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Labor Market Dynamics and the Business Cycle: Structural Evidence for the United States

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Labor Market Dynamics and the Business Cycle: Structural Evidence for the United States

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Abstract

We use a 12-dimensional VAR to examine the dynamic e®ects on the labor market of four structural technology and policy shocks. For each shock, we examine the dynamic effects on the labor market, the importance of the shock for labor market volatility, and the comovement between labor market variables and other key aggregate variables in response to the shock. We document that labor market indicators display "hump-shaped" responses to the identified shocks. Technology shocks and monetary policy shocks are important for labor market volatility but the ranking of their importance is sensitive to the VAR specification. The conditional correlations at business cycle frequencies are similar in response to the four shocks apart from the correlations between hours worked, labor productivity and real wages. To account for the unconditional correlations between these variables, a mixture of shocks are required.

JEL classification: C32, E24, E32, E52, E62.
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Table of contents

1. Introduction

2. Stylized Facts

3. Identification and Estimation Strategy

4. Results

5. Robustness Analysis

6. Summary and Conclusions

7. References

1 Introduction

The labor market plays a special role in business cycle research. As stressed by Kydland (1995), the labor input is the key cyclical production factor. Moreover, aggregate employment is one of the central business cycle indicators and changes in aggregate unemployment receive substantial attention in discussions about the state of the economy. The labor markets has also been central to much of past and current debate about business cycle theory. Following Kydland and Prescott's (1982) seminal contribution, much research during the 1980's and the early 1990's focused upon the difficulty of accounting for the volatilities of hours worked and of labor productivity and for the low covariance between these variables at the business cycle frequencies. This led to the development of theories with labor market indivisibilities (Hansen, 1985, Rogerson, 1988), homework (Benhabib, Rogerson and Wright, 1991), and fiscal policy shocks (Christiano and Eichenbaum, 1992, McGrattan, 1994).[1]

Recently, the profession's interest into the labor market has been revived. Following Galí (1999), a large literature has questioned the validity of standard business cycle theories' implications for the cyclical movements in the labor input and in aggregate labor productivity. Using a structural vector autoregression (SVAR) technique, Galí (1999) finds a positive permanent neutral technology shock is associated with a *decline* in hours worked. Since hours worked are procyclical in U.S. data, this questions the role of technology shocks for business cycles. Galí (1999) also finds a negative correlation between hours worked and aggregate labor productivity *conditional* upon permanent productivity shocks. The debate surrounding these results still has not reached a firm conclusion.[2]

Building upon Mortensen and Pissarides (1994), a growing literature[3] has adopted labor market search models to examine the movements in unemployment and vacancies. An important insight from this literature is that it is difficult to account for the large and persistent cyclical movements in unemployment, vacancies, and in labor market tightness (the ratio of vacancies to unemployment). Hall (2005) and Shimer (2005) conclude that, in response to a productivity shocks, labor market matching

[1] Indivisibilities in hours worked increase the volatility of aggregate hours worked but does not affect much the correlation between hours worked and labor productivity. Fiscal policy shocks and shocks to home production technologies can generate a lower correlation between hours and productivity because these shocks affect mainly labor supply.

[2] Studies that find evidence of Gali (1999) include, amongst many others, Alexius and Carlsson (2005), Basu, Fernald and Kimball (2006), Francis and Neville (2005), and Pesavento and Rossi (2005). Christiano, Eichenbaum and Evans (2004) is a prominent example of studies that challenge Gali's results.

[3] See e.g. Andolfatto, 1996, Cheron and Langot, 2004, Den Haan, Ramey and Watson, 2000, Gertler and Trigari, 2006, Hall, 2006, Merz, 1995 or Ravn, 2005 amongst many others.

models predict little variation in unemployment and in vacancies if wages are determined according to a Nash bargain. This has led to the development of theories with non-standard wage setting schemes.[4]

This paper aims at providing empirical impetus to the debate on labor market dynamics over the business cycle. We study U.S. quarterly data for the sample period 1959 - 2003, and using a SVAR approach examine how the economy, and central labor market variables in particular, respond to structural shocks. Our list of labor market indicators includes total hours and its components, unemployment, vacancies, labor market tightness, average labor productivity, and real wages. We focus attention upon four structural shocks that traditionally have played prominent roles in business cycle research. The first shock that we identify is a (permanent) neutral technology shock. The second shock is an investment specific technology shock. The other two shocks are related to economic policy. First, we identify monetary policy shocks studied in the line of research that has been concerned with nominal rigidities. Secondly, we identify government spending shocks that have been highlighted as potentially important for accounting for the relationship between hours and labor productivity.

We address three key questions about labor market dynamics: (i) What are the dynamic effects of the structural shocks on the labor market variables? We evaluate this on the basis of impulse response functions; (ii) How important are the structural shocks for the volatility of the labor market variables at the business cycle frequencies? We examine this by computing variance decompositions and by investigating the business cycle moments of counterfactual experiments; (iii) How do the labor market variables and other key macroeconomic aggregates comove at the business cycle frequencies conditional upon the structural shocks? We shed light on this by examining the moments of counterfactual experiments.

Our analysis complements and extends earlier contributions to the literature on business cycle dynamics. In particular, we analyze a more comprehensive list of structural shocks than most other papers and examine the impact on a greater selection of labor market indicators than many other studies. This allows us to bring out a number of new insights. moreover, we put special emphasis on evaluating the implications of the SVAR estimates for conditional business cycle moments and this aspect of the paper allows us to take a stand on how the structural shocks shape business cycle dynamics of the US economy.

One difficulty with the VAR analysis is that it is hard to establish exactly the most suitable specifi-

[4] Hagedorn and Manovskii (2005) show that high bargaining power of firms combined with high value of not working of workers may imply high volatility of unemployment and vacancies even if wages are determined by Nash bargaining.

cation of the trend stationarity of a number of the labor market indicators. In particular, average hours worked, unemployment, and vacancies are all borderline non-stationary in the sample that we examine. Therefore, we examine in some detail the robustness of the results to the specification of the VAR. We also investigate whether the results are robust over time.

The most interesting results can be summarized as follows:

- Hours worked, employment, vacancies, the vu-ratio increase in response to positive technology shocks and expansionary monetary policy shocks while unemployment declines and follow hump-shaped dynamics with peak effects occurring after 3-5 quarters. Government spending shocks leads to very outdrawn responses.

- Technology shocks are key for business cycle fluctuations in labor market indicators but the relative importance of neutral and investment specific technology shocks depends on the VAR specification. Monetary policy shocks are also important for labor market fluctuations.

- The conditional correlations between the business cycle components of output, consumption, investment, hours worked, unemployment and vacancies are remarkably similar in response to the four different shocks and match closely the unconditional moments. The covariance between output and labor productivity and between hours, real wages and productivity instead depend critically on the source of shocks to the economy. Neutral technology shocks lead to positive comovements of hours and real wages but orthogonality of hours and productivity; investment specific shocks are associated with negative hours-real wage and hours-productivity comovements. A mixture of shocks are required to account for the unconditional cross-correlations between key labor market indicators.

- While the impact effect of neutral technology shocks on average hours worked depends critically on the VAR specification, there is robust evidence that hours and output are positively correlated at the business cycle frequencies in response to neutral technology shocks.

- The results are stable over time.

Section 2 below discusses the stylized facts of the data. Section 3 outlines the identification and estimation strategies. In Section 4 we present the results. Section 5 examines the robustness of the results and Section 6 summarizes and concludes.

2 Stylized Facts

We start by analyzing the unconditional business cycle moments of the data. We study U.S. quarterly data for the sample period 1959:3 - 2003:1 and examine output, its components, and a number of labor market indicators relating to labor as a production factor and to labor market search indicators. The labor input is measured by average hours worked and its extensive and intensive components, employment and hours per worker. The search indicators are unemployment, the number of non-employed search active workers, and its equivalent from the perspective of firms, vacancies, and their ratio, labor market tightness. We also examine average labor productivity and real wages given their central role in many business cycle theories. We measure hours worked, employment, unemployment, and vacancies in per adult equivalents. Precise definitions and sources are given in Table A.1.

Table 1 reports the business cycle moments of the data. We compute the percentage standard deviations of the Hodrick and Prescott (1997) filtered data; the correlation of each variable with output; and an indicator of a phase shift between output and each of the other variables.[5] The percentage standard deviation of real output per capita is 1.56 percent. This number is smaller than the estimate of e.g. Kydland and Prescott (1990) due to the well-documented "great moderation" of the 1980's and the 1990's. Consistently with conventional wisdom, aggregate consumption is smoother than output while aggregate investment is more volatile than output. Both of these variables are highly procyclical. Government spending instead is acyclical but possibly lagging output with as much as 6-7 quarters. Section 4 will shed some further light on this large phase-shift.

There is a large positive correlation (0.87) between average hours worked and output. Moreover, the standard deviation of hours worked exceeds that of output by 11 percent (and that of labor productivity by 100 percent). The relatively high volatility of hours worked is partly due our hours worked series being based on the establishment survey.[6] The standard deviation of employment is almost three times higher than the volatility of hours per worker. The extensive margin of the labor input is therefore much more important than the intensive margin at the business cycle frequencies (see Burdett and Wright, 1989, for a theoretical analysis). It is also evident that employment is more closely related with output

[5]The latter is derived from the correlation between output and leads and lags of each of the other variables. If these correlations reach a maximum within a 21 quarter window we report the phase shift at this lead or lag and the corresponding correlation.

