Productivity, Aggregate Demand and Unemployment Fluctuations*

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Abstract

This paper presents new empirical evidence on the cyclical behavior of US unemployment that poses a challenge to standard search and matching models. The correlation between cyclical unemployment and the cyclical component of labor productivity switched sign in the mid 80s: from negative it became positive, while standard search models imply a negative correlation. I argue that the inconsistency arises because search models do not allow output to be demand determined in the short run, and I present a search model with nominal rigidities that can rationalize the empirical findings. In addition, I show that the interaction of hiring frictions and nominal frictions can generate a new propagation mechanism absent in standard New-Keynesian models.

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1 Introduction

What drives unemployment fluctuations at business cycle frequencies? Since the seminal work of Mortensen-Pissarides (1994), a vast literature, including the influential work from Shimer (2005a), has focused on labor productivity to explain movements in unemployment.[1] In a Mortensen-Pissarides (MP) search and matching model, an increase in productivity raises the surplus of a match between a firm and a worker, leads firms to post more job vacancies and pulls down the unemployment rate. Shifts in labor demand are caused by changes in productivity, and productivity is seen as the central driving force of unemployment fluctuations.

Given the major role played by productivity, there is surprisingly little empirical evidence on the impact of productivity changes on unemployment. In fact, this paper uncovers new empirical findings that are inconsistent with the standard MP prediction that an increase in productivity leads to lower unemployment. I argue that the inconsistency arises because the MP model does not allow output to be demand determined in the short run, and I present a search model with nominal rigidities that can rationalize the empirical findings. In addition, I show that the interaction of hiring frictions and nominal frictions can generate a new propagation mechanism absent in standard New-Keynesian models.

The first contribution of this paper is empirical. It provides a thorough study of the relationship between unemployment fluctuations and labor productivity (measured as real output per hour) in the US and highlights new empirical facts that posit a challenge to the standard MP model. I find that ρ, the contemporaneous correlation between labor productivity and unemployment switched sign in the mid 80s; from negative it became positive. Furthermore, I find that a positive technology shock, identified as in Gali (1999) as the only disturbance with a permanent impact on labor productivity, increases unemployment temporarily, whereas a positive non-technology shock (temporarily) increases productivity and decreases unemployment.

The standard search model of unemployment is confronted with two problems. First, it predicts that an increase in productivity leads to lower unemployment and implies a negative value for ρ. Second, with only one mechanism through which productivity affects the labor market, it cannot generate two different impulse responses or explain large changes in ρ.

The second contribution of this paper is theoretical. I develop a tractable search and matching model with nominal rigidities in which hiring firms are demand constrained in a New-Keynesian fashion. I also make a distinction between the extensive (number of workers) and the intensive (hours and effort) labor margins. In this framework, unemployment fluctuations are

[1] See also, among others, Merz (1995), Andolfatto (1996), den Haan, Ramey and Watson (2000), Hall (2005) and Mortensen and Nagypal (2005).

the product of two disturbances: technology shocks and monetary policy (or aggregate demand) shocks. Positive technology shocks temporarily raise unemployment because with sticky prices, aggregate demand does not adjust immediately to the new productivity level, and firms use less labor. The correlation between unemployment and productivity, ρ, is positive. In contrast, positive aggregate demand disturbances decrease unemployment and increase productivity temporarily, because firms increase labor effort to satisfy demand in the short run. As a result, ρ is negative. In this model, movements in ρ reflect changes in the relative importance (or volatility) of technology and aggregate demand shocks.

The volatility of the non-technology shocks identified with long run restrictions displays a large drop in the early 80s. By interpreting non-technology shocks as aggregate demand shocks in the model, this can explain why ρ increased. Model simulations suggest that changes in shock volatilities can account for about 40 percent of the increase in ρ. Evidently some other force must be at work. New evidence suggests that a structural change took place in the early 80s and that productivity became less procyclical, i.e. the endogenous component of productivity due to variable capacity utilization of inputs decreased. With a less endogenous response of productivity, the negative impact that aggregate demand shocks have on ρ is diminished. This can also explain why ρ increased. I simulate the impact of the simultaneous structural change and drop in the volatility of aggregate demand shocks, and I find that these two events can quantitatively explain the sign switch of ρ in the mid 80s.

Moreover, the combination of two major macroeconomic frameworks, the New-Keynesian model and the MP model, has interesting properties that extend beyond the explanation of unemployment fluctuations. By explicitly considering the interaction between hiring frictions and nominal frictions and by allowing labor to adjust along the extensive and intensive margin, the model highlights a new propagation mechanism that originates in the trade-off existing between the two labor inputs: the extensive margin can be less expensive than the intensive one but it is also less flexible because of hiring frictions. Once the firm has posted its price, demand (and hence revenue) is given, and the contribution of an additional worker is not its marginal product. Instead, it is the reduction of the wage bill through substitution of an expensive input (the intensive margin) for a cheaper one (the extensive margin), and the firm chooses the combination of labor inputs that minimizes the cost of supplying the required amount of output. In this setup, I show that the volatility of unemployment and the persistence of inflation increase with the magnitude of the trade-off.

The seminal contributions of Galí (1999) and Basu, Fernald and Kimball (1999) spawned an important empirical literature on the negative effect of technology shocks on total hours worked, but the focus has mostly been on hours and not employment or unemployment. Galí (1999) offered a New-Keynesian explanation, and the present model invokes a similar mechanism to account for an increase in unemployment following a technology shock. A growing literature introduces search models of unemployment into New-Keynesian frameworks but to my knowledge, this paper is the first to propose a model emphasizing the interaction between hiring frictions and nominal frictions and capable of rationalizing large movements in ρ. Models in the spirit of Trigari (2004) or Walsh (2004) introduce a separation between firms facing price stickiness (the retail sector) and firms evolving in a MP labor market without nominal rigidities (the wholesale sector).[2] While the separation simplifies greatly the analysis, this paper shows that it is possible to model the interaction of both frictions without compromising tractability. In Krause and Lubik (2007), hiring firms are demand constrained, but without intensive margin, the model displays a different propagation mechanism and cannot generate endogenous productivity movements. Finally, Blanchard and Galí (2008) incorporate both hiring and nominal frictions in a very elegant framework but without modeling the intensive margin and with a focus on optimal monetary policy.

The remainder of the paper is organized as follows: Section 2 studies the relationship between labor productivity and unemployment; Sections 3 and 4 describe the model and its properties; Section 5 explores whether the model can quantitatively account for the empirical impulse responses to shocks and the change in the sign of ρ; Section 6 discusses an alternative interpretation of the sign switch for ρ; and Section 7 offers some concluding remarks.

2 Empirical Evidence

2.1 The ρ puzzle

Figure 1 shows the detrended series for US unemployment and labor productivity (i.e. output per hour) over 1948-2007.[3] Until 1985, the two series seem negatively correlated with unemployment lagging labor productivity. After 1985, however, the correlation becomes positive. This is especially true for 1992 when both unemployment and labor productivity increase sharply but it is apparent throughout the post-1985 period. The magnitude of this sign flip is large: looking at Table 1, ρ goes from -0.31 over 1948-1984 to 0.46 over 1985-2007, and both estimates are significant at the 5%-level.[4] To see more sharply this change in the correlation,

[2] See also, among others, Christoffel, Kuester and Linzert (2006), Gertler and Trigari (2006) and Ravenna and Walsh (2007).

[3] The data are taken from the U.S. Bureau of Labor Statistics (BLS). Labor productivity is measured as real average output per hour in the non-farm business sector and unemployment is the quarterly average of the monthly unemployment rate series constructed by the BLS from the Current Population Survey. All series are expressed as deviations from an HP-filter with smoothing parameter 1600. The conclusions are independent of the smoothing parameter.

[4] Gali and Gambetti (2007), in recent work conducted independently, stress that the correlation of total hours with labor productivity experienced a remarkable decline, shifting from values close to zero in the pre-84 period

Figure 2 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. But ρ_{10} also displays large fluctuations throughout the whole period, and before 1984, ρ_{10} deviates sometimes by 50% from its 1948-1984 mean. The unemployment-productivity cross-correlogram before and after 1985 gives the same conclusion. As we can see on Figure 3, the two cross-correlograms look dramatically different. Notably, the correlation between unemployment and labor productivity lagged two quarters is positive after 1985 but corresponds to the peak negative correlation before 1985.

As a robustness check, I verify that the swift jump of ρ is not the result of a change in the definition of unemployment or the labor force: in Figure 4, I plot the 10-year rolling correlation between employment (in millions) and output per hour and the 10-year rolling correlation between vacancies and output per hour.[5] Both display a large jump similar to ρ. Table 1 confirms this result as the correlation between productivity and vacancies went from 0.34 over 1951-1984 to -0.19 over 1985-2005.

Finally, in Figure 5, I consider unemployment inflows and outflows, and I plot the 10-year rolling correlation between the job finding probability and output per hour and the 10-year rolling correlation between the employment exit probability and output per hour.[6] While the correlation with the job finding probability behaves similarly to ρ, the correlation with the employment exit probability remains roughly constant and negative, displaying only a small jump in the mid-80s. This suggests that an explanation of the behavior of ρ lies with inflows to unemployment and not outflows.

2.2 The impact of technology shocks on unemployment

There is little empirical evidence on the impact of productivity movements on cyclical unemployment. Galí (1999) and Basu, Fernald and Kimball (1999) spawned an important literature on the negative effect of technology shocks on total hours worked and its implication for business cycle models. However, the issue has little been studied in the context of models of unemployment.[7]

to large negative values after 1984.

[5] The employment series is the number of employed workers (in millions) in the non-farm business sector and is taken from the BLS. The vacancy series is the Conference Board help advertising index. Both series cover 1951:Q1-2005:Q4 and are detrended with an HP-filter with smoothing parameter 1600.

[6] Both series were constructed by Shimer (2007). They cover 1948-2006 and are detrended with an HP-filter with smoothing parameter 1600.

[7] Two important exceptions are Michelacci and Lopez-Salido (2007) and Braun, Bock and Di Cecio (2007). First, Michelacci and Lopez-Salido (2007), recently extended in Canova, Michelacci and Lopez-Salido (2007), study the impact of technology shocks on the labor market using US data covering 1972-1993 for the first paper and 1955-2000 for the second. They find impulse responses similar to the present paper but focus on the creative destruction aspect of technological progress. I will discuss this interpretation in Section 6. Second, Braun, Bock

Galí (1999), following the seminal work by Blanchard and Quah (1989), impose long-run restrictions in a structural VAR model to identify technological disturbances. Technology shocks are identified as the only shocks with a permanent impact on productivity. Using a similar framework, I study the response of unemployment (instead of hours) to a technology shock. Specifically, I am interested in estimating the system

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

where x_t is 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 of ε_t^a technology shocks and ε_t^m non-technology shocks. I use the estimation method of Shapiro and Watson (1988) and Francis and Ramey (2003) to allow for time-varying variance of the structural innovations. The details of the estimation are described in the Appendix.

I use quarterly data taken from the U.S. Bureau of Labor Statistics (BLS) covering the period 1948:Q1 to 2007:Q4. Labor productivity x_t is measured as real average output per hour in the non-farm business sector, and unemployment u_t is the quarterly average of the monthly unemployment rate series constructed by the BLS from the Current Population Survey. Following Fernald (2007), I allow for two breaks in Δx_t, 1973:Q1 and 1997:Q1, and I filter the unemployment series with a cubic trend. Fernald (2007) showed that the presence of a low-frequency correlation between labor productivity growth and unemployment, while unrelated to cyclical phenomena, could significantly distort the estimates of short run responses obtained with long run restrictions.[8]

The first row of Figure 6 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. Quantitatively, a 0.5% rise in productivity is associated with a 0.2 percentage point *increase* in unemployment. The second row of Figure 6 shows the dynamic effects of a non-technology shock. On impact, productivity jumps by 0.6% and reverts to its long run value in one year. Unemployment decreases, reaches a trough after one year, and reverts slowly

and Di Cecio (2007) do not remove the low-frequency movements in productivity. This may bias their estimates and may explain the large error-bands around their impulse response functions.

[8] At low frequencies, unemployment displays a low-high-low pattern. With high growth in the 60s followed by a slowdown in the 70s and an acceleration in the late 90s, productivity growth displays a similar U-shape trend. To get non-distorted impulse responses, I remove the low-frequency movement in productivity growth and unemployment. An alternative proposed by Fernald (2007) would be to separately analyze subsamples with no breaks in technology growth. In a robustness check, I restrict the sample period to 1973-1997 where there is no clear trend break. Results remain very similar.

to its long run value. Quantitatively, a 0.6% increase in productivity is correlated with a 0.2 percentage point *drop* in unemployment.

As a robustness check, I reproduce this exercise using the TFP series from Beaudry and Portier (2006) instead of output per hour in (1).[9] Figure 7 shows the impulse response functions to technology and non-technology shocks. Encouragingly, the impulse responses look very similar to the ones using output per hour, and technology shocks increase unemployment temporarily.

