivity in the upper-panel of Fig. 1, the two series seem negatively correlated up until 1984, but positively correlated thereafter. This positive correlation is especially striking for 1992 when both unemployment and labor productivity increase sharply, but it is apparent throughout the post-1984 period. Indeed, as we can see in Table 1, the correlation between unemployment and productivity, ρ, goes from −0.24 over 1948–1984 to 0.44 over 1985–2008, and both estimates are significant at the 5%-level. Interestingly, this finding is consistent with Gali and Gambetti (2009) who recently documented that the correlation of total hours with labor productivity experienced a decline during the 1980s, shifting from values close to zero in the pre-1984 period to negative values after 1984.

To see more sharply the large change in ρ, the middle-left panel of Fig. 1 plots ρ_{10}, the 10-year rolling contemporaneous correlation between unemployment and labor productivity. In about a year's time, the rolling correlation switches swiftly from negative to positive values. The unemployment-productivity cross-correlograms before and after 1984 give the same conclusion. As we can see on the middle-right panel of Fig. 1, the two cross-correlograms look dramatically different. Notably, the correlation between unemployment and labor productivity lagged three quarters is positive after 1984 but corresponds to the peak negative correlation before 1984.

Looking at other labor market indicators gives a similar result. The lower-left panel of Fig. 1 displays the 10-year rolling correlations between output per hour and, respectively, employment, vacancies, and hours per worker. All three series experienced a large jump similar to ρ. Table 2 confirms this visual inspection as all correlations increase by about 0.7. In particular, the hours per worker-productivity correlation decreased from 0.50 over 1948–1984 to −0.25 over 1985–2008.

The lower-right panel of Fig. 1 considers alternative measures of productivity: output per worker and total factor productivity (TFP). Again, both rolling correlations displayed a large increase and became positive in the mid-1980s.

2.2. The impact of technology and non-technology shocks on ρ

To study the impact of different shocks on ρ, I estimate a bivariate VAR with productivity and unemployment:

$$\begin{pmatrix} \Delta x_t \\ u_t \end{pmatrix} = C(L) \begin{pmatrix} \varepsilon_t^a \\ \varepsilon_t^m \end{pmatrix} = C(L)\varepsilon_t \tag{1}$$

where x_t is (logged) labor productivity defined as output per hours, u_t unemployment, $C(L)$ an invertible matrix polynomial and ε_t the vector of structural orthogonal innovations comprised ε_t^a technology shocks and ε_t^m non-technology shocks. As in Gali (1999), technology shocks are identified as the only disturbance with a permanent impact on labor productivity. I use the estimation method of Shapiro and Watson (1988) and Francis and Ramey (2004) to allow for time-varying variance of the structural innovations.

The first row of Fig. 2 displays the impulse response functions of productivity and unemployment following a technology shock. Labor productivity undershoots its new long-run level by around 20% and plateaus after about one and a half years. After an initial jump, unemployment displays a hump-shaped positive response that peaks quite rapidly, in about 2 quarters.

