Technology Shocks and Robust Sign Restrictions in a Euro Area SVAR[*]

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Abstract

We use a model-based identification strategy to estimate the impact of technology shocks on hours worked and employment in the euro area. The restrictions applied in the SVAR analysis are consistent with a large class of DSGE models and are robust given a sensible range of parameterization. In contrast to most of the existing literature for the United States, our results are in line with the conventional real business cycle interpretation that hours worked rise as a result of a positive technology shock. In addition, we also find an important role for technology shocks in explaining business cycle fluctuations.

JEL classification: E32, E24

Keywords: Technology shocks; Real business cycle models; Sticky price/wage models; Vector autoregressions, DSGE priors.

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[*] We thank Michael Artis, Anindya Banerjee, Paul Bergin, Günter Coenen, Gabriel Fagan, Jordi Galí, Freddy Heylen, Ricardo Mestre, Pau Rabanal, Frank Smets, conference participants at the ESEM annual meeting in Madrid and seminar participants at the European Central Bank, ECARES, Antwerp University and European University Institute for their useful comments. We are also most grateful to the ECB for its hospitality. The views expressed are solely our own and do not necessarily reflect those of the International Monetary Fund. All remaining errors are ours.

1 Introduction

The direction and magnitude of the response of hours worked and employment following a stochastic technology shock is subject to an active controversy in the academic literature. The debate has its origin in the real business cycle (RBC) research program. The workhorse of this program, as demonstrated in the seminal paper by Kydland and Prescott (1982), has been a flexible price, full-scale structural model with maximizing agents. The motivation behind this approach was to explain aggregate fluctuations in actual economies using the RBC model subject to stochastic technology shocks. In the RBC framework, technology shocks act as labor demand shifters and have therefore a positive impact on both per capita hours worked and output. This prediction has been challenged in Galí (1999). By using United States data and long-run restrictions in a structural VAR, Galí (1999) provides evidence that hours worked fall as a result of a positive technology shock. The results questioned the suitability of RBC models to mimic the behavior of the economy in several respects. First, the unconditional correlation between output and hours worked is close to zero and even negative in the data, therefore technology shocks cannot play a major role in business cycle behavior. Second, the fact that RBC models predict an increase in hours worked following a positive technology shock questioned also the ability of the model to reproduce the conditional moments in the data. Galí (1999) demonstrates that sticky price models are able to mimic the results of the VAR analysis. Price rigidities imply that aggregate demand cannot change immediately, which forces firms to contract employment after an exogenous increase in productivity.[1] Other papers in the literature e.g., Shea (1998), Basu, Kimball and Fernald (1999), Francis and Ramey (2002), Francis, Owyang and Theodorou (2003), confirm Galí's results.

Recent studies, however, questioned the robustness of the empirical results provided in Galí (1999). First, in Galí's set up, only technology shocks have a long-run impact on labor productivity. Uhlig (2004) shows, however, that capital income taxation shocks or long-run shifts in the social attitudes to the work place can also be a source of changes in long-run labor productivity. In addition, Faust and Leeper (1997) demonstrate that by using long-run restrictions substantial distortions are possible due to small sample biases

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[1] The ability to hold inventory might change the nature of firms' reponse to technology shocks even under sticky prices. Chang, Hornstein and Pierre-Sarte (2004) demonstrate that even when the prices are fixed, firms may want to produce more, hire workers and build up inventories for future sales in response to a favorable technology shock.

and measurement errors. In a similar framework as Galí (1999), Christiano, Eichenbaum and Vigfusson (2003) test the sensitivity of the results to the stochastic specification of the hours worked series. If per capita hours worked is modeled as a difference stationary process the results confirm that hours worked will fall as a result of a positive technology shock. But in case the system is estimated by using the level of the hours worked series, the impulse responses are in line with the predictions of the RBC model. Other papers casting doubts on Galí's results are Bils (1998) and Chang and Hong (2005).

In this paper we propose an alternative, model-based identification strategy to estimate the effects of technology shocks on hours worked and employment in the euro area. Our approach searches robust implications of theoretical models that hold, given a range of sensible parametrization and independent of the existence of nominal price rigidities. In particular, we use the common predictions of dynamic stochastic general equilibrium models (DSGE) with flexible and sticky prices as sign restrictions in a structural VAR.[2] To identify the shocks, however, we use only a minimum set of sign restrictions as our DSGE priors. Since we are mainly interested in the response of hours worked following a technology shock, we do not apply any restrictions on its response. Hence, the estimated reaction of hours worked in our VAR allows us to discriminate between both models.

The results presented in the paper are in favor of the RBC paradigm. We observe a significant positive reaction of hours worked following a positive technology shock. The results are robust whether we estimate the model in levels or first differences or when we use total employment instead of hours. We also find an important role for technology shocks in explaining business cycle fluctuations.[3]

The paper is organized as follow. In section 2 we describe the model-based identifica-

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[2] Sign restrictions are introduced by Faust (1998), Uhlig (1999) and Canova and De Nicoló (2002) to identify monetary policy shocks. Peersman (2005) extended this method to a larger set of shocks.

[3] In related work, Dedola and Neri (2004) also confirm by using sign restrictions that hours work increase following a technology shock in the U.S. The advantage of our methodology, however, is that we impose fewer restrictions on the data which results in the estimation of an empirical model with fewer variables. Specifically, in Dedola and Neri (2004), a positive technology shock is identified as a shock that has positive effects on labor productivity, output, investment, consumption and real wages. But these restrictions, for example, are not sufficient to disentangle productivity shocks from government spending shocks in new-Keynesian models with limited asset market participation (e.g. see Gali, Lopez-Salido and Valles, 2004). Notice that these type of new-Keynesian models generate positive effects on consumption following a government spending shock which is in line with the VAR literature as discussed e.g. in Fatas and Mihov (2001).

tion strategy. First, we set up a baseline DSGE model that nests both a new-Keynesian sticky price/wage model and a real business cycle model as a special case, and utilize the impulse responses of the models to derive a minimal set of robust restrictions for the euro area VAR. In section 3, we present the results of the structural VAR. Section 4 tests the robustness of the empirical results by using different stochastic specifications and by replacing the hours worked series by employment. In section 5, we discuss the importance of technology shocks for the euro area business cycle and section 6 concludes the analysis.

2 Identification

In this section we present the properties of a standard DSGE model which is utilized to derive the sign restrictions imposed in the empirical exercise. As we will discuss in the next section, the model presented below nests both a new-Keynesian sticky price/wage model and a real business cycle model as a special case.

2.1 Households

In the first step we present the optimization problem of a representative household denoted by h. The household maximizes lifetime utility by choosing consumption $C_{h,t}$, financial wealth in form of bonds $B_{h,t+1}$, and the next period capital stock $K_{h,t+1.}$

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{1}{1-\sigma} C_{h,t}^{1-\sigma} - \frac{\varepsilon_t^n}{1+\zeta} N_{h,t}^{1+\zeta} \right\} \tag{1}$$

where β is the discount factor, σ denotes the coefficient of relative risk aversion and ζ is the inverse of the elasticity of work effort with respect to the real wage. Household's utility depends positively on the level of consumption, $C_{h,t}$, and negatively on hours worked, $N_{h,t}$. ε_t^n represents a serially correlated shock to labor supply.[4] The intertemporal budget constraint of the representative household is given by:

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[4] Recent literature presents empirical evidence for the importance of labor supply shifts in explaining business cycle fluctuation. Chang and Schorfheide (2003) e.g., show that labor supply shocks account for about 30 percent of the cyclical fluctuation in the US hours worked series. Smets and Wouters (2003) report that after two and half years about 33 percent of the variation of euro area output is caused by labor supply shocks.