Finally, I estimate a higher dimensional (4 variable) VAR with the (logged) job finding probability and the (logged) employment exit probability as additional variables.[10] Figure 8 plots the impulse responses to a positive technology shock. The responses of unemployment and output per hour are similar to the ones obtained from a bivariate VAR. The job finding probability declines significantly on impact and after two quarters displays a similar behavior to that of unemployment. The employment exit probability increases on impact before reverting quickly to its long run value. However, the initial response is only marginally significant.

2.3 Confronting the MP model with the data

These results confront the standard search model with productivity shocks used in Mortensen-Pissarides (1994), Shimer (2005a) or Hall (2005) with two problems. First, it predicts a negative value for ρ, as an increase in productivity raises the surplus of a match, leads firms to post more vacancies and pulls down the unemployment rate. However, ρ is positive since the mid 80s, and I find that a positive technology shock increases unemployment in the short run. Second, the standard MP model cannot account for changes in the sign of ρ because it embeds only one mechanism through which productivity affects the labor market.

I now argue that the interaction of technology and non-technology shocks is key to understand the behavior of ρ.

[9] Chang and Hong (2006) question Gali's (1999) finding that technology shocks decrease total hours worked and attribute it to the use of output per hour as a measure of productivity. They argue that, because output per hour, unlike TFP, is influenced by permanent shifts in input mix (e.g. shocks affecting permanently the capital-labor ratio), Gali (1999) mislabels changes in input mix as technology shocks and does not properly identify the response of total hours worked to technology shocks.

[10] In another robustness check, I follow Fisher (2006) and estimate a more general specification allowing for two types of technology shocks: neutral technology shocks (N-shocks) and investment specific technology shocks (I-shocks). Both shocks can have a permanent effect on productivity but only I-shocks can affect the price of investment in the long-run. Using a trivariate VAR with the real price of equipment, output per hour and unemployment, I find that the Blanchard-Quah aggregation theorem holds because the responses of productivity and unemployment to I-shocks resemble the responses to non-technology shocks. The results are available upon request.

2.3.1 A change in the volatility of shocks

Since technology and non-technology shocks generate opposite comovements of unemployment and productivity, ρ will depend on their relative strength. If the average "size" of one type of shock increased relative to the other, the resulting correlation could theoretically switch between positive and negative values. For example, smaller non-technology shocks or larger technology shocks would increase ρ. Figure 9 shows 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 80s.[11] 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 80s. Was the sign switch of ρ caused by a large decrease in the volatility of all shocks except for technological shocks? In Figure 10, I plot simultaneously ρ_5, the 5-year rolling correlation between unemployment and labor productivity, and the ratio of the 5-year rolling standard deviation of technology shocks to the 5-year rolling standard deviation of non-technology shocks. The result is striking: the two series look very similar despite different construction methods. Moreover, ρ_5 lags the shock series by about a year, suggesting a causal role for volatility fluctuations and an explanation for the sign flip of ρ.

2.3.2 Structural changes

The discussion so far has ignored structural changes as a potential explanation for rapid movements in ρ. In fact, significant changes occurred in the early- to mid 80s: a change in the conduct of monetary policy, a change in inventory management and a change in the regulatory environment.[12] Moreover these changes could bias impulse response functions identified over the whole post-WWII period. Analyzing the response of total hours worked to technology shocks, Galí, López-Salido and Vallés (2003) and Fisher (2006) report very different impulse response functions after splitting their data over two sub-periods before and after the early 80s.

To allow for a structural change, I also split the sample in two sub-periods, 1948-1983 and 1984-2005, and Figure 11 shows the impulse responses obtained for each period. The responses differ in two points: (a) technology shocks have a smaller impact on unemployment after 1984, and (b) non-technology shocks have a smaller impact on labor productivity after 1984.

[11] Stock and Watson (2002, 2003) argue that smaller shocks may be responsible for half or more of the "great moderation", a decline in the cyclical volatility of output and inflation since 1984.

[12] See, for example, Stock and Watson (2002, 2003).

Monetary policy and the response of unemployment to technology shocks: Galí, López-Salido and Vallés (2003) argue that the Fed's conduct of monetary policy significantly changed after 1982 and became more accommodating to technology shocks. They show that, in the context of a New-Keynesian model where the firm is demand-constrained in the short-run, a more accommodating monetary policy can decrease or reverse the decline in labor demand caused by positive technology shocks. Figure 11 is consistent with this hypothesis with a smaller and less significant response of unemployment after 1984 that can be attributed to a change in monetary policy. 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.

A decline in the procyclicality of productivity: As we can see in Figure 11, productivity is less responsive after 1984. Following the same aggregate demand shock, productivity responds about half as much after 1984, with the response on impact going from 0.82 to 0.44 and becoming non significant at the 10% level after 1984.[13] The responses for unemployment, on the other hand, are comparable. A lower endogenous 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 sign flip.

This evidence indicates that the interaction of technology and non-technology shocks plays an important role in explaining unemployment fluctuations and productivity movements. I interpret non-technology shocks as aggregate demand shocks, and I now present a New-Keynesian model with search unemployment.

3 A New-Keynesian model with unemployment

In this section, I develop a general equilibrium model with monopolistic competition in the goods market, hiring frictions in the labor market and nominal price rigidities. There are three types of agents: households, firms and a monetary authority. In contrast to models such as Trigari (2004) and Walsh (2004), there is only one type of firm making both hiring and price setting decisions. In this framework, unemployment fluctuations and productivity movements are the product of two disturbances: technology shocks and monetary policy (i.e. aggregate demand) shocks.

[13] Gali and Gambetti (2007), in recent work conducted independently, come to similar conclusions.

3.1 Households

I consider an economy populated by a continuum of households of measure one and a continuum of firms of measure one. With equilibrium unemployment, ex-ante homogenous workers become heterogeneous in the absence of perfect income insurance because each individual's wealth differs based on his employment history. To avoid distributional issues, I follow Merz (1995) and Andolfatto (1996) in assuming that households form an extended family that pools its income and chooses per capita consumption and assets holding to maximize its expected lifetime utility. There are $1 - n_t$ unemployed workers who receive unemployment benefits b in units of utility of consumption, 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}.[14] Denoting $g(h_{it}, e_{it})$ the individual disutility from working, the representative family seeks to maximize

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

subject to the budget constraint

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

with λ_m a positive constant, M_t nominal money holdings, Π_t total transfers to the family and C_t the composite consumption good index defined by $C_t = \left(\int_0^1 C_{it}^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$ where C_{it} is the quantity of good $i \in [0,1]$ consumed in period t and P_{it} is the price of variety i. $\varepsilon > 1$ is the elasticity of substitution among consumption goods. The aggregate price level is defined as $P_t = \left(\int_0^1 P_{it}^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}$. 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:

$$g(h_{it}, e_{it}) = \frac{\lambda_h}{1 + \sigma_h} h_{it}^{1+\sigma_h} + h_{it} \frac{\lambda_e}{1 + \sigma_e} e_{it}^{1+\sigma_e}$$

where $\lambda_h,\ \lambda_e,\ \sigma_h$ 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.

[14] I introduce variable effort per hour in order to generate procyclical productivity movements.

3.2 Firms and the labor market

Each differentiated good is produced by a monopolistically competitive firm using labor as the only input. At date t, each firm i hires n_{it} workers to produce a quantity

$$y_{it} = A_t n_{it} L_{it}^{\alpha} \tag{2}$$

where A_t is an aggregate technology index, L_{it} the effective labor input supplied by each worker and $0 < \alpha < 1$.[15] I define effective labor input as a function of hours h_{it} and effort per hour e_{it} such that $L_{it} = h_{it}e_{it}$. Total effective labor input can be adjusted through three channels: the extensive margin n_{it}, and the two intensive margins: hours h_{it} and effort per hour e_{it}. Being a monopolistic producer, the firm faces a downward sloping demand curve $y_{it}^d = (\frac{P_{it}}{P_t})^{-\varepsilon} Y_t$ and chooses its price P_{it} to maximize its value function given the aggregate price level P_t and aggregate output Y_t. When changing their price, firms face quadratic adjustment costs $\frac{\nu}{2}\left(\frac{P_{i,t}}{P_{i,t-1}} - \pi^*\right)^2 Y_t$ with ν a positive constant and π^* the steady-state level of inflation.[16]

In a search and matching model of the labor market, workers cannot be hired instantaneously and must be hired from the unemployment pool through a costly and time-consuming job creation process. Firms post vacancies at a unitary cost c (in units of utility of consumption), and unemployed workers search for jobs. Vacancies are matched to searching workers at a rate that depends on the number of searchers on each side of the market. I assume that 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 $\theta_t \equiv \frac{v_t}{u_t}$ is the labor market tightness. Similarly, the probability for an unemployed worker to find a job is $m(u_t, v_t)/u_t = m_0\theta_t^{1-\eta}$. Matches are destroyed at a rate λ. I take λ to be constant and exogenous following Hall (2005) and Shimer (2007), who argue that movements in the separation rate only play a marginal role in explaining unemployment fluctuations.

Because of hiring frictions, a match formed at t will only start producing at $t + 1$, i.e. n_{it} the employment of firm i at date t is a state variable. For a firm posting v_{it} vacancies at date

[15] The model does not explicitly consider capital for tractability reasons but (2) can be rationalized by assuming a constant capital-worker ratio and a standard Cobb-Douglas production function $y_{it} = A_t (nL_{it})^{\alpha} K_{it}^{1-\alpha}$.

[16] The more common assumption of Calvo-type price setting introduces ex-post heterogeneity amongst firms. This complicates slightly the analysis and for clarity purposes, I present the model with costly price adjustment. However, I show in the Appendix that the two assumptions imply the same log-linearized equations.

t, the law of motion for its employment is given by

$$n_{it+1} = (1-\lambda)n_{it} + q(\theta_t)v_{it}.$$

3.3 Hours/effort decision and procyclical productivity

When a firm and a worker meet, they must decide on the allocation of hours and effort to satisfy demand. I assume that both parties negotiate the hours/effort decision by choosing the optimal allocation. More precisely, they solve:

$$\min_{h_{it},e_{it}} \frac{\lambda_h}{1+\sigma_h} h_t^{1+\sigma_h} + h_t \frac{\lambda_e}{1+\sigma_e} e_t^{1+\sigma_e} \tag{3}$$

subject to satisfying demand $A_t n_{it} h_{it}^{\alpha} e_{it}^{\alpha} = y_{it}^d$ at date t. The firm and the worker choose hours and effort per hour to satisfy demand at the lowest utility cost for the worker.

The first-order conditions imply that effort per hour is a function of hours per worker:

$$e_{it} = e_0 h_{it}^{\frac{\sigma_h}{1+\sigma_e}} \tag{4}$$

where $e_0 = \left(\frac{1+\sigma_e}{\sigma_e}\frac{\lambda_h}{\lambda_e}\right)^{\frac{1}{1+\sigma_e}}$ is a positive constant. Thus, changes in hours can proxy for changes in effort, and from now on I will only keep track of hours. Using (4), I can write a reduced-form relationship between output and hours

$$y_{it} = y_0 A_t n_{it} h_{it}^{\varphi} \tag{5}$$

with $y_0 = e_0^{\alpha}$ and $\varphi = \alpha\left(1 + \frac{\sigma_h}{1+\sigma_e}\right)$. 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. It holds with sufficiently high marginal product of efficient hour (high α) or high effort elasticity with respect to hours (high $\frac{\sigma_h}{1+\sigma_e}$), and from now on, I assume that the model's parameters ensure $\varphi > 1$.

Finally, because employment is a state variable, once the firm has set its price, it can only meet demand by adjusting the intensive margin so that the hours level is given by

$$h_{it} = \left(\frac{y_{it}^d}{y_0 A_t n_{it}}\right)^{\frac{1}{\varphi}} \quad \text{with} \quad y_{it}^d = (\frac{P_{i,t}}{P_t})^{-\varepsilon} Y_t.$$

3.4 Wage bill setting

The discussion has so far left the wage unspecified. As is usual in the search literature, firms and workers bargain individually about the real wage and split the surplus in shares determined by an exogenous bargaining weight γ. Denoting $J_i(w_{it})$ the value of a matched worker to firm i at date t, and $W_i(w_{it})$ and $U(w_{it})$ the value for a worker of being respectively employed by firm i and unemployed, the equilibrium wage w_{it} satisfies $w_{it} = \underset{w_{it}}{\text{argmax}} \; (W_i(w_{it}) - U(w_{it}))^{\gamma} (J_i(w_{it}))^{1-\gamma}$ and is a solution of the first-order differential equation

$$w_{it} = \gamma \left(\frac{h_{it}}{\varphi} \frac{\partial w_{it}}{\partial h_{it}} + \frac{c_t}{\lambda_t} \theta_t \right) + (1-\gamma) \left(\frac{b_t}{\lambda_t} + \frac{g(h_t, e_t)}{\lambda_t} \right) \tag{6}$$

with $\lambda_t = \frac{1}{C_t}$.[17] While the wage equation (6) is a weighted average of both parties surpluses and is similar to other bargained wages derived in e.g. Trigari (2004), Walsh (2004) or Krause and Lubik (2007), the firm's surplus is *not* given by the marginal product of labor. Indeed, once the firm has chosen its price, it is demand constrained and a marginal worker will not increase the firm's revenue. Instead, the first term of (6) is given by $-\frac{\partial w_{it}}{\partial n_{it}} = \frac{h_{it}}{\varphi} \frac{\partial w_{it}}{\partial h_{it}}$, the change in the wage bill caused by substituting the intensive margin (hours and effort) with the extensive one (employment).