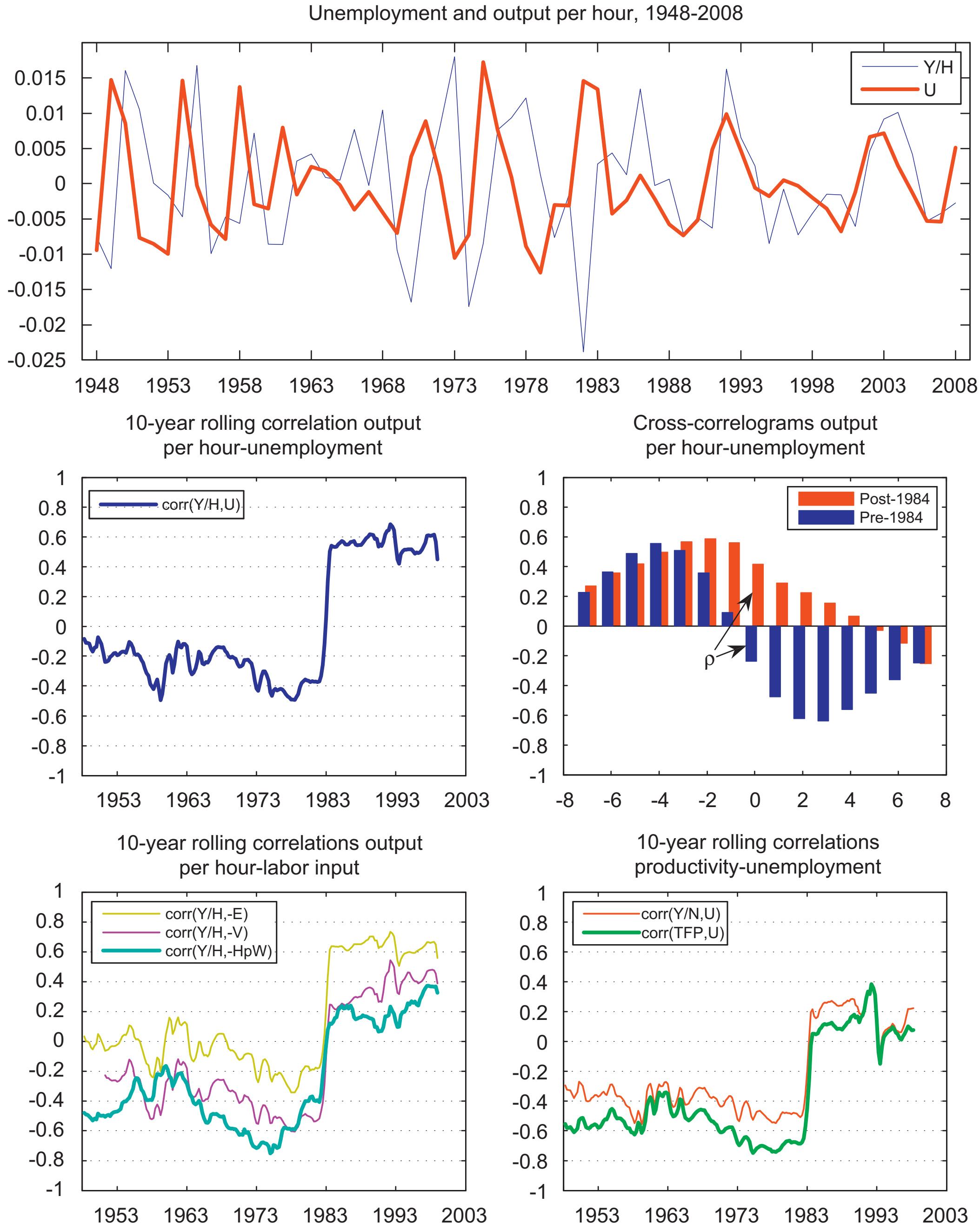

Fig. 1. Upper panel: unemployment and output per hour over 1948–2008. The quarterly series are annualized for clarity of exposition. Middle-left panel: 10-year rolling correlations between unemployment and output per hour. At each year T on the x-axis corresponds the correlation over $(T,T+10)$. Middle-right panel: empirical cross-correlogram of output per hour and unemployment pre-1984 (foreground) and post-1984 (background). Lower panels: 10-year rolling correlations (output per hour, employment), (output per hour, vacancies), (output per hour, hours per worker), (output per worker, unemployment) and (TFP, unemployment). All variables are logged (except unemployment) and detrended with an HP-filter ($\lambda=1600$).

Quantitatively, a 0.5% rise in productivity is associated with a 0.2 percentage point *increase* in unemployment.[7] The second row of Fig. 2 shows the dynamic effects of a non-technology shock. Productivity jumps on impact and reverts to its long-run value in one year. Unemployment decreases, reaches a trough after one year, and reverts slowly to its long-run value. Quantitatively, a 0.6% increase in productivity is correlated with a 0.2 percentage point *drop* in unemployment.

[7] A number of researchers (see Christiano et al., 2003; Chang and Hong, 2006; Holly and Petrella, 2008) question the robustness of Galí's (1999) findings, and my approach may suffer from similar critiques. Appendix A3 discusses the robustness of the VAR evidence in light of their findings.

Table 2
Summary statistics for US and model data, 1948–2008.

	U		***V***		***HpW***		***Y***		***Y/H***	
	US	model	US	model	US	model	US	model	US	model
Standard deviation	0.007	0.009	0.141	0.181	0.005	0.010	0.020	0.019	0.010	0.009
Quarterly autocorrelation	0.88	0.85	0.90	0.71	0.80	0.60	0.83	0.72	0.71	0.64

Note: Standard-deviations and quarterly autocorrelations of unemployment, vacancies, hours per worker, output and output per hour. All series start cover 1948–2008 except for vacancy posting which starts in 1951. All variables are reported in logs except unemployment and all series are detrended with an HP trend with smoothing parameter 1600.

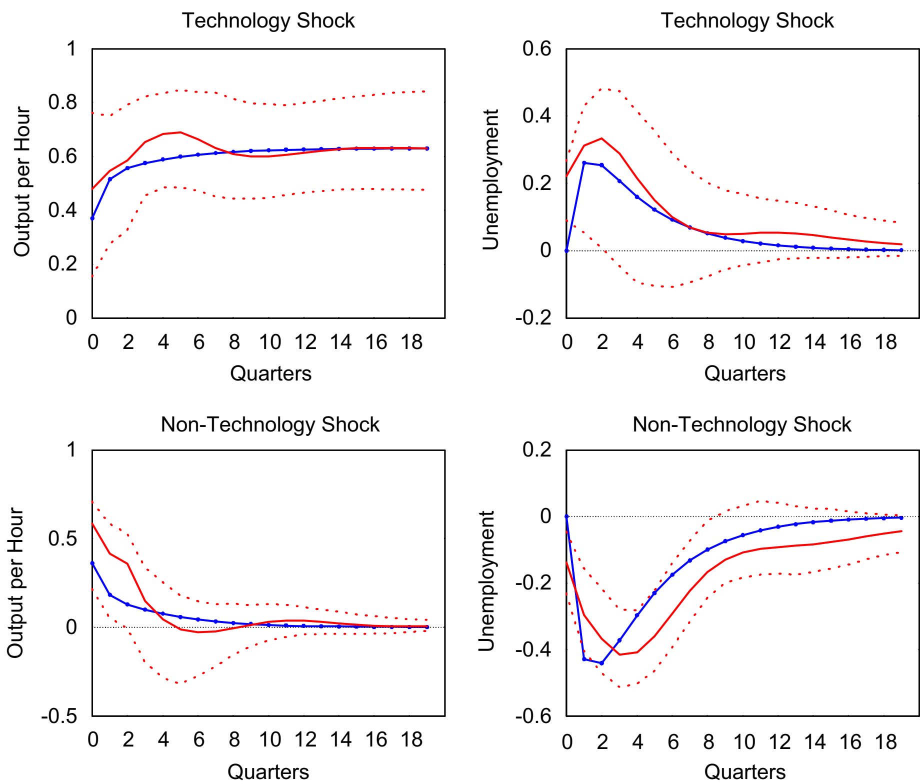

Fig. 2. Empirical (plain line) and model (dotted line) impulse response functions to a technology and a non-technology shock. Dashed lines represent the 95% confidence interval.

2.2.1. *A change in the volatility of shocks*

Gali and Gambetti (2009) document a shrinking contribution of non-technology shocks to output volatility after the mid-1980s, which could indicate that non-technology shocks have become smaller.[8] Fig. 3 plots the 5-year rolling standard deviations of technology and non-technology shocks previously identified. Although the variances of both shocks display a downward trend, it is more pronounced for non-technology shocks, with a large drop in the mid-1980s. The standard deviation of non-technology shocks decreased by more than 70% while the standard deviation of technology shocks was roughly constant in the mid-1980s.[9] Since technology and non-technology shocks generate opposite comovements in unemployment and productivity, smaller non-technology shocks may have caused ρ to switch sign in the mid-1980s.

