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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 aggregate effects of two structural technology shocks and two 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 is required.

Keywords: Structural VAR; labor market dynamics; the Beveridge curve

JEL classification: *C*32; *E*24; *E*32; *E*52; *E*62

I. Introduction

The labor market plays a special role in business cycle research. As stressed by Kydland (1995), 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 market has also been central to much of the past and current debate about business cycle theory. Following Kydland and Prescott's (1982) seminal contribution, a great deal of research during the 1980s and early 1990s focused on the difficulty of accounting for the volatilities of hours worked and of labor productivity,

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and for the low covariance between these variables at business cycle frequencies. This led to the development of theories with labor market indivisibilities by Hansen (1985) and Rogerson (1988), homework by Benhabib, Rogerson and Wright (1991), and fiscal policy shocks by Christiano and Eichenbaum (1992) and McGrattan (1994).[1]

More recently, the profession has revived its interest in the labor market. Following Galí (1999), a large literature has questioned the validity of the implications of standard business cycle theories for the cyclical movements in labor input and in aggregate labor productivity. Using a structural vector autoregression (SVAR) technique, Galí (1999) finds that 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* on permanent productivity shocks. The debate surrounding these results has still not reached a firm conclusion.[2]

Building on 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 labor market tightness (the ratio of vacancies to unemployment). Hall (2005) and Shimer (2005) conclude that, in response to productivity shocks, labor market matching 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. Using a SVAR approach, we examine how the economy, and central labor market variables in particular, respond to structural shocks. Our list of labor market indicators includes average

[1] Indivisibilities in hours worked increase the volatility of aggregate hours worked but do not have much effect on 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 mainly affect labor supply.

[2] Studies that find evidence consistent with Galí (1999) include, among many others, Alexius and Carlsson (2005), Basu, Fernald and Kimball (2006), Francis and Ramey (2005), and Pesavento and Rossi (2005). Christiano, Eichenbaum and Evans (2005) is a prominent example of studies that challenge Galí'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).

[4] Hagedorn and Manovskii (2006) show that high bargaining power of firms combined with a high value of not working on the part of workers may imply high volatility of unemployment and vacancies even if wages are determined by Nash bargaining.

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hours worked, employment, hours per worker, unemployment, vacancies, labor market tightness, average labor productivity, and real wages. We focus our attention on 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 is an investment-specific technology shock. The other two shocks are related to economic policy. We identify monetary policy shocks studied in the line of research on nominal rigidities, as well as government spending shocks highlighted as potentially important in 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 function. (ii) How important are the structural shocks for the volatility of the labor market variables at business cycle frequencies? We examine this by computing forecast error 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 business cycle frequencies conditional on 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. This aspect of the paper allows us to take a stand on how the structural shocks shape business cycle dynamics of the U.S. economy.

One difficulty with the VAR analysis is that it is hard to establish exactly the most suitable specification of the trend stationarity of a number of the labor market indicators. In particular, average hours worked and unemployment are borderline non-stationary in our sample. 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:

(i) Hours worked, employment, vacancies, and the *vu*-ratio increase gradually over time in response to positive technology shocks and to expansionary monetary policy shocks, while unemployment declines. The dynamic responses of these variables are markedly hump-shaped with peak effects occurring after three to five quarters. Government spending shocks lead to very outdrawn responses.

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(ii) The *impact* effect of neutral technology shocks on average hours worked depends critically on the VAR specification. However, there is robust evidence that hours and output are positively correlated at business cycle frequencies in response to neutral technology shocks.
(iii) 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.
(iv) 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.
(v) The covariance between output and labor productivity and between hours, real wages and productivity depends critically on the source of shocks to the economy. Neutral technology shocks lead to positive comovements of hours and real wages but orthogonal movements of hours and productivity; investment-specific shocks are associated with negative comovements between hours and real wages and between hours and labor productivity. A mixture of shocks is required to account for the unconditional cross-correlations between key labor market indicators.
(vi) The results are stable over time.

The stylized facts of the data are described in Section II. In Section III we outline the identification and estimation strategies. After reporting the results in Section IV, we examine the robustness of the results in Section V. Section VI summarizes and concludes.

II. 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 related to labor as a production factor and to labor market search indicators. 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, 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 A1.

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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 A1 for sources and definitions. The business cycle moments were computed from Hodrick–Prescott filtered data using a value of 1,600 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 numbers in parentheses report the correlation at this lead or lag.

Table 1 reports the business cycle moments of the data. We computed 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 1980s and 1990s. Consistent 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 is acyclical, but possibly lags output by as much as six to seven quarters.

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). A partial explanation for the relatively high volatility of hours worked is that our hours-worked series is 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 labor input is therefore much

[5] The indicator 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.

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more important than the intensive margin at business cycle frequencies; see Burdett and Wright (1989) for a theoretical analysis. It is also evident that employment is more closely related to output 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. In contrast, previous contributions 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), Hansen and Wright (1992) and Kydland and Prescott (1990).[7] The real wage is mildly procyclical and displays almost exactly the same volatility as labor productivity. We confirm the Dunlop–Tarshis observation regarding the near orthogonality of real wages and hours worked (the cross-correlation is 0.01).

Unemployment and vacancies display large volatilities at business cycle frequencies. The standard deviation of unemployment per capita is almost seven times higher than the standard deviation of output, while the corresponding number for vacancies is above eight. 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. We also report the correlation of unemployment and vacancies. In our sample, this correlation is −0.93 which is consistent with the existence of a Beveridge curve.

III. Identification and Estimation Strategy

We apply a 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 literature. This minimizes problems of omitted variables. Second, 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.

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Identification

We identify four structural shocks considered important in the business cycle literature: two types of permanent productivity shocks and two shocks related to economic policy. Much of the past literature has studied the impact of neutral technology shocks,[8] and such shocks also play a prominent role in the recent literature on business cycles and labor market matching.[9] Fisher (2006) argues that 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. These are the first two structural shocks that we identify.

Other parts of the business cycle literature have paid more attention to "demand-type" shocks, particularly monetary policy shocks and fiscal policy shocks. The former have been studied intensively in the literature that builds on the existence of nominal rigidities; see e.g. Christiano *et al.* (2005).[10] Fiscal shocks have also been studied 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 focus on unexpected changes in government purchases of goods and services as a candidate for fiscal policy shocks.