A solution to (6) is given by

$$w_{it} = \gamma \frac{c_t}{\lambda_t} \theta_t + (1-\gamma) \frac{b_t}{\lambda_t} + (1-\gamma) \varkappa \frac{h_{it}^{1+\sigma_h}}{\lambda_t} \tag{7}$$

with $\varkappa = \frac{\lambda_h \frac{1+\sigma_h+\sigma_e}{(1+\sigma_h)\sigma_e}}{1-\frac{\gamma}{\varphi}(1+\sigma_h)} > 0$, so that the wage increases with hours per worker at the rate $1+\sigma_h$.[18] With $\varphi < 1+\sigma_h$, the firm would rather hire an extra worker than use the intensive margin because the cost of longer hours increases faster than output, and this despite short-run increasing returns to hours. However, employment is a state variable and is costly to adjust because of hiring friction, so that the firm must also rely on the intensive margin to satisfy demand in the short run. This property of the model captures the fact that the intensive margin is more flexible than the extensive one, but that this flexibility comes at a higher cost. Although it is easier to increase the workload of an employee than to hire and train a new one, overtime hours are more expensive than regular ones because of convex disutility costs of hours and effort. From now on, I assume that the model's parameters ensure $\varphi < 1+\sigma_h$.

[17] The derivation is relatively standard and is available upon request.

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

3.5 The firm's problem

Firm i will choose a sequence of price $\{P_{it}\}$ and vacancies $\{v_{it}\}$ to maximize the expected present discounted value of future profits subject to the demand constraint, the hours/effort choice and the law of motion for employment. Formally, the firm maximizes its value

$$E_t \sum_j \beta^j \frac{u'(C_{t+j})}{u'(C_t)} \left[\frac{P_{i,t+j}}{P_{t+j}} y^d_{i,t+j} - n_{i,t+j} w_{i,t+j} - \frac{c}{\lambda_{t+j}} v_{i,t+j} - \frac{\nu}{2} \left(\frac{P_{i,t+j}}{P_{i,t+j-1}} - \pi^* \right)^2 Y_{t+j} \right]$$

subject to the demand constraint

$$y^d_{it} = y_0 A_t n_{it} h^{\varphi}_{it} = (\frac{P_{i,t}}{P_t})^{-\varepsilon} Y_t$$

the law of motion for employment

$$n_{it+1} = (1-\lambda) n_{it} + q(\theta_t) v_{it}$$

and the bargained wage

$$w_{it} = \gamma \frac{c_t}{\lambda_t} \theta_t + (1-\gamma) \frac{b_t}{\lambda_t} + (1-\gamma) \varkappa \frac{h^{1+\sigma_h}_{it}}{\lambda_t}.$$

3.6 Technological progress and the central bank

In order to be consistent with the long run identifying assumption made in Section 2, the technology index series should be non-stationary with a unit root originating in technological innovations. Hence, technology is comprised of a deterministic and a stochastic component: $A_t = e^{a.t+a_t}$ with $a_t = a_{t-1} + \varepsilon^a_t$ and $\varepsilon^a_t \sim N(0, \sigma^a)$ is a technology shock with a permanent impact on productivity.

Consistent with a growing economy and zero inflation in "steady-state", the money supply evolves according to $M_t = e^{a.t+m_t}$ with $\Delta m_t = \rho_m \Delta m_{t-1} + \varepsilon^m_t + \tau^{cb} \varepsilon^a_t$, $\rho_m \in [0,1]$ and $\varepsilon^m_t \sim N(0, \sigma^m)$. I interpret ε^m_t 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.

The degree of monetary accommodation plays a key role as it determines the response of unemployment to technology shocks. Following a positive technology shock, if monetary policy is not too accommodating ($\tau^{cb} < 1$), the price level has to decrease in order to bring aggregate demand in line with the new productivity level. But with price stickiness this is not possible, and aggregate demand is sticky in the short run. Being more productive, each firm meets its demand by using less labor, and unemployment will increase.

3.7 Closing the model

Averaging firms' employment, total employment evolves according to $n_{t+1} = (1-\lambda)n_t + v_t q(\theta_t)$. The labor force being normalized to one, the number of unemployed workers is $u_t = 1 - n_{t.}$ 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 Dynamics of the model

I now present the first-order conditions for vacancies and prices and discuss some properties of the model. By explicitly considering the interaction between hiring frictions and nominal frictions, the model displays a new propagation mechanism that originates in the trade-off existing between the two labor margins: the extensive margin is less expensive than the intensive one in the long run but it is also less flexible because of hiring frictions. In this section, I show that the volatility of unemployment and the persistence of inflation increase with the magnitude of this trade-off.

4.1 The vacancy posting condition

The optimal vacancy posting condition takes the form

$$\frac{c_t}{q(\theta_t)} = E_t \beta_{t+1} \left[\chi_{it+1} + \frac{c_{t+1}}{q(\theta_{t+1})}(1-\lambda) \right] \tag{8}$$

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

$$\begin{aligned} \chi_{it} &= -\frac{\partial n_{it} w_{it}}{\partial n_{it}} = -w_{it}\left(h_{it}\right) + \frac{1}{\varphi} h_{it} \frac{\partial w_{it}}{\partial h_{it}} \\ &= -w_{it} + (1-\gamma)\varkappa \frac{1+\sigma_h}{\varphi} \frac{h_{it}^{1+\sigma_h}}{\lambda_t} \end{aligned}$$

Since $\frac{1}{q(\theta_t)}$ is the expected duration of a vacancy, equation (8) has the usual interpretation: each firm posts vacancies until the expected cost of hiring a worker $\frac{c_t}{q(\theta_t)}$ equals the expected discounted future benefits $\left\{\chi_{it+j}\right\}_{j=1}^{\infty}$ from an extra worker. Because the firm is demand constrained, 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 achieved with that extra worker. Indeed, looking at the wage equation (7), we can see that the firm can reduce hours per worker and lower the wage by increasing its number of workers.

With $\chi_{it} > 0$, the marginal worker reduces the cost of satisfying a given level of demand. Similarly 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 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.

Using the wage equation (7), I can rewrite the marginal worker's value as

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

The level of hours per worker drives the firm's incentives to post vacancies. With $\varphi < 1 + \sigma_h$, the longer hours are, the larger is the wage bill reduction obtained with an extra worker. As hours increase because of a higher demand for the firm's products, the worker's marginal value increases, and the firm post more vacancies to increase employment.[19]

Log-linearizing the vacancy posting condition equation around the (zero-inflation) steady state and using the fact that firms are homogenous so that $P_{it} = P_t$ and $y_{it} = Y_t$ in equilibrium , I get

$$\frac{c\eta}{q(\theta^*)} \hat{\theta}_t = E_t \beta \left[\chi^* \hat{\chi}_{t+1} + \frac{c(1-\lambda)\eta}{q(\theta^*)} \hat{\theta}_{t+1} \right]$$

where the value of a marginal worker $\hat{\chi}_t$ is given by

$$\begin{aligned} \chi^* \hat{\chi}_t &= -\gamma c \theta \hat{\theta}_t + \frac{\varphi}{n\mu} \left(\frac{1+\sigma_h}{\varphi} - 1 \right) \hat{h}_t \\ &= -\gamma c \theta \hat{\theta}_t + \frac{1}{n\mu} \left(\frac{1+\sigma_h}{\varphi} - 1 \right) (\hat{y}_t - \hat{n}_t) \end{aligned}$$

where $\hat{\theta}_t = \ln \left(\frac{\theta_t}{\theta^*} \right)$ and $\hat{h}_t = \ln \left(\frac{h_t}{h^*} \right)$.[20] Since $\hat{\chi}_t$ is driving the firm's incentives to post vacancies, $\frac{1+\sigma_h}{\varphi} - 1$ influences the volatility of unemployment relative to that of hours and effort. Indeed, $\frac{1+\sigma_h}{\varphi} - 1$ measures the difference between the two labor inputs (the intensive and the extensive margins) in terms of the cost of providing the required amount of output. While the intensive margin displays increasing returns with $\varphi > 1$, the wage bill increases at the rate $1 + \sigma_h$ so that the cost of producing a given quantity increases at the rate $\frac{1+\sigma_h}{\varphi}$. For the extensive margin, on the other hand, both output and costs increase linearly, so that the rate

[19] Note that this mechanism is different from the one at play in models with a retail sector and a wholesale sector as in Trigari (2004) and Walsh (2004). In those models, hiring firms are not demand constrained and the contribution of an additional worker is given by the marginal product of labor minus the wage bill.

[20] I rescale the non-stationary variables with the technology index A_t. See the Appendix for further details.

is one. The larger the difference between the two rates, the stronger is the incentive for the firm to react to changes in hours, and the more volatile is unemployment.

4.2 The price setting condition

For the price-setting condition, I get the standard result for models with quadratic price adjustment

$$(1-\varepsilon)\frac{y_{it}}{P_t} - \varepsilon\frac{y_{it}}{P_{it}}s_{it} - \nu\frac{y_t}{P_{it-1}}\left(\frac{P_{it}}{P_{it-1}} - \pi^*\right) = E_t\beta_{t+1}\nu y_{t+1}\left(\pi_{t+1} - \pi^*\right)\frac{P_{it+1}}{P_{it}^2}$$

with the real marginal cost s_{it} given by

$$\begin{aligned} s_{it} &= \frac{\partial w_{it} n_{it}}{\partial y_{it}} = \frac{1}{\varphi}\frac{n_{it}h_{it}}{y_{it}}\frac{\partial w_{it}}{\partial h_{it}} \\ &= \frac{1+\sigma_h}{\varphi}(1-\gamma)\varkappa\frac{Y_t}{A_t}h_{it}^{1+\sigma_h-\varphi} \end{aligned}$$

In order to produce an extra unit of output, the firm needs to increase hours since employment is a state variable. As a result, the wage response to changes in hours is driving the firm's real marginal cost.

Log-linearizing the price-setting condition and imposing symmetry in equilibrium yields the standard New-Keynesian Phillips curve

$$\pi_t = \delta\hat{s}_t + \beta E_t\pi_{t+1} \tag{10}$$

where $\delta = \frac{\varepsilon-1}{\nu}$ and the average firm's real marginal cost $\hat{s}_t$ is given by

$$\begin{aligned} \hat{s}_t &= \hat{y}_t + (1+\sigma_h)\hat{h}_t \\ &= \frac{1+\sigma_h}{\varphi}\hat{y}_t - \left(\frac{1+\sigma_h}{\varphi} - 1\right)\hat{n}_t \end{aligned} \tag{11}$$

where $\hat{n}_t = \ln\left(\frac{n_t}{n^*}\right)$ and $\hat{y}_t = \ln\left(\frac{Y_t/A_t}{y^*}\right)$.

With $\frac{1+\sigma_h}{\varphi} > 1$, the real marginal cost increases with demand but decreases with the employment level. As a result, firms can lower the impact of shocks on their real marginal cost and optimal price by adjusting their extensive margin. Inflation will be less responsive to shocks than in a standard New-Keynesian model without unemployment but will display more persistence. Following an increase in demand, the value of a marginal worker goes up and leads the firm to increase its level of employment. But this decreases future real marginal cost and leads the firm to post lower prices, which itself increases demand and output next period. This in turn leads to a future rise in employment, and, as the process goes on, the response to a demand shock will die out more slowly than in the standard New-Keynesian case.

As a result, the responsiveness and persistence of inflation and output depend on the trade-off between the two labor margins: $\frac{1+\sigma_h}{\varphi} - 1$. This happens for two reasons. First, looking at (11), the higher $\frac{1+\sigma_h}{\varphi} - 1$ is, the more the firm's real marginal cost will react to changes in demand, and the more aggressive the firm will be in setting prices. Second, we saw in the previous section that when $\frac{1+\sigma_h}{\varphi} - 1$ increases, employment is more responsive to shocks so that it has an even stronger dampening effect on real marginal costs.

5 Confronting the model with the data

In this section, I study whether a calibrated version can account for the impulse responses to technology and non-technology shocks, as well as quantitatively explain the sign flip of ρ.