[6]See Hansen and Wright (1992) for a discussion.

over the business cycle than hours per worker and that employment lags output by around one quarter.

A central variable in business cycle research is labor productivity. This variable has a standard deviation of 0.84 percent, an estimate that is almost identical to earlier estimates in the literature. Most interestingly, the contemporaneous correlation between labor productivity and output is approximately equal to zero in our sample. Previous contributions instead tend to find procyclical labor productivity. The unconditional correlation between hours worked and labor productivity is negative with a point estimate of -0.45 (see the last column of Table 1). This estimate is lower than earlier estimates in the business cycle literature (see e.g. Hansen, 1985, Kydland and Prescott, 1990, Hansen and Wright, 1992).[7] The real wage is mildly procyclical and displays almost exactly the same volatility as labor productivity. We confirm the Dunlop-Tarshis observation, the near orthogonality of real wages and hours worked (the cross-correlation is 0.01).

Unemployment and vacancies, display large volatilities at the business cycle frequencies, an observation that is currently attracting a lot of attention. The standard deviation of unemployment per capita is almost 7 times higher than the standard deviation of output while the corresponding number for vacancies is above 8. Moreover, unemployment is strongly countercyclical and lags output by a quarter while vacancies are strongly procyclical and contemporaneous. Labor market tightness is highly volatile with a standard deviation of 23.4 percent per quarter (15 times the standard deviation of output). This is by far the highest volatility of any variable that we examine. Labor market tightness is strongly procyclical. Finally, we also report the correlation of unemployment and vacancies. In our sample, this correlation is -0.93 which is consistent with existence of a Beveridge curve. We return to this point later in Section 4.

3 Identification and Estimation Strategy

We employ an SVAR method with standard identifying assumptions. There are two distinguishing features of our analysis. First, we identify a larger set of structural shocks than in much of the earlier contributions to the literature. This minimizes problems of omitted variables. Secondly, we pay special attention to the behavior of the key aggregate labor market variables in order to gain a better understanding of the labor market dynamics.

[7]There is a positive correlation between hours worked and labor productivity if we exclude post-1990 data.

3.1 Identification

We identify four structural shocks considered important in the business cycle literature. Much past literature have studied the impact of neutral technology shocks[8], and play also a prominent role in the recent literature on business cycles and labor market matching.[9] Recently, Fisher (2006) argues investment specific shocks account for much of the variations in average hours worked. Moreover, Fisher's (2006) analysis shows that failure to control for the presence of investment specific technology shocks might lead to identification problems when estimating the effects of neutral technology shocks. This are the two first structural shocks that we identify.

Other parts of the business cycle literature have instead paid more attention to "demand type" shocks prominently monetary policy shocks and fiscal policy shocks. The former of these have been studied intensively in the part of the literature that builds upon the existence of nominal rigidities, see Christiano, Eichenbaum and Evans (2005) amongst many others.[10] Fiscal shocks have also been studied in a number of papers in the business cycle literature. Christiano and Eichenbaum (1992), for example, introduce shocks to government spending in order to break the strong correlation between hours and productivity implied by models with only neutral technology shocks. We measure of fiscal policy shocks by government spending shocks.

Consider the following reduced form 12-dimensional VAR:

$$\begin{aligned} x_t &= a + B(L)\,x_{t-1} + e_t \\ x_t &= \begin{bmatrix} \triangle g_t & \triangle p_t^i & \triangle a_t & z_t & r_t \end{bmatrix}', \; z_t = \begin{bmatrix} \triangle w_t & \triangle p_t^y & uc_t & \widetilde{h}_t & cy_t & iy_t & \widetilde{u}_t & \widetilde{v}_t \end{bmatrix}' \end{aligned} \tag{1}$$

where $B(L)$ is a lag polynomial of order M. The variables in the VAR are the changes in government purchases of goods and services $(\triangle g_t)$, in the relative price of investment goods $\left(\triangle p_t^i\right)$ [11], in average labor productivity $(\triangle a_t)$, in real wages $(\triangle w_t)$, in the price level of GDP $(\triangle p_t^y)$; the logarithm of the capacity utilization rate (uc_t); a measure of aggregate average hours worked $\left(\widetilde{h}_t\right)$; the logarithm of

[8] See e.g. Kydland and Prescott (1982), Hansen (1985), Christiano and Eichenbaum (1992), and Prescott (1986).

[9] See e.g. Andolfatto (1996), Cheron and Langot (2004), Hall (2005), Merz (1995), and Shimer (2005)

[10] Trigari (2004) and Walsh (2000) explore the effects of monetary shocks in the presence of labor market matching.

[11] Following Justiniano and Primiceri (2006), p_t^i is defined as the implict investment deflator divided by the implicit consumption deflator.

the nominal consumption share of output (cy_t) ; the logarithm of the investment share of output (iy_t); measures of unemployment $(\widetilde{u}_t)$ and of vacancies $(\widetilde{v}_t)$; and the Federal funds rate (r_t). Precise definitions of the variables are given in Table A.2.

The specification of (1) is based on examinations of the time series properties of the variables. We impose stationarity of the growth rate of government spending, the change in the relative price of investment goods, and labor productivity. We also impose stationarity on the Federal funds rate, velocity, and the elements of the vector z_t. In Table 2 we report the outcomes of tests for non-stationarity of the labor market indicators. Aggregate hours is, as is well-known, borderline non-stationary. In particular, the outcomes of augmented Dickey-Fuller tests depend critically on the number of lags included in the test.[12] Employment instead appears to be stationary once we allow for a trend (which is significant). Unemployment and vacancies are found to be stationary (when including a trend in the vacancy regressions and excluding the trend from the unemployment regressions), but for unemployment the results are borderline with non-stationarity being rejected only at the 10 percent level.

Given these results we examine the sensitivity of the results to the specification of the labor market variables. In our baseline specification, we use the log of average hours, the log of unemployment and the log of vacancies. We then re-examine the results when we use the growth rate of hours instead of its level and the growth rates of unemployment and vacancies instead of their levels.The structural VAR is:

$$\beta_0 x_t = \alpha + \beta(L)\, x_{t-1} + \varepsilon_t \tag{2}$$

where ε_t denotes the vector of structural shocks. We assume that the covariance matrix of ε_t, $V_\varepsilon = E(\varepsilon_t' \varepsilon_t)$ is diagonal. The parameters of the (1) and (2) are related through $a = \beta_0^{-1}\alpha,\ B(L) = \beta_0^{-1}\beta(L)$, and $V_e = \beta_0^{-1\prime} V_\varepsilon \beta_0^{-1}$ where $V_e = E(e_t' e_t)$. The diagonal of β_0 is normalized to a 12x1 vector of ones.

As Fisher (2006), the investment specific shock is identified assuming that this is the only shock that can affect the level of the relative price of investment in the *long run.* Moreover, the investment specific shock is allowed to have long run effects on aggregate labor productivity. A permanent neutral technology shock is identified by assuming that while it cannot affect the long run relative price of investment, it *can* affect the long run level of labor productivity. No other shocks are allowed to have permanent effects on labor productivity. These assumptions generalize Galí's (1999) identification of

[12] For this variable, the trend is insignificant so we report the ADF tests with no trend in the regression.

neutral technology shocks and imply that we identify *permanent* technology shocks.[13]

Following Blanchard and Perotti (2002) we assume that, in quarterly data, government spending does not react to unexpected movements in any other variable. Thus the process for government spending depends on lagged values of government spending and other variables but *not* on the current realizations of any other structural shocks (the first row of β_0 therefore consists of zeros apart from the first element which is normalized to unity). The monetary policy shock is identified using assumptions on the Fed's information set, c.f. Christiano and Eichenbaum (1996). We assume that the Fed's policy instrument is the Federal funds rate, that the policy rule is linear, and that when setting the interest rate at date t, the Fed's information set includes the current values of all other variables in the VAR. Therefore, the vector $\begin{bmatrix} \triangle g_t & \triangle p_t^i & \triangle a_t & z_t' \end{bmatrix}'$ is assumed not to be affected contemporaneously by the monetary policy shock.[14]

3.2 Estimation

The four structural shocks are estimated from the following equations (in that order):

$$\triangle g_t = \alpha^g + \sum_{j=1}^{M} \beta_j^g x_{t-1} + \varepsilon_t^g \tag{3}$$

$$\begin{aligned}\triangle p_t^i = {} & \alpha^p + \sum_{j=0}^{M-1} \beta_{g,j}^p \triangle^2 g_{t-j} + \sum_{j=1}^{M} \beta_{p,j}^p \triangle p_{t-j}^i + \sum_{j=0}^{M} \beta_{a,j}^p \triangle^2 a_{t-j} \\ & + \sum_{j=0}^{M-1} \beta_{z,j}^p \triangle z_{t-j} + \sum_{j=1}^{M} \beta_{r,j}^p \triangle r_{t-j} + \varepsilon_t^p \end{aligned} \tag{4}$$

$$\begin{aligned}\triangle a_t^i = {} & \alpha^a + \sum_{j=0}^{M-1} \beta_{g,j}^a \triangle^2 g_{t-j} + \sum_{j=0}^{M} \beta_{p,j}^a \triangle p_{t-j}^i + \sum_{j=1}^{M} \beta_{a,j}^a \triangle a_{t-j} \\ & + \sum_{j=0}^{M-1} \beta_{z,j}^a \triangle z_{t-j} + \sum_{j=1}^{M} \beta_{r,j}^a \triangle r_{t-j} + \varepsilon_t^a \end{aligned} \tag{5}$$

$$r_t = \alpha^r - \beta_{0,g}^r \triangle g_t - \beta_{0,p}^r \triangle p_t^i - \beta_{0,a}^r \triangle a_t - \beta_{0,z}^r z_t + \sum_{j=1}^{M} \beta_j^r x_{t-1} + \varepsilon_t^r \tag{6}$$

where $\triangle^2$ denotes the double difference operator.