Consider the following reduced-form 12-dimensional VAR:

$$x_t = a + B(L)x_{t-1} + e_t, \tag{1}$$

where

$$x_t \equiv [\Delta g_t \;\; \Delta p_t^i \;\; \Delta a_t \;\; z_t \;\; r_t]' \quad \text{and} \quad z_t \equiv [\Delta w_t \;\; \Delta p_t^y \;\; uc_t \;\; \tilde{h}_t \;\; cy_t \;\; iy_t \;\; \tilde{u}_t \;\; \tilde{v}_t]'$$

are vectors of variables and $B(L)$ is a lag polynomial of order M. The variables in the VAR are the changes in government purchases of goods and services (Δg_t), in the relative price of investment goods (Δp_t^i),[11] in average labor productivity (Δa_t), in real wages (Δw_t), and in the implicit GDP deflator (Δp_t^y); the logarithm of the capacity utilization rate (uc_t); a measure of aggregate average hours worked ($\tilde{h}_t$); the logarithm of the nominal consumption share of output (cy_t); the logarithm of the investment

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

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share of output (iy_t); measures of unemployment ($\tilde{u}_t$) and of vacancies ($\tilde{v}_t$); and the federal funds rate (r_t). Precise definitions of the variables are given in Table A2.

We assume stationarity of the growth rate of government spending, the changes in the relative price of investment goods, labor productivity, the federal funds rate, and of the elements of the vector z_t. As is well known, aggregate hours are borderline non-stationary.[12] Unemployment and vacancies are stationary, but non-stationarity of unemployment can be rejected only at the 10 percent level. In our baseline specification, we use the log of average hours, the log of unemployment and the log of vacancies. Later we examine the sensitivity of the results to these assumptions.

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 (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 12×1 vector of ones.

The two productivity shocks are identified using long-run restrictions, while the policy shocks are identified on the basis of short-run restrictions. As in Fisher (2006), the investment-specific shock is identified by 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 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 on goods and services does not react to unexpected movements in any other variable. Thus, it 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).

Following Christiano and Eichenbaum (1996) we identify the monetary policy shock by assuming that the Fed can react to the current realizations

[12] Detailed ADF tests are omitted here but are reported in Ravn and Simonelli (2007).

[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.

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of all other variables in the VAR, but that these variables are affected by monetary policy shocks only with a one-period lag. This corresponds to the assumption that the Fed's information set includes the current values of all other variables in the VAR. Moreover, the Fed's policy instrument is assumed to be the federal funds rate and we assume a linear policy rule.[14]

Estimation

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

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

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

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

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

where Δ^2 denotes the double difference operator.

Equation (3), estimated by least squares, identifies the fiscal policy shock (ε_t^g). This equation imposes the identifying assumption that government spending does not react contemporaneously to any other unexpected shocks by including only lagged regressors. 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 change in) the relative investment goods price itself. Moreover, the contemporaneous value of

[14] We repeated the analysis by expanding the VAR with velocity (and excluding the current value of this variable from the Fed's information set). None of the results changes significantly.

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the federal funds rate is excluded from this regression. This equation is estimated by 2SLS since Δa_t and z_t may depend on ε_t^p. The instruments are a constant, the vector $[\Delta g_{t-j}, \Delta p_{t-j}, \Delta a_{t-i}, z_{t-j}, r_{t-j}]_{j=1}^M$ and $\hat{\varepsilon}_t^g$ (the estimate of ε_t^g). By including this disturbance as an instrument, we impose our assumption that investment technology and government shocks are orthogonal. 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 effect on labor productivity. Again, this relationship is estimated using 2SLS. The instruments are the same as those above extended with $\hat{\varepsilon}_t^p$. The monetary policy shock (ε_t^r) is estimated from (6) using least squares.

We adopt the recursive 2SLS approach of Altig, Christiano, Eichenbaum and Linde (2005) to estimate the parameters of the equations for the vector z_t. Denote the components of z_t by z_t^i, $i = 1, \ldots, 8$. The parameters of the first of these equations are obtained by estimating:

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

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

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

$$\tilde{n}_t = \alpha_n + \sum_{j=0}^{M} \beta_j^n x_{t-j} + \sum_{j=1}^{M} \gamma_j \tilde{n}_{t-j} + \varepsilon_t^n, \tag{8}$$

where $\tilde{n}_t$ denotes linearly detrended log employment per capita. We impose that $\beta_{0,r}^n = 0$, which is consistent with the assumptions made when identifying the monetary policy shock. Technically, by extending the VAR in equation (2) with employment, the specification in equation (8) restricts the last columns of $\beta_0 - \beta_M$ to have zeros in all but the last position. While this restriction may be questioned, entering employment into the VAR without such a restriction leads to serious multicollinearity problems (due to the close relationship between employment and average hours worked).

From this regression we computed the responses of employment per capita. We derived the dynamics of hours per worker by combining these

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responses with those of average hours worked.[15] This decomposition is informative 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]

IV. Results

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

Dynamic Responses to Structural Shocks

We computed impulse responses for forecast horizons of 16 quarters and report the point estimates along with one standard error (66 percent) confidence intervals (computed with a non-parametric bootstrap). In all cases the size of the innovation is set equal to the standard deviation of the identified structural shock.

Neutral Technology Shocks. Figure 1, Panel A, illustrates the responses of the variables to the identified permanent neutral technology shock. A positive neutral technology shock leads to hump-shaped increases in output, consumption and investment. The peak effects on output and investment occur around one year after the impulse at which horizon output (investment) increased by about 0.6 (1.5) percent above its original level. 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 our elasticities tend to be slightly lower.

Hours worked increase by approximately 0.25 percent on impact and this response goes up to 0.5 percent at the five-quarter horizon. In contrast to Galí (1999), we do *not* find a decline in hours worked in response

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

[16] Many standard business cycle theories do not make a distinction between the extensive and 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 center of labor input fluctuations. The extensive margin is also emphasized by many other labor market theories such as efficiency wage theories, and by bargaining and union models.

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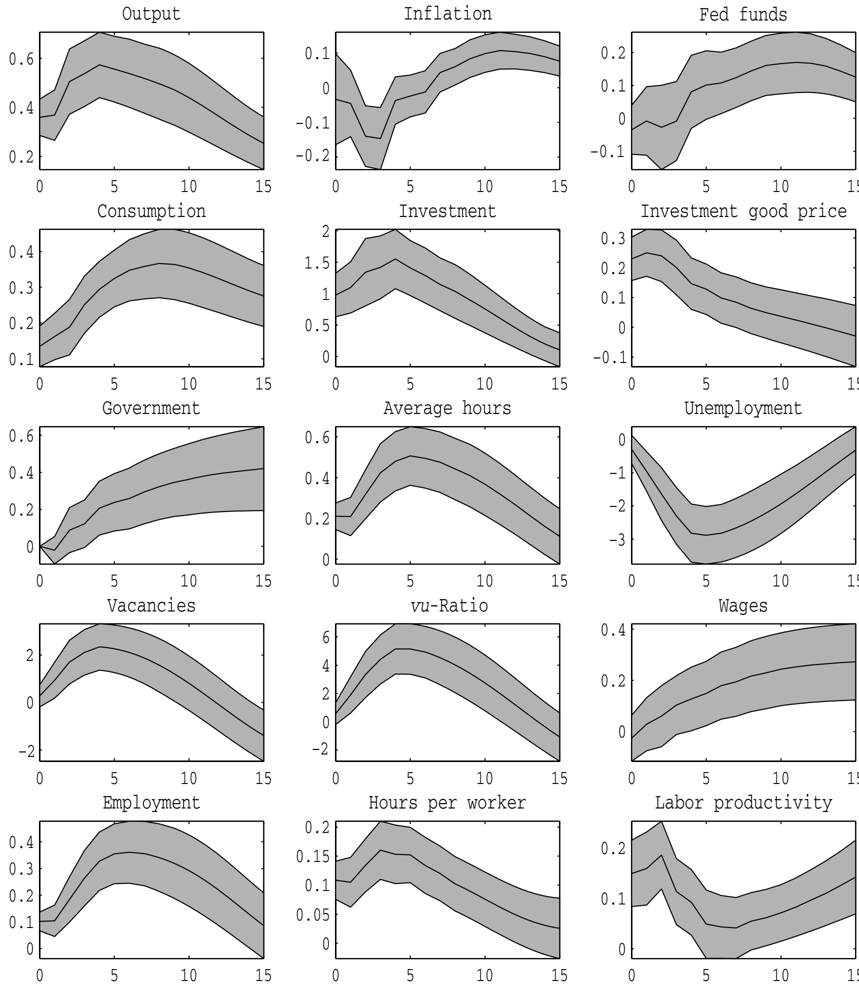