[8] Unlike the present paper, Gali and Gambetti's (2009) empirical procedure does not allow for time-varying variance of the structural innovations, and cannot identify whether this "shrinking contribution of non-technology shocks" is due to smaller shocks or to a weaker transmission mechanism of these shocks.

[9] In an F-test of equal variance between the variances of non-technology shocks for the pre-1984 and post-1984 periods, the ratio of the pre-1984 variance and post-1984 variance of non-technology shocks is 3.6 with sample sizes of 140 and 95. So the null of equal variance can be rejected for all conventional values of the F-statistics.

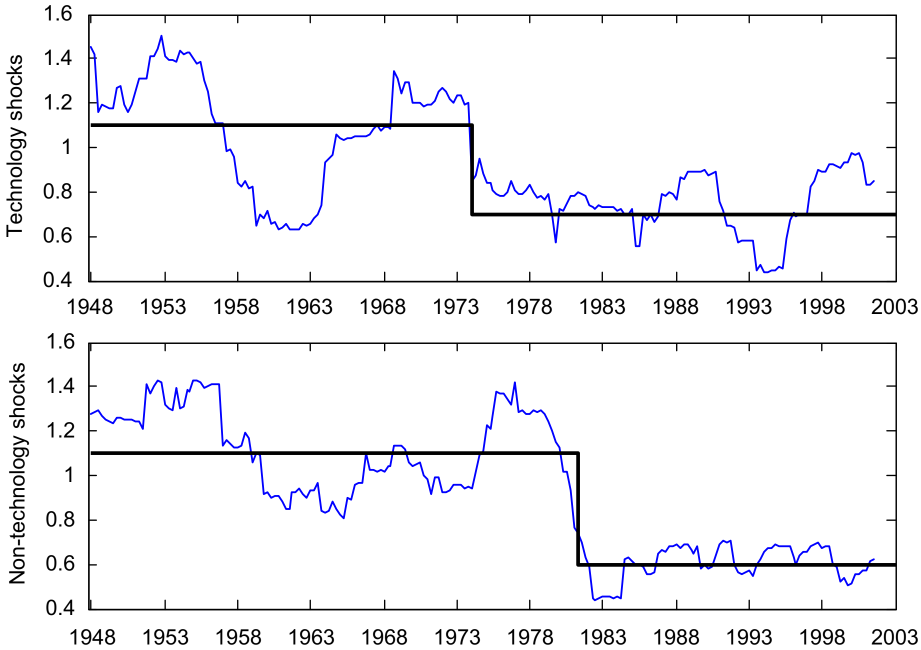

Fig. 3. 5-year rolling standard-deviation of technology and non-technology shocks and step functions approximating the standard deviations. Both standard deviations are normalized to one for ease of comparison.

2.2.2. Structural changes

The US economy experienced a number of structural changes in the early 1980s; a change in the conduct of monetary policy, a change in inventory management, a change in the regulatory environment, and since the 1970s, a progressive shift away from manufacturing towards services (Stock and Watson, 2002). These changes could bias impulse response functions identified over the whole post-war period.[10] In this section, I split the sample into two sub-periods, pre-1984 and post-1984, and Fig. 4 shows the impulse responses obtained for each period. The responses differ in two points: (a) non-technology shocks have a smaller impact on labor productivity after 1984, and (b) technology shocks have a smaller impact on unemployment after 1984.

A decline in the procyclicality of productivity: As we can see in Fig. 4, productivity is much less responsive after 1984. Following the same non-technology shock, the productivity response on impact goes from 0.8 to close to 0 after 1984. Output per hour even becomes negative after one quarter, although the response is non-significant at the 10% level. The responses for unemployment, on the other hand, are comparable. This finding is in line with Gali and Gambetti (2009, Fig. 6) who report a steady decline in the procyclicality of productivity following non-technology shocks since the 1970s and the eventual disappearance of any procyclical response in the early 1990s. Importantly, a lower response of productivity for the same response in unemployment tends to decrease the negative impact that a demand shock has on ρ and could explain the increase in the unconditional correlation and the sign flip.

Monetary policy and the response of unemployment to technology shocks: Gali et al. (2003) argue that the Fed's conduct of monetary policy became more accommodating to technology shocks after 1982, and that this affected the response of total hours to technology shocks. Fig. 4 is consistent with this hypothesis, with a smaller and less significant response of unemployment after 1984. However, as unemployment becomes less responsive to technology shocks, a change in the conduct of monetary policy contributes to lower ρ and cannot explain the sign switch.

3. A New-Keynesian model with unemployment

The empirical evidence suggests that the interaction of technology and non-technology shocks plays an important role in explaining unemployment fluctuations and productivity movements. This section presents a New-Keynesian model with search unemployment and interpret non-technology shocks as aggregate demand shocks.[11] The general equilibrium

[10] Analyzing the response of total hours worked to technology shocks, Gali et al. (2003) report very different impulse response functions after splitting their data over two sub-periods before and after the early 1980s. After allowing for time-varying coefficients in a bivariate VAR with long-run restrictions, Gali and Gambetti (2009) document significant changes in the impulse responses of total hours and productivity over the 1980s.

[11] Aggregate demand shocks are modeled as monetary policy shocks because they provide a parsimonious and tractable way of introducing demand shocks. Importantly, Appendix A3 shows that monetary policy shocks (identified by Romer and Romer, 2004) display a similar volatility drop to the one experienced by non-technology shocks in the mid 1980s.