[13] Much of the business cycle literature has instead studied persistent but non-permanent technology shocks. Transitory changes in technology are not easily identified with SVAR approaches. Ravn (1997) integrates both types of technology shocks in the same analysis.

[14] We have repeated the analysis expanding the VAR with velocity. None of the results change significantly.

Equation (3), estimated with least squares, identifies the fiscal policy shock (ε_t^g). Equation (4) identifies the investment specific technology shock (ε_t^p). The identifying assumptions are imposed by differencing all the regressors in x_t apart from the relative investment goods price itself. Moreover, the contemporaneous value of the Federal funds rate is excluded from this regression. This equation is estimated with 2SLS since $\triangle a_t$ and z_t may depend on ε_t^p and on ε_t^g. The instruments are a constant, the vector $[\triangle g_{t-j}, \triangle p_{t-j}, \triangle a_{t-i}, z_{t-j}, r_{t-j}]_{j=1}^M$ and $\widehat{\varepsilon}_t^g$ (the estimate of ε_t^g). The neutral technology shock (ε_t^a) is estimated from equation (5) which imposes that only investment specific and neutral technology shocks can have a permanent effects on labor productivity. Again, this relationship is estimated using 2SLS. The instruments are the same as those above extended with $\widehat{\varepsilon}_t^p$. The monetary policy shock (ε_t^r) are estimated from (6) using least squares.

We adopt the recursive 2SLS approach of Altig et al (2005) to estimate the parameters of the equations for the vector z_t. Denote the components of z_t by z_t^i, $i = 1, ..8$. The parameters of the first of these equations are estimated as:

$$z_t^1 = \alpha^1 + \sum_{j=0}^{M} \beta_{j,g}^1 \triangle g_{t-j} + \sum_{j=0}^{M} \beta_{j,p}^1 \triangle p_{t-j}^i + \sum_{j=0}^{M} \beta_{j,a}^1 \triangle a_{t-j} + \sum_{j=1}^{M} \beta_{j,z}^1 z_{t-j} + \sum_{j=1}^{M} \beta_{j,r}^1 r_{t-j} + e_t^1 \qquad (7)$$

using as instruments a constant, $\left[\triangle g_{t-i}, \triangle p_{t-i}^i, \triangle a_{t-i}, z_{t-i}, r_{t-i}\right]_{i=1}^M$ and $\left[\widehat{\varepsilon}_t^g, \widehat{\varepsilon}_t^p, \widehat{\varepsilon}_t^A\right]'$. The second equation extends the set of regressors with z_t^1 and the list of instruments with $\widehat{e}_t^1$. We continue this procedure recursively for all the variables included in z_t.

Finally, we decompose the average hours response into the extensive and the intensive margins by estimating the following equation (by ordinary least squares):

$$\widetilde{n}_t = \alpha_n + \sum_{j=0}^{M} \beta_j^n x_{t-j} + \sum_{j=1}^{M} \gamma_j \widetilde{n}_{t-j} + \varepsilon_t^n$$

where $\widetilde{n}_t$ denotes linearly detrended log employment per capita. We impose that $\beta_{0,r}^n = 0$ consistently with the assumptions made when identifying the monetary policy shock. From this regression we compute the responses of employment per capita. We derive the dynamics of hours per worker by combining these responses with those of average hours worked.[15] This decomposition is informative

[15] Alternatively one could assume that $\beta_0^n = 0$ so that employment does not react contemporaneously to *any* of the identified shocks. This restriction, while common, is not a necessary restriction of matching models (see e.g. Hall, 2006) and contrasts with the fact that many unemployed find employment within a few weeks of losing their previous job.

about the extent to which firms rely on the adjustment of hours per worker and/or adjustment of employment in response to shocks to the economy.[16]

4 Results

We estimate the VAR assuming that $M = 3$. We first present the impulse responses. After that we evaluate the importance of the four identified shocks for the volatilities of the variables. Finally, we examine the conditional comovements between the variables at the business cycle frequencies.

4.1 Dynamic Responses to Structural Shocks

We compute impulse responses for forecast horizons of 16 quarters and report the point estimates along with 1 standard error (66 percent) confidence intervals (computed with a non-parametric bootstrap).

4.1.1 Neutral Technology Shocks

Figure 1A illustrates the impulse responses to the identified permanent neutral technology shock. This shock leads to hump-shaped increases in output, consumption and investment. The peak effects on output and consumption occur around 1 year after the impulse at which horizon investment increases around 1.5 percent above its original level. Consistent with standard intuition, consumption rises in a more gradual fashion. This shock increases the relative investment price in the short run but the effect disappears relatively quickly. These responses are qualitatively similar to the results in Altig et al (2005) although we tend to find slightly lower elasticities than these authors.

Hours worked increase by approximately 0.25 percent on impact and this response goes up to 0.5 percent at the 5 quarters horizon. In contrast to Galí (1999), we do *not* find that any evidence of a decline in hours worked in response to a positive technology shock, a result we return to below. Consistent with the unconditional moments (hours worked lagging output), the peak effect of hours worked is reached later than the peak effect of output. The decomposition into the intensive and extensive margin show that each of these are positively affected by the neutral technology shock but with noticeable different

Technically, extending the VAR (2) with employment, we restrict the last columns of $\beta_0 - \beta_M$ to have zeros in all but the last position. Without such a restriction we found serious multicollinearity problems.

[16] Many standard business cycle theories do not make a distinction between the extensive and the intensive margins. Hansen (1985) assumes that all the variation occurs at the extensive margin. Moreover, theories of labor adjustment costs and theories of labor market matching put the extensive margin at the centre of labor input fluctuations.

dynamics. In particular, hours per worker rises fast but with a small elasticity (0.15 at the peak) while employment rises sluggishly (with a peak 6-7 quarters after the technology shock) but with a much higher elasticity (0.35 percent at the peak). Both the lagging behavior of employment and the differential elasticities appear consistent with the results in Table 1.

The responses of unemployment and vacancies in response to neutral technology shocks display large and marked hump-shaped responses to the neutral technology shock. Unemployment react little upon impact but then drops by 3 percent 4 quarters after the technology shock. Vacancies follow a bell-shaped response that reaches a maximum 2.5 percent increase with a 4 quarters delay. Together these imply a gradual but large impact on labor market tightness that rises by 5 percent with a 4 quarter delay.

Average labor productivity is estimated to increase on impact in response to a neutral technology shock. We find a U-shaped impact on labor productivity consistent with the tendency for labor productivity to lead output by several quarters. It is worthwhile to notice that the elasticity of labor productivity to the neutral technology shock is much lower than the elasticity of output to this shock. In contrast, the real wage rises slowly in response to the neutral technology shock with little response upon impact but a 0.3 percent rise at the 4 years horizon.[17]

4.1.2 Investment Specific Technology Shocks

Figure 1B shows the effects of investment specific technology shocks. This shock lowers the relative investment price upon impact and in the long run. Output, consumption and investment rise in response to the investment specific technology shock with peak effects occurring with a 3-4 quarters delay after the increase in technology. At longer forecast horizons, the impact on these variables is muted although still significantly positive. These responses are similar to those of Altig et al (2005) but imply smaller responses of output and investment than the estimates of Fisher (2006).

The increase in investment specific technology is associated with a small but positive impact effect on hours worked. After 3 quarters there is quite a large increase in hours worked of 0.65 percent above its initial level. The peak response of average hours worked coincides with that of output. This implies that average labor productivity first rises slightly but then falls over a prolonged period before eventually rising at long forecast horizons. The relatively small impact on labor productivity is consistent with

[17]Dedola and Neri (2007) find similar responses of real wages and hours to neutral productivity shocks using an identification scheme based on sign restrictions.

the findings of Altig et al (2005) and Fisher (2006).[18]

As in the case of neutral shocks, investment specific shocks imply an important asymmetry in the effects on the extensive and the intensive margin. Hours per worker rise faster than employment but with a much smaller elasticity. Interestingly, the investment specific shock appears to be associated with a small but persistent decline in the real wage although the confidence interval is sufficiently wide that we cannot reject no response of the real wage to the investment specific shock.

We also confirm the tendency for hump-shaped dynamics of unemployment and vacancies. Upon impact, there is little effect upon aggregate unemployment while vacancies increase by approximately 1.5 percent. During the second and third quarters after the investment specific technology shock, however, unemployment declines fast with a peak response of a 2.5 percent decline in unemployment. After this, unemployment returns to its original level around 2 years after the technology shock. Vacancies reach a peak effect (a 3.5 percent rise) 3 quarters after the investment specific shock. These responses implies large volatility of the vu-ratio which rises by more than 1 percent on impact and by more than 6 percent with a 3 quarters delay.