5.1 Calibration

First, I discuss the calibration of the parameters of the model. Whenever possible, I use the parameter values typically used in the literature. I set the quarterly discount factor β to 0.99 and the returns to efficient labor α to 0.64.. I assume that the markup of prices over marginal costs is on average 10 percent, which amounts to setting ε equal to 11. To pick a value for the price adjustment cost parameter ν and the Phillips curve coefficient δ, I exploit the mapping between my model with costly price adjustment and the model with Calvo-type price setting described in the Appendix. Both models imply the same linearized New-Keynesian Phillips curve but in the latter, δ is determined by the frequency of price adjustment. When, as consistent with recent micro estimates (Bils and Klenow, 2004), firms reset their price every 2 quarters, δ takes the value 0.10, so I choose $\nu = 100$ to match δ. I set the growth rate of technology (and money supply) to $a = 0.5\%$ a quarter so that the economy is growing by 2% on average each year. I use a money growth autocorrelation parameter ρ_m of 0.5, in line with the first autocorrelations of M1 and M2 growth in the US. Turning to the labor market, I set the matching function elasticity to $\eta = 0.4$ as measured by Blanchard and Diamond (1989). The scale parameter of the matching functions m_0 is chosen such that, as reported in den Haan, Ramey and Watson (2000), a firm fills a vacancy with a quarterly probability $q(\theta) = 0.7$ and, as reported by Shimer (2005b) and used in Shimer (2005a), a worker finds a job with probability $\theta q(\theta) = 0.6$. Following Shimer (2005a), the separation rate is 10% so jobs last for about 2.5 years on average, and the income replacement ratio is set to 40%. I choose $\sigma_h = 2$ (i.e. an hours per worker elasticity of 0.5) and need decide on σ_e to fix a value for φ. Bils and Cho (1994) build a model to account for the procyclicality of labor productivity. In doing so, they allow for variable effort *and* variable capital utilization. The present model does not consider capital explicitly but implicitly if one assumes a constant capital-labor ratio. A key hypothesis of Bils and Cho (1994) is that the capital utilization rate is proportional to hours. 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 (1997) estimate for the elasticity of effort with respect to hours $\frac{\sigma_h}{1+\sigma_e} = 0.5$ delivers a value for φ of 1.5. I set σ_e accordingly in order to match this estimate.[21] The last variable to specify is τ^{cb}, the degree of monetary policy accommodation to technology shocks. As in Altig, Christiano, Eichenbaum and Linde (2005), I estimate it by fitting the simulated impulse response to the empirical one and obtain an estimated τ^{cb} of -0.4.[22]

5.2 Impulse response functions

The dotted lines in Figure 12 and 13 show the simulated impulse response functions of productivity, unemployment, output and inflation to a technology and a monetary policy shock.

Following a positive technology shock, real money balances (i.e. aggregate demand) do not increase as much as productivity because prices are sticky and because the central bank does not accommodate the shock. 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.

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

[22] A negative value for τ^{cb} is surprising given that central banks should accommodate technology shocks, not contract the money supply. However, as Galí and Rabanal (2005) argue, the Taylor rule originally proposed by Taylor (1993) was $i_t = \phi_\pi \pi_t + \phi_y y_t$ in which the central bank responds to the output gap (i.e. deviation from trend), not the real marginal cost, difficult to observe for the policy maker. Positive technology shocks may have been misinterpreted as a deviation from trend that should be avoided to keep inflation at bay, leading the central bank to pursue a contractionary policy. Indeed, Orphanides (2002) claims that the Great Inflation of the 1970's "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."

As prices adjust to the new money supply level, both labor margins return slowly to their long run values. Finally, as we saw in Section 4, the interaction of nominal frictions and hiring frictions can generate a strong propagation mechanism: output and inflation show persistent responses to a monetary shock despite a low degree of nominal rigidity.

Apart from a slight departure from the 95% confidence interval for the unemployment response, the model is remarkably successful at matching the empirical responses. Moreover, the model's output response to a technology shock is similar to the empirical response reported by Galí (1999).

5.3 The sign switch of ρ

In Section 2, I argue that two events could be responsible for the large increase in ρ in the mid-80s: (a) a decline in the relative importance (or volatility) of non-technology shocks versus technology shocks, and (b) a structural change in the transmission mechanism of shocks. In this subsection, I test whether they can quantitatively explain the magnitude of the change in ρ.

5.3.1 Changes in the volatility of shocks

In Section 2, I document a large drop in the volatility of non-technology shocks relative to technology shocks and present some evidence suggesting that changes in the relative size of technology and non-technology shocks drive fluctuations in ρ. To explore whether the volatility movements around 1980 are quantitatively large enough to explain the sign flip of ρ, I use my calibrated model to simulate the impact of a drop in the volatility of aggregate demand shocks on the correlation between productivity and unemployment. I generate unemployment and productivity series using technology and monetary innovations with standard deviations following step functions that mimic the volatility movements that occurred around 1980. Figure 9 depicts the step functions used in the simulation. The validity of this approach is subject to the correct identification and separation of technology and non-technology shocks. There is reassuring evidence (see Galí and Rabanal, 2004) that technology shocks are correctly identified by long run restrictions but, since I emphasize the role played by aggregate demand shocks, I also look at the Romer and Romer (2004) monetary shocks. Those shocks are identified with a different method, but we can see in Figure 14 that, notwithstanding the large volatility increase in the late 70s, their volatility in 1975 is twice as high as that in 1990, a volatility drop similar to the one used in the simulation.

I simulate 60 years of data for unemployment and productivity. After filtering the (non-stationary) productivity series, I can calculate $\hat{\rho}_{10}$, the simulated 10-year rolling correlation between simulated productivity and unemployment. I repeat this exercise 5000 times to obtain the empirical distribution of $\hat{\rho}_{10}$. As shown in Figure 15, $\hat{\rho}_{10}$ increases by around 0.3 and explains about 40% of the total increase in $\tilde{\rho}_{10}$. In addition, $\tilde{\rho}_{10}$ overestimates $\tilde{\rho}_{10}$ until 1980 and underestimates $\tilde{\rho}_{10}$ afterwards, lying marginally inside the 95% confidence interval.[23] If a drop in aggregate demand volatility seems to be part of the story, something else contributed to the sign switch in the mid 80s.

5.3.2 Structural changes

In Section 2, I argued that two structural changes could be responsible for the large movement in ρ in the mid-80s: (a) the central bank became more accommodating to technology shocks after 1984, and (b) the procyclicality of measured labor productivity declined after 1984. In my model, a decrease in the procyclicality of productivity appears as a decrease in φ, the short run returns to hours. Explicitly modeling a decrease in φ is beyond the scope of the model but it would still be interesting to test if the decrease in the procyclicality of productivity is enough to account for the sign flip of ρ. I estimate the value of φ and τ^{cb} for each sub-sample, and I find that φ decreased from 1.6 to 1.05 between 1948-1983 and 1984-2005, while τ^{cb} increased from -0.6 to 0.

To study the impact of more accommodating monetary policy *and* less procyclical productivity on ρ, I proceed as previously and simulate 60 years of data for unemployment and productivity but allowing for different φ and τ^{cb} over the two sub-periods as well as a drop in the volatility of monetary policy shocks. As shown in Figure 16, $\hat{\rho}_{10}$ increases this time from around -0.5 to 0.2, lies comfortably within the 95% confidence interval and does not over overestimate $\tilde{\rho}_{10}$ before the 80s.

A remaining question is why productivity became less procyclical after 1984. A possible answer lies with a change in the behavior of inventories. The covariance between inventory investment and sales switched sign in 1984 and turned from positive to negative. A negative covariance means that inventories are used to smooth production fluctuations. To satisfy demand in the short run, firms use their inventories and do not rely as much on the intensive labor margin. With short run increasing returns to hours, productivity is less procyclical. On the other hand, with a positive covariance, inventory investment increases with sales, and in the short run, firms use their intensive margin to satisfy demand and increase inventories. Productivity is more procyclical. Various explanations have been proposed to explain this change in the covariance. Kahn, McConnell and Perez-Quiros (2002) argue that the late 70s

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

and early 80s were times of dramatic innovations in manufacturing technology and inventory management. This has facilitated using inventories to smooth production. Looking at the automobile industry, Ramey and Vine (2004) propose a different explanation after showing that the serial correlation of sales decreased after 1984. With more transitory shocks, firms can more easily allow for deviations from their desired inventory-sales ratio since they know that deviations will be short-lived. Again, this facilitates the use of inventories to smooth production.

6 Embodied Technology and creative destruction

In this section, I discuss an alternative interpretation of the empirical relationship between labor productivity and unemployment studied in Section 2. In this alternative, we could ignore aggregate demand altogether and emphasize instead the Schumpeterian aspect of technological progress. Indeed Michelacci and Lopez-Salido (2007) and Canova, Michelacci and Lopez-Salido (2007) argue that a technology shock with a permanent impact on productivity may increase unemployment through creative destruction. The introduction of new technologies brings about a simultaneous increase in the destruction of technologically obsolete jobs which prompts a contractionary period during which employment temporarily falls. In that framework, the sign flip of ρ in the mid 80s could be due to an acceleration of creative destruction spawned by the Information Technology (IT) revolution. Put differently, technology was disembodied before 1984 but became more embodied with the IT revolution, and there is no need to appeal to aggregate demand to explain the sign switch. However, I see a number of arguments suggesting that creative destruction is not the most plausible explanation.

First, if technical progress had become more embodied, this should have appeared in the empirical impulse responses. But as we saw, technology shocks had a quantitatively *smaller* negative impact on unemployment after 1984; exactly the opposite of what more creative destruction would imply but consistent with an improvement in the conduct of monetary policy.

Second, in a world with creative destruction, when productivity increases, unemployment goes up temporarily because firms destroy old and less productive jobs. If technology had become more embodied after 1984, movements in the separation rate should contribute to a larger fraction of unemployment fluctuations. However, Shimer (2005b) finds that the proportion of unemployment fluctuations accounted for by variations in the separation rate actually decreased from 21% to only 5% after 1985.[24]

Moreover, with embodied technology, firms need to post vacancies to create new matches

[24] The job-finding rate accounting for the residual.

with the latest level of technology. Hence, an acceleration of creative destruction in the mid 80s could have caused the correlation between productivity and unemployment to become positive, but it could not have caused the correlation between productivity and vacancies to become negative. In contrast, an explanation emphasizing the role of aggregate demand shocks is consistent with large movements in both correlations: when productivity increases because of a technology shock, aggregate demand does not adjust immediately, firms post fewer vacancies, *and* unemployment goes up. Looking again at Figure 4, the 10-year rolling correlation of labor productivity and vacancies displays a sign switch similar to ρ and favors the latter explanation.

Finally, it is important to distinguish between embodiment in new jobs and embodiment in new capital. For example, technology may be embodied in capital but disembodied in jobs.[25] In order to explain the sign switch of ρ with creative destruction, technological progress needs to be embodied in new jobs. Studying the impact of productivity growth on unemployment, Pissarides and Vallanti (2005) find that technology embodied in jobs and creative destruction play no role in the dynamics of unemployment.

7 Conclusion

By studying the joint behavior of labor productivity and unemployment, I uncover a sign switch in their correlation that poses a puzzle to the MP model of unemployment. From negative, the correlation turned positive in the mid 80s. Further, using long run restrictions to identify technological innovations, I find that, contrary to what search models imply, a positive technology shock increases unemployment in the short run.

I present a model with hiring frictions, variable effort and costly price adjustment that can rationalize the empirical observations. In this framework, positive technology shocks temporarily raise unemployment because with costly price adjustment, aggregate demand does not increase as much as productivity, and firms use less labor. The correlation between unemployment and productivity, ρ, is positive. On the other hand, positive aggregate demand disturbances decrease unemployment and increase productivity temporarily because firms increase workers' effort to satisfy demand in the short run. As a result, ρ is negative. I document two new facts that can account for the large and swift increase in ρ in the mid 80s: (a) an increase in the size of technology shocks relative to other shocks, and (b) a decline in the procyclicality of measured productivity since the mid 80s. Using a calibrated version of the model, I simulate the impact of these two events and find that they quantitatively explain the sign switch of ρ. I suspect that the decrease in the procyclicality of labor productivity after

[25] An example given by Pissarides and Vallanti (2005) is the one of a secretary using Microsoft Windows. A new version of Windows may require a more powerful computer but the secretary keeps the job and only needs to learn how to use the new version: technology is embodied in new capital but not in new jobs.

1984 is linked to a change in inventory management after 1984 but a precise examination would require a theoretical integration of capacity utilization decisions (such as workers' effort) *and* inventory decisions, and I leave this task for future research.

Finally, by explicitly considering the interaction between hiring frictions and nominal frictions and by allowing labor to adjust along the extensive and intensive margin, the model highlights a new propagation mechanism that originates in the trade-off existing between the two labor inputs: the extensive margin is less expensive than the intensive one in the long run but it is also less flexible because of hiring frictions. In this setup, I show that the volatility of unemployment and the persistence of inflation increase with the magnitude of the trade-off.