Fig. 1, Panel A. Response to a neutral technology shock
Notes: The figures illustrate the responses to a one-standard-deviation neutral technology shock—baseline case. Gray area represents the 66 percent bootstrapped confidence interval.

to a positive technology shock. This result, however, is not robust to the VAR specification. In particular, we show later that the *impact effect* of neutral technology shocks on average hours worked is zero or even negative when the VAR includes first differences of average hours worked or of unemployment and vacancies. Consistent with the unconditional moments (hours worked lagging output), the peak effect of hours worked is reached later than the peak effect of output.

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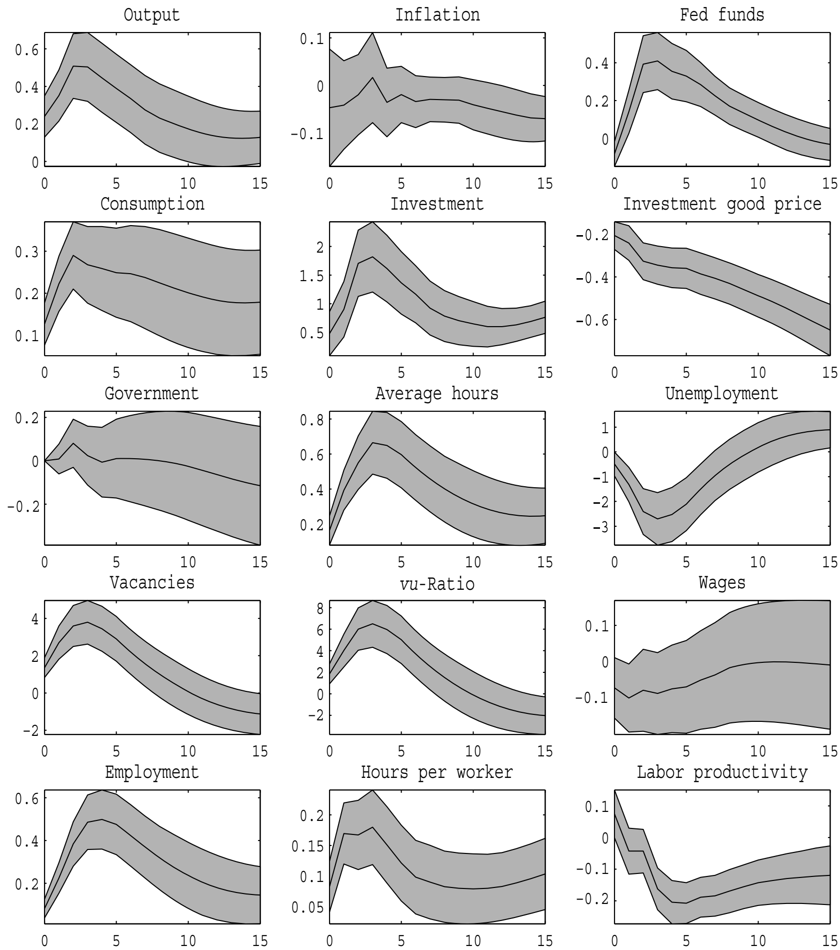

Fig. 1, Panel B. Response to an investment-specific technology shock
Notes: The figures illustrate the responses to a one-standard-deviation investment-specific technology shock—baseline case. Gray area represents the 66 percent bootstrapped confidence interval.

The decomposition into the intensive and extensive margins shows that each is positively affected by the neutral technology shock, but with noticeably different dynamics. In particular, hours per worker rise fast but with a small elasticity (0.15 at the peak), while employment increases sluggishly (with a peak six to seven 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 of employment and

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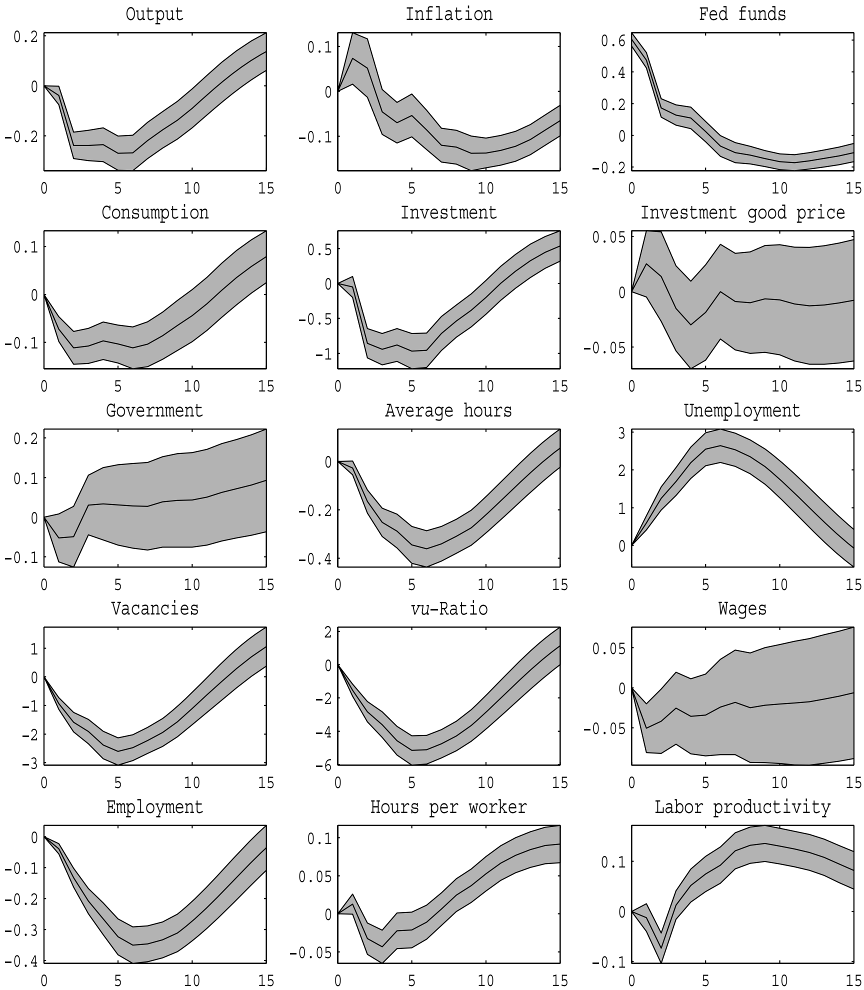