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\begin{aligned}
& C_{h,t} + I_{h,t} + R_t^{-1}\frac{B_{h,t+1}}{P_t} \\
= \; & \frac{W_{h,t}}{P_t}N_{h,t} + R_t^K K_{h,t} + D_{h,t} + T_{h,t} + \frac{B_{h,t}}{P_t}
\end{aligned} \tag{2}
$$

and the capital accumulation process by:

$$K_{h,t+1} = (1-\delta)K_{h,t} + I_{h,t} \tag{3}$$

Here, R_t is the nominal interest rate, R_t^K rate of return to capital, $W_{h,t}$ is the nominal wage, $K_{h,t}$ is the capital stock, $T_{h,t}$ are lump-sum taxes paid to the fiscal authority, P_t is the price level and $D_{h,t}$ is the dividend income. The terms on the left hand side of equation (2) show how the households use their resources, while terms on the right hand side indicate what resources (net of taxes) the households have at their disposal. In the following we will assume the existence of state-contingent securities that are traded amongst households in order to insure households against variations in household-specific wage income. As a result where possible, we neglect the indexation of individual households.

The maximization of the objective function with respect to consumption, bond holding and next period capital stock can be summarized by the following two standard Euler equations:

$$\beta R_t \mathrm{E}_t\left[\frac{C_t{}^{\sigma}}{C_{t+1}{}^{\sigma}}\frac{P_t}{P_{t+1}}\right] = 1 \tag{4}$$

$$1 = \beta \mathrm{E}_t\left[\frac{C_t{}^{\sigma}}{C_{t+1}{}^{\sigma}}\left(1-\delta+R_{t+1}^K\right)\right] \tag{5}$$

2.2 Firms

There are two types of firms. A continuum of monopolistically competitive firms indexed by $f \in [0,1]$, each of which produces a single differentiated intermediate good, $Y_{f,t}$, and a distinct set of perfectly competitive firms, which combine all the intermediate goods into a single final good, Y_t.

2.2.1 Final-Good Firms

The final-good producing firms combine the differentiated intermediate goods $Y_{f,t}$ using a standard Dixit-Stiglitz aggregator:

$$Y_t = \left(\int_0^1 Y_{f,t}^{\frac{1}{1+\lambda_p}}\, df\right)^{1+\lambda_p} \tag{6}$$

where λ_p is a parameter determining the degree of imperfect competition in the goods market. Minimizing the cost of production subject to the aggregation constraint (6) results in demand for the differentiated intermediate goods as a function of their price $P_{f,t}$ relative to the price of the final good P_t,

$$Y_{f,t} = \left(\frac{P_{f,t}}{P_t}\right)^{-\frac{1+\lambda_p}{\lambda_p}} Y_t \tag{7}$$

where the price of the final good P_t is determined by the following index:

$$P_t = \left(\int_0^1 P_{f,t}^{-\frac{1}{\lambda_p}} df\right)^{-\lambda_p}$$

2.2.2 Intermediate-Goods Firms

Each intermediate-goods firm f produces its differentiated output using a production function of a standard Cobb Douglas form:

$$Y_{f,t} = A_t^{\alpha} N_{f,t}{}^{1-\alpha} K_{f,t}^{\alpha} \tag{8}$$

where A_t is a technology shock and α the capital share of output in the steady state. Taking the rental cost of capital, R_t^k, and the aggregate wage index, W_t, as given, cost minimization subject to the production technology (8) yields first-order conditions for the inputs which can be expressed as relative factor demands and nominal marginal cost MC_t:

$$\frac{K_{f,t}}{N_{f,t}} = \left(\frac{\alpha}{1-\alpha}\right) \frac{W_t}{R_t^k}$$

$$MC_t = \frac{1}{A_t\, \alpha^{\alpha}(1-\alpha)^{(1-\alpha)}} W_t^{(1-\alpha)} (R_t^k)^{\alpha}$$

2.2.3 Price Setting

Following Calvo (1983), intermediate-goods producing firms receive permission to optimally reset their price in a given period t with probability $1-\xi_p$. All firms that receive permission to reset their price choose the same price $P_{f,t}^*$. Each firm f receiving permission to optimally reset its price in period t maximizes the discounted sum of expected nominal profits,

$$\mathrm{E}_t \left[\sum_{k=0}^{\infty} \xi_p^k\, \chi_{t,t+k}\, D_{f,t+k} \right]$$

subject to the demand for its output (7) where $\chi_{t,t+k}$ is the stochastic discount factor of the households owing the firm and

$$D_{f,t} = P_{f,t}\, Y_{f,t} - MC_t Y_{f,t}$$

are period-t nominal profits which are distributed as dividends to the households.

Hence, we obtain the following first-order condition for the firm's optimal price-setting decision in period t:

$$P^*_{f,t}\, Y_{f,t} - (1+\lambda_p)\, MC_t Y_{f,t} \; + \mathrm{E}_t \left[\sum_{k=1}^{\infty} \xi_p^k \,\chi_{t,t+k}\, Y_{f,t+k} \left(P^*_{f,t} \; - (1+\lambda_p)\, MC_{t+k} \right) \right] = 0 \quad (9)$$

With the intermediate-goods prices $P_{f,t}$ set according to equation (9), the evolution of the aggregate price index is then determined by the following expression:

$$P_t = \left((1-\xi_p)(P^*_{f,t})^{-\frac{1}{\lambda_p}} + \xi_p \,(P_{f,t-1})^{-\frac{1}{\lambda_p}} \right)^{-\lambda_p}$$

2.3 Wage Setting

There is a continuum of monopolistically competitive unions indexed over the same range as the households, $h \in [\,0, 1\,]$, which act as wage setters for the differentiated labor services supplied by the households taking the aggregate nominal wage rate W_t and aggregate labor demand N_t as given. Following Calvo (1983), unions receive permission to optimally reset their nominal wage rate in a given period t with probability $1-\xi_w$. All unions that receive permission to reset their wage rate choose the same wage rate $W^*_{h,t}$. Each union h that receives permission to optimally reset its wage rate in period t maximizes the household's lifetime utility function (1) subject to its intertemporal budget constraint (2) and the demand for labor services of variety h, the latter being given by

$$N_{h,t} = \left(\frac{W_{h,t}}{W_t} \right)^{-\frac{1+\lambda_w}{\lambda_w}} N_t$$

where λ_w is a parameter determining the degree of imperfect competition in the labor market. As a result, we obtain the following first-order condition for the union's optimal wage-setting decision in period t:

$$\frac{W^*_{h,t}}{P_t} - (1+\lambda_w)\, \varepsilon^n_t \, MRS_t + \mathrm{E}_t \sum_{k=1}^{\infty} \xi_w^k \,\beta^k \left[\frac{W^*_{h,t}}{P_{t+k}} - (1+\lambda_w)\, \varepsilon^n_{t+k}\, MRS_{t+k} \right] = 0 \qquad (10)$$

where MRS_{t+k} stands for the marginal rate of substitution:

$$MRS_t = {N_{h,t}}^{\zeta} {C_{h,t}}^{\sigma}$$

Aggregate labour demand, N_t, and the aggregate nominal wage rate, W_t, are determined by the following Dixit-Stiglitz indices:

$$N_t = \left(\int_0^1 (N_{h,t})^{\frac{1}{1+\lambda_w}} \, dh \right)^{1+\lambda_w}$$

$$W_t = \left(\int_0^1 (W_{h,t})^{-\frac{1}{\lambda_w}} \, dh \right)^{-\lambda_w}$$