Appendix:

Estimation of technology and non-technology shocks

I am interested in estimating the system

$$\begin{pmatrix} \Delta x_t \\ u_t \end{pmatrix} = C(L) \begin{pmatrix} \varepsilon_t^a \\ \varepsilon_t^d \end{pmatrix} = C(L)\varepsilon_t \tag{12}$$

where x_t is 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 of ε_t^a technology shocks and ε_t^d non-technology shocks. I use the estimation method of Shapiro and Watson (1988) and Francis and Ramey (2003) to allow for time-varying variance of the structural innovations.

Without loss of generality, (12) can be written

$$\begin{aligned} \Delta x_t &= \sum_{j=1}^{p} \beta_{xx,j} \Delta x_{t-j} + \sum_{j=0}^{p} \tilde{\beta}_{xu,j} u_{t-j} + \varepsilon_t^a \\ u_t &= \sum_{j=1}^{p} \beta_{uu,j} u_{t-j} + \sum_{j=1}^{p} \beta_{ux,j} \Delta x_{t-j} + \alpha \varepsilon_t^a + \varepsilon_t^m \end{aligned}$$

As discussed in Shapiro and Watson (1988), imposing the long run restriction that only technology shocks have a permanent effect on x_t is equivalent to restricting the variable u_t to enter the first equation in differences. Consequently, the system reduces to

$$\Delta x_t = \sum_{j=1}^{p} \beta_{xx,j} \Delta x_{t-j} + \sum_{j=0}^{p-1} \beta_{xu,j} \Delta u_{t-j} + \varepsilon_t^a \tag{13}$$

$$u_t = \sum_{j=1}^{p} \beta_{uu,j} u_{t-j} + \sum_{j=1}^{p} \beta_{ux,j} \Delta x_{t-j} + \alpha \varepsilon_t^a + \varepsilon_t^m \tag{14}$$

Since Δu_{t-j} is correlated with ε_t^a, equation (13) must be estimated with instrumental variables. I use lags 1 to $p = 4$ of Δx_t and u_t as instruments. The residual from this IV regression is the estimated technology shock $\hat{\varepsilon}_t^a$. The second equation can be identified by OLS but using $\hat{\varepsilon}_t^a$ in place of ε_t^a. Finally to allow for time-varying variance of the structural innovations (or more generally heteroskedasticity), I follow Francis and Ramey (2003) and estimate both equations jointly using GMM. That way, I can estimate the variance-covariance matrix of the estimates and generate the standard error bands for the impulse response functions. The error bands are derived by generating random vectors from a multivariate normal distribution with mean equal to the coefficient estimates and variance-covariance matrix equal to the estimated one, and then calculating the impulse response functions.

(Non-stationary) Equilibrium

In this non-stationary model economy, I rescale the non-stationary variables with the technology index A_t. Denoting rescaled variables with lower-case letters, the frictionless economy is described by the following system with 5 equations and 5 unknowns θ^*, y^*, h^*, e^* and n^*:

$$\begin{aligned}
y^* &= \left(\frac{Y_t}{A_t}\right)^* = y_0 n^* h^{*\varphi} \\
e^* &= e_0 \left(h^*\right)^{\frac{\sigma_h}{1+\sigma_e}} \\
\beta\chi^* &= \frac{c}{q(\theta^*)}\left(1-\beta(1-\lambda)\right) \\
\chi^* &= -\gamma c\theta^* - (1-\gamma)b + (1-\gamma)\left(\frac{1+\sigma_h}{\varphi}-1\right)\varkappa h^{*1+\sigma_h} \\
1 &= \mu\frac{1+\sigma_h}{\varphi}(1-\gamma)\varkappa y^* h^{*1+\sigma_h-\varphi} \\
n^* &= \frac{\theta^* q(\theta^*)}{\lambda+\theta^* q(\theta^*)}
\end{aligned}$$

where y_0, e_0 and $\varkappa$ are positive constants defined previously.

An equivalent model with Calvo price setting

In this section, I describe a model similar to the one presented on Section 3 but with the assumption of Calvo price setting instead of costly price adjustment. Specifically, firms can only reset their price (at no cost) at random dates, and each period a fraction ν of randomly selected firms cannot reset its price.

Since the job posting condition remains unchanged, I do not repeat it here. With Calvo-type price setting however, the optimal price setting rule is different, and a firm resetting its price at date t will satisfy the standard Calvo price setting condition:

$$E_t \sum_{j=0}^{\infty} \nu^j \beta_j \left[\frac{P_{it}^*}{P_{t+j}} - \mu s_{it+j}\right] Y_{t+j} P_{t+j}^{\varepsilon} = 0$$

where the optimal mark-up is $\mu = \frac{\varepsilon}{\varepsilon-1}$ and the firm's real marginal cost

$$s_{it} = \frac{1+\sigma_h}{\varphi}(1-\gamma)\varkappa\frac{Y_t}{A_t} h_{it}^{1+\sigma_h-\varphi}$$

The firm will choose a price P^*_{it} that is, in expected terms, a constant mark-up μ over its real marginal cost for the expected lifetime of the price.

To derive the New-Keynesian Phillips curve, I log-linearize around the zero inflation equilibrium. However, because of firms' ex-post heterogeneity, the derivation is not as straightforward as with costly price adjustment. I follow Woodford's (2004) similar treatment of endogenous capital in a New-Keynesian model with Calvo price rigidity. In my case, employment is the state variable and plays the role of capital in Woodford's model. I start by log-linearizing the first-order conditions around the zero-inflation equilibrium. For any $t > 0$, the vacancy posting condition becomes

$$\frac{c\eta}{q(\theta^*)}\hat{\theta}_t = E_t\beta\left[\chi^*\hat{\chi}_{it+1} + \frac{c(1-\lambda)\eta}{q(\theta^*)}\hat{\theta}_{t+1}\right] \tag{15}$$

with the value of a marginal worker $\hat{\chi}_{it+1}$ given by

$$\chi^*\hat{\chi}_{it+1} = -\gamma c\theta\hat{\theta}_t + \frac{1}{n\mu}(\frac{1+\sigma_h}{\varphi} - 1)\left(\hat{y}_{it+1} - \hat{n}_{it+1}\right)$$

and the price-setting condition becomes

$$\sum_{k=0}^{\infty}(\nu\beta)^k \hat{E}^i_t\left[\tilde{p}_{it+k} - \hat{s}_{it+k}\right] = 0 \tag{16}$$

with

$$\hat{s}_{it+k} = \hat{n}_{it+k} + \frac{1+\sigma_h}{\varphi}\left(\hat{y}_{it+k} - \hat{n}_{it+k}\right) - \hat{y}_{it+k} + \hat{y}_{t+k} \tag{17}$$

The notation $\hat{E}^i_t$ denotes an expectation conditional on the state of the world at date t but integrating only over future states in which firm i has not reset its price since period t. $\tilde{p}_{it} \equiv \log\left(\frac{P_{it}}{P_t}\right)$ is the firm's relative price.
Denoting log prices by lower-case letters and p^*_{it} the optimal (log) price for firm i at t, the demand curve for firm i at date $t+1$ can be written $\hat{y}_{it+1} = \hat{y}_{t+1} - \varepsilon(p_{it} - p_{t+1})$ if it cannot reset its price at $t+1$ and $\hat{y}_{it+1} = \hat{y}_{t+1} - \varepsilon(p^*_{it+1} - p_{t+1})$ if it can reset its price.
Averaging across all firms, I get

$$\begin{aligned}\int_0^1 \hat{y}_{it+1}di &= \hat{y}_{t+1} - \varepsilon\left[\nu(\int_0^1 p_{it}di - p_{t+1}) + (1-\nu)(\int_0^1 p^*_{it+1}di - p_{t+1})\right] \\ &= \hat{y}_{t+1} - \varepsilon\left[\nu(p_t - p_{t+1}) + (1-\nu)(p^*_{t+1} - p_{t+1})\right] \end{aligned} \tag{18}$$

where $p^*_{t+1} = \int_0^1 p^*_{it+1}di$ is the average price chosen by all price setters at date $t+1$.

With Calvo price-setting, I can write

$$p_{t+1} = \left((1-\nu)p_{t+1}^{*1-\varepsilon} + \nu p_t^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$$

or

$$1 = (1-\nu)\left(\frac{p_{t+1}^*}{p_{t+1}}\right)^{1-\varepsilon} + \nu\left(\frac{p_t}{p_{t+1}}\right)^{1-\varepsilon}.$$

Log-linearizing around the zero-inflation equilibrium gives $-\nu(p_{t+1}-p_t) = (1-\nu)(p_{t+1}^* - p_{t+1})$ and combining with (18) gives $\int_0^1 \hat{y}_{it+1}di = \hat{y}_{t+1}$. Further, $\int_0^1 \hat{n}_{it}di = \hat{n}_t$.

Averaging (17) across all firms, I can rewrite the real marginal cost as

$$\hat{s}_{it+k} = \hat{s}_{t+k} + \left(\frac{1+\sigma_h}{\varphi} - 1\right)(-\varepsilon\tilde{p}_{it+k} - \tilde{n}_{it+k}) \tag{19}$$

where $\tilde{n}_{it+k} = n_{it+k} - n_{t+k}$ is the relative employment of firm i.

Using that $\hat{E}_t^i \tilde{p}_{it+k} = p_{it} - E_t p_{t+k}$ and (19) in (17) yields

$$\left(1+\varepsilon\left(\frac{1+\sigma_h}{\varphi}-1\right)\right)p_{it}^* = (1-\nu\beta)\sum_{k=0}^{\infty}(\nu\beta)^k \hat{E}_t^i\left[\hat{s}_{t+k} + \left(1+\varepsilon\left(\frac{1+\sigma_h}{\varphi}-1\right)\right)p_{t+k} - \left(\frac{1+\sigma_h}{\varphi}-1\right)\tilde{n}_{it+k}\right] \tag{20}$$

Moreover, subtracting (15) from its average, I get

$$\begin{aligned}
\tilde{n}_{it+1} &= E_t(\hat{y}_{it+1} - \hat{y}_{t+1}) \qquad (21)\\
&= -\varepsilon E_t\left[\nu(p_{it} - p_{t+1}) + (1-\nu)(p_{it+1}^* - p_{t+1}\right] \\
&= -\varepsilon\nu\tilde{p}_{it} - \varepsilon(1-\nu)(p_{it+1}^* - p_{t+1}^*)
\end{aligned}$$

since $p_{t+1} = \nu p_t + (1-\nu)p_{t+1}^*$.

The firm's pricing decision depends on its employment level and the economy's aggregate state. But to a first order, the log-linearized equations are linear so that the difference between p_{it}^* and p_t^*, the average price chosen by all price setters, is independent from the economy's aggregate state and depends only on the relative level of employment $n_{it} - n_t = \tilde{n}_{it}$. So as in Woodford (2004), I guess that the firm's pricing decision takes the form

$$p_{it}^* - p_t^* = -\epsilon\tilde{n}_{it} \tag{22}$$

with ϵ a constant to be determined. Hence, (21) becomes

$$\tilde{n}_{it+1} = \frac{-\varepsilon\nu}{1-\varepsilon(1-\nu)\epsilon}\tilde{p}_{it} = -f(\epsilon)\tilde{p}_{it}$$

Since this was shown for any $t > 0$, I also get $\tilde{n}_{it+k} = -f(\epsilon)\tilde{p}_{it+k-1}$, $\forall k > 0$ so that I can rewrite (20) as

$$\phi p_{it}^{*} = (1-\nu\beta)\sum_{k=0}^{\infty}(\nu\beta)^{k}\hat{E}_{t}^{i}\left[\hat{s}_{t+k} + \left(1+\varepsilon\left(\frac{1+\sigma_h}{\varphi}-1\right)\right)p_{t+k}\right] - (1-\nu\beta)\left(\frac{1+\sigma_h}{\varphi}-1\right)\tilde{n}_{it} \tag{23}$$

with $\phi = \left(1+\varepsilon\left(\frac{1+\sigma_h}{\varphi}-1\right) - \nu\beta\left(\frac{1+\sigma_h}{\varphi}-1\right)f(\epsilon)\right)$.
Subtracting (23) from its average, I obtain

$$\phi(p_{it}^{*} - p_{t}^{*}) = -(1-\nu\beta)\left(\frac{1+\sigma_h}{\varphi}-1\right)\tilde{n}_{it}. \tag{24}$$

This equation is of the conjectured form (22) if and only if ϵ satisfies

$$\epsilon = \frac{(1-\nu\beta)\frac{1+\sigma_h}{\varphi}-1}{1+\varepsilon\left(\frac{1+\sigma_h}{\varphi}-1\right) - \nu\beta\left(\frac{1+\sigma_h}{\varphi}-1\right)f(\epsilon)}. \tag{25}$$

Finally, averaging (23) and using $\pi_t = \frac{1-\nu}{\nu}(p_t^{*} - p_t)$, I obtain the New-Keynesian Phillips curve

$$\pi_t = \delta.\hat{s}_t + \beta E_t \pi_{t+1}$$

with $\delta = \frac{(1-\nu)(1-\nu\beta)}{\nu\phi}$.