Fig. 1, Panel C. Response to a monetary policy shock
Notes: The figures illustrate the responses to a one-standard-deviation monetary policy shock—baseline case. Gray area represents the 66 percent bootstrapped confidence interval.

hours worked reveal a pattern similar to that apparent in the unconditional moments reported in Table 1.

The dynamics of unemployment and vacancies in response to neutral technology shocks display large and marked hump-shaped responses to the neutral technology shock. Unemployment reacts only slightly on impact but then drops by 3 percent four quarters after the technology shock. Vacancies follow a bell-shaped response that reaches a maximum 2 percent increase with a delay of four quarters. Together these imply a gradual but large

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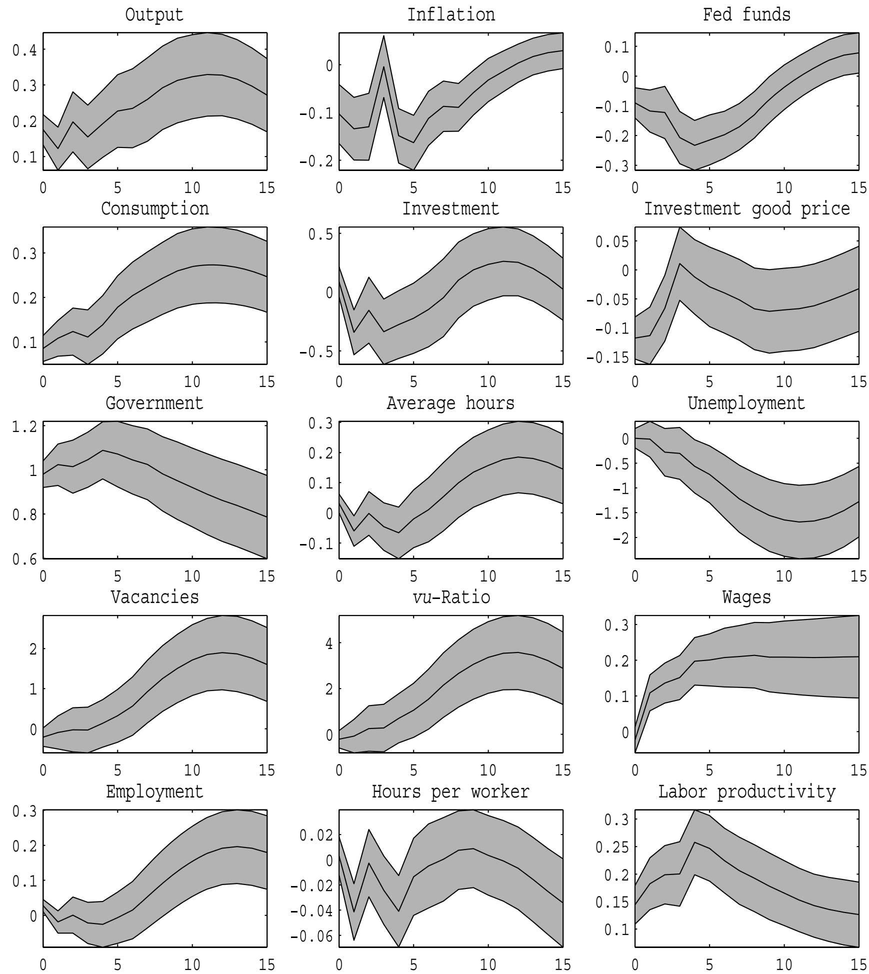

Fig. 1, Panel D. Response to a government spending shock
Notes: The figures illustrate the responses to a one-standard-deviation government spending shock—baseline case. Gray area represents the 66 percent bootstrapped confidence interval.

impact on labor market tightness that rises by 5 percent with a four-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 note that the elasticity of labor productivity to the neutral technology shock is much lower than the

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elasticity of output to this shock. The real wage does not display hump-shaped dynamics. We find that the real wage rises slowly in response to the neutral technology shock with little response on impact, but a 0.3 percent rise at the four-year horizon.[17]

Investment-specific Technology Shocks. Figure 1, Panel B, shows the effects of an investment-specific technology shock. This shock lowers the relative investment price on impact and in the long run. Output, consumption and investment rise in response to the investment-specific technology shock with peak effects occurring three to four quarters 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).

An improvement in investment-specific technology is associated with a small but positive impact effect on hours worked. After three quarters there is quite a large increase in hours worked of 0.65 percent above their 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 rising again at long forecast horizons. The relatively small impact on labor productivity is consistent with 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 labor margins. Hours per worker rise faster than employment but with a much smaller elasticity.

Interestingly, the investment-specific shock sets off 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. On impact, there is little effect on 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 decrease. After this, unemployment returns to its original level around two years after the technology shock. Vacancies reach a peak effect (a 3.5 percent rise) three quarters after the investment-specific shock. These responses imply large volatility of the *vu*-ratio which rises by more than

[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.
[18] Fisher's (2006) results depend critically on the VAR specification—see Figure 6 in his paper. We return to this issue below.

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1 percent on impact and by more than 6 percent with a delay of three quarters.

Our results on the labor market impact of the two types of technology shocks are consistent with Braun, De Bock and DiCecio (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 finds 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.

In contrast, Canova, Michelacci and López-Salido (2006) and Michelacci and López-Salido (2006) find 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 the period 1972–1993.

Monetary Policy Shocks. Figure 1, Panel C, shows the responses to a contractionary monetary policy shock. This shock corresponds to a persistent rise in the federal funds rate which leads to a temporary decline in output, consumption and investment with the largest effects taking place five to six quarters after the contraction of monetary policy. At longer forecast horizons, these variables gradually return 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 of "inflation persistence" (a long-lived subsequent drop in inflation).

Hours worked fall persistently in response to a monetary policy contraction. The fall in average hours worked reaches a maximum of 0.35 percent six quarters after the rise in the interest rate. Note 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, labor productivity first declines briefly in response to the increase in interest rates, but rises after a few quarters. The real wage, in contrast,

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is left approximately unaltered by the monetary policy shock. This result seems inconsistent with the presence of substantial nominal wage rigidity.