With the labor-specific wage rates $W_{h,t}$ set according to (10), the evolution of the aggregate nominal wage rate is then determined by the following expression:

$$W_t = \left((1-\xi_w)(W^*_{h,t})^{-\frac{1}{\lambda_w}} + \xi_w \, (W_{h,t-1})^{-\frac{1}{\lambda_w}} \right)^{-\lambda_w}$$

2.4 Market Clearing and Shock Processes

The labor market is in equilibrium when the demand for the index of labor services by the intermediate-goods firms equals the differentiated labor services supplied by households at the wage rates set by unions. Similarly, the market for physical capital is in equilibrium when the demand for capital services by the intermediate-goods firms equals the capital services supplied by households at the market rental rate. Lastly, the final-good market is in equilibrium when the supply by the final-good firms equals the demand by households:

$$Y_t = C_t + I_t + G_t$$

where G_t is an aggregate demand shock, e.g. a shock to government spending. The model is simulated in its log-linearized form, i.e. small letters will characterize in the following percentage deviations form the steady state. The exogenous technology, labor supply and aggregate demand shocks follow an AR(1) process described by the following equations:

$$\begin{aligned} a_t &= \rho^a a_{t-1} + \eta^a_t \qquad (11) \\ \varepsilon^n_t &= \rho^n \varepsilon^n_{t-1} + \eta^n_t \\ g_t &= \rho^g g_{t-1} + \eta^g_t \end{aligned}$$

Finally, monetary policy follows a standard log-linearized Taylor rule:

$$r_t = \rho^r r_{t-1} + (1-\rho^r)\left(\phi^y y_t + \phi^\pi \pi_t\right) + \eta^r_t \qquad (12)$$

where η^r_t is a white noise monetary policy shock.

2.5 Sign Restrictions and Robustness Analysis

In this section we discuss the choice of the sign restrictions derived from the impulse responses of the above model. First, notice when prices and wages are perfectly flexible i.e. $\xi_p = 0$ and $\xi_w = 0$, the share of household and firms able to reset their price equals to 1 and the equilibrium condition in the goods and the labor market converges to:

$$P_t = (1 + \lambda_p)\, MC_t$$

$$\frac{W_t}{P_t} = (1 + \lambda_w)\, \varepsilon_t^n\, MRS_t$$

We will simulate the model under both scenarios, i.e. assuming that the economy is subject to nominal and real rigidities as in the New-Keynesian case and under the scenario that prices and wages are flexible as in the standard RBC case.[5]

To test whether a flexible price RBC model or a New-Keynesian model with nominal and real rigidities are better in matching the dynamics present in the data, we use the methodology discussed e.g. in Canova (2002), Pappa (2004) and Peersman (2005). In the first step, we identify robust implications in each of the two models that do not depend on the parameter values chosen. To do so, we define a range for each of the structural parameters by conducting a brief survey of the related empirical literature. The papers by Smets and Wouters (2003 and 2004) use Bayesian methods to estimate a model of this form on euro area and US data respectively, and provide the corresponding posterior distribution of the structural parameters. Similar models by using alternative estimation techniques have been analyzed by Christiano, Eichenbaum and Evans (2005), Altig, Christian, Eichenbaum and Linde (2002), Onatski and Williams (2004), Rabanal and Rubio-Ramirez (2003) and Coenen and Straub (2005). We use the parameter range estimated in these models as a benchmark. For example, the preference parameter driving the labor supply utility ζ is allowed to vary in the interval $[1, 3]$ which covers the range estimated by Smets and Wouters (2003, henceforth SW) for the euro area. We allow for a wider range of parameter values than SW for the risk averse coefficient σ which is allowed to vary in our case in the interval $[1, 3]$ and for the degree of nominal wage and

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[5] We could further assume that $\lambda_p \rightarrow 0$ and $\lambda_w \rightarrow 0$, and the model would converge to the standard RBC model with perfect competition in goods and labor markets and flexible prices. Remark, however, that the presented qualitative impulse response functions following structural shocks in a flexible RBC model are not sensitive to the assumption of imperfect competitition.

price rigidities ξ_p and ξ_w which both are restricted in the New-Keynesian model in the interval $[0.25, 0.85]$. This was necessary since the estimated posterior mode of the price and wage rigidity parameters in SW are high compared to the related literature. For example, Rotemberg and Woodford (1997) and Altig, Christian, Eichenbaum and Linde (2002), both estimate a lower degree of nominal rigidities for the United States. For the monetary policy rule, we delimited the range of reasonable parameters to cover the values generally discussed in the Taylor-rule literature. To ensure determinacy of the model, we restrict the inflation response to the range between $[1, 3]$ while the output response and the degree of interest rate smoothing are allowed to vary in the interval $[0, 1]$. Notice that although the mode of the posterior output response is close to 0 in SW, this is partly driven by the different specification of the monetary policy rule. On the other hand, Judd and Rudebusch's (1998) point estimate for the United States using a similar type of Taylor-rule equals 0.98. Finally, and in line with the empirical literature, we restrict the persistence of the shocks in the interval $[0.5, 0.9]$. Note that some of the parameters are set to a fixed value from the start. We set the subjective discount rate $\beta = 0.99$, which implies an annual steady-state real interest rate of 4 percent. We set $\alpha = 0.3$, which implies roughly a steady-state share of labor income of 70 percent and the depreciation rate $\delta = 0.025$ generating an annual depreciation of capital of 10 percent. In addition, we set the price mark-up $\lambda_p = 0.3$ and the wage mark-up parameter $\lambda_w = 0.5$. The intervals for the parameter values are reported in Table 1.

After defining the range of sensible parameter values, we proceed with a simulation exercise. First, we assume that the parameters are uniformly distributed over the selected parameter range. Second, we draw a random value for each parameter from the presented intervals and calculate the corresponding impulse response functions of the model. This exercise is repeated for 10000 simulations. The median, 10th and 90th percentiles of all the conditional responses are shown in Figure 1.

Table 1: Parameter values and ranges [6]

Parameter	**Description**	Range
β	discount factor	0.99
σ	risk aversion coefficient	$[1-3]$
ζ	preference parameter	$[1-3]$
λ_p	degree of monopolistic competition in the goods market	0.3
λ_w	degree of monopolistic competition in the labor market	0.5
ξ_p	degree of nominal rigidities in the goods market	$[0.25-0.85]$
ξ_w	degree of nominal rigidities in the labor market	$[0.25-0.85]$
α	capital share	0.3
δ	depreciation rate	0.025
ϕ^y	coefficient on output in the monetary policy rule	$[0-1]$
ϕ^π	coefficient on inflation in the monetary policy rule	$[1-3]$
ρ^r	degree of interest rate smoothing	$[0-1]$
ρ^a	persistence of technology shocks	$[0.5-0.9]$
ρ_n	persistence of labor supply shocks	$[0.5-0.9]$
ρ_g	persistence of aggregate demand shocks	$[0.5-0.9]$