Hence, a model with a Calvo price setting mechanism is described by the same log-linearized first-order conditions as a model with costly price adjustment.

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Table 1. Correlation Estimates

	1948-1984	1985-2007
$\rho_{U,Y/H}$	-0.31**	0.46**
	(0.11)	(0.18)
$\rho_{V,Y/H}$	0.34**	-0.19
	(0.14)	(0.17)

Note: Table 1 reports estimates of the correlation between unemployment and labor productivity over 1948:Q1-1984:Q4 and 1985:Q1-2007:Q4, and between vacancies and labor productivity over 1951:Q1-1984:Q4 and 1985:Q1-2007:Q4. 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).

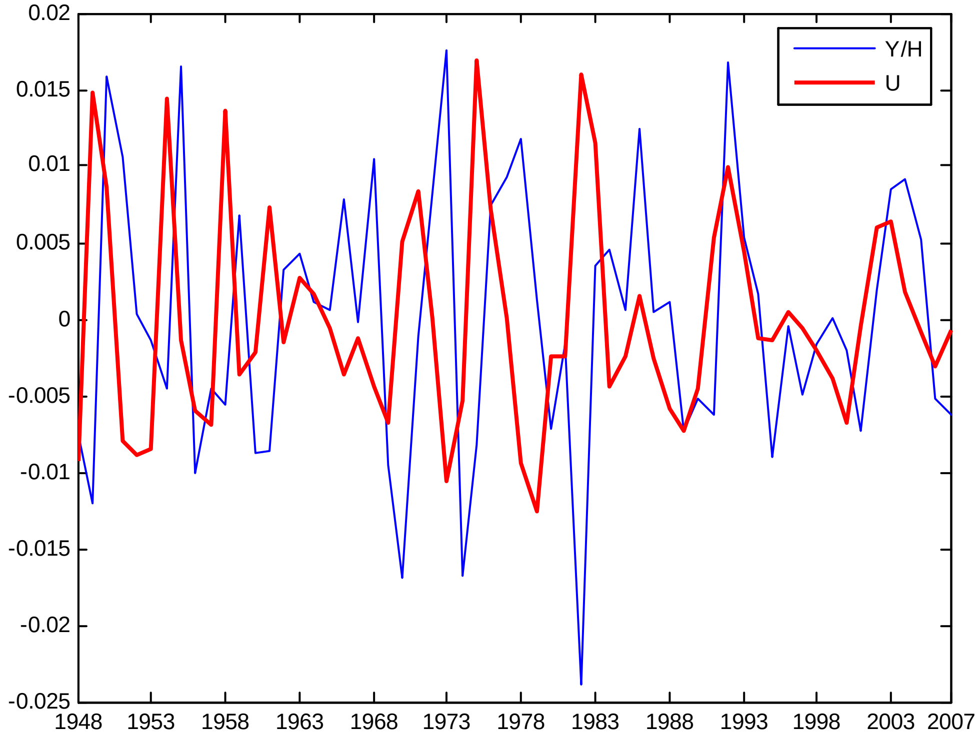

Figure 1: Unemployment and labor productivity (output per hour) over 1948-2007. The quarterly series are detrended with an HP-filter λ=1600 and annualized for clarity of exposition.

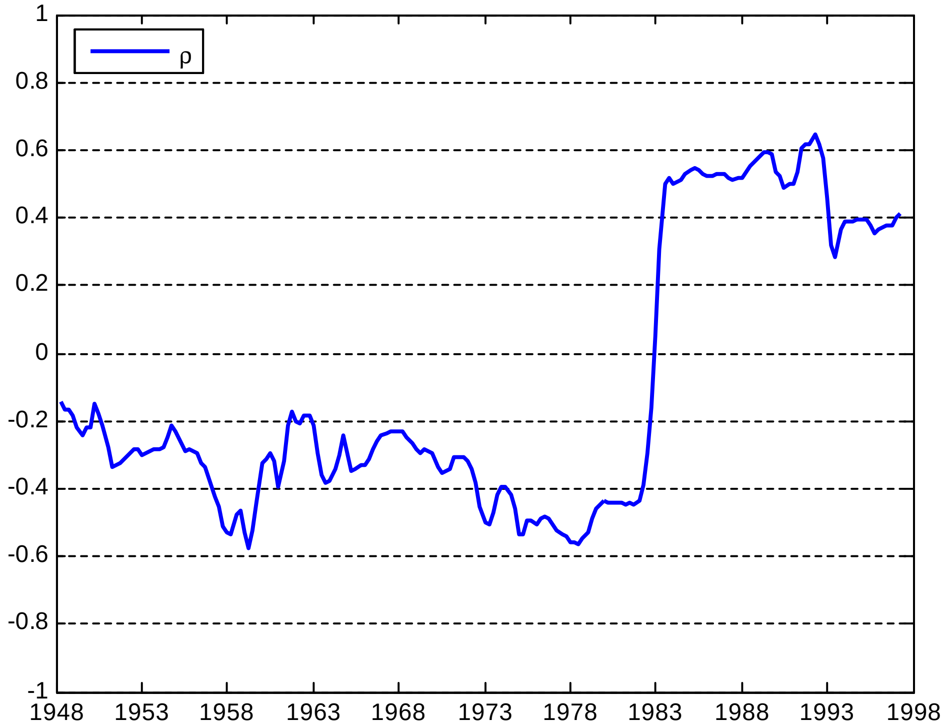

Figure 2: 10-year rolling correlation unemployment-productivity over 1948-2007. At each year T on the x-axis corresponds the correlation over (T,T+10).

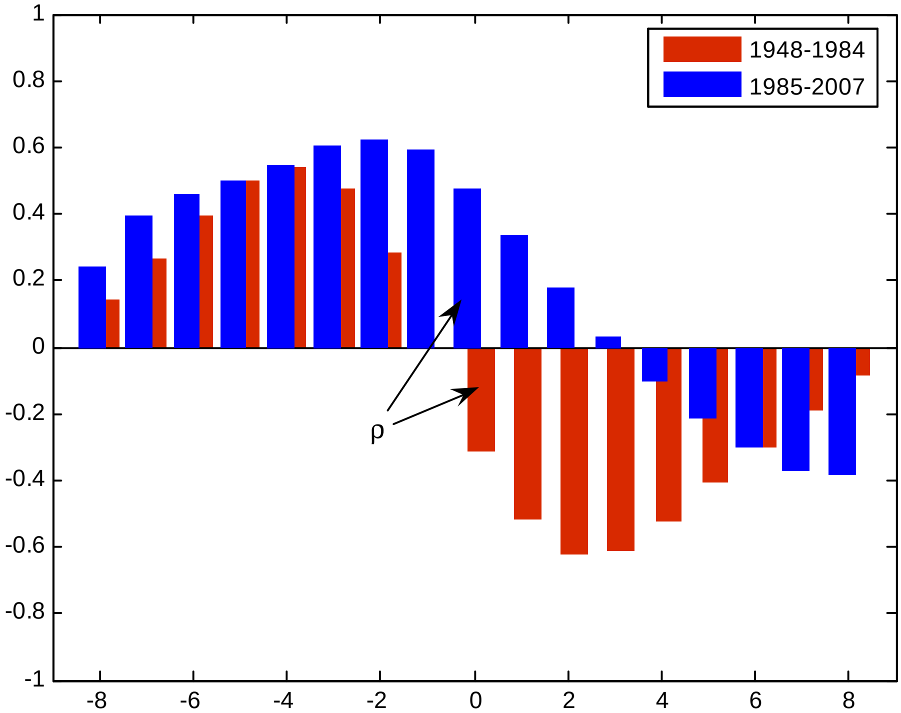

Figure 3: Empirical Cross-Correlogram of Output per Hour and Unemployment over 1948-1984 (background) and 1985-2007 (foreground).

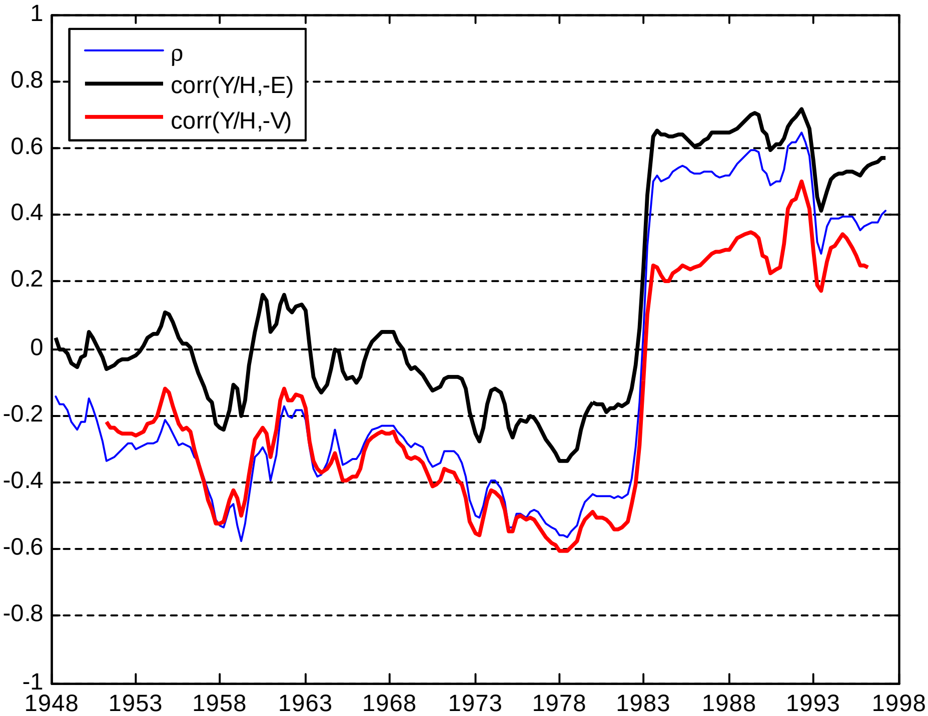

Figure 4: ρ and the10-year rolling correlations (output per hour, (logged) employment) and (output per hour, (logged) vacancies) over 1948-2007. All variables are detrended with an HP-filter ($\lambda = 1600$). At each year T on the x-axis corresponds the correlation over (T,T+10).

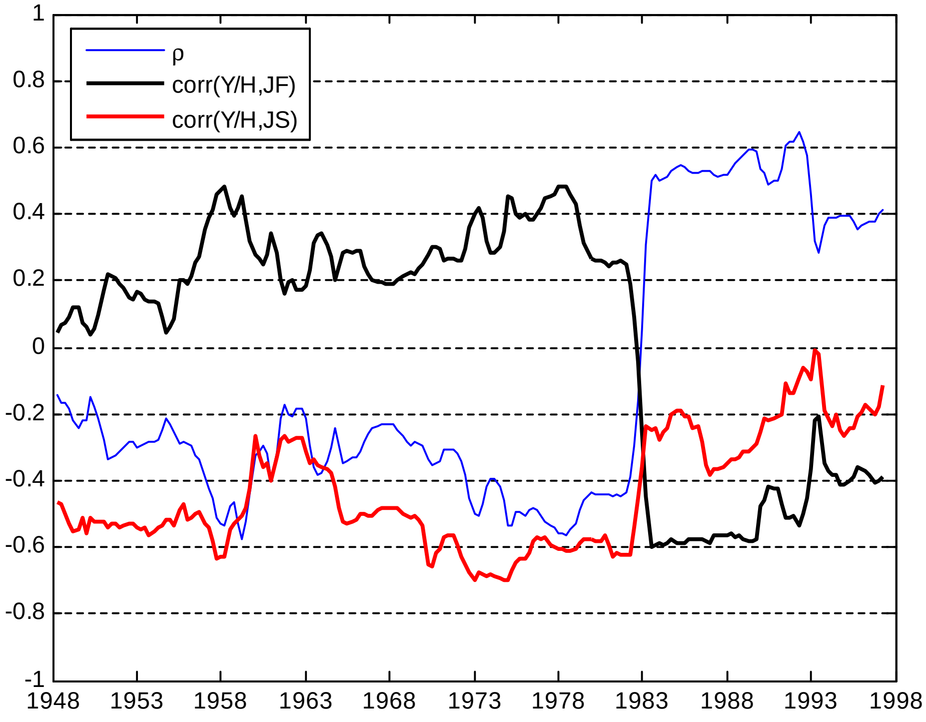

Figure 5: ρ and the10-year rolling correlations (output per hour, (logged) job finding probability) and (output per hour, (logged) employment exit probability) over 1948-2007. All variables are detrended with an HP-filter ($\lambda = 1600$). At each year T on the x-axis corresponds the correlation over (T,T+10).