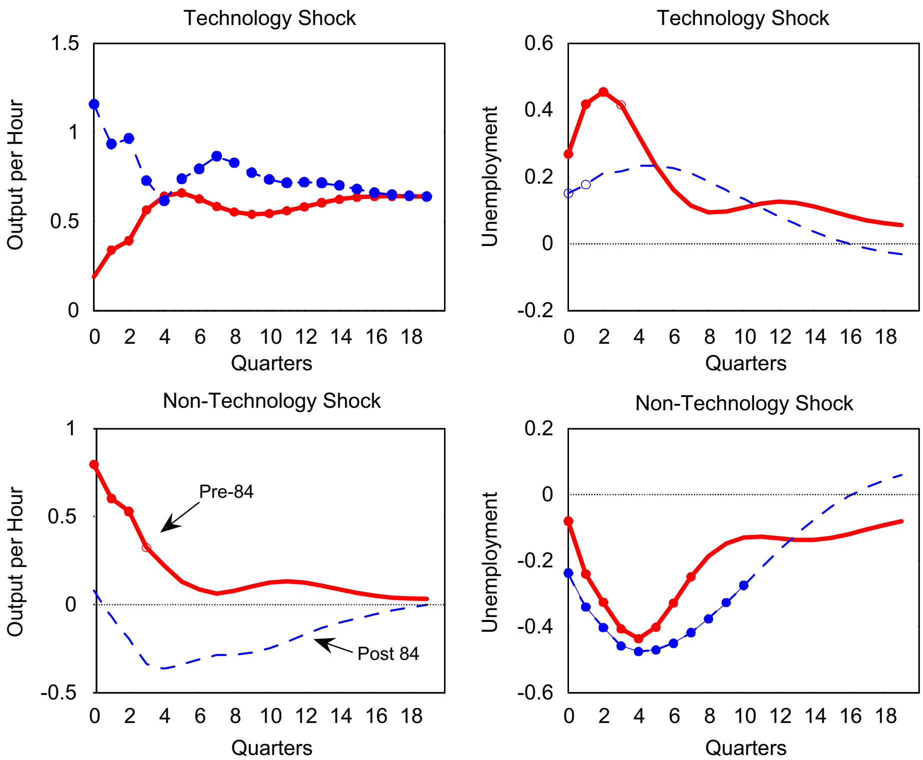

Fig. 4. Impulse response functions to technology and non-technology shocks. The first two rows display the estimates over the whole sample and dashed lines represent the 95% confidence interval. The last two rows display the estimates for pre-1984 (solid line) and for post-1984 (dashed line). Solid circles indicate that the response is significant at the 5% level and open circles at the 10% level.

model features monopolistic competition in the goods market, hiring frictions in the labor market, variable labor effort and nominal price rigidities. There are three types of agents: households, firms and a monetary authority.

3.1. Households

There exists a continuum of households of measure one. To avoid distributional issues, I follow Mertz (1995) and Andolfatto (1996) and assume that households form an extended family that pools their income and chooses per capita consumption and assets holding to maximize their expected lifetime utility. There are $1-n_t$ unemployed workers who receive unemployment benefits b_t, and n_t employed workers who receive the wage payment w_{it} from firm i for providing hours h_{it} and effort per hour e_{it}. Denoting $g(h_{it},e_{it})$ the individual disutility from working, the representative family maximizes

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\ln(C_t) + \lambda_m \ln\left(\frac{M_t}{P_t}\right) - n_t \int_0^1 g(h_{it},e_{it})\, di \right] \tag{2}$$

subject to the budget constraint

$$\int_0^1 P_{jt} C_{jt}\, dj + M_t = \int_0^1 n_t w_{it}\, di + (1-n_t) b_t + \Pi_t + M_{t-1} \tag{3}$$

with λ_m a positive constant, M_t nominal money holdings and Π_t total transfers to the family. C_t is the composite consumption good index $C_t = (\int_0^1 C_{it}^{(\varepsilon-1)/\varepsilon}\, di)^{\varepsilon/(\varepsilon-1)}$ where C_{it} is the quantity of good $i \in [0,1]$ consumed in period t, P_{it} is the price of variety i, and $\varepsilon > 1$ is the elasticity of substitution among consumption goods. The aggregate price level is defined as $P_t = (\int_0^1 P_{it}^{1-\varepsilon}\, di)^{1/(1-\varepsilon)}$. The disutility from supplying hours of work h_t and effort per hour e_t is the sum of the disutilities of the members who are employed. Following Bils and Cho (1994), the individual period disutility of labor takes the form $g(h_{it},e_{it}) = (\lambda_h/(1+\sigma_h)) h_{it}^{1+\sigma_h} + h_{it}(\lambda_e/(1+\sigma_e)) e_{it}^{1+\sigma_e}$ where λ_h, λ_e, σ_h and σ_e are positive constants. The last term reflects disutility from exerting effort with the marginal disutility of effort per hour rising with the number of hours. An infinite value for σ_e generates the standard case with inelastic effort.

3.2. Firms and the labor market

Each differentiated good is produced by a monopolistically competitive firm using labor as the only input. There is a continuum of large firms distributed on the unit interval. At date t, each firm i hires n_{it} workers to produce a quantity $y_{it} = A_t n_{it} L_{it}^{\alpha}$ where A_t is an aggregate technology index, L_{it} the effective labor input supplied by each worker and $0<\alpha<1$. Effective labor input is a function of hours h_{it} and effort per hour e_{it} with $L_{it}=h_{it}e_{it}$.

Being a monopolistic producer, the firm faces a downward sloping demand curve $y_{it}^d = (P_{it}/P_t)^{-\varepsilon} Y_t$ and chooses its price P_{it} to maximize its value function given the aggregate price level P_t and aggregate output Y_t. Firms are subject to Calvo-type price setting, and each period a fraction v of randomly selected firms cannot reset its price.

In a search and matching model of the labor market, firms post vacancies at a cost c_t, and unemployed workers search for jobs. The matching function takes the usual Cobb–Douglas form so that the flow m_t of successful matches within period t is given by $m_t = m_0 u_t^{\eta} v_t^{1-\eta}$ where m_0 is a positive constant, $\eta \in (0,1)$, u_t denotes the number of unemployed and $v_t = \int_0^1 v_{it}\, di$ the total number of vacancies posted by all firms. Accordingly, the probability of a vacancy being filled in the next period is $q(\theta_t) \equiv m(u_t,v_t)/v_t = m_0 \theta^{-\eta}$ where $\theta_t \equiv v_t/u_t$ is the labor market tightness. Matches are destroyed at a constant rate λ, and the law of motion for employment of firm i is given by $n_{it+1} = (1-\lambda)n_{it} + q(\theta_t)v_{it}$.