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 six quarters after the rise in interest rates. Vacancies follow a mirror image of the unemployment dynamics and reach a maximum decline of 2.5 percent five quarters after the monetary policy shock. Therefore, the *vu*-ratio displays a large and persistent decline with a peak of close to 6 percent five to six quarters after the monetary policy shock. This evidence appears to indicate a role for monetary policy shocks for labor market fluctuations.

Government Spending Shocks. Figure 1, Panel D, plots the responses of the variables to an identified government spending shock. This shock is estimated to be a very persistent rise that peaks one year after the initial increase in government spending, consistent with e.g. Galí, López-Salido and Vallés (2007). We find very protracted responses of the other variables. Output rises but the maximum impact does not occur until three years after the initial increase in government spending. Like Blanchard and Perotti (2002), Fatas and Mihov (2001) and Galí *et al.* (2007), we find that the increase in government spending is associated with a persistent rise in private consumers' expenditure. However, investment 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 three years after the increase in government spending, when average hours worked 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 three-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 three years

[19] This result might be consistent with theories that emphasize declines in markups 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.

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after the increase in government spending and, at this horizon, unemployment declines by around 1.5 percent and vacancies rise by around 1.5 percent.

Importance of the Structural Shocks

We now examine the importance of the identified shocks for the volatilities of the variables. We begin by inspecting forecast error variance decompositions. Next, we compute the volatilities of the variables on the basis of HP-filtered simulated data from counterfactual experiments. The difference between these two sets of computations is that the latter concentrates the moments at business cycle frequencies while the former involves a mixture of fluctuations at alternative frequencies. The moments derived from the second set of experiments are therefore comparable to the unconditional moments of Table 1 while the former are not.

Variance Decompositions. Figure 2 displays the forecast error variance decompositions of output and the labor market indicators at forecast horizons of five years. Neutral technology shocks are the dominating impulse to output dynamics and, regardless of the forecast horizon, account 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 two 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 dominated by the investment-specific shock that accounts for 30–45 percent of the hours variance. Neutral technology shocks are also of some importance and account for around 20 percent of the forecast error variance of hours worked. The four shocks combined account for nearly 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 quite significantly to the volatility in unemployment (around 52 percent). The volatility of vacancies is 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.

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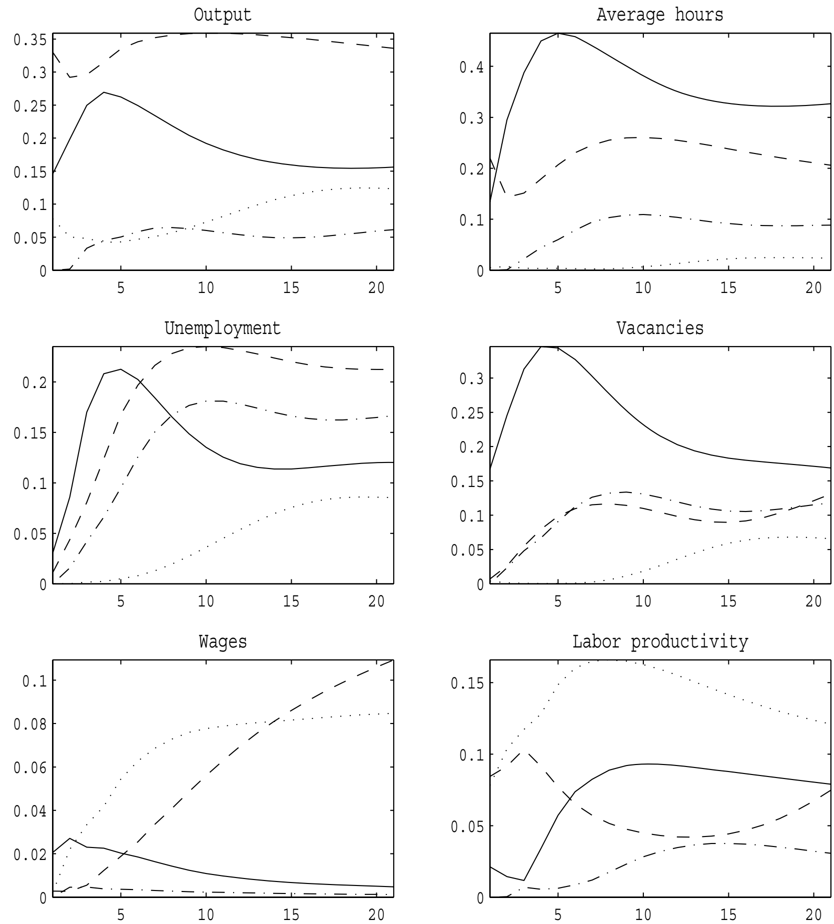

Fig. 2. Forecast error variance decomposition
Notes: The figures illustrate forecast error variance decomposition for different forecast horizons. The dashed line refers to the neutral technology shock, the solid line to the embodied technology shock, the dotted line to the government spending shock and the dash-dotted line to the monetary policy shock.

Perhaps the most interesting insights from the forecast error variance decomposition are related to the results for labor productivity. According to our computations, 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 it is only at long forecast horizons that the four shocks in total

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Table 2. *Conditional standard deviations*

	Percentage standard deviation conditional on innovations to				
	Technology shocks		Policy shocks		
Variable	Investment	Neutral	Government	Monetary	All
Output	0.48	0.70	0.39	0.54	1.12
Consumption	0.29	0.39	0.23	0.25	0.61
Investment	1.72	2.20	1.27	2.03	3.81
Labor productivity	0.24	0.27	0.28	0.21	0.53
Hours	0.58	0.64	0.40	0.61	1.19
Employment	0.46	0.50	0.33	0.53	0.97
Hours per worker	0.17	0.19	0.11	0.14	0.32
Unemployment	3.37	3.96	2.70	4.15	7.51
Vacancies	4.25	4.47	2.98	4.68	8.69
vu-Ratio	7.49	8.33	5.58	8.76	16.01
Wages	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 structural shock. The last column reports the results when allowing for all four shocks simultaneously.

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 important sources of volatility in real wages and in labor productivity that are not identified by the four structural shocks.

Business Cycle Volatility. Using our parameter estimates and the estimated structural shocks, we computed the time paths of output using counterfactual experiments. More precisely, we computed the time path of a variable x_t using the VAR parameter estimates feeding in randomly drawn sequences of each of the identified shocks separately (or all four shocks jointly) while setting all other innovations equal to zero. We then HP-filtered the artificially generated data. The standard deviations over 100 experiments are reported in Table 2.

At 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

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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. Nevertheless, in the robustness analysis in Section V we show that the relative importance of neutral and investment-specific technology shocks is very sensitive to the VAR specification and is reversed if we include average hours worked or unemployment and vacancies in first differences in the VAR.