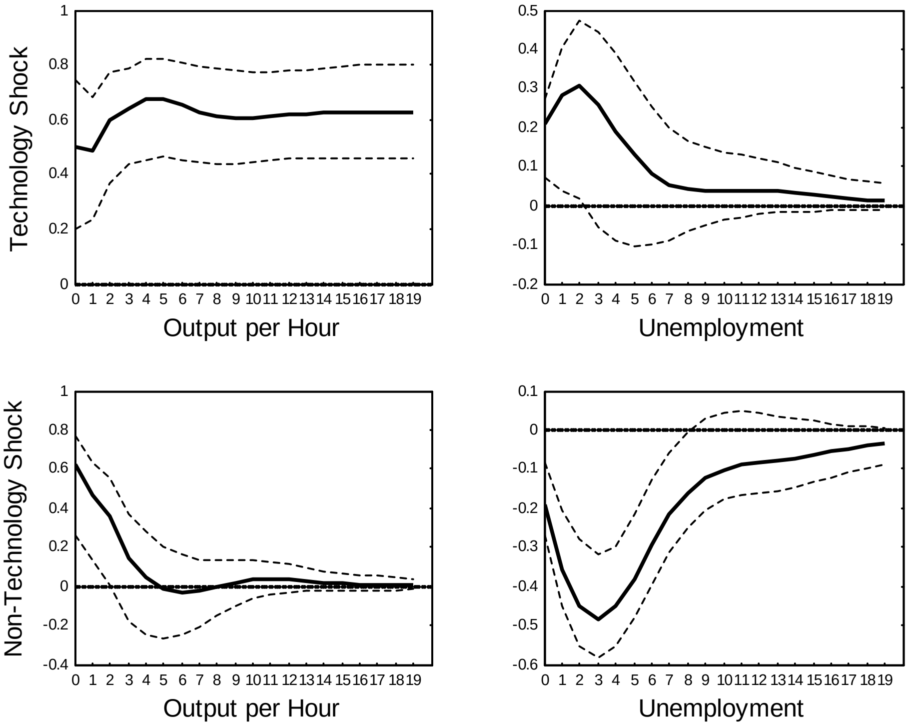

Figure 6: Impulse response functions to technology and non-technology shocks. Dashed lines represent the 95% confidence interval.

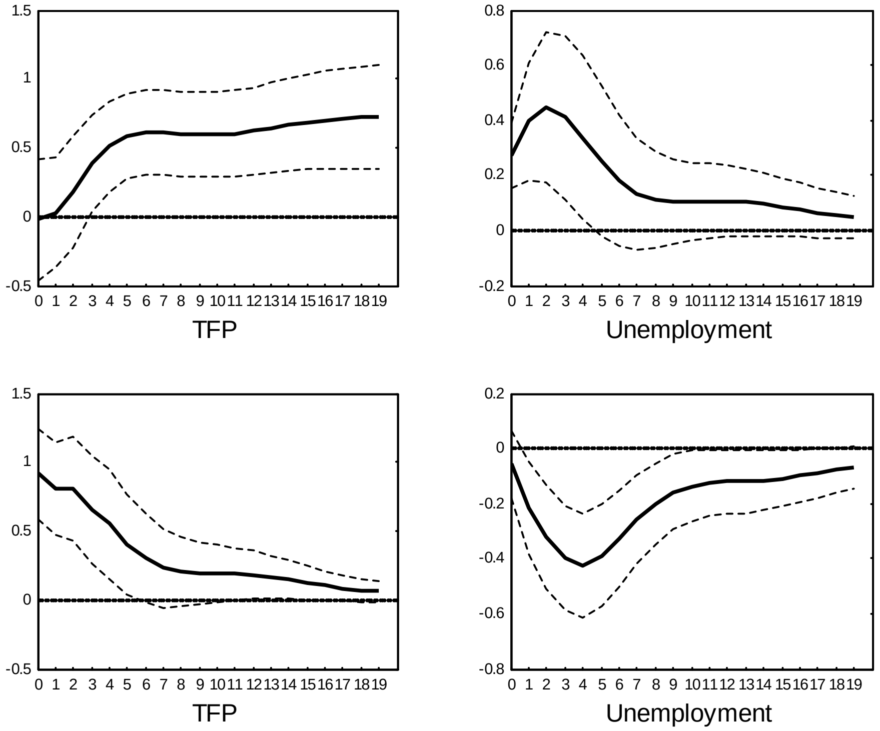

Figure 7: Impulse response functions to technology and non-technology shocks. Productivity is measured with TFP unadjusted for capacity utilization. Dashed lines represent the 95% confidence interval.

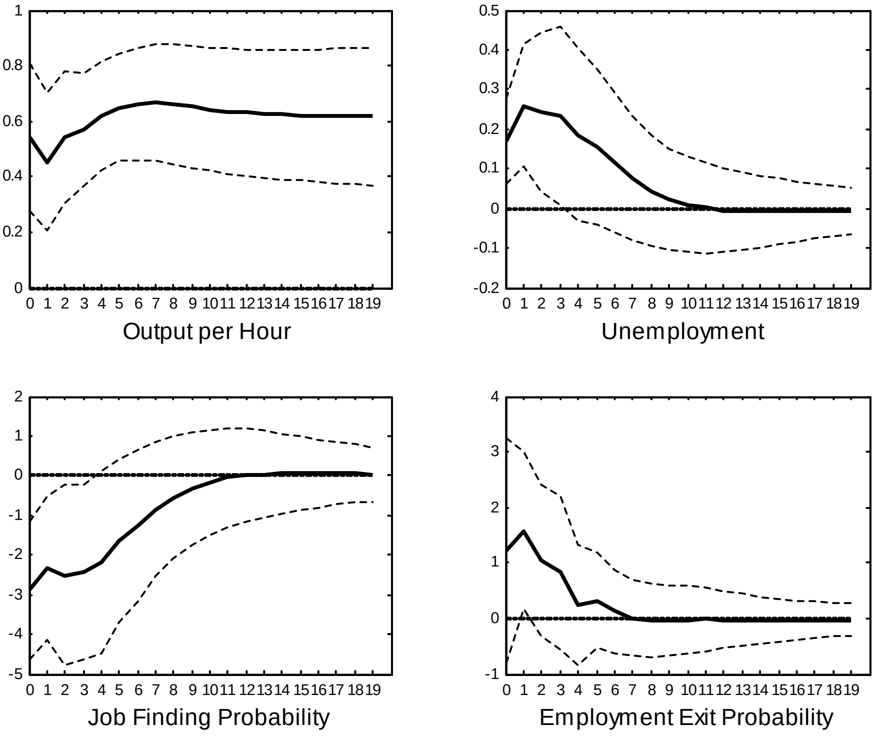

Figure 8: Impulse response functions to a technology shock in a 4 variables VAR over 1948-2006. Dashed lines represent the 95% confidence interval.

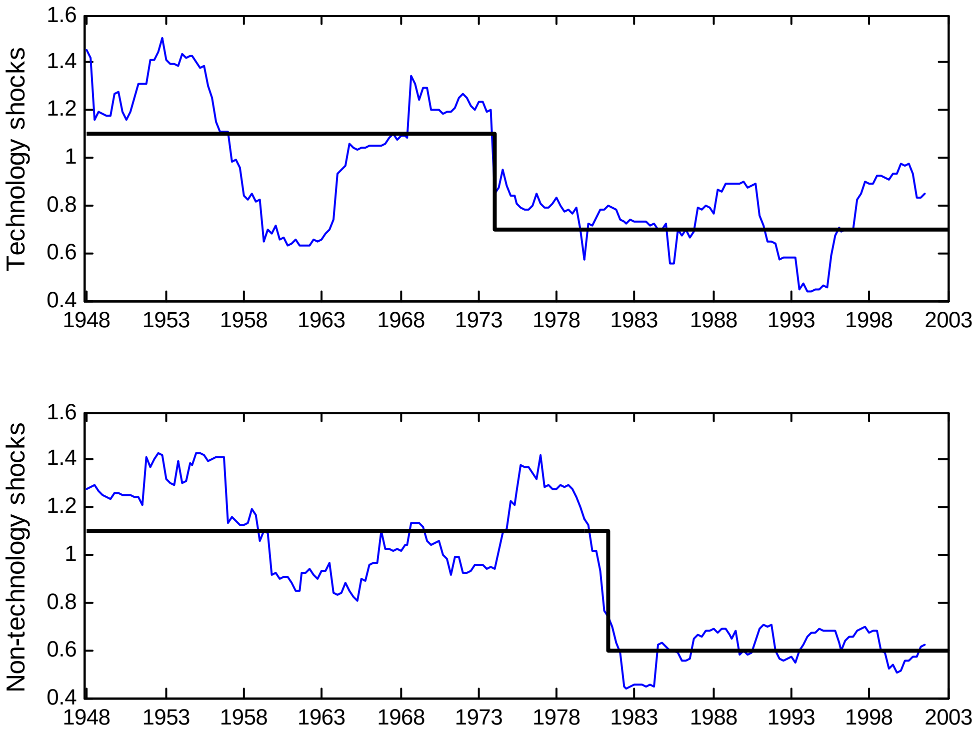

Figure 9: 5-year rolling standard-deviation of technology and non-technology shocks and step functions approximating the standard deviations. Both standard deviations are normalized to one for ease of comparison, 1948-2007.

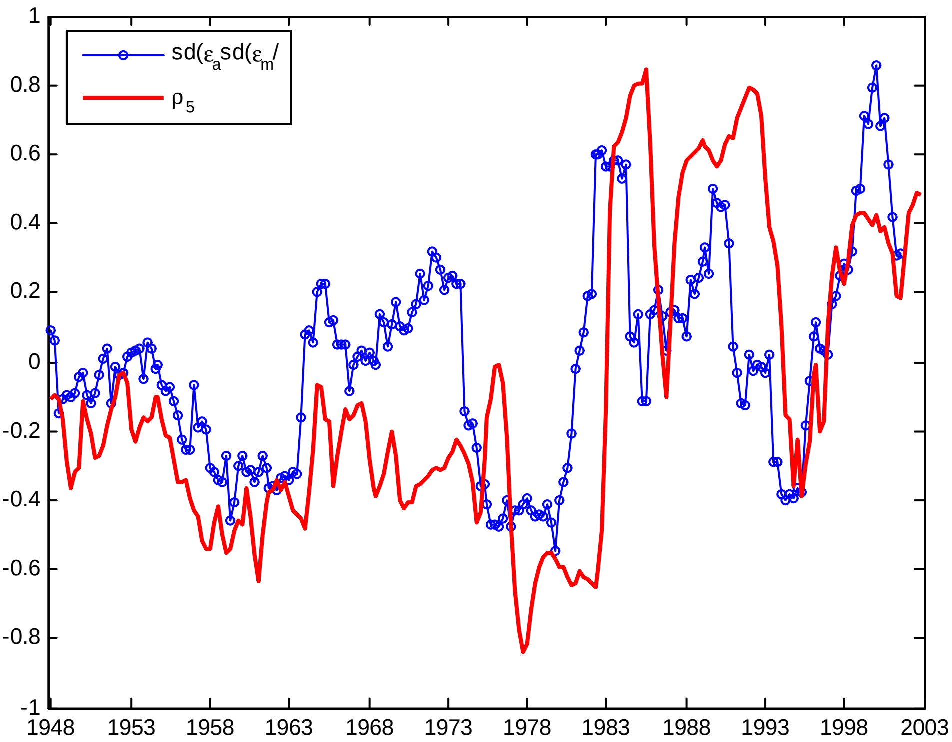

Figure 10: 5-year rolling correlation (unemployment,output per hour) and ratio of the 5-year rolling standard deviation of technology shocks to the 5-year rolling standard deviation of non-technology shocks. Deviations from the mean, 1948-2007. At each year T on the x-axis corresponds the correlation over (T,T+5).

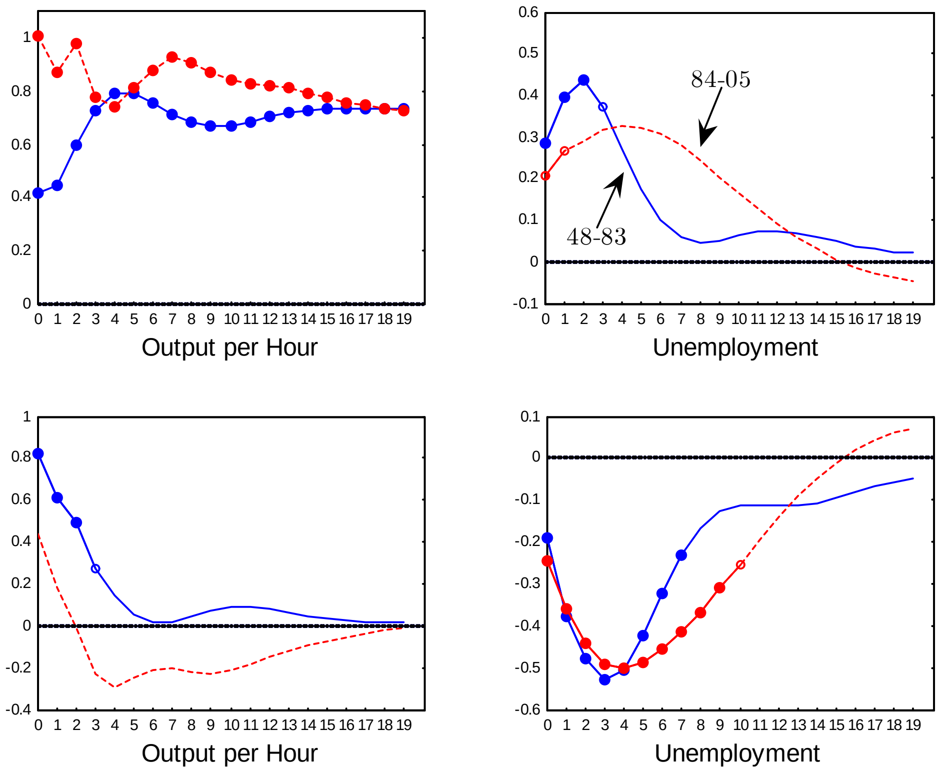

Figure 11: Impulse response functions to technology and non-technology shocks. Solid lines show estimates for 1948-1983 and dashed lines for 1984-2005. Solid circles indicate that the response is significant at the 5% level and open circles at the 10% level.