When a firm and a worker meet, they must decide on the allocation of hours and effort to satisfy demand. It is assumed that both parties negotiate the hours/effort decision by choosing the optimal allocation, i.e., by choosing hours and effort per hour to satisfy demand at the lowest utility cost for the worker. As shown in Appendix A4, this implies that effort per hour is a function of hours per worker $e_{it} = e_0 h_{it}^{\sigma_h/(1+\sigma_e)}$ where e_0 a positive constant. Thus, changes in hours can proxy for changes in effort, and the firm production function can be rewritten

$$y_{it} = y_0 A_t n_{it} h_{it}^{\varphi} \tag{4}$$

with $y_0 = e_0^{\alpha}$ and $\varphi = \alpha(1+\sigma_h/(1+\sigma_e))$. With $\varphi > 1$, the production function displays short run increasing returns to hours. In times of higher demand, firms respond by increasing hours and effort, which increases output per hour, i.e., measured labor productivity. This condition is critical to generate the procyclical response of measured productivity to aggregate demand shocks, and from now on, it is assumed that the model parameters ensure $\varphi > 1$.[12]

As is usual in the search literature, firms and workers bargain individually about the real wage and split the surplus into shares determined by an exogenous bargaining weight γ. As shown in Appendix A4, the wage must then satisfy

$$w_{it} = \gamma c_t \theta_t + (1-\gamma) b_t + (1-\gamma)\varkappa \frac{h_{it}^{1+\sigma_h}}{\lambda_t} \tag{5}$$

with

$$\lambda_t = \frac{1}{C_t} \quad \text{and} \quad \varkappa = \frac{\lambda_h \dfrac{1+\sigma_h+\sigma_e}{(1+\sigma_h)\sigma_e}}{1-\dfrac{\gamma}{\varphi}(1+\sigma_h)} > 0,$$

so that the wage increases with hours per worker at the rate $1+\sigma_h$.[13]

Given the aggregate price level, firm i will choose a sequence of price $\{P_{it}\}$ and vacancies $\{v_{it}\}$ to maximize the expected present discounted value of future profits

$$E_t \sum_j \beta^j \frac{u'(C_{t+j})}{u'(C_t)} \left[\frac{P_{i,t+j}}{P_{t+j}} y_{i,t+j}^d - n_{i,t+j} w_{i,t+j} - c_{t+j} v_{i,t+j} \right] \tag{6}$$

subject to the Calvo price setting rule, the demand constraint $y_{it}^d = (P_{i,t}/P_t)^{-\varepsilon} Y_t$, the hours-effort choice (4), the law of motion for employment $n_{it+1} = (1-\lambda)n_{it} + q(\theta_t)v_{it}$ and the bargained wage (5).

To keep the presentation of the model short, I discuss here only the less standard condition for vacancy posting.[14] The vacancy posting condition takes the form

$$\frac{c_t}{q(\theta_t)} = E_t \beta_{t+1} \left[\chi_{it+1} + \frac{c_{t+1}}{q(\theta_{t+1})}(1-\lambda) \right] \tag{7}$$

with χ_{it}, the shadow value of a marginal worker, given by

$$\chi_{it} = -\frac{\partial n_{it} w_{it}}{\partial n_{it}} = -w_{it} + (1-\gamma)\varkappa \frac{1+\sigma_h}{\varphi} \frac{h_{it}^{1+\sigma_h}}{\lambda_t} \tag{8}$$

[12] This condition holds with sufficiently high marginal product of hours and effort (high α) or high effort elasticity with respect to hours (high $\sigma_h/(1+\sigma_e)$).

[13] The model is well behaved only if $\varkappa > 0$. This imposes that $1-(\gamma/\varphi)(1+\sigma_h) > 0$, which will be verified by the calibrated parameters.

[14] The other first-order conditions are relatively standard and are presented in Appendix A4. In particular, despite hiring frictions, the (log-linearized) Calvo price setting condition yields a standard New-Keynesian Phillips curve.

Each firm posts vacancies until the expected cost of hiring a worker $c_t/q(\theta_t)$ equals the expected discounted future benefits $\{\chi_{it+j}\}_{j=1}^{\infty}$ from an extra worker. Once the firm has chosen its price, it is demand constrained, and the flow value of a marginal worker is not his contribution to revenue but his reduction of the firm's wage bill. The first term of χ_{it} is the wage payment going to an extra worker, while the second term represents the savings due to the decrease in hours and effort of all other workers achieved with an extra worker. Indeed, hiring an extra worker allows the firm to reduce hours per worker for all its workers, and through (5) to lower the wage of all its workers.[15] Using the wage equation, the marginal worker's value takes the form

$$\chi_{it} = -\gamma c_t \theta_t - (1-\gamma) b_t + (1-\gamma)\left(\frac{1+\sigma_h}{\varphi} - 1\right) \varkappa \frac{h_{it}^{1+\sigma_h}}{\lambda_t}. \tag{9}$$

Provided that $(1+\sigma_h)/\varphi - 1 > 0$, the worker's marginal value increases with hours per worker.[16] If demand for the firm's product increases, the firm initially meets this higher demand by increasing hours per worker because employment is a state variable. Longer hours per worker increase the worker's marginal value, and the firm posts more vacancies to increase employment.

3.3. Technological progress and the central bank

Consistent with the long-run identifying assumption made in Section 2, the technology index series is non-stationary with a unit root originating in technological innovations. Technology evolves according to $A_t = \overline{A}_t e^{a_t}$ with $\overline{A}_t = (1+g_a)\overline{A}_{t-1}$ the deterministic component with growth rate g_A and a_t the stochastic component with $a_t = a_{t-1} + \varepsilon_t^a$. $\varepsilon_t^a \sim N(0, \sigma^a)$ is a technology shock with a permanent impact on productivity. Consistent with a growing economy and zero inflation in "steady-state", money supply evolves according to $M_t = \overline{A}_t e^{m_t}$ with $\Delta m_t = \rho_m \Delta m_{t-1} + \varepsilon_t^m + \tau^{cb}\varepsilon_t^a$, $\rho_m \in [0,1]$ and $\varepsilon_t^m \sim N(0, \sigma^m)$. ε_t^m is interpreted as an aggregate demand shock. As in Gali (1999), when $\tau^{cb} \neq 0$, the monetary authority responds in a systematic fashion to technology shocks.