The four shocks account for 44–47 percent of the volatilities of the search indicators. 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 those of the monetary policy shocks. In contrast, there is little role for government spending 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.

Consistent 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.

Conditional Comovements. Table 3 reports the conditional correlations between the variables computed from counterfactuals. 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 evident for the correlations between output and consumption, investment, average hours worked, employment, unemployment, vacancies and the *vu*-ratio in response to the two types of technology shocks and 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 does not account for more than 45–55 percent of the variance of the variables, the

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

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Table 3. *Conditional cross-correlations*

Variable	Correlation with output conditional on innovations to				
	Technology shocks		Policy shocks		
	Investment	Neutral	Government	Monetary	All
Consumption	0.84	0.90	0.87	0.93	0.89
Investment	0.90	0.94	0.68	0.97	0.91
Labor productivity (a)	−0.14	0.38	0.36	−0.15	0.11
Hours (h)	0.89	0.92	0.68	0.93	0.89
Employment	0.84	0.83	0.66	0.87	0.82
Hours per worker	0.74	0.87	0.50	0.79	0.79
Unemployment	−0.89	−0.84	−0.79	−0.93	−0.88
Vacancies	0.94	0.86	0.70	0.97	0.90
vu-Ratio	0.94	0.86	0.76	0.96	0.90
Wages	−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 the 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.

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. In contrast, investment-specific technology shocks give rise to countercyclical movements in real wages and in labor productivity. Moreover, in response to investment-specific shocks, the VAR estimates imply a large negative cross-correlation between labor productivity and hours worked. Conditional on monetary policy shocks, labor productivity comoves negatively with output and with average hours worked, while real wages move 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 U.S. business cycles. This is examined more closely in Figure 3 which plots hours against labor productivity (Panel A), and hours

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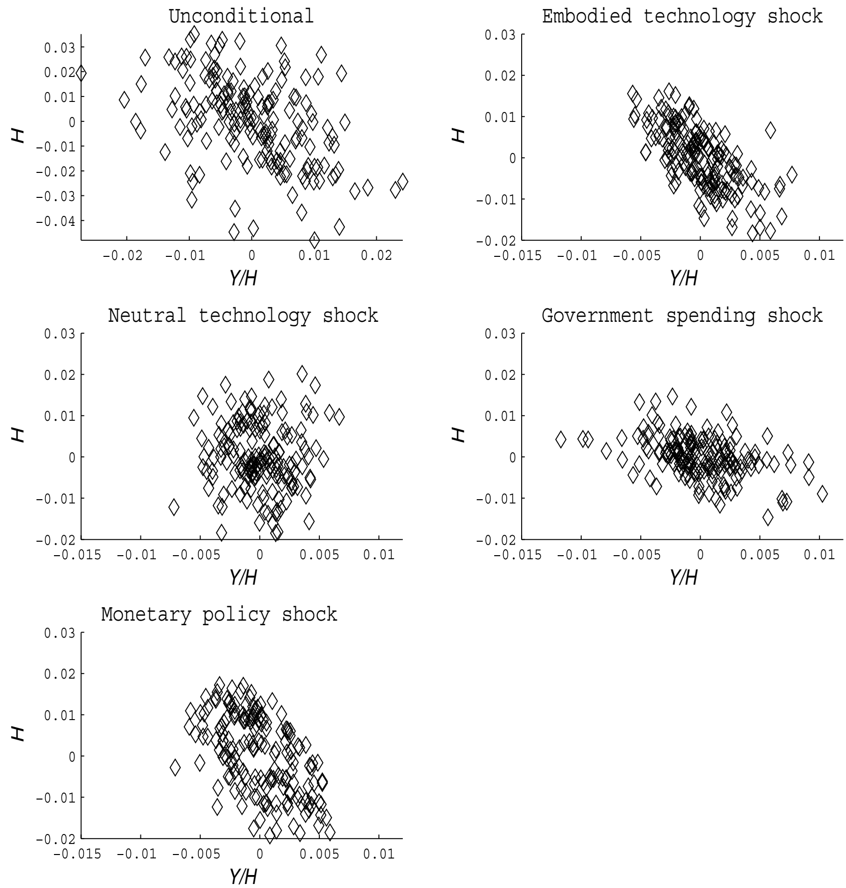

Fig. 3, Panel A. Business cycle components of hours worked vs. average labor productivity
Note: The figures illustrate the scatterplots of the business cycle components of hours worked and average labor productivity conditional on each of the four structural shocks.

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 evident that investment-specific shocks are the main culprit regarding the negative unconditional correlation between average hours worked and labor productivity, while neutral technology shocks weaken this correlation. 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 generate negative comovements between these variables. We believe that these results deserve further attention in future research.

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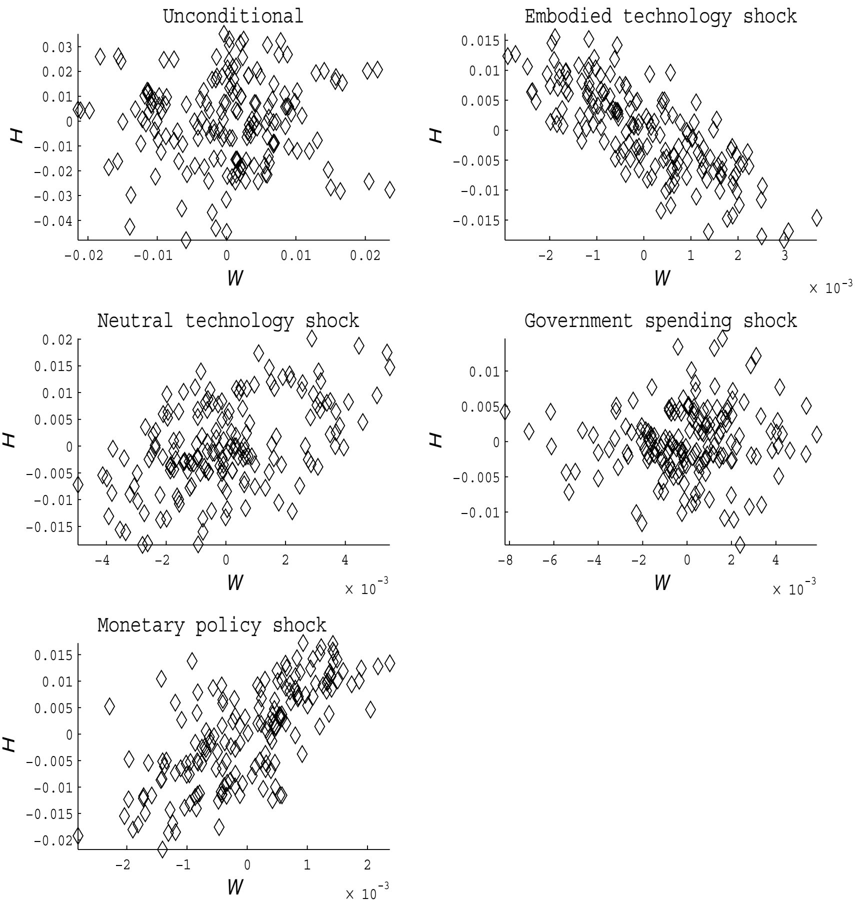

Fig. 3, Panel B. Business cycle components of hours worked vs. real wages
Note: The figures illustrate the scatterplots of the business cycle components of hours worked and real wages conditional on each of the four structural shocks.