Our results on the labor market impact of the two types of technology shocks are consistent with Braun et al (2006) who apply a sign restrictions identification scheme, study a slightly longer sample period, and use a different VAR-specification. These authors find that vacancies and unemployment follow bell-shaped and U-shaped dynamics, respectively, in response to the two types of technology shocks. Fujita and Ramey (2005) find that the vu-ratio displays hump-shaped dynamics in response to innovations to labor productivity. Ravn (2005) identifies a neutral technology shock and find dynamics of unemployment, vacancies, and the vu-ratio similar to those that we report here. Fujita (2004) identifies an "aggregate shock" using sign restrictions and finds that vacancies display a hump-shaped response to this shock.

Canova, Michelacci and Lopez-Salido (2006) and Michelacci and Lopez-Salido (2006) find instead that a positive neutral technology shock is associated with an increase in unemployment and a persistent (and permanent) drop in employment while hours per worker increase permanently. Their VAR specification is quite different from ours and they study a short sample period spanning only the 21 years period 1972-1993. We later return to this in some detail.

[18]Fisher's (2006) results depend critically on the VAR specification - see Figure 6 in his paper - an issue that we will return to below.

4.1.3 Monetary Policy Shocks

Figure 1C shows the responses to a contractionary monetary policy shock. This shock corresponds to a persistent rise in the Federal funds rate which sets of a temporary decline in output, consumption and investment with the largest effects taking place 5-6 quarters after the contraction of monetary policy. At longer forecast horizons, these variables return gradually to their initial level. The shapes and elasticities of each of the responses are practically identical to the estimates of Altig et al (2005). We confirm the presence of a price puzzle (a short-lived rise in inflation) and inflation persistence (a long-lived subsequent drop in inflation).

Hours worked fall persistently in response to a monetary policy contraction. Moreover, the fall in hours worked is large reaching a maximum of 0.35 percent 6 quarters after the rise in the interest rate. Notice that this implies a larger fall in hours worked than in output which is consistent with the relatively large volatility of hours worked. Decomposing this change into hours per worker and employment reveals that adjustments in employment by far dominate changes in hours per worker. This finding is in line with the estimates of Trigari (2004). According to our results, there is a tendency for countercyclical movements in labor productivity in response to monetary policy shocks. In particular, while labor productivity declines briefly in response to the rise in interest rates, from 3 quarters after the rise in interest rates, labor productivity rises. The real wage, in contrast, is left approximately unaltered by the monetary policy shock.

Unemployment and vacancies both respond with large elasticities to the monetary policy shock and display hump-shaped dynamics. Unemployment reaches a peak increase of around 2.5 percent 6 quarters after the rise in interest rates. Vacancies follow a mirror image of the unemployment dynamics and reaches a maximum decline of a 2.5 percent decline 5 quarters after the monetary policy shock. Therefore, the vu-ratio displays a large and persistent decline with a peak decline of close to 6 percent 5-6 quarters after the monetary policy shock. This evidence appears indicate a role for monetary policy shocks for labor market fluctuations

4.1.4 Government Spending Shocks

Figure 2D plots the responses to the identified government spending shock. This shock is estimated to be a very persistent rise in government spending that peaks one year after the initial increase in government spending (consistent with e.g. Galí, Lopez-Salido and Valles, 2006). We find very protracted responses of the other variables. Output rises but the maximum impact occurs not until 3 years after the initial increase in government spending. Like Blanchard and Perotti (2002), Fatas and Mihov (2001) and Galí, Lopez-Salido and Valles (2006), the increase in government spending is associated with a persistent rise in private consumers' expenditure. Investment instead is estimated to decline in response to the government spending shock. Another puzzling result is that the aggregate inflation rate declines persistently following the rise in government spending.[19]

There is little impact on average hours worked until 3 years after the increase in government spending when average hours worked eventually increase by 0.15 percent. Decomposing this into employment and hours per worker reveals that hours per worker remain unaffected while employment follows practically the same path as average hours. We find, quite surprisingly, that average labor productivity rises persistently in response to the increase in government spending. This increase peaks one year after the increase in government spending but is significant even at the 3 year horizon where the response of output peaks. Similarly, the increase in government spending sets off an increase in real wages.[20]

In line with the results above, unemployment declines gradually in response to changes in government spending while vacancies rise steadily. Both unemployment and vacancies reach their peak effects 3 years after the increase in government spending and, at this horizon, unemployment declines with around 1.5 percent and vacancies rise with around 1.5 percent.

4.2 Importance of the Structural Shocks

We now examine importance of the identified shocks for the volatilities of the variables. We first inspect forecast error variance decompositions. These calculations, however, do not directly shed light on the importance of the shocks for fluctuations in the variables of interest at the business cycle frequencies. Therefore, as a second step, we compute the volatilities of the variables on the basis of HP-filtered simulated data from counterfactual experiments. These moments comparable to the unconditional moments of Table 1.

[19] This result might be consistent with theories that emphasize declines in mark-ups in response to expansionary government spending shocks (see e.g. Ravn, Schmitt-Grohe and Uribe, 2006, or Rotemberg and Woodford, 1992).

[20] This result is again consistent with theories of countercyclical markups.

4.2.1 Variance Decompositions

Figure 2 displays the forecast error variance decompositions of output and the labor market indicators at forecast horizons going up to 5 years. Neutral technology shocks are the dominating impulse to output dynamics and accounts, regardless of the forecast horizon, for 30-35 percent of the forecast error variance of output. The investment specific shock is also of some importance at shorter horizons but less so for forecast horizons above 2 years. In total, the four shocks account for 65-70 percent of the total forecast error variance of output. Thus, neutral technology shocks appear to be indispensable when accounting for the cyclical variations in output.

The forecast error variance of hours worked is instead dominated by the investment specific shock that accounts for 30-45 percent of the hours variance. Neutral technology shocks are also of some importance accounting for around 20 percent of the forecast error variance of hours worked. The four shocks altogether account for around 70 percent of the total forecast error variance of hours worked, an estimate that is very similar to that of output.

The variance decompositions of unemployment and vacancies are interesting. At very short forecast horizons only a small fraction of the forecast error variance of unemployment is accounted for by the four identified shocks. Beyond the one year horizon, however, the two technology shocks and monetary policy shocks contribute both quite significantly to the volatility in unemployment (around 52 percent altogether). The volatility of vacancies are instead more dominated by the investment specific shock that accounts for between 17 and 34 percent of the variance depending on the forecast horizon. Neutral technology shocks and monetary policy shocks also appear important but less so than for unemployment.

Perhaps the most interesting insights the forecast error variance decomposition relate to the results for labor productivity. According to our results, the four shocks rarely account for more than 30 percent of the forecast error variance of labor productivity. Given that we account for large fractions of the volatility of output and average hours, it follows that the covariance between these variables is not well accounted for. Similarly, the four shocks account for little of the forecast error variance of real wages and only at long forecast horizons do the four shocks in total account for more than 20 percent of the real wage forecast error variance (which is dominated by the neutral shock). Thus, it appears that there are importance sources of volatility in real wages and in labor productivity that are not identified by the four structural shocks.

4.2.2 Business Cycle Volatility

Using our parameter estimates and the estimated structural shocks, we compute the time-paths of output using counterfactual experiments. Precisely, we compute the time path of a variable x_t using the VAR parameter estimates feeding in randomly drawn sequences of the identified shocks setting all other innovations equal to zero. We then HP-filter the artificially generated data and report the standard deviations over 100 experiments. The results are reported in Table 3.

At the business cycle frequencies, the neutral technology shock is the single most important source of volatility in output, consumption, and investment. By itself, this shock accounts for approximately 20 percent of the unconditional variance of output (computed as $0.70^2/1.56^2$). Investment specific shocks and monetary policy shocks are also of some importance while government spending shocks appear less important for output volatility. In total, the four shocks account for around 52 percent of the unconditional variance of output. The corresponding numbers, and the relative importance of the shocks, are similar as regards consumption and investment.

The results for hours worked are not too dissimilar to those of output. The four shocks account for around 47 percent of the variance of HP-filtered hours and most of this variance is due to the two technology shocks and to monetary policy shocks. Interestingly, the neutral technology shock is the single most important source of hours volatility, a result that contrasts with the dominance of the investment specific shock according to the forecast error variance decompositions. Therefore, the results do not entirely support Fisher's (2006) findings regarding the significance of investment specific shocks for labor market volatility.

The four shocks account for 44-47 percent of the volatilities of the search indicators. There is little role for government spending shocks. For each of these variables, the single most important source of volatility is the monetary policy shock although the estimates of the contribution of neutral and investment specific shocks are not much lower than that of the monetary policy shocks. This indicates that theories attempting to explain the cyclical variations in unemployment, vacancies and labor market tightness need to rely on multiple shocks rather than neutral technology shocks only.

Consistently with the forecast error variance decompositions, the four identified shocks account for relatively little of the business cycle volatility in average labor productivity and in real wages (39 percent and 23 percent, respectively). This is a puzzling result which we believe deserves further research.