3.4. Closing the model

Averaging firms' employment, total employment evolves according to $n_{t+1} = (1-\lambda)n_t + \upsilon_t q(\theta_t)$. The labor force being normalized to one, the number of unemployed workers is $u_t = 1 - n_t$. In this non-stationary economy, unemployment benefits and vacancy posting costs grow in line with technology so $c_t = cA_t$ and $b_t = bA_t$. Finally, as in Krause and Lubik (2007), vacancy posting costs are distributed to the aggregate households so that $C_t = Y_t$ in equilibrium.

4. Confronting the model with the sign switch of ρ

Section 2 argued that two developments could be responsible for the large increase in the unemployment-productivity correlation in the mid-1980s: (i) a sharp drop in the volatility of aggregate demand shocks (i.e., non-technology shocks), and (ii) a decline in the response of productivity to non-technology shocks, which from procyclical became acyclical. After calibrating the model and evaluating its empirical performances, I simulate (i) and (ii) to test whether these developments can quantitatively account for the magnitude of the change in ρ.

4.1. Calibration

The quarterly discount factor β is set to 0.99 and the returns to labor α to 0.64, as typically used in the literature (e.g., Bils and Cho, 1994).[17] The markup of prices over marginal costs is assumed to average 10%, which amounts to setting ε equal to 11. Consistent with Bils and Klenow (2004), firms reset their price every 2 quarters. The growth rate of technology (and money supply) is set to a=0.5% a quarter so that the economy is growing by 2% on average each year. A money growth autocorrelation parameter ρ_m of 0.5 is in line with the first autocorrelations of M1 and M2 growth in the US. Turning to the labor market, the matching function elasticity is set to $\eta = 0.4$ as measured by Blanchard and Diamond (1989), and the bargaining weight satisfies $\gamma = \eta$ following the Hosios (1990) condition. Similarly to Blanchard and Gali (2010), the quarterly job separation rate λ is set to 0.1, consistent with US evidence that jobs last for two years and a half

[15] This mechanism is similar to Woodford's (2004) New-Keynesian model with endogenous capital: the marginal contribution of an additional worker is to reduce the wage bill through substitution of one input for another. Here, the intensive and the extensive labor margins are two different inputs. The former is flexible but costly, while the latter takes time and resources to adjust. The firm chooses the combination of labor margins that minimizes the cost of supplying the required amount of output.

[16] $1+\sigma_h > \varphi$ captures the fact that, absent hiring frictions, the firm would rather hire an extra-worker than use the intensive margin because the cost of longer hours increases faster than output. This property of the model captures the fact that although it is easier to increase the workload of an employee than to hire a new one, overtime hours are more expensive than regular ones because of convex disutility costs of hours. The model's parameters will verify $(1+\sigma_h)/\varphi - 1 > 0$.

[17] The model does not explicitly consider capital for tractability reasons but the production function $y_{it} = A_t n L_{it}^{\alpha}$ corresponds to a standard Cobb–Douglas production function $y_{it} = A_t (nL_{it})^{\alpha} K_{it}^{1-\alpha}$ with a constant capital-worker ratio.

(Shimer, 2005), and the job finding rate is set to 0.6, implying a steady-state unemployment rate of 10%.[18] I choose $\sigma_h = 2$ (i.e., an hours per worker elasticity of 0.5) and need to decide on σ_e to fix a value for φ. Bils and Cho (1994) show that if a worker works longer hours and at a more intense pace, the utilization of the capital he operates will also tend to increase. As a result, changes in hours per worker proxy not only for variations in effort but also for unobserved changes in capital utilization. In that case, Schor's (1987) estimate for the elasticity of effort with respect to hours $\sigma_h/(1+\sigma_e) = 0.5$ delivers a short-run increasing return to hours parameter of 1.5. σ_e is set accordingly in order to match this estimate.[19] There is little microevidence for c, the vacancy posting cost, and τ^{cb}, the degree of monetary policy accommodation to technology shocks, so these variables are estimated by fitting the simulated impulse response to the empirical one, as in Altig et al. (2004). I find that hiring costs equal 1% of GDP, a value frequently used in the literature (e.g. Blanchard and Gali, 2010), and $\tau^{cb} = -0.5$.[20]

4.2. Impulse response functions and second moments

Fig. 4 shows the simulated impulse response functions of productivity, unemployment, output and inflation to a technology and a monetary policy shock. Apart from a slight departure from the 95% confidence interval for the unemployment response, the model is remarkably successful at matching the empirical responses. Unlike the standard Mortensen–Pissarides framework (Shimer, 2005), the model is able to capture the relative volatilities of unemployment and productivity conditional on each shock.[21]

Following a positive technology shock, aggregate demand does not increase as much as productivity because prices are sticky and because the central bank does not accommodate the shock.[22] As a result, aggregate demand is sticky in the short run. Being more productive, firms initially meet their demand by decreasing hours and effort since employment is a state variable. Measured labor productivity undershoots its new long-run level because of short-run increasing returns to hours. With shorter hours and lower effort, the value of a marginal worker (i.e., the reduction in labor costs achieved with an extra worker) goes down, firms post fewer vacancies, and unemployment increases. As prices adjust to the new productivity level, both labor margins return to their long-run values.

Following a positive monetary policy shock, firms increase their labor input in order to satisfy demand. Again, since they must first rely on the intensive margin, measured labor productivity initially increases as hours and effort increase. With higher hours and effort, the value of a marginal worker goes up, firms post more vacancies and unemployment goes down. As prices adjust to the new money supply level, both labor margins return slowly to their long-run values.