The impulse responses of both models are in line with our expectations. In the RBC model, technology shocks act as labor demand shifters and result in an increase of the equilibrium real wage, output and the real interest rate. In contrast, an exogenous shock to labor supply decreases the real wage on impact but has a positive effect on the equilibrium value of output and interest rate. Aggregate demand shocks generate a wealth effect that leads to an increase in labor supply and a corresponding fall of the real wage while the real interest rate rises. In a New-Keynesian model, technology shocks have the expected negative impact on hours worked. Although the rise in productivity induces a decline in the firms marginal cost, the introduction of Calvo-type of price stickiness allows only for a restricted share of firms to adjust prices downwards in the short run. Therefore, aggregate demand will rise less than proportionally to the increase in productivity and hours worked will decrease. Note that, similarly to the RBC model, real wages increase following a positive shock to technology in the New-Keynesian model. The wealth effects induced

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[6] Notice that in the RBC model $\xi_p = 0$, $\xi_w = 0$.

by the increase in productivity and the corresponding labor supply shift in combination with wage stickiness dominates the labor demand effect. On the other hand, the sign of the impact response of hours worked, output and real wages following a labor supply shock appear to be insensitive to the existence of nominal rigidities in the goods and labor markets. As a result, we can exploit the asymmetric response of real wages, which is robust across the models for a wide range of parameters, to discriminate between labor supply and technology shocks. Notice also that after both technology and labor supply shocks, the price level decreases on impact. To disentangle technology shocks from demand and monetary policy shocks, we use the restriction that prices rise on impact following an expansionary monetary policy and aggregate demand shock. This is demonstrated in Figure 1 for the new-Keynesian case, but is also similarly implied in flexible price models.[7]

To conclude, the two models differ with regards to the sign of hours worked following a technology shock, but have on the other hand several similarities with regards to the response of other variables. As a result, the described properties of the impulse response functions enable us to use a sufficient set of restrictions in the empirical exercise. The corresponding sign restrictions are presented in Table 2.

Table 2: Sign restrictions

	output	prices	interest rate	hours	wages
monetary policy	↑	↑			
aggregate demand	↑	↑			
technology	↑	↓			↑
labor supply	↑	↓			↓

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[7] Notice that in flexible price models with imperfect competition only relative prices are pinned down, but the price level is indeterminate. Expansionary demand shocks, which by definition have larger impact on the the demand side of the economy than on the supply side, induce implicitly an increase in the price level which will be completely offset by the corresponding increase in individual prices so that relative prices remain constant. Notice also that in contrast to sticky price models, monetary policy has no real effects in a frictionless RBC world. We allow, however, for a possible zero impact of monetary policy shocks in our empirical approach because restrictions are imposed as $\geqslant$ or $\leqslant$.

3 Empirical evidence

In this section we present the results of our structural VAR using euro area data for the sample period 1982:1-2002:4. All data are taken from the area-wide model (Fagan et al., 2001). Hours Worked is a series constructed by the ECB Euro Area Department. The latter is only available from 1981 onwards, which determines our sample period.

Consider the following specification for a vector of endogenous variables Y_t:

$$Y_t = c + \sum_{i=1}^{n} A_i Y_{t-i} + B\varepsilon_t \tag{13}$$

where c is an $(n \times 2)$ matrix of constants and linear trends, A_i is an $(n \times n)$ matrix of autoregressive coefficients and ε_t is a vector of structural disturbances. The endogenous variables, Y_t, that we include in the VAR are real GDP (y_t), the GDP deflator (p_t), short-term nominal interest rate (i_t), hours worked (h_t) and real wages (w_t). We estimate this VAR-model in levels with three lags. By doing the analysis in levels, we allow for implicit cointegration relationships in the data, and still have consistent estimates of the parameters (Sims et. al., 1990).[8]

Within this VAR, we only identify technology shocks. In order to identify these shocks, we use the restrictions reported in Table 2.[9] Specifically, a positive technology shock is a shock with a non-negative effect on output, prices do not rise and there is no decrease in real wages. These restrictions are sufficient to uniquely disentangle them from respectively monetary policy, aggregate demand and labor supply shocks as shown in the previous section. No restrictions are imposed for the response of hours, which allows us to compare the theoretical responses with the data and discriminate between an RBC and New-Keynesian model. For all variables, the time period over which the sign restriction is binding is set equal to four quarters $(k = 4)$. For the implementation of the restrictions, we refer to Peersman (2005) or the appendix of this paper. All restrictions are imposed as $\leq$ or $\geq$. Impulse responses and error bands are computed based on Monte Carlo integration

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[8] Including or excluding the time trend has no qualitative impact on all results reported in the paper. Results are also not sensitive with respect to the number of lags. In section 4.1, we check the robustness of our results when we use a first difference specification of the VAR. We can, however, not reject the hypothesis of the existence of a cointegration relation in the level specification when we perform the tests on the reduced form point estimates using the procedure of Johansen and Juselius in CATS.

[9] For the estimation results of respectively a monetary policy, aggregate demand and labor supply shock, we refer to the ECB Working Paper no. 373 version of this paper.

with 1000 draws from the posterior. In all figures, we report the median of the responses together with 84th and 16th percentiles error bands.

The first column of Figure 2 shows the baseline results. The positive and significant reaction on impact of hours worked is striking. This effect even lasts for more than three years after the technology shock. We also find a positive effect on the nominal interest rate, a response which was also unrestricted. These findings do not depend on the number of lags for which the sign restrictions are imposed. The right panel of figure 2 shows the results when we only impose the restrictions for one lag after the shock ($k = 1$). Error bands are a bit wider, but the results are robust. Also for other alternative estimations (consumer price index instead of GDP deflator, measurement of real wages and number of lags in VAR), the results are still robust. Additional robustness checks are also presented in the next section. In sum, the results are in favor of the RBC model and stand in contrast to the results of Galí (1999) and others. Since Galí (2004) finds similar results with his methodology for the euro area, i.e. a fall in employment, and Dedola and Neri (2004) find a confirmation of the RBC hypothesis when applying a variant of our sign restrictions on US data, we can conclude that these contrasting results depend on the methodology used and not the data set or sample period.

4 Robustness of the Empirical Results

We now want to check the robustness of our empirical results. In particular, following the results of Christiano, Eichenbaum and Vigfusson (2003), we investigate whether the specification of the variables in levels or first differences matters for the results. Furthermore, we run a VAR in both specifications by replacing the hours worked series by the employment series. Finally, we evaluate the exogeneity of the identified technology shocks as in Francis and Ramey (2002).

4.1 Difference Specification

Christiano, Eichenbaum and Vigfusson (2003) show that the results of Galí (1999) are highly sensitive to the stochastic specification of the VAR. The negative response of hours worked of Galí (1999) are obtained with a VAR in first difference specification. If the model is estimated in levels, the results do not hold any longer. In contrast, a positive effect on hours is found. Since we also estimate our basic model in levels, we check whether we still find a positive effect using a first difference specification. We are aware of the problem that our empirical model is misspecified in first differences in the case of cointegration. Nevertheless, we run this exercise as a robustness check. We first re-estimate the VAR when we only include the first difference of hours worked in the system. The results, shown in the left column of Figure 3, indicate that this treatment of the hours worked time series has no consequences. We still find a significant positive effect of a technology shock on hours. In the right panel of Figure 3, the results are reported when all variables in the VAR are measured as first differences. Like Galí (1999), we now find a permanent effect on the level of output, prices and the interest rate. This is not surprising given the stochastic specification of the VAR. However, in contrast to Galí (1999), we still find a positive (and permanent) effect of a technology shock on hours worked. The results illustrate that the positive response of hours worked after a technology shock is independent from the stochastic specification of the series, in contrast to the results of Christiano, Eichenbaum and Vigfusson (2003).