4.3 Conditional Comovements

Table 4 reports the conditional correlations between the variables computed using counterfactuals. The results are interesting. With some important exceptions, the conditional correlations between the variables are extremely similar across the four different structural shocks and, importantly, very similar to the unconditional correlations reported in Table 1. This pattern is evidence for the correlations between output and consumption, investment, hours worked, employment, unemployment, vacancies and the vu-ratio in response to the two types of technology shocks and in response to the monetary policy shock.[21] This result is quite surprising since many business cycle theories would suggest much less conformity in these moments and a much worse fit with the unconditional moments. The similarity between the conditional correlations and the unconditional correlations, suggests that even if our list of structural shocks do not account for more than 45-55 percent of the variance of the variables, the covariance structure between these variables and output is well accounted for.

The conditional covariances of labor productivity and of real wages, however, depend critically on the shocks to the economy. Neutral technology shocks are associated with procyclical movements in labor productivity and in real wages while at the same time giving rise to little covariance between hours worked and average labor productivity. Investment specific technology shocks, instead, give rise to countercyclical movements in wages and in labor productivity and with a large negative cross-correlation between labor productivity and hours worked. Conditional upon monetary policy shocks, labor productivity comoves negatively with output and with average hours worked while the real wages moves procyclically (but with a very low elasticity).

Recall from Table 1, that in the data we study, the real wage is mildly procyclical, labor productivity is acyclical while hours worked and labor productivity are negatively correlated. The results above indicate quite clearly that none of the structural shocks can reproduce this correlation pattern individually. In combination, however, the four shocks give rise to cross-correlations similar to the unconditional moments. Therefore, we conclude that multiple shocks are required to account for the labor market features of US business cycles. This is examined more closely in Figure 3 in which we plot hours against labor productivity (Panel A), and hours against real wages (Panel B). We show the U.S. data and the counterfactual components of these series conditional on each of the four shocks. From Panel A, it is

[21] The cross-correlations conditional on government spending shocks are instead typically lower than the unconditional cross-correlations.

evident that investment specific shocks are the main culprit for the negative unconditional correlation between hours and labor productivity while neutral technology shocks weaken this correlation. Perhaps even more interesting, Panel B clearly shows that the Dunlop-Tarshis observation is due to the contrasting effects of neutral technology shocks, which set off positive comovements between hours and real wages, and investment specific shocks, which set of negative comovements between these variables. We believe that these results deserve further attention in future research.

Finally we examine the relationship between unemployment and vacancies at the business cycle frequencies. Figure 4 illustrates the relationship between these two series computed from the counterfactual exercise. As is evident, each of the four shocks give rise to a Beveridge type relationship This strongly suggests that the Beveridge curve is due to the propagation of shocks to the economy rather than particular sources of impulses.

5 Robustness Analysis

We examine the sensitivity of key findings to the VAR specification and to the sample period. We reestimate the VAR with hours in differences rather than in levels, and, alternatively, with unemployment and vacancies in differences rather than in levels. This analysis is motivated by the fact that both hours worked and unemployment are borderline non-stationary. Secondly, we examine the sub-sample stability of the results.

The assumptions towards the trend stationarity of hours worked and the labor market search indicators affect mainly the labor market effects of technology shocks. Other findings (the effects of the two types of policy shocks, and the effects of the structural shocks on output and its components) are remarkably stable. Figure 5 illustrates the impulse response functions of hours worked, unemployment and vacancies to the two types of productivity shocks in the baseline VAR and in the two alternative VAR specifications. In the baseline VAR, neutral technology shocks dominate the volatility of hours worked while investment specific technology shocks dominate the fluctuations in vacancies. This ranking is reversed when unemployment and vacancies enter in first differences. Table 5 reports the variance decomposition at the business cycle frequencies. While the contribution of the four shocks to the volatility of output is approximately unchanged, the importance of the two types of technology shocks for hours worked volatility is reversed. Thus, it appears that the SVAR is not very helpful for evaluating the relative importance of neutral and investment specific technology shocks for labor market volatility. At the same time, the tendency for hump-shaped dynamics of unemployment and vacancies is extremely robust and thus should be considered a stylized fact.

The top left diagram of Figure 6 shows that the VAR specification affects the *impact effect* of neutral technology shocks on hours worked. Hours worked increase upon impact in response to a positive neutral technology shock in the baseline VAR but falls (albeit marginally) in the alternative VAR specifications. However, according to Table 6, regardless of the VAR specification, there is a positive correlation between output and hours worked at the business cycle frequencies conditional upon neutral technology shocks. Thus, our results challenge the view that this evidence can be used to conclude against the role of technology shocks over the business cycle.

As discussed earlier, Canova, Michelacci and Lopez-Salido (2006) find that a positive technology shock is associated with a persistent decrease in employment and an increase in unemployment. These authors consider the sample period 1972-93 and include hours in levels in their VAR specification. We examine if the sample period is critical for our results, a finding that would be consistent with structural breaks biasing our results. We consider three alternative sub-samples: (i) 1972-93, (ii) an early sub-sample, 1959-1993, and (iii) a late sub-sample, 1972-2003. We let the time-series properties of the data guide our VAR specification. The tests reported in Table 7 indicate trend stationarity of hours worked in the 1959-1993 sub-sample but non-stationarity in the other two sub-samples. Vacancies appear to be trend stationary in all the sub-samples while unemployment is non-stationary in the 1959-1993 sub-sample but trend-stationary in the other two sub-samples. Therefore, our VARs include hours in differences for sub-samples (i) and (iii), hours in levels for sub-sample (ii), unemployment in levels for sub-samples (ii) and (iii) and in differences for sub-sample (i) and vacancies in levels for all sub-samples.[22]

Figure 6 illustrates the impulse responses of employment and unemployment to the neutral technology shock for the three sub-samples. In Panel A we illustrate the results for the 1972-1993 sample when (as Canova, Michelacci and Lopez-Salido, 2006), we use hours (and unemployment and vacancies) in levels in the VAR. The results confirm these authors' finding of a persistent drop in employment and an increase in unemployment following a positive technology shock. When we follow the outcome

[22]Consistently with the Dickey-Fuller tests, we use employment in levels for sub-samples (i) and (ii) and in differences for the last sub-sample.

of the Dickey-Fuller tests and use hours in differences instead, unemployment and employment are basically left unaffected by the neutral technology shock. For the other two sub-samples, instead, we firmly confirm that employment increases persistently in response to a positive technology shock and that unemployment drops persistently. Moreover, the hump-shaped responses are evident in both of these samples. Therefore, we believe that the labor market effects of neutral technology shocks that we uncovered in Section 4 are robust features of the data.

6 Summary and Conclusions

Using a SVAR approach, we have provided an account of the business cycle properties of key US labor market indicators. We examined the response of the economy to two types of technology shocks and to two sources of economic policy related shocks. This exercise unravelled a number of interesting features that we believe should be taken into account when constructing business cycle theories.

A particularly interesting result is that employment, unemployment, vacancies and the vu-ratio follow hump-shaped dynamics in response to each of the structural shocks that we analyzed. This implies that theory must be consistent with the stylized fact that labor market variables adjust gradually over time. Therefore, attempts to refine labor market theories in order to generate higher volatility of unemployment and vacancies must do so subject to the high elasticity of these variables being brought about not upon impact when shocks hit the economy, but with a delay of 3-5 quarters. Moreover, we have shown that this result is a robust feature of US data.

We also showed that the two types of technology shocks are indispensable when accounting for labor market volatility. However, monetary policy shocks also contribute towards accounting for the volatility in the labor market. This implies that attempts to account for labor market volatility with neutral technology shocks only are likely to miss important features of the data. Furthermore, most likely, multiple shocks are required to account for the covariance structure between hours, productivity and real wages. In particular, the orthogonality between hours and real wages appears to be the result of the combined effects of neutral and investment specific productivity shocks, the former being associated with negative hours-real wage comovements, the latter instead implying positive comovements between these two variables. Another important, and surprising result, is that the conditional business cycle moments are very similar in response to the four different types of shocks that we identify with the exception of movements in average labor productivity. Accounting for this, we believe, might be challenging.

It is also worth stressing that despite uncertainty towards the impact effects of neutral technology shocks on hours worked, we found that, at the business cycle frequencies, hours worked remains procyclical conditional upon neutral technology shocks. On the other hand, the relative importance of the two types of technology shocks for labor market volatility is sensitive towards stationarity assumptions that are difficult to establish firmly in the US data. Apparently, SVARs are not well-suited to evaluate this issue.