Table 2 displays the standard-deviations and autocorrelations of unemployment, vacancy, hours per worker, output and productivity for US data and for the model. All second moments of the model economy are reasonably close to their empirical counterparts. The volatility of hours per worker compared to that of unemployment is about 50% too high in the model. This is due to the simplifying assumption that employment is a state variable in the model so that, in response to a shock, all labor adjustment initially takes place along the intensive margin.[23]

4.3. The sign switch of ρ

This section explores whether the calibrated model can account for the magnitude of the change in ρ.

4.3.1. Changes in the volatility of shocks

To study whether changes in the volatility of technology and non-technology shocks identified with the VAR are large enough to explain the sign flip of ρ, I simulate 60 years of data using technology and monetary innovations with standard deviations following step functions that mimic the changes in volatility that occurred around 1980. Fig. 3 depicts the step functions used in the simulation. After filtering the (non-stationary) productivity series, I calculate the pre-1984 and

[18] As in Mertz (1995), Andolfatto (1996), den Haan et al. (2000) and others, model unemployment includes those individuals registered as inactive that are actively searching.

[19] This calibration is consistent with Basu and Kimball (1997) evidence that φ ranges between 1.28 and 1.6.

[20] A negative value for τ^{cb} is surprising given that central banks should accommodate technology shocks. However, as Gali and Rabanal (2004) argue, potential output is difficult to observe for the policy maker, and some positive technology shocks may have been misinterpreted, leading the central bank to pursue a contractionary policy. Indeed, Orphanides (2002) claims that the Great Inflation of the 1970s "could be attributed to [...] an adverse shift in the natural rate of unemployment that could not have been expected to be correctly assessed for some time."

[21] Important parameters behind this quantitative result are c, σ_h and φ, which determine the trade-off between the intensive margin and the extensive margin. The intensive margin displays increasing returns with $\varphi > 1$ but its cost increases at the rate $1+\sigma_h$ so that the cost of producing a given quantity increases at the rate $(1+\sigma_h)/\varphi > 1$. For the extensive margin, on the other hand, both output and costs increase linearly, so that the rate is one. The larger the difference between the two rates, the stronger is the incentive for the firm to avoid increases in effort, the less volatile is measured productivity and the more volatile is (un)employment.

[22] Note that the assumption of sticky prices does not always guarantee a contractionary effect of productivity on employment. The employment response can be positive despite sticky prices if the model allows for an accommodative monetary policy (Dotsey, 1999), if firms can hold inventories, or if firms face an elastic demand (Chang et al., 2009).

[23] Vacancy posting is also slightly too volatile with too little persistence, a standard problem with search models of unemployment already pointed out by Fujita and Ramey (2007). This is due to the excessively rapid response of vacancies; and incorporating sunk costs for vacancy creation as in Fujita and Ramey (2007) would presumably correct this shortcoming.

Table 3
Summary statistics for US and model data before and after 1984.

	Data		Smaller AD shocks		Smaller AD shocks with structural change	
	Pre-1984	Post-1984	Pre-1984	Post-1984	Pre-1984	Post-1984
$\hat{\rho}_{U_{+1},Y/H}$	−0.47** (0.13)	0.28** (0.14)	−0.25 (0.13)	0.04 (0.15)	−0.46 (0.10)	0.24 (0.17)
$\hat{\rho}_{V,Y/H}$	0.34** (0.13)	−0.31** (0.15)	0.24 (0.12)	−0.01 (0.14)	0.57 (0.08)	−0.23 (0.15)
$\hat{\rho}_{HpW,Y/H}$	0.50** (0.11)	−0.25** (0.12)	0.35 (0.11)	0.05 (0.13)	0.55 (0.09)	−0.25 (0.14)
$\frac{sd(N_{>84})/sd(N_{<84})}{sd(Y_{>84})/sd(Y_{<84})}$	1.40		1.03		1.27	
$\frac{sd(HpW_{>84})/sd(HpW_{<84})}{sd(N_{>84})/sd(N_{<84})}$	1.21		1.02		1.20	

Note: The first three rows report the correlations between output per hour and respectively unemployment, vacancies and hours per worker for US and model data. The last two rows display the ratio of the standard-deviations of employment relative to that of output before and after 1984, and the ratio of the standard-deviations of hours per worker relative to that of employment before and after 1984. The second column shows the results for the scenario with smaller aggregate demand chocks after 1984, and the third column shows the results for the scenario with smaller aggregate demand shocks and structural change after 1984. For US data, standard-errors are shown in parentheses, and significance is indicated by one asterisk (10-percent level) or two asterisks (5-percent level). For the model, standard errors—the standard deviation across 5000 model simulations—are reported in parentheses.

post-1984 correlations between simulated productivity and unemployment and repeat this exercise 5000 times to obtain the distribution of the simulated statistics. Table 3 presents the results and shows that the unemployment-productivity correlation increases by around 0.3, about 40% of the total increase in ρ. In addition, the model correlation overestimates ρ in the pre-1984 period but underestimates it in the post-1984 period.[24] Looking at the vacancy-productivity correlation and the hours per worker-productivity correlation gives a similar conclusion; the model can account for about 0.3 points of the increases in the correlations.

4.3.2. Structural changes

Section 2 argued that two structural changes took place in the mid-1980s: (a) the central bank became more accommodating to technology shocks after 1984, and (b) the cyclical response of measured labor productivity to non-technology shocks declined after 1984.