Finally we examine the relationship between unemployment and vacancies at 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 gives 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.

V. Robustness Analysis

We now examine the sensitivity of key findings to the VAR specification and to the sample period. We re-estimated the VAR with hours in

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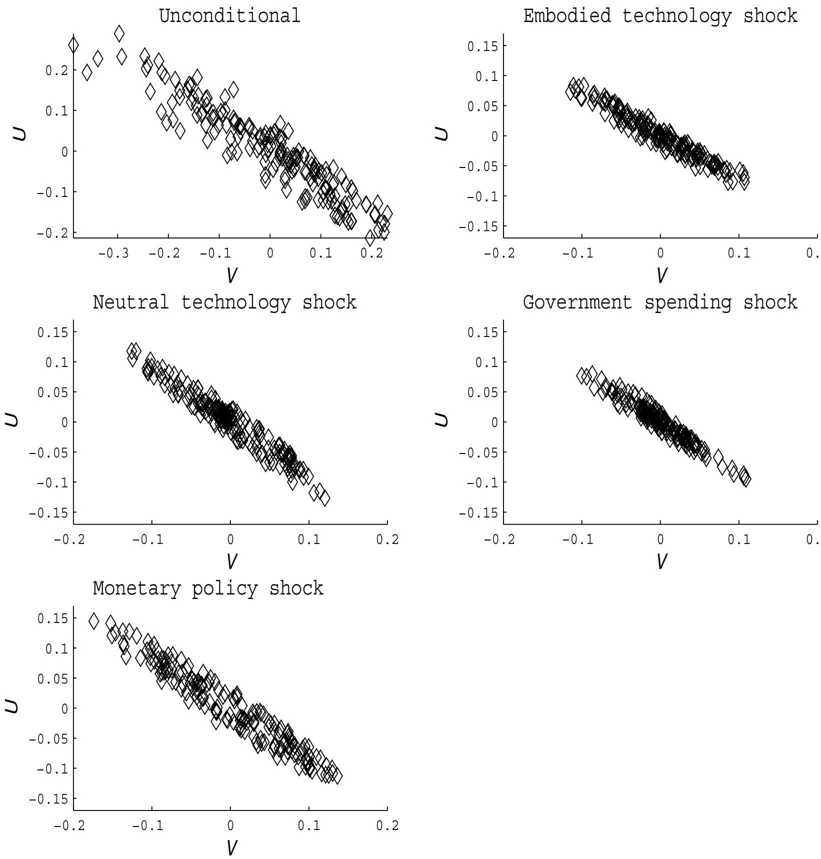

Fig. 4. Conditional and unconditional Beveridge curve
Note: The figures illustrate the scatterplots of the business cycle components of unemployment and vacancies conditional on each of the four structural shocks.

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. Second, we examine the sub-sample stability of the results.

The assumptions concerning 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 dynamics of hours worked, unemployment and vacancies in response to the two types of productivity shocks in the baseline VAR and in the two alternative VAR

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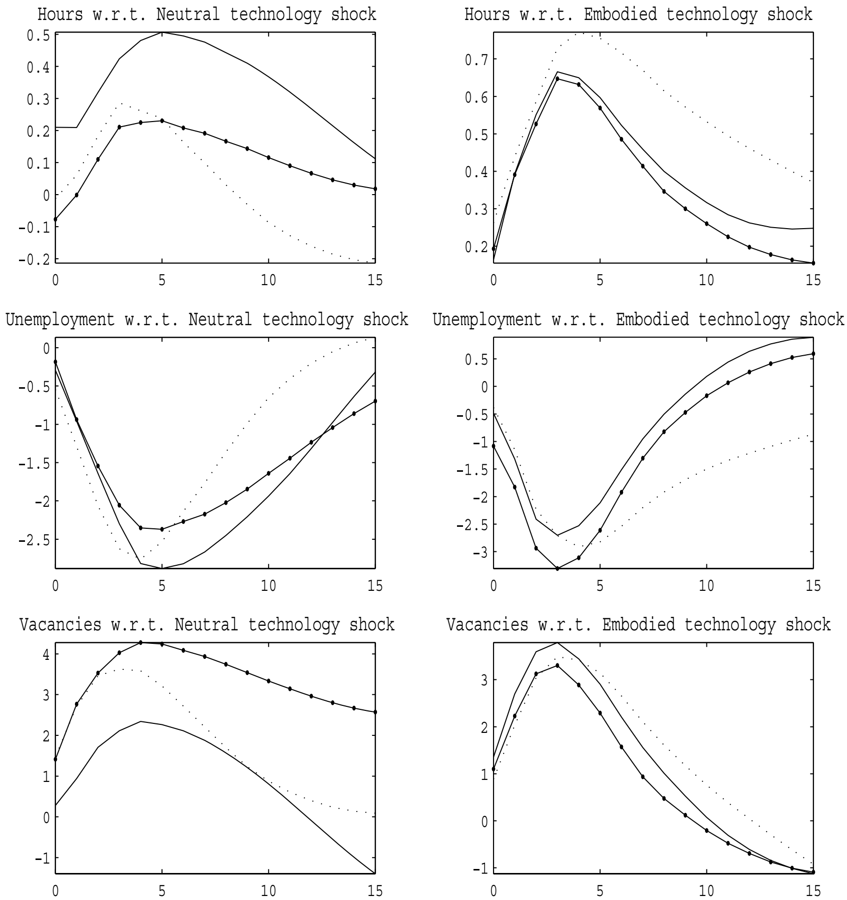

Fig. 5. Labor market response to technology shocks
Notes: The figures illustrate the response to a neutral (left-hand side) and an investment-specific (right-hand side) technology shock for different VAR specifications. The solid line refers to the baseline VAR specification, the dash-dotted line to the VAR specification with hours in first differences and the dotted line to the VAR specification with unemployment and vacancies in first differences.

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 4 reports the variance decomposition at business cycle frequencies. While the joint contribution of the four shocks to the volatility of output is approximately unchanged, the importance of the two types of technology shocks for the volatility of hours worked is reversed. Thus, it appears that the SVAR

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Table 4. *Variance decomposition*

Panel A. Variance of counterfactual output as percent of 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

Panel B. Variance of counterfactual hours as percent of 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

Notes: The table reports in Panel A (B) the average variance of counterfactual output (hours) as a percentage of total output (hours) variance computed over 100 simulations of the estimated VAR process drawing the innovations from the estimated structural shocks. The variables have been HP-filtered. The first four rows report the results when allowing for shocks only to each individual structural shock. The last row reports the results when allowing for all four shocks simultaneously.