4.2 Specification with Employment

As a second robustness check, we re-estimate the basic model and the first difference model with employment included instead of hours worked. The latter was also done by Galí (1999). Results are reported in Figure 4. The magnitude of the effects is slightly smaller for employment, but there are no significant differences between the estimated impulse response functions of the employment and the hours worked specification. The results in this subsection are therefore also in favor of the RBC model. We find a positive reaction of employment to a technology shock.

4.3 Exogeneity of the Identified Technology Shocks

Francis and Ramey (2002) argue that technology shocks could be correlated with other exogenous shocks that are not related to technology. They therefore test whether other exogenous variables are correlated with the shocks. Accordingly, they regress the identified technology shock on three sets of dummy variables, in particular monetary policy indicators, oil shock dummies and war dates. Given that we disentangle technology from monetary policy shocks with our identification strategy, there is no correlation with technology shocks by construction. In addition, our sample period does not include important war dates for the euro area. To check the potential correlation with oil price shocks, we perform two robustness checks. First, we calculate a simple correlation between the identified technology shocks and pure oil price shocks obtained from the study of Peersman (2005). This correlation varies between -0.17 and -0.20 depending on the specification and is always insignificant. Second, we re-estimate all VAR-models with oil prices (or commodity prices) as an additional exogenous variable. This never has an effect on the quality of the results. We still find a significant positive effect of technology shocks on hours worked for all specifications.[10] As a consequence, these results provide additional support for the plausibility of the shocks being technology shocks.

5 How important Are Technology Shocks for Aggregate Fluctuations?

In Figure 5, we report the contribution of technology shocks to the forecast error variance of output and hours worked series for respectively the level and first difference specification. In contrast to the work of Galí (1999), who finds almost no role for technology shocks in explaining business cycle fluctuations, we find a substantial impact on output and hours. Error bands are, however, very wide which is typical for this type of exercise in VARs. On the other hand, the impact based on the median estimate is still smaller than in the bivariate model of Christiano, Eichenbaum and Vigfusson (2003). We find a value around 25% at a five-year horizon while they find that more than 40% of variation in hours worked can be explained by technology shocks.

In Figure 6, we plot the actual time series of hours worked and employment, together with the contribution of technology shocks to hours worked as percentage points deviations from the baseline for our two benchmark specifications using respectively levels and first differences of all variables. From this figure, it is clear that technology shocks also played an important role in explaining fluctuations of hours worked at some periods in time. There was a negative contribution of technology shocks between 1983 and 1987, and again between 1992 and 1999. On the other hand, there was a persistent positive contribution in between these two periods. The magnitude and timing is rather similar for the levels and first differences specifications. There is only a difference of some quarters in identifying

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[10] These results are not reported but available upon request.

the turning points. Focusing on the more recent period, we find a significant positive contribution between 1999 and 2001. A sequence of positive technology shocks made a positive contribution to hours worked of more than 1 percent for the levels specification. For the differences specification, this is, however, only around 0.5 percent. Between 2001 and the end of the sample period, there is again a substantial negative impact on hours worked of the same magnitude. This is consistent with the results of Peersman (2005) who finds an important role for negative aggregate supply shocks in explaining the early millennium slowdown.

6 Conclusions

This paper has provided empirical evidence for the effects of technology shocks on hours worked in the euro area. The structural shocks are identified building on sign restrictions obtained from DSGE models. This model-based identification takes seriously the fact that the predictions of the models are only appropriate in few dimensions. Consequently, the suggested procedure only uses robust restrictions derived from both RBC and New-Keynesian models. The remaining unrestricted responses of the variables can then be used to discriminate between the models. The results presented in the paper are in favor of the RBC paradigm. First, hours worked increase significantly after a positive shock to technology. Second, we find also an important role for technology shocks as a driving force of cyclical fluctuations in the euro area. The results are in contrast to Galí (1999) and others who find a negative reaction of hours worked to a technology shock in the US, but is consistent with Christiano, Eichenbaum and Vigfusson (2003) and Uhlig (2004) who use an alternative strategy.

However, our findings do not necessarily imply that New-Keynesian models are not a good representation of reality. But the results indicate that New-Keynesian models are at least in one particular aspect not in line with the empirical results for the euro area, namely the transmission of technology shocks to the aggregate labor market. Hence, reconsidering the discussed transmission mechanism and introducing new properties into the sticky price framework might be a worthwhile exercise.[11] Also, the structural shocks in our empirical analysis are identified at a fairly aggregated level. Identifying additional

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[11] See also, on a similar issue, the discussion on the effects of government spending shocks and private consumption in Galí, López-Salido and Vallés (2004) and Bilbiie and Straub (2004).

shocks, like price and wage mark-up shocks, could potentially provide further information. This is left for future research.

A Appendix: Implementation of the Sign Restrictions

In this appendix, we explain how to implement the sign restrictions in our SVAR. For a detailed explanation, we refer to Peersman (2005). Consider equation (13) in section 3. Since the shocks are mutually orthogonal, $E\left(\varepsilon_t \varepsilon_t^{'}\right) = I$, the variance-covariance matrix of equation (13) is equal to: $\Omega = BB'$. For any possible orthogonal decomposition B, we can find an infinite number of admissible decompositions of Ω, $\Omega = BQQ'B'$, where Q is any orthonormal matrix, that is $QQ' = I$. Possible candidates for B are the Choleski factor of Ω or the eigenvalue-eigenvector decomposition, $\Omega = PDP' = BB'$, where P is a matrix of eigenvectors, D is a diagonal matrix with eigenvalues on the main diagonal and $B = PD^{\frac{1}{2}}$. Following Canova and De Nicoló (2002) and Peersman (2005), we start from the latter in our analysis. More specifically, $P = \prod_{m,n} Q_{m,n}(\theta)$ with $Q_{m,n}(\theta)$ being rotation matrices of the form:

$$Q_{m,n}(\theta) = \begin{bmatrix} 1 & \cdots & 0 & \cdots & 0 & \cdots & 0 \\ \cdots & \ddots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & \cdots & \cos(\theta) & ... & -\sin(\theta) & \cdots & 0 \\ \vdots & \vdots & \vdots & 1 & \vdots & \vdots & \vdots \\ 0 & \cdots & \sin(\theta) & \cdots & \cos(\theta) & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \ddots & \cdots \\ 0 & \cdots & 0 & \cdots & 0 & \cdots & 1 \end{bmatrix} \tag{14}$$

Since we have five variables in our model, there are ten bivariate rotations of different elements of the VAR: $\theta = \theta_1, \cdots, \theta_{10}$, and rows m and n are rotated by the angle θ_i in equation (14). All possible rotations can be produced by varying the ten parameters θ_i in the range $[0, \pi]$. For the contemporaneous impact matrix determined by each point in the grid, B_j , we generate the corresponding impulse responses:

$$R_{j,t+k} = A(L)^{-1} B_j \varepsilon_t \tag{15}$$

A sign restriction on the impulse response of variable p at lag k to a shock in q at time t is of the form:

$$R_{j,t+k}^{pq} \gtrless 0 \tag{16}$$

Following Uhlig (1999) and Peersman (2005), we use a Bayesian approach for estimation and inference. Our prior and posterior belong to the Normal-Wishart family used in the RATS manual for drawing error bands. Because there are an infinite number of admissible decompositions for each draw from the posterior when using sign restrictions, we use the following procedure. To draw the "candidate truths" from the posterior, we take a joint drawing from the posterior for the usual unrestricted Normal-Wishart posterior for the VAR parameters as well as a uniform distribution for the rotation matrices. We then construct impulse response functions. If all the imposed conditions of the impulse responses are satisfied, we keep the draw. Decompositions that do not match the restrictions are rejected. This means that these drawings receive zero prior weight. Based on the drawings kept, we calculate statistics and report the median responses, together with 84th and 16th percentiles error bands.