In the model, (a) corresponds to an increase in τ^{cb}, and (b) can be caused by a decline in hiring frictions or by an increase in the elasticity of hours per worker. First, if hiring costs decline, firms can more easily adjust their number of workers in response to fluctuations in demand. As a result, hours per worker and effort fluctuate less, and because effort is responsible for the procyclicality of productivity, productivity becomes less procyclical. Empirically, the rising share of temporary workers, the decline in the unionization rate since the late 1970s (Blau and Kahn, 2002) and the emergence of online recruitment sites in the 1990s could suggest a more flexible labor market with lower hiring costs in the post-1984 period. Second, if the elasticity of hours per worker increases, hours per worker become more volatile compared to effort. Since fluctuations in hours per worker generate countercyclical productivity movements whereas fluctuations in effort generate procyclical productivity movements, productivity becomes less procyclical. Empirically, the sectoral shift from manufacturing to services, in which hours are arguably more flexible, could suggest a higher hours per worker elasticity in the post-1984 period.[25]

In the model, lower hiring costs can be captured by a reduction in c, the vacancy posting cost, and a higher elasticity of hours per worker corresponds to an increase in $1/\sigma_h$.[26] The values of c, σ_h and τ^{cb} are estimated for each sub-sample period before and after 1984 by fitting the simulated impulse responses to the empirical ones as in Altig et al. (2004). I find that vacancy posting costs decreased from 1.7% of GDP in the pre-1984 period to 0.6% of GDP in the post-1984 period, and that the hours per worker elasticity increased from 0.3 ($\sigma_h = 3.2$) to 1.2 ($\sigma_h = 0.8$), i.e., that $\varphi = \alpha(1+\sigma_h/(1+\sigma_e))$, the short-run increasing return to hours parameter, decreased from 1.9 to 1.0. Finally, τ^{cb} increased from around -0.8 to 0.0.

[24] Since the model implies no response of unemployment on impact (employment is a state variable), I compute the simulated correlation $\hat{\rho} \equiv corr(\hat{U}_{t+1}, \hat{y}_t/\hat{h}_t)$ and compare $\hat{\rho}$ to $\tilde{\rho} \equiv corr(U_{t+1}, y_t/h_t)$ instead of $\rho \equiv corr(U_t, y_t/h_t)$. This does not change any of the conclusions since ρ and $\tilde{\rho}$ are very similar up to a vertical translation.

[25] The smooth and progressive decline in the procyclicality of productivity documented by Gali and Gambetti (2009, Fig. 6) started in the 1970s and coincides with the progressive decline in the employment share of manufacturing and the rise of services (see e.g., Filardo, 1997).

[26] See also Gali and van Rens (2010) for a study of the effect of lower hiring frictions. Regarding σ_h, longer hours in manufacturing are arguably more strenuous than in services, which could imply a higher disutility cost of longer hours in manufacturing. In this context, the shift from manufacturing to services could be interpreted as a decline in σ_h.

To study the impact of these structural changes on ρ, I proceed as previously and generate 60 years of data but allowing for different τ^{cb}, σ_h and c over the two sub-periods as well as a drop in the volatility of monetary policy shocks. Table 3 presents summary statistics for the simulated data. This time, the model can match the increase in the unemployment-productivity correlation of about 0.7 points, as well as the large shifts in the vacancy-productivity correlation and the hours per worker-productivity correlation. The structural changes introduced in the model have implications for the relative volatilities of employment, hours per worker and output, and it is reassuring that the model's implications are consistent with the data.[27] As Table 3 shows, the model is remarkably close to matching the 40% *increase* in the volatility of employment relative to that of output after 1984 as well as the 21% *decrease* in the volatility of employment relative to that of hours per worker.[28]

5. Conclusion

The low correlation of labor productivity and unemployment over the post-war period hides a large sign shift in the mid-1980s; from significantly negative, the correlation became significantly positive. To provide a structural interpretation for this new fact, I present a New-Keynesian model with three key elements: sticky prices, search and matching frictions, and variable labor effort. In this framework, a positive aggregate demand shock decreases unemployment and increases productivity temporarily, because firms increase labor effort to satisfy demand in the short-run as employment takes time to adjust. In contrast, a positive technology shock temporarily raises unemployment because with sticky prices, aggregate demand does not adjust immediately to the new productivity level, and firms use less labor. In this context, two events can quantitatively explain the large increase in the unemployment-productivity correlation: (i) an increase in the size of technology shocks relative to other shocks, and (ii) a decline in the procyclicality of measured productivity since the mid-1980s.

In the model, the weaker procyclicality of productivity after 1984 is the result of a more flexible labor market with lower hiring frictions and more elastic hours per worker. Interestingly, these structural changes are consistent with another new fact about the labor market: since 1984, the volatility of employment has increased relative to the volatility of output but has decreased relative to the volatility of hours per worker. Exploring what factors (such as the emergence of online recruitment, the higher share of temporary workers, the lower unionization rate and/or the sectoral shift from manufacturing to services) could have increased the flexibility of the labor market is thus an important task for future research.

While the present model relies on sticky prices to generate a contractionary effect of productivity on employment, other explanations with flexible prices have been proposed, and it would be interesting to study the sign shift in the unemployment-productivity correlation from other perspectives. López-Salido and Michelacci (2007) argue that the introduction of new technologies leads to the destruction of technologically obsolete jobs which prompts a contractionary period during which employment temporarily falls. Wang and Wen (2010) present a real business cycle model with firm entry and exit and micro-rigidity in factor-demand that can generate a contractionary effect of technology shocks on employment. Chang et al. (2009) show that the response of employment to technology shocks depends on the cost of holding inventories and on the elasticity of demand. Studying the role of inventories appears particularly important because the covariance between inventory investment and sales changed sign (Kahn et al., 2002) at the same time as the unemployment-productivity covariance.

Finally, the existence of large fluctuations in the correlations between productivity and labor input measures provides a strong constraint on business cycle theories, and exploring the relationship between productivity and the labor market in other OECD countries would be a useful goal for future research.[29]

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[27] In particular, the two structural changes have different implications. With lower hiring frictions, the volatility of employment rises relative to that of output, and the volatility of hours per worker (and effort) declines. In contrast, with a higher elasticity of hours per worker, the volatility of hours per worker increases, and the volatility of employment (and effort) declines.

[28] As far as I know, this change in the relative volatilities of labor market variables has not been emphasized before. Gali and Gambetti (2009) document that the volatility of total hours increased relative to output after 1984, but they do not look at unemployment and hours per worker.

[29] Preliminary findings indicate that for a number of countries, the unemployment-productivity relationship did also switch sign over the post WWII period. In particular, the UK experienced a sign switch in the late 1970s/early 1980s (from negative, the correlation became positive).

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jmoneco.2010.09.006.

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