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 should thus 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 on impact in response to a positive neutral technology shock in the baseline VAR, but fall (albeit marginally) in the alternative VAR specifications. However, regardless of the VAR specification, the response of hours worked to neutral technology shocks is positive a few quarters after the shock. Moreover, according to Table 5, independently of the VAR specification, there is a positive correlation between output and hours worked at business cycle frequencies conditional on neutral technology shocks. Thus, our results challenge the view that the negative impact effect of neutral technology shocks on hours worked can be used to conclude against the role of technology shocks over the business cycle.

As discussed earlier, Canova *et al.* (2006) find that a positive technology shock is associated with a persistent decrease in employment and an

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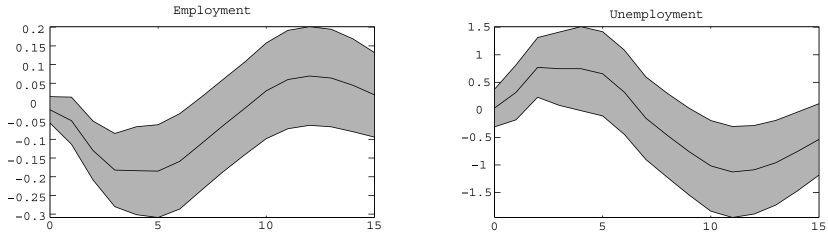
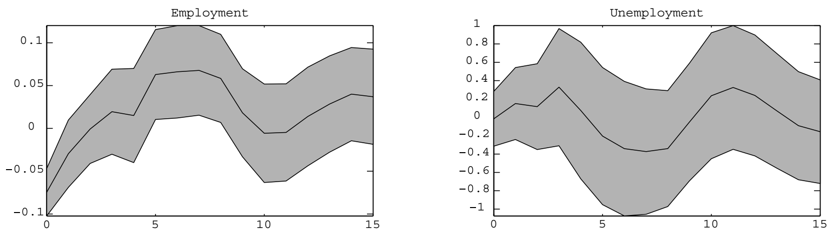
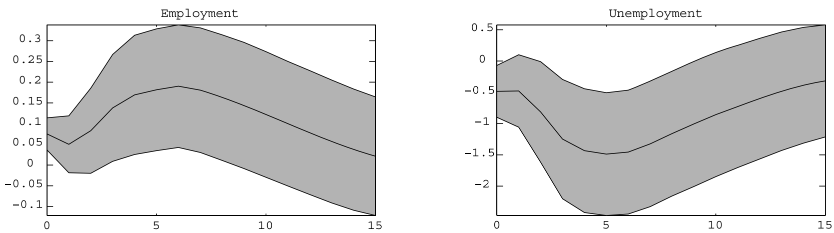


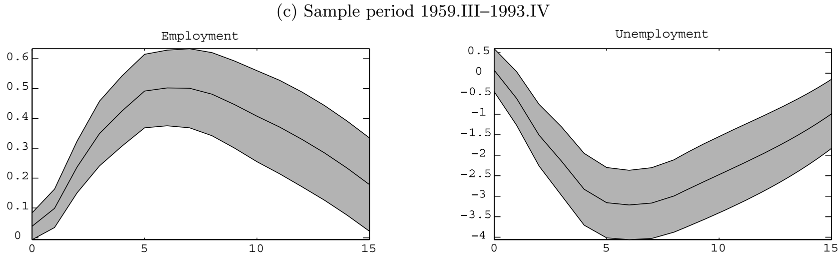
(a) Sample period 1972.I–1993.IV



(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

Fig. 6. Employment and unemployment response to a neutral technology shock
Notes: 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 are in levels 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 levels, and hours in differences.

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Table 5. *Conditional correlations*

Panel 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

Panel 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

Notes: The table reports in Panel A (B) the average cross-correlation between output and hours (average labor productivity) computed over 100 simulations of the estimated VAR process drawing the innovations from the estimated structural shocks. The variables have been HP-filtered. The first four rows report the results when allowing for shocks only to each individual structural shock. The last row reports the results when allowing for all four shocks simultaneously.

increase in unemployment. These authors consider the sample period 1972–1993 and include hours in levels in their VAR specification. We examined whether the sample period is critical for our results, a finding that would be consistent with structural breaks biasing our results. We considered three alternative sub-samples: (i) 1972–1993, (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 (not reported[22]) 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.[23]

Figure 6 illustrates the impulse responses of employment and unemployment to the neutral technology shock for the three sub-samples. In

[22] See Ravn and Simonelli (2007) for details of the ADF tests.

[23] 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.

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Panel A we illustrate the results for the 1972–1993 sample when, as in Canova *et al.* (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 of the Dickey–Fuller tests and use hours in differences instead, unemployment and employment are basically left unaffected by the neutral technology shock. However, for the other two sub-samples 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 IV are robust features of the data.

VI. Summary and Conclusions

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

We showed 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 should 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 should take into account that the high elasticity of these variables is not brought about on impact when shocks hit the economy, but with a delay of three to five quarters. Moreover, we have shown that this result is a robust feature of U.S. 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 volatility in the labor market. This implies that attempts to account for labor market volatility solely on the basis of neutral technology shocks are likely to miss important features of the data.

Instead, multiple shocks are most likely required to account for the covariance structure between hours, productivity and real wages. In particular, the orthogonality between hours and real wages appears to result from the combined effects of neutral and investment-specific productivity shocks, where the former is associated with positive hours–real wage comovements, and the latter instead implies negative comovements between

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these two variables. Another 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. The process of accounting for this, we believe, might be challenging.

It should also be emphasized that despite uncertainty regarding our estimates of the impact effects of neutral technology shocks on hours worked, we found that, at the business cycle frequencies, average hours worked remain firmly procyclical, conditional on neutral technology shocks. On the other hand, the relative importance of the two types of technology shocks for labor market volatility is sensitive to stationarity assumptions that are difficult to establish firmly in the U.S. data. Apparently, SVARs are not well suited to evaluate this issue.

Appendix

Table A1. *Sources and definitions of data*

Series	Definition	Source
Population	Civilian non-institutional population aged 16 and above	BLS
Real output	GDP in constant chained prices divided by population	BEA
Price level	Ratio of GDP in nominal prices to 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 aged 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 defaltor to implicit consumption price defaltor	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

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Table A2. *Definition of variables in the VAR*

Variable	Symbol	Definition
Growth in real government spending	Δg_t	First difference of logarithm of real government spending
Growth in relative investment price	Δp_t^i	First difference of logarithm of relative investment price
Growth in labor productivity	Δa_t	First difference of logarithm of labor productivity
Growth in real wages	Δw_t	First difference of logarithm of real wages
Inflation rate	Δp_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

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