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8 Appendices

Table A.1. Sources and Definitions of Data

Series	Definition	Source
Population	Civilian non-institutional population of age 16 and above	BLS
Real output	GDP in constant chained prices divided by population	BEA
Price level	Ratio of GDP in nominal prices divided by GDP in constant chained prices	BEA
Real Consumption	Sum of consumers' nominal expenditure on non-durables and services divided by price level and by population	BEA
Real Investment	Sum of consumers' nominal expenditure on durables and private fixed investment expenditure divided by price level and by population	BEA
Real government spending	Nominal government expenditure divided by price level and by population	BEA
Hours per worker	Average hours worked per worker in the private non-farm sector (Establishment data)	BLS
Employment	Number of workers in employment in the private non-farm sector divided by population	BLS
Average Hours	Product of hours per worker and employment	BLS
Labor productivity	Real output divided by average hours	BLS
Capacity Utilization	Index of capital utilization rate in manufacturing (NAICS)	Board of Governors
Unemployment	Number of unemployed of age 16 and above divided by population	BLS
Vacancies	Index of help wanted advertising in newspapers divided by population	Conference Board
Relative investment price	Ratio of implicit investment price deflator to implicit consumption price deflator	BEA
Federal Funds rate	Effective Federal funds rate (average of daily rates)	Board of Governors
Real Wages	Ratio of nominal wages to price deflator	Federal Reserve Bank St. Louis

Table A.2: Definition of Variables in the VAR

Variable	Symbol	Definition
Growth in real government spending	$\triangle g_t$	First difference of logarithm of real government spending
Growth in relative investment price	$\triangle p_t^i$	First difference of logarithm of relative investment price
Growth in labor productivity	$\triangle a_t$	First difference of logarithm of labor productivity
Growth in real wages	$\triangle w_t$	First difference of logarithm of real wages
Inflation rate	$\triangle p_t^y$	First difference of logarithm of price level
Capacity utilization	uc_t	Logarithm of capacity utilization
Average hours worked	h_t	Logarithm of average hours
Consumption share	cy_t	Logarithm of ratio of real consumption to real output
Investment share	iy_t	Logarithm of ratio of real investment to real output
Unemployment	u_t	Logarithm of unemployment
Vacancies	v_t	Logarithm of vacancies
vu-ratio	vu_t	Logarithm of ratio of vacancies to unemployment
Federal funds rate	r_t	Logarithm of Federal funds rate

9 Tables and Figures

Table 1. Stylized Facts, United States, 1959:3 - 2003:1

	Moments of HP-filtered data				
	% std. dev.	Corr. with output	Phase	Corr. with hours	Corr. with vacancies
Output	1.56	1	-	-	-
Consumption	0.86	0.81	0	-	-
Investment	5.75	0.92	0	-	-
Gov. Spending	1.60	0.16	7 (0.33)	-	-
Average hours worked	1.74	0.87	1 (0.88)	-	-
Employment	1.46	0.81	1 (0.87)	-	-
Hours per worker	0.51	0.67	0	-	-
Labor Productivity	0.85	0.04	3 (-0.52)	-0.45	-
				-3 (0.23)	-
Wages	0.86	0.18	1 (0.19)	0.01	-
Unemployment	10.76	-0.87	1 (-0.88)	-	0.93
Vacancies	13.01	0.91	0	-	-
vu-ratio	23.41	0.91	0	-	-

Notes: See Table A.1 for sources and definitions. The business cycle moments were computed from Hodrick-Prescott filtered data using a value of 1600 for the smoothing parameter. The column "Phase" reports the lead or lag at which the correlation between output at date t and each of the other variables at date t+i reaches its (absolute) maximum. The number in parenthesis reports the correlation at this lead or lag.

Table 2. Augmented Dickey-Fuller test for unit root

Lags	Employment	Average hours	Unempl.	Vacancies	VU ratio	Wages
Trend	Yes	No	No	Yes	Yes	Yes
0	-1.20	-1.26	-1.34	-0.07	-0.12	-0.18
1	-3.72*	-2.47	-2.55**	-3.14*	-2.85	-0.54
2	-3.72*	-2.59*	-2.77**	-2.76	-2.56	-0.75
3	-3.39*	-2.45	-2.53**	-3.12*	-2.99	-0.59

Notes: The table reports the t-ratio of the level of the lagged dependent variable in augmented Dickey-Fuller regressions. The sample period is 1959.3-2003.1. ** denotes significance at the 10 percent, level, and * at the 5 percent level.

Table 3. Conditional Standard Deviations

Variable	Percentage standard deviation conditional upon innovations to				
	technology shocks		policy shocks		
	Investment	Neutral	Government	Monetary	All
y	0.48	0.70	0.39	0.54	1.12
c	0.29	0.39	0.23	0.25	0.61
i	1.72	2.20	1.27	2.03	3.81
a	0.24	0.27	0.28	0.21	0.53
h	0.58	0.64	0.40	0.61	1.19
n	0.46	0.50	0.33	0.53	0.97
(h/n)	0.17	0.19	0.11	0.14	0.32
u	3.37	3.96	2.70	4.15	7.51
v	4.25	4.47	2.98	4.68	8.69
vu	7.49	8.33	5.58	8.76	16.01
w	0.20	0.23	0.22	0.12	0.41

Notes: The table reports the average percentage standard deviations of the variables computed from 100 simulations of the estimated VAR process drawing the innovations from the estimated structural shocks. The variables have been HP-filtered. The first four columns report the results when allowing for shocks only to each individual strucutral shock. The last column reports the results when allowing for all four shocks simulaneously.

Table 4: Conditional Cross Correlations

Variable	Correlation with output conditional upon innovations to				
	technology shocks		policy shocks		
	Investment	Neutral	Government	Monetary	All
c	0.84	0.90	0.87	0.93	0.89
i	0.90	0.94	0.68	0.97	0.91
a	−0.14	0.38	0.36	−0.15	0.11
h	0.89	0.92	0.68	0.93	0.89
n	0.84	0.83	0.66	0.87	0.82
(h/n)	0.74	0.87	0.50	0.79	0.79
u	−0.89	−0.84	−0.79	−0.93	−0.88
v	0.94	0.86	0.70	0.97	0.90
vu	0.94	0.86	0.76	0.96	0.90
w	−0.11	0.25	0.31	0.23	0.18
$Corr(a,h)$	−0.53	0.03	−0.37	−0.47	−0.34
$Corr(w,h)$	−0.28	0.25	−0.09	0.14	−0.01

Notes: The table reports the average cross correlations between each variable and output (apart from the last row) computed over 100 simulations of the estimated VAR process drawing he innovations from the estimated structural shocks. The last row reports the cross correlation between labor productivity and average hours. The first four columns report the results when allowing for shocks only to each individual structural shock. The last column reports the results when allowing for all four shocks simultaneously

Table 5: Variance Decomposition

A. Variance of counterfactual output as percent total output variance

	VAR specification		
Shock	Baseline VAR	Hours in diffs.	u and v in diffs.
Investment	9.4	9.5	11.5
Neutral	20.1	19.6	20.7
Government	6.2	5.03	4.8
Monetary	11.9	9.1	9.8
All	51.5	48.8	50.6

B.Variance of counterfactual hours as percent total hours variance

	VAR specification		
	Baseline	Hours in diffs.	u and v in diffs
Investment	11.1	8.3	16.6
Neutral	13.5	12.9	8.6
Government	5.2	5.02	4.5
Monetary	12.2	8.9	10.4
All	46.7	39.9	44.4

Table 6: Conditional Correlations

A. Correlation between hours and output

	VAR specification		
Shock	Baseline VAR	Hours in diffs.	u and v in diffs.
Investment	0.88	0.88	0.87
Neutral	0.91	0.82	0.67
Government	0.67	0.64	0.61
Monetary	0.93	0.92	0.92
All	0.89	0.85	0.80

B.Correlations between output and average labor productivity

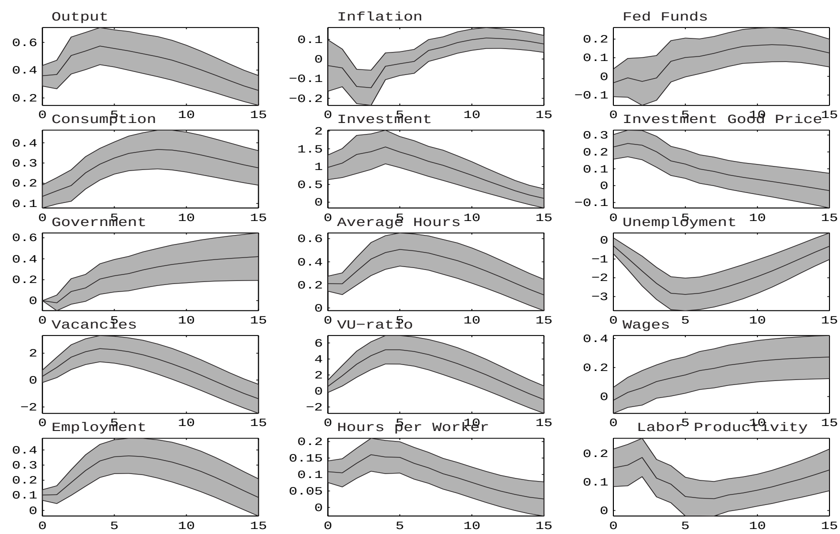
	VAR specification		
	Baseline	Hours in diffs.	u and v in diffs
Investment	-0.14	0.14	-0.34
Neutral	0.38	0.46	0.69
Government	0.40	0.29	0.33
Monetary	-0.15	-0.09	-0.14
All	0.11	0.25	0.24