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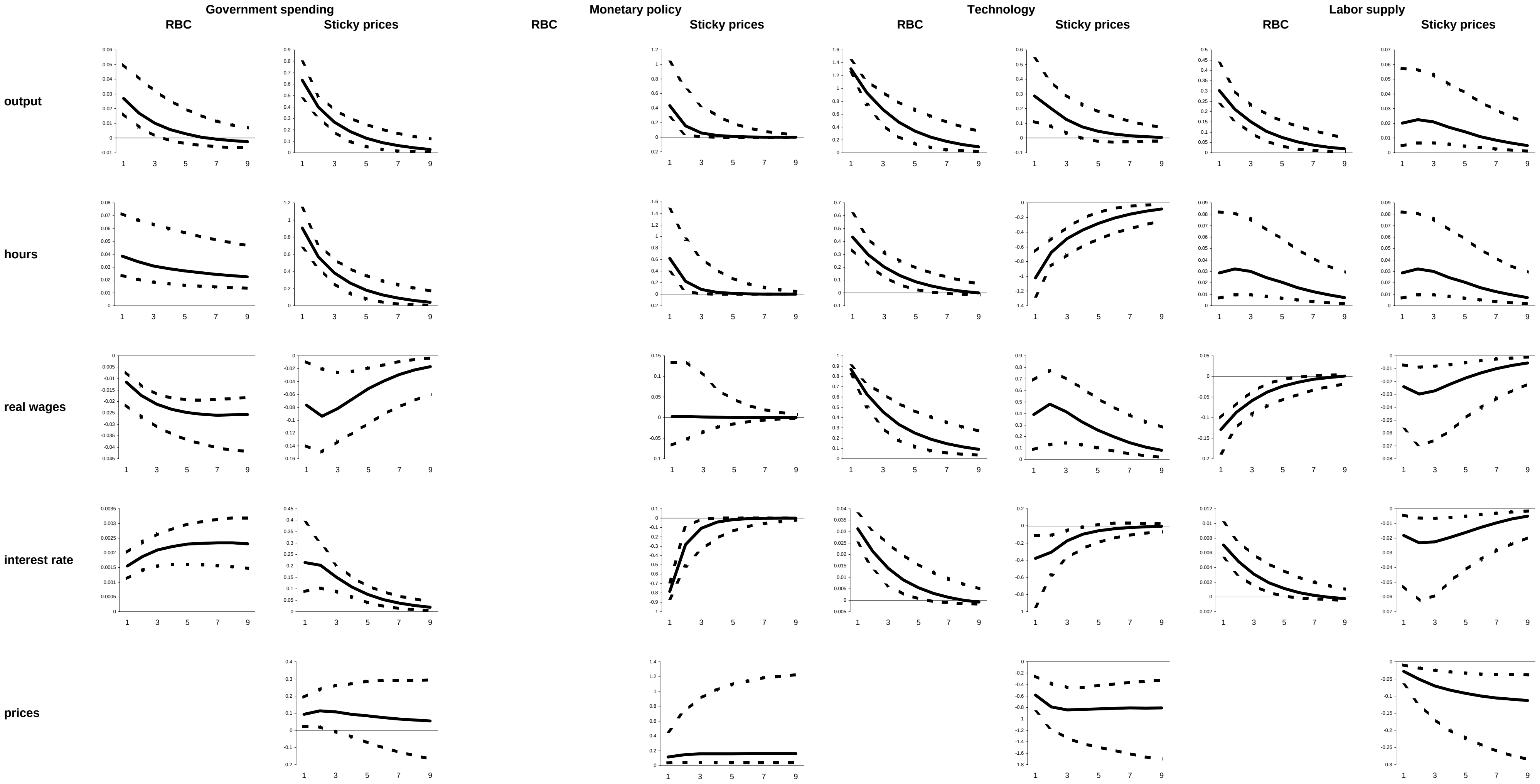
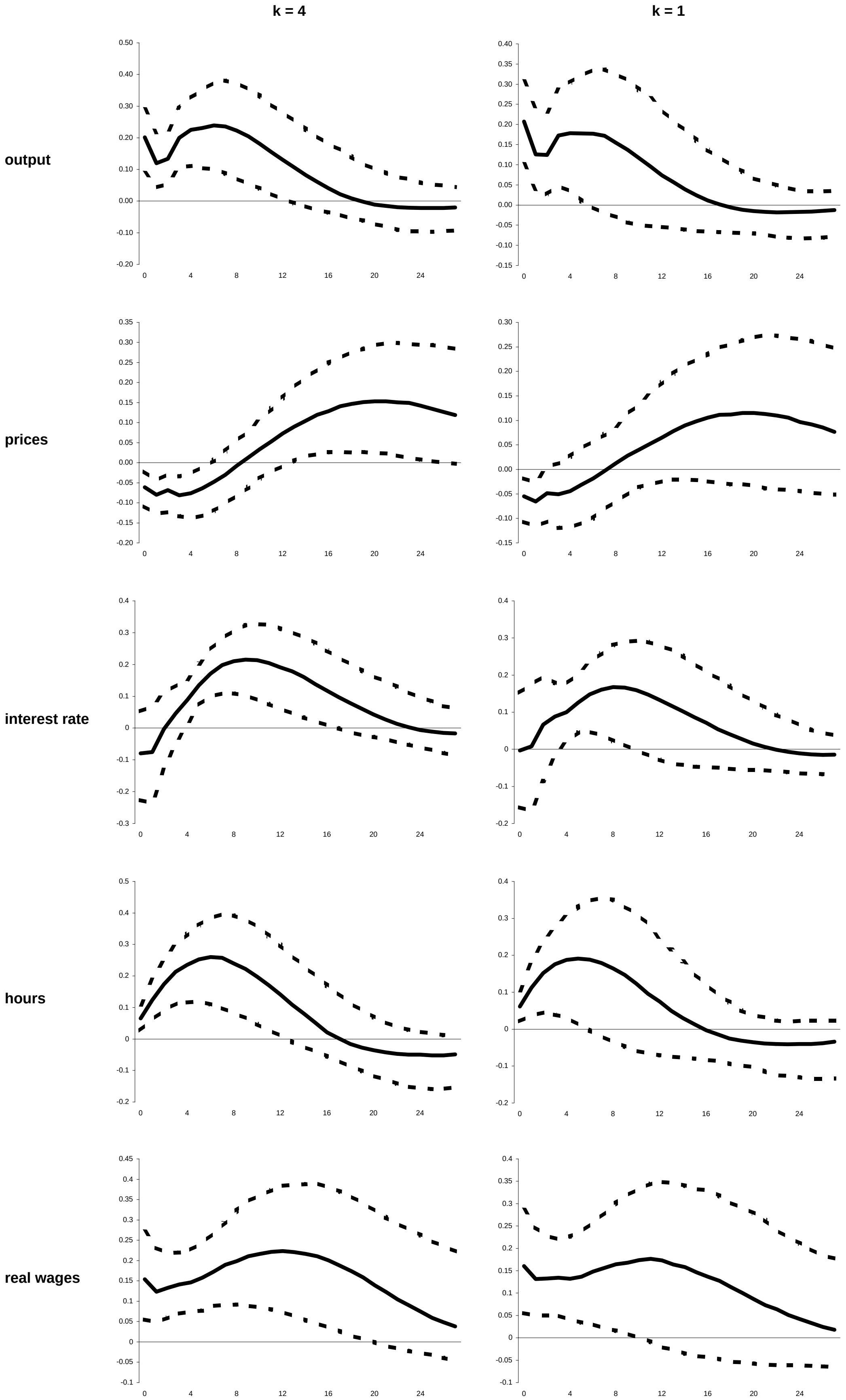
Figure 1 - Theoretical impulse response functions