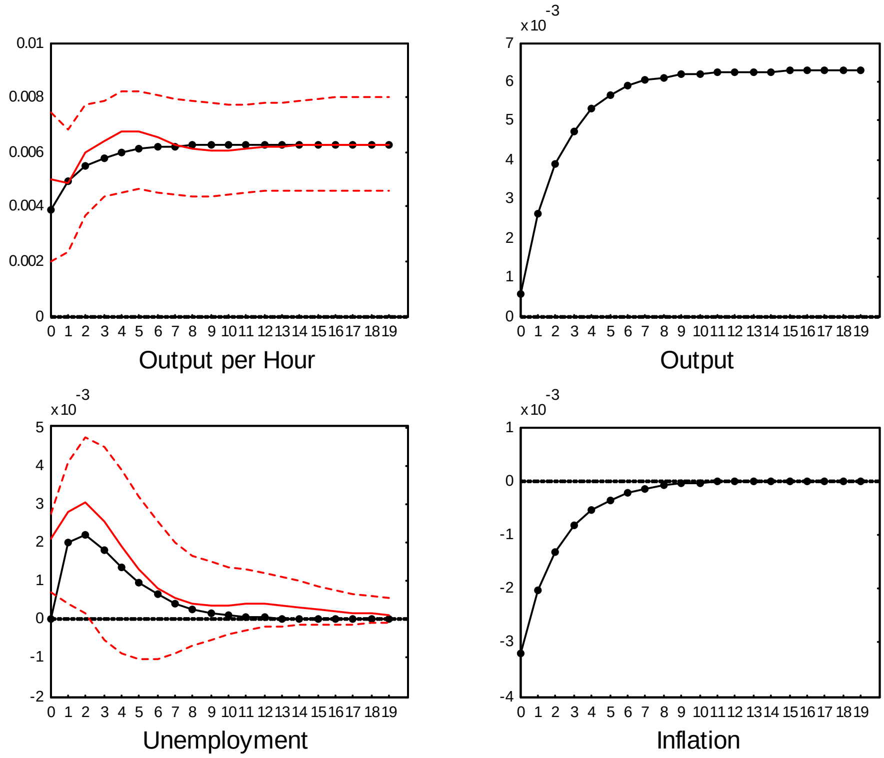

Figure 12: Model (dotted line) and Empirical (plain line) impulse response functions to a technology shock. Dashed lines represent the 95% confidence interval.

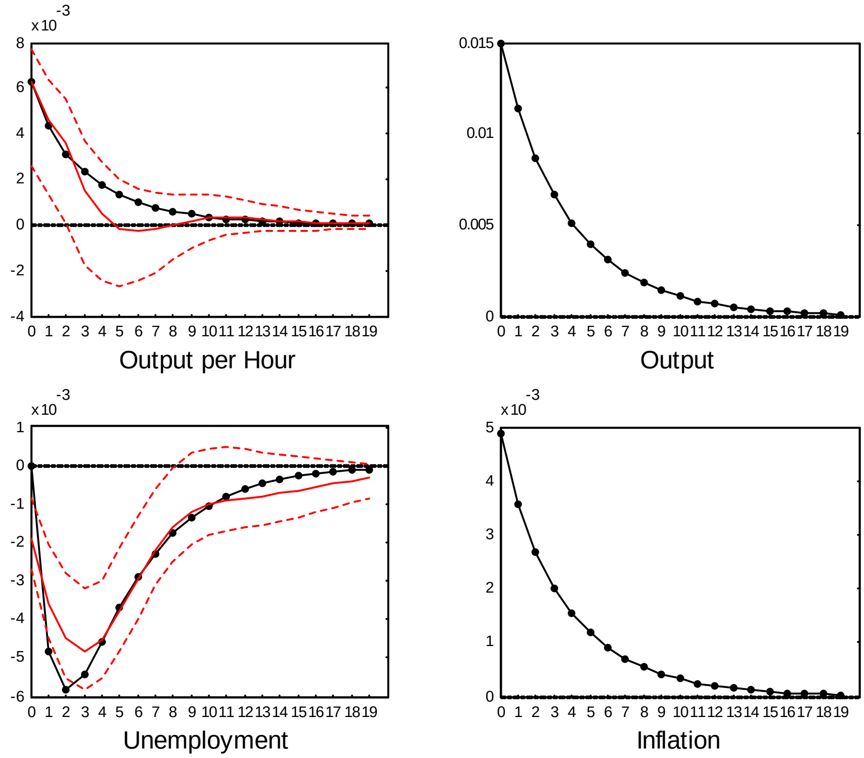

Figure 13: Model (dotted line) and Empirical (plain line) impulse response functions to a non-technology shock. Dashed lines represent the 95% confidence interval.

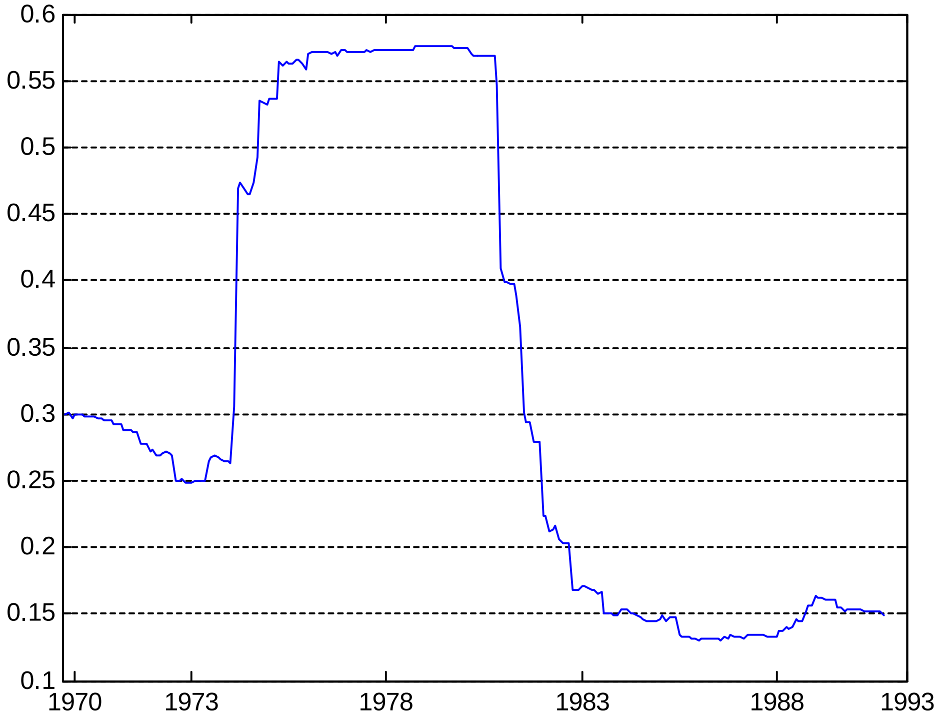

Figure 14: 5-year rolling standard-deviation of Romer and Romer monetary shocks. 1969:Q1-1996:Q4.

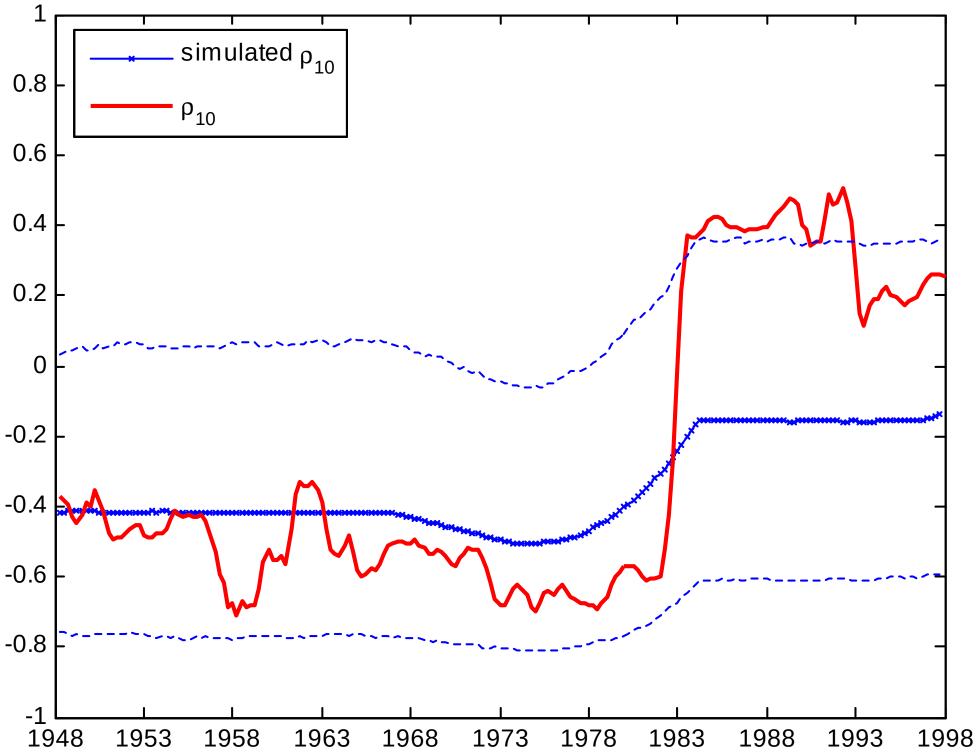

Figure 15: Simulation of ρ with volatility drop after 1984. (dashed lines represent the 95% confidence interval)

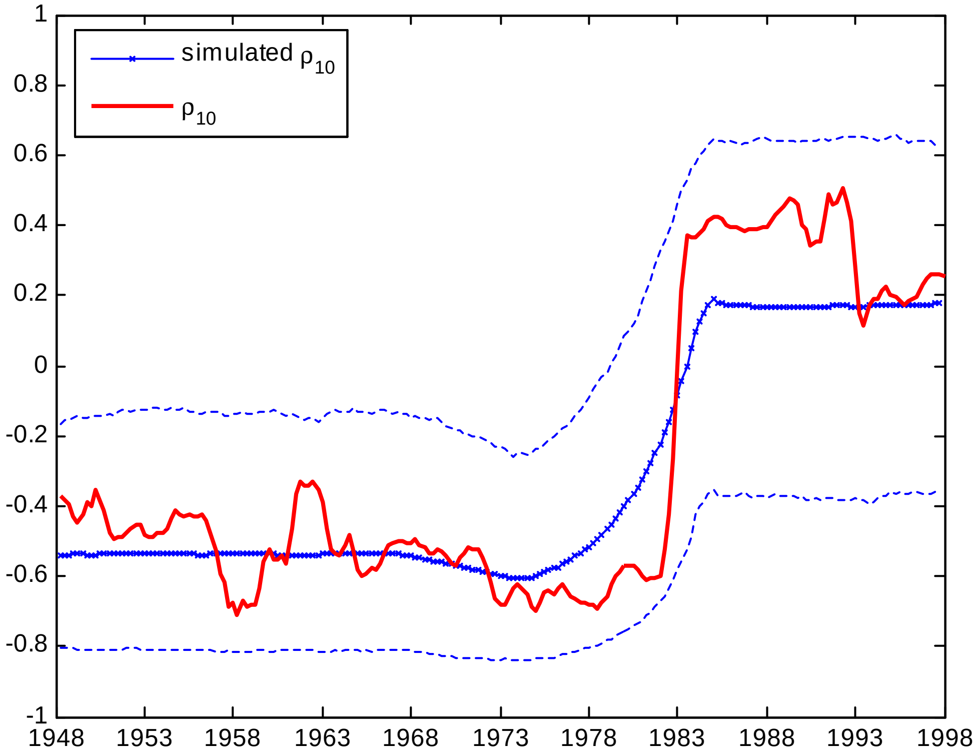

Figure 16: Simulation of ρ with volatility drop *and* structural change after 1984. (dashed lines represent the 95% confidence interval)