Table 7. Augmented Dickey-Fuller test for unit root

A. Sample 1972:I -1993:IV					
Lags	Employment	Average Hours	Unemployment	Vacancies	Wages
Trend	Yes	No	No	No	Yes
0	-1.13	-1.19	-1.38	-1.23	-2.70
1	-3.65**	-2.37	-2.94*	-3.50*	-2.96
2	-3.26*	-2.39	-2.60**	-3.11*	-3.28**
3	-3.40**	-2.26	-2.69**	-3.54**	-3.43**
B. Sample 1959:III -1993:IV					
Lags	Employment	Average Hours	Unemployment	Vacancies	Wages
Trend	Yes	No	No	No	Yes
0	-1.70	-1.53	-1.01	-1.43	-1.92
1	-4.00*	-2.96*	-2.24	-3.83*	-1.87
2	-3.74*	-2.95*	-2.28	-3.27*	-1.90
3	-3.48*	-2.79*	-2.05	-3.54*	-1.6
C. Sample 1972:I -2003:I					
Lags	Employment	Average Hours	Unemployment	Vacancies	Wages
Trend	Yes	No	No	Yes	Yes
0	-0.25	-1.09	-1.36	-0.43	0.24
1	-3.11**	-2.01	-2.72**	-3.08	-0.17
2	-3.03	-2.16	-2.73**	-2.85	-0.71
3	-3.03	-2.05	-2.70**	-3.40**	-0.73

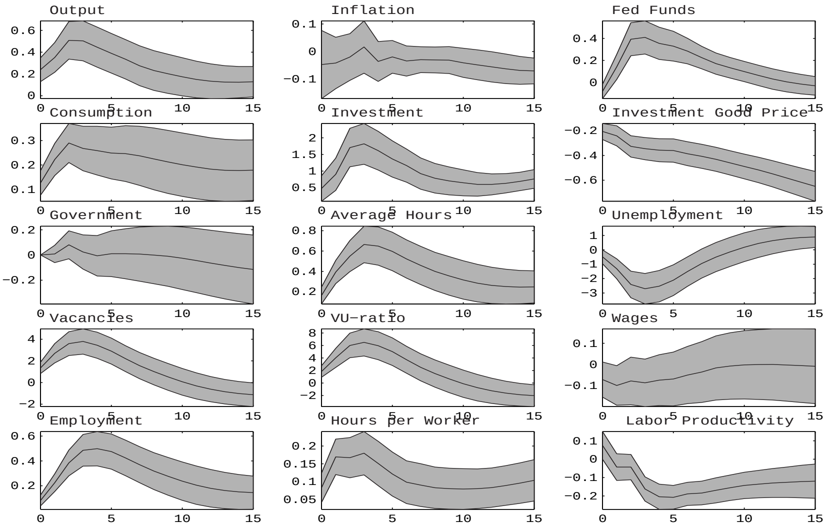
Notes: The table reports the t-ratio of the level of the lagged dependent variable in augmented Dickey-Fuller regressions for different samples. ** denotes significance at the 10 percent level, and * at the 5 percent level.

Figure 1-A: Response to a Neutral Technology Shock.



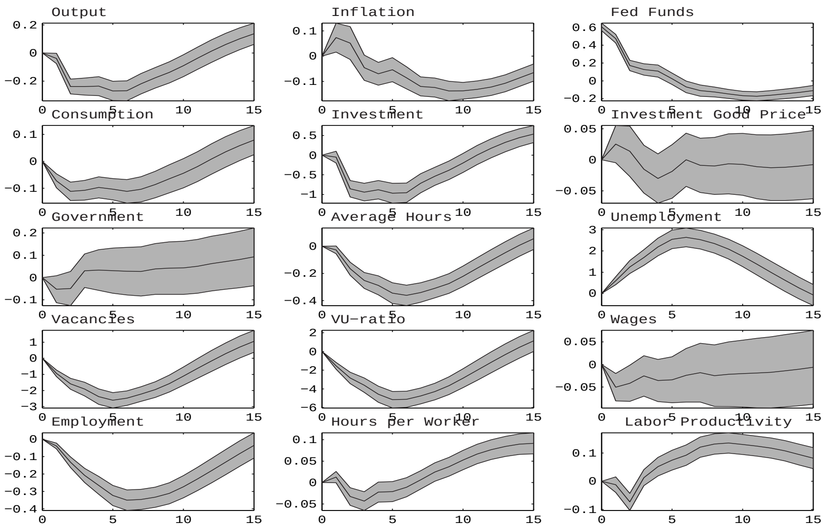
The figures illustrate the responses to a neutral technology shock - baseline case. Grey area represents the 66 % confidence interval.

Figure 1-B: Response to an Investment-Specific Technology Shock.



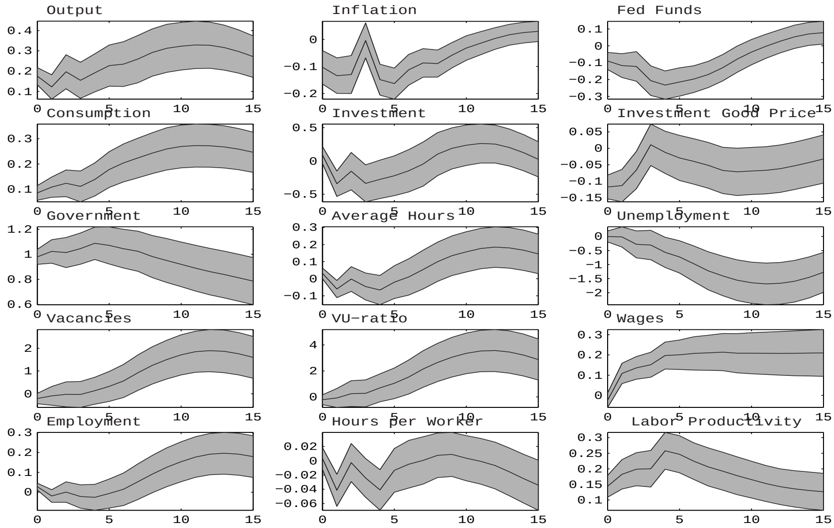
The figures illustrate the responses to an investment-specific technology shock - baseline case. Grey area represents the 66 % confidence interval.

Figure 1-C: Response to a Monetary Policy Shock.



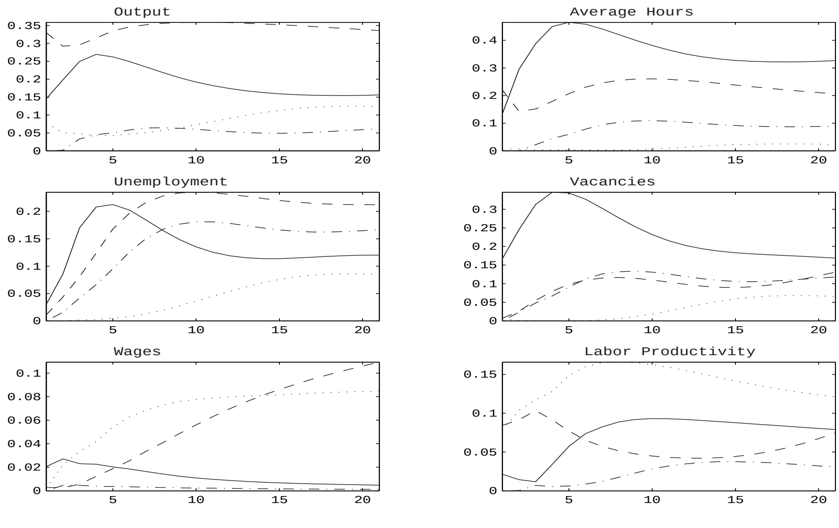
The figures illustrate the responses to a monetary policy shock - baseline case. Grey area represents the 66 % confidence interval.

Figure 1-D: Response to a Government Spending Shock.



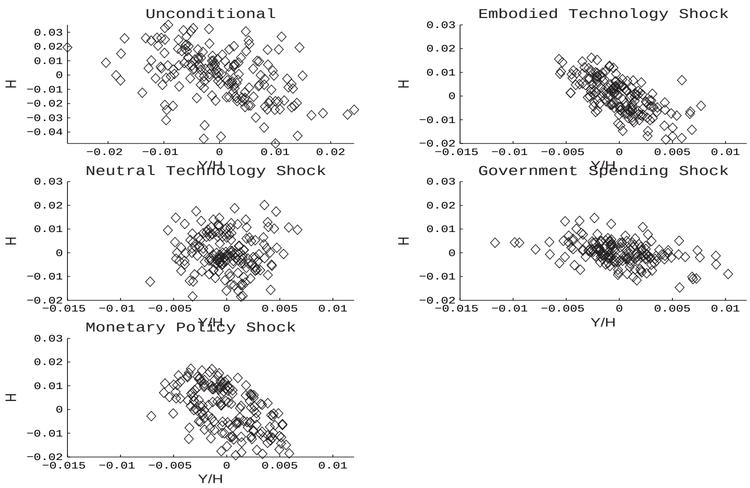
The figures illustrate the responses to a government spending shock - baseline case. Grey area represents the 66 % confidence interval.

Figure 2: Forecast Error Variance Decomposition.