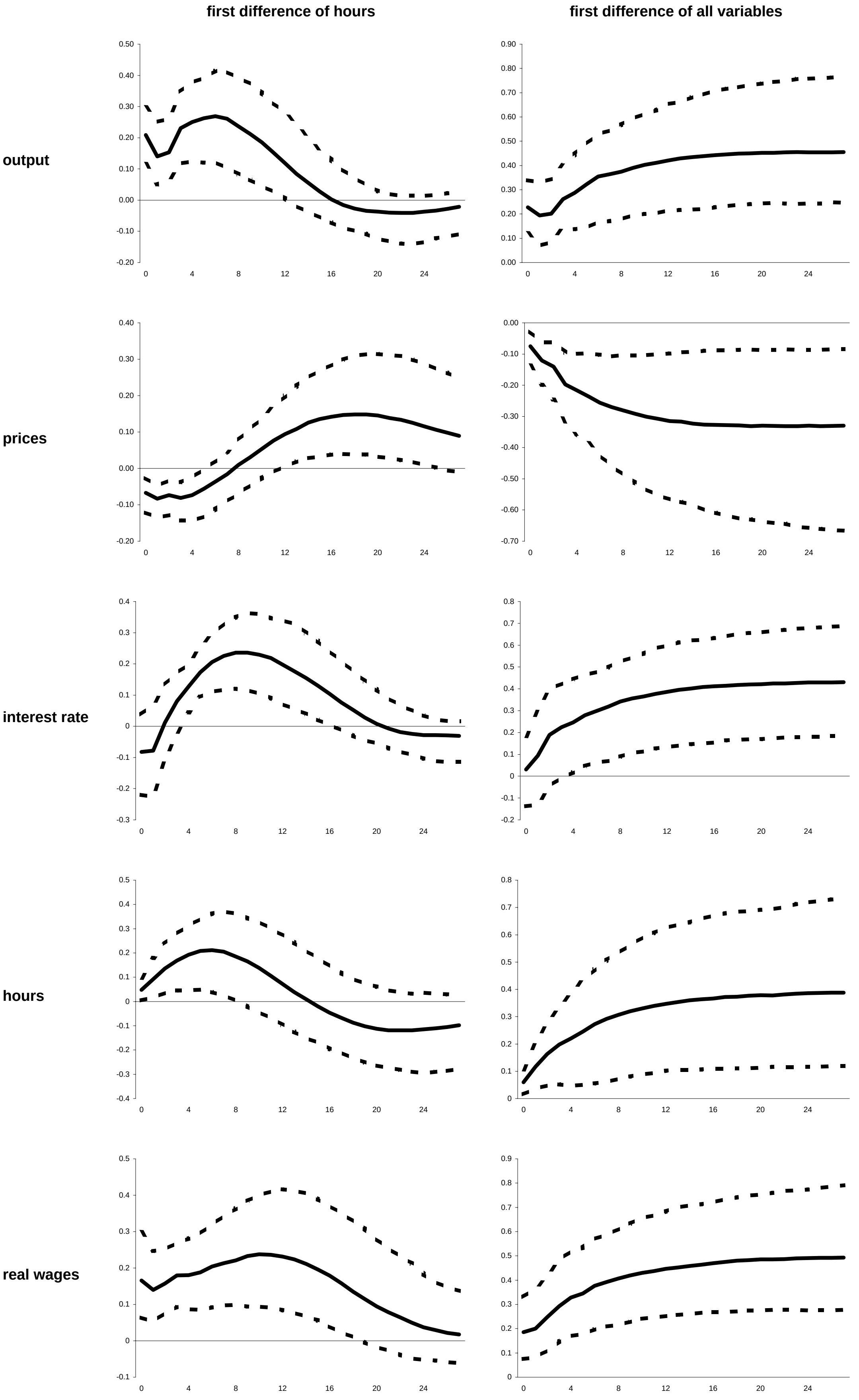
Note: median of simulations with 90th and 10th percentiles

Figure 2 - Impulse responses to a technology shock



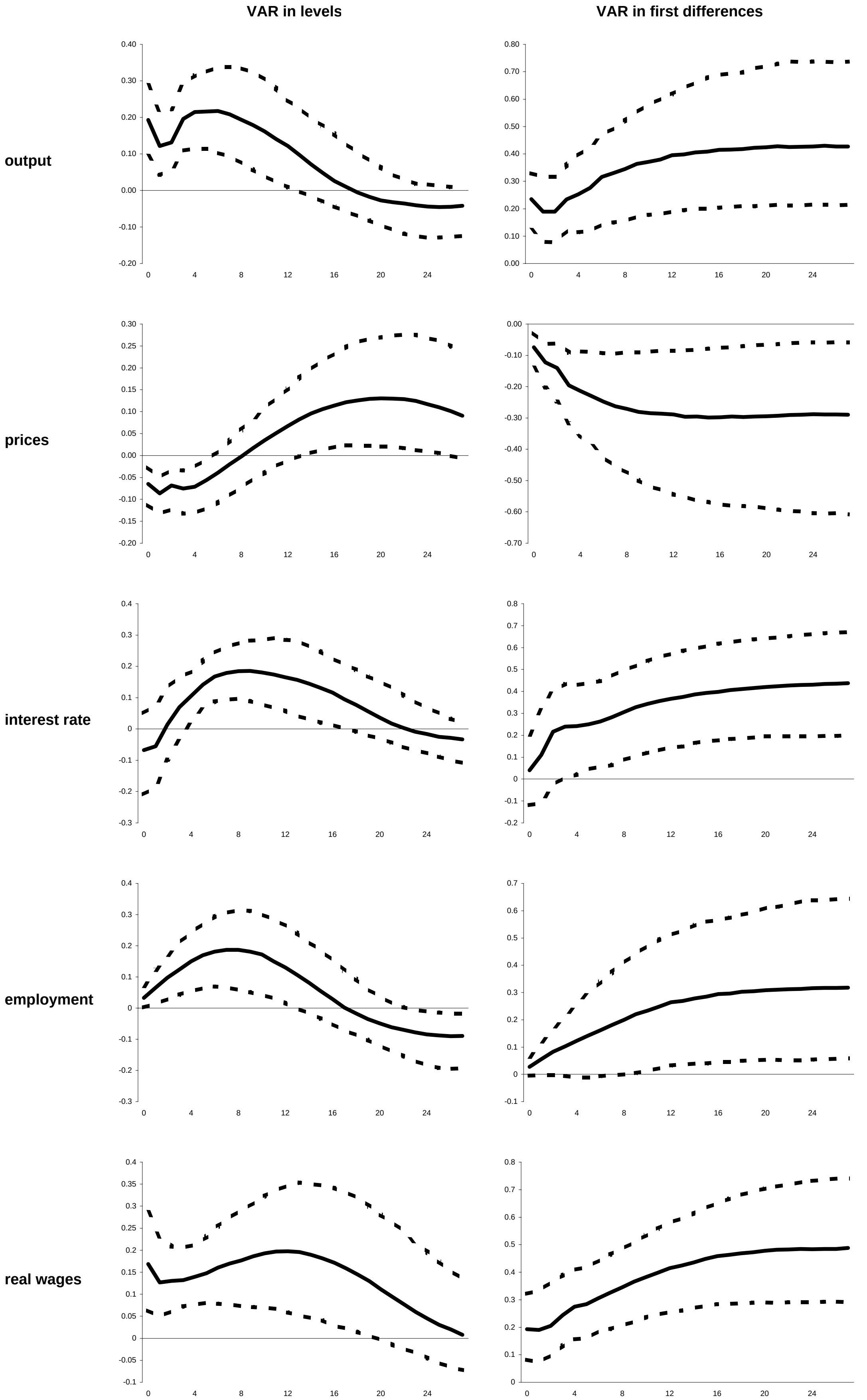
Note: median impulse responses with 84th and 16th percentiles error bands based on Monte Carlo integration, horizon is quarterly
k = number of lags for which sign restrictions are imposed