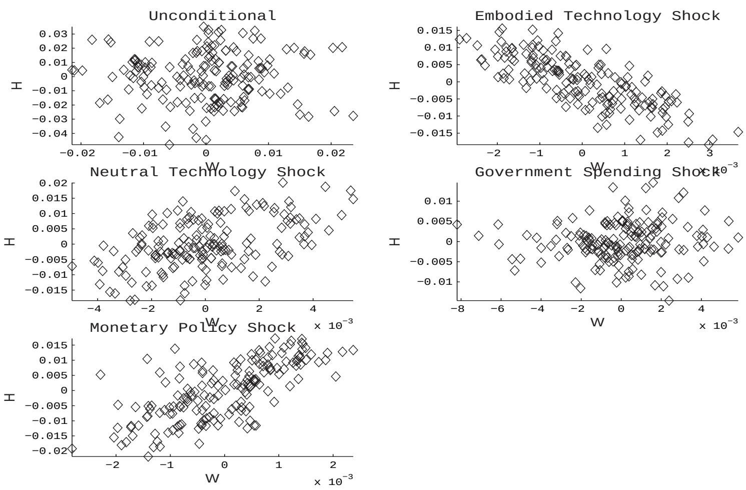
The figures illustrate forecast error variance decomposition for different forecast horizons. The dashed line refers to the neutral technology shock, the solid line to the embodied technology shock, the dotted line to the government spending shock and the dash-dotted line to the monetary policy shock.

Figure 3-A: Business cycle components of hours worked vs. average labor productivity



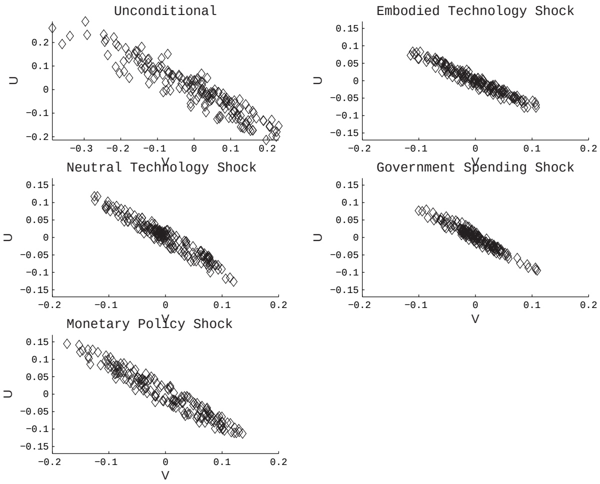
The figures illustrate the scatterplots of the business cycle components of hours worked and average labor productivity conditional upon each of the four structural shocks.

Figure 3-B: Business cycle components of hours worked vs. real wages



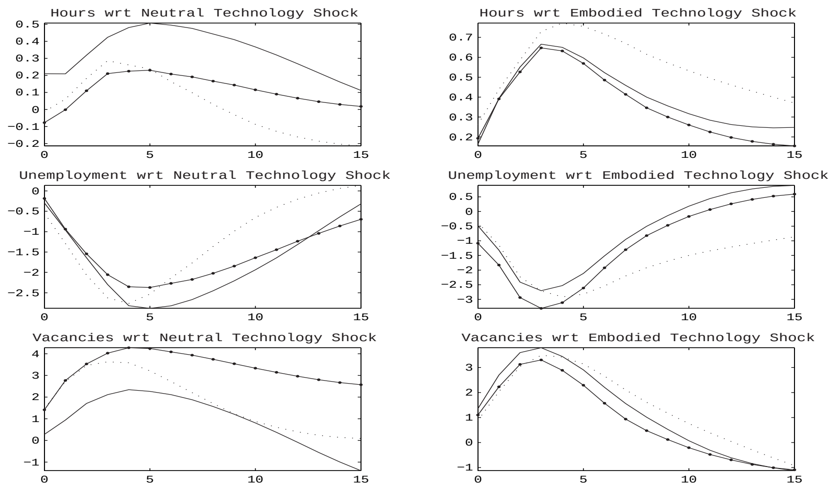
The figures illustrate the scatterplots of the business cycle components of hours worked and real wages conditional upon each of the four structural shocks.

Figure 4: Conditional and Unconditional Beveridge Curve



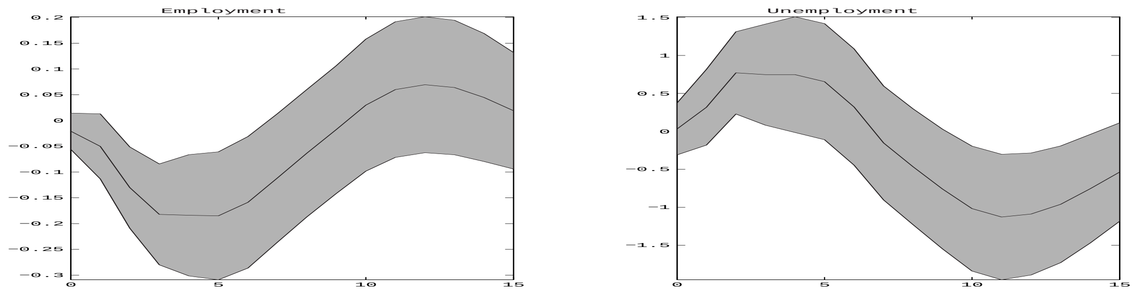
The figures illustrate the scatterplots of the business cycle components of unemployment and vacancies conditional upon each of the four structural shocks.

Figure 5: Labor Marked Response to Technology Shocks.

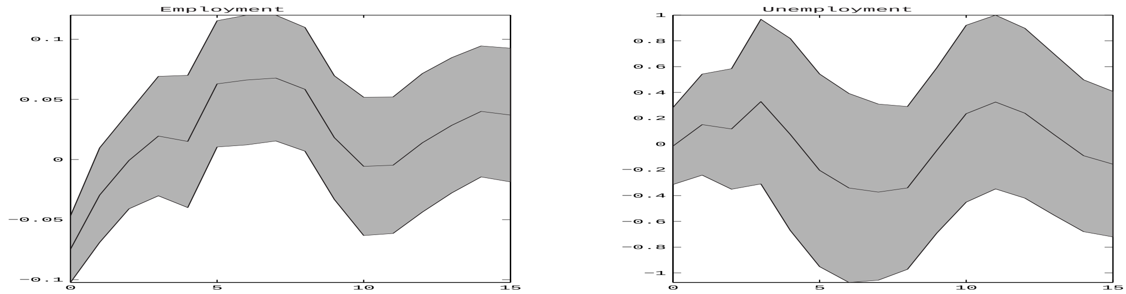


The figures illustrate the responses to a neutral (left-hand side) and an investment-specific (right-hand side) technology shock for different VAR specifications. The solid line refers to the baseline VAR specification, the dash-dotted line to the VAR specification with hours in first differences and the dotted line to the VAR specification with unemployment and vacancies in first differences.

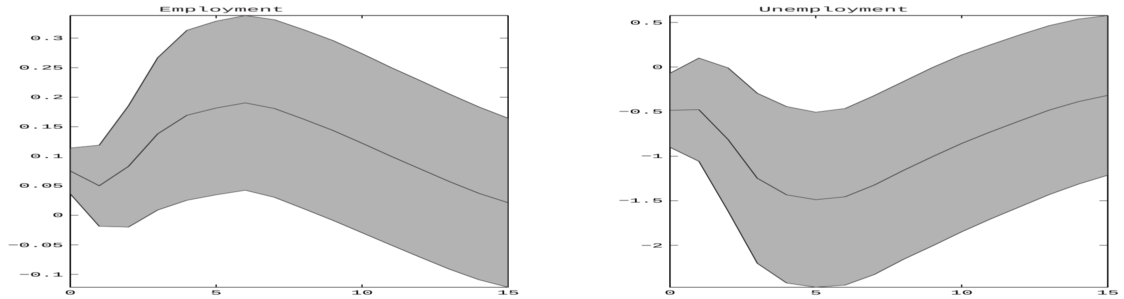
Figure 6: Employment and Unemployment response to a Neutral Technology Shock



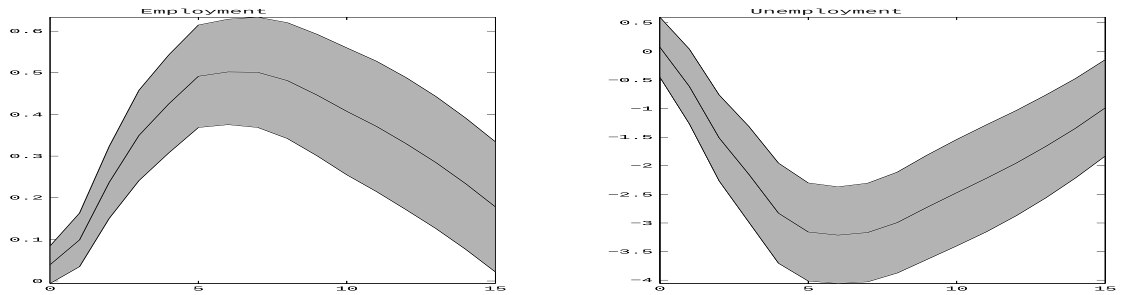
(a) sample period 1972:I-1993.IV



(b) sample period 1972:I-1993.IV (hours in first differences)



(c) sample period 1959:III - 1993.IV



(d) sample period 1972:I - 2003.IV

The figures illustrate the employment (left-hand side) and unemployment (right-hand side) responses to a neutral technology shock for different samples. The labor variables enter the VAR with the following transformation: in the sub-sample 1972-1993 unemployment and vacancies are in levels and hours is in level in panel (a) and in first differences in panel (b); in the sub-sample 1959-1993 hours and vacancies in levels, and unemployment in first differences; in the sub-sample 1972-2003 unemployment and vacancies in level, and hours in differences.