Figure 3 - Impulse responses to a technology shock



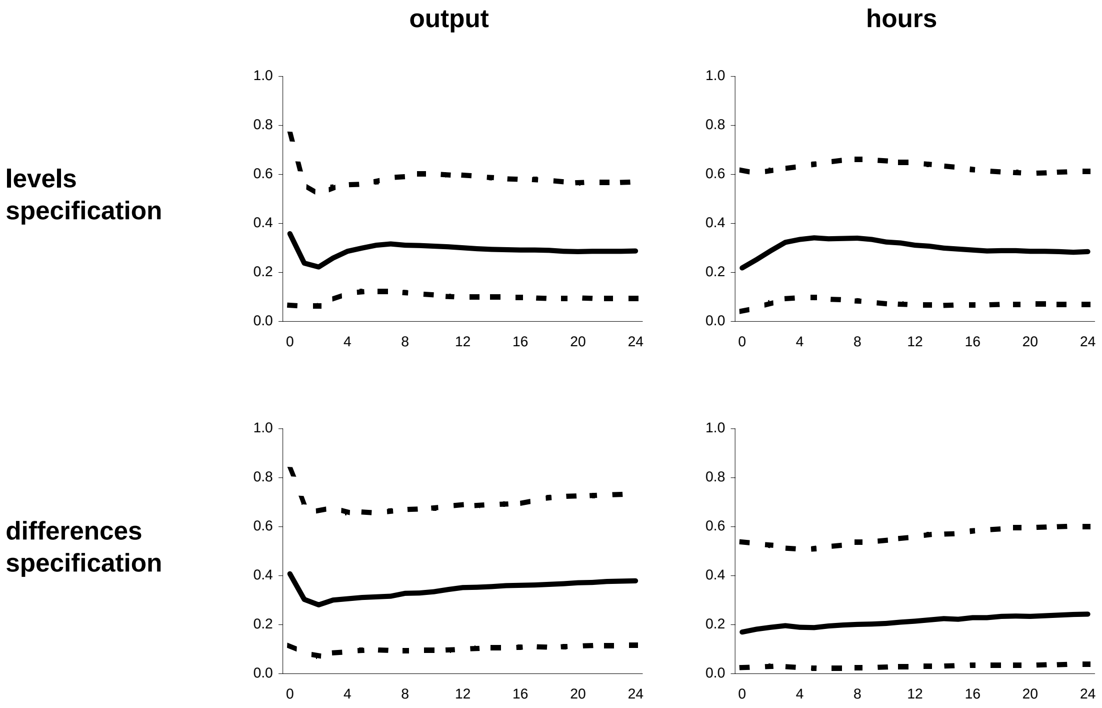
Note: median impulse responses with 84th and 16th percentiles error bands based on Monte Carlo integration, horizon is quarterly

Figure 4 - Impulse responses to a technology shock (employment)



Note: median impulse responses with 84th and 16th percentiles error bands based on Monte Carlo integration, horizon is quarterly

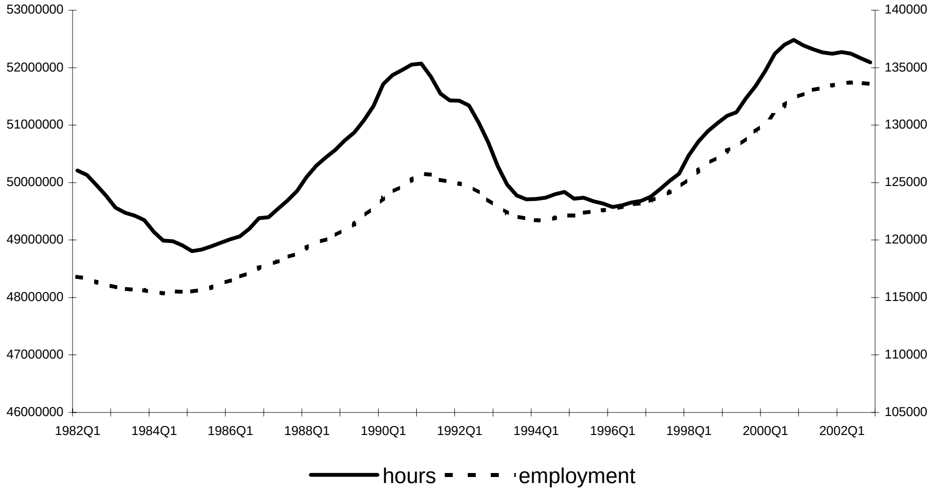
Figure 5 - Contribution of technology shocks to forecast variance



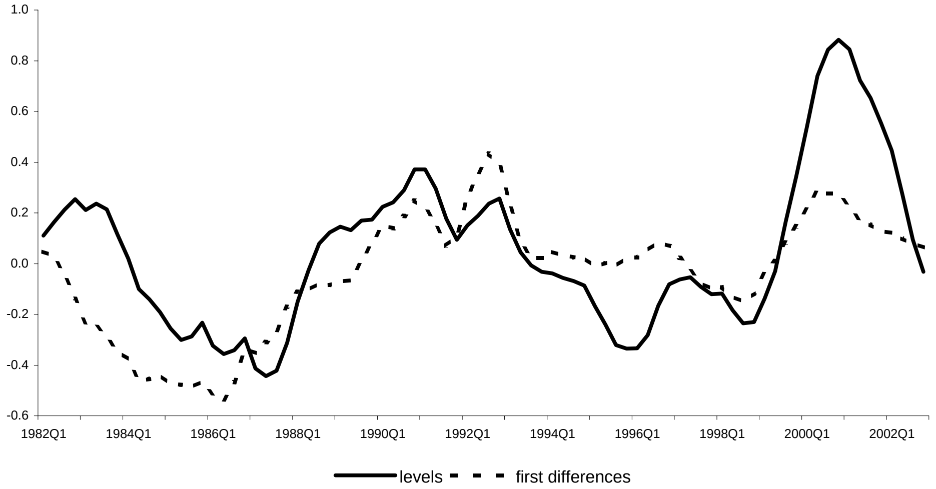
Note: median values with 84th and 16th percentiles error bands based on Monte Carlo integration, horizon is quarterly

Figure 6 - Historical contribution of technology shocks to hours worked in the Euro area

Actual



contribution of shocks



Note: actual employment is thousands of persons (right axis); hours is total hours worked per quarter (left axis)
contributions of shocks are measured as percentage point deviations from baseline