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In 2004 all publications will carry a motif taken from the €100 banknote.

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Abstract

This paper provides evidence for the impact of technology, labor supply, monetary policy and aggregate spending shocks on hours worked in the Euro area. The evidence is based on a vector autoregression identified using sign restrictions that are consistent with both sticky price and real business cycle models. In contrast to most of the existing literature for the US, evidence of a positive response of hours to technology shocks is found, which is consistent with the conventional real business cycle interpretation and at odds with sticky price models. In addition, an important role for technology shocks in explaining business cycle fluctuations is found.

JEL classification: E32, E24

Keywords: Technology shocks; Real business cycle models; Sticky price models; Vector autoregressions.

Non-technical summary

The question whether technology shocks have a positive effect on hours worked is a very controversial issue in the theoretical and empirical literature. In a Real Business Cycle (RBC) Model, technology shocks act as labor demand shifters. Consequently, a positive technology shock has an unambiguous positive impact on hours worked and real wage. However, in a reasonable parameterized new-keynesian sticky price models the effect of technology shocks on labor demand is negative. The reason is that, though all firms will experience a decline in their marginal cost, they will adjust the price only partially in the short run. Accordingly, aggregate demand will rise less than proportionally to the increase in productivity and labor demand will fall.

In the empirical literature, the seminal work by Gali (1999) challenged the predictions of the RBC model. By using long-run restrictions in a structural VAR, Gali (1999) shows that output increases and hours worked fall after a positive technology shock in the US. Some recent papers, however, questioned the robustness of the empirical results. Using long run restrictions as in Gali (1999), Christiano, Eichenbaum and Vigfusson (2003) show that the results are very sensitive to the stochastic specification of the hours worked series. In a different framework, by using medium-run identification of technology shocks, Uhlig (2004) shows that hours worked slightly increases after a technology shock.

In this paper we provide new evidence on this issue by using Euro Area data, based on an alternative identification strategy in a structural vector autoregression. Our approach searches robust implications of theoretical models that hold given a range of sensible parameterization. Once robust implications are discovered, they are used as sign restrictions to identify structural shocks in a VAR.

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 result 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.

1 Introduction

The seminal paper by Kydland and Prescott (1982) can be considered as the starting point of the real business cycle (RBC) research programme. The workhorse of this programme is a flexible price, full-scale structural model with maximizing agents which are subject to stochastic technology shocks. The motivation behind this approach was to explain aggregate fluctuations in actual economies using a plausible calibrated RBC model. The performance of these models was not judged by estimating its equations econometrically but instead by comparing the model-generated and actual conditional and unconditional moments of aggregate variables. Despite its partial success the RBC model stands in one aspect in contrast to the data, namely its prediction of high positive correlation between hours and labor productivity. Since this result is based on the root of the RBC mechanism, i.e. the fact that technology shocks act as labor demand shifters, one obvious possibility to generate the observed near-zero correlation between hours and labor productivity is to introduce additional shocks that cause shifts in the labor supply, as shown e.g. in Christiano and Eichenbaum (1992). These modifications, however, have been undertaken without altering the models prediction regarding the conditional responses of aggregate variables after a technology shocks. In the RBC model, e.g. per capita hours worked and output rise jointly after a shock to technology. This prediction has been challenged by the empirical work of Gali (1999). The paper provides evidence that technology shocks are a source of negative correlation between output and hours worked. By using long-run restrictions in a structural VAR, Gali (1999) shows that output increases and hours worked fall after a positive technology shock in the US. 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 can not play a major role in business cycle behavior. Second, the fact that RBC models predict an increase in hours worked after positive technology shock questioned even the ability of the model to reproduce the conditional properties of the data. Gali (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 leads firms to contract employment after an exogenous increase in productivity. Other papers in the literature, e.g. Shea (1998), Basu, Kimball and Fernald (1999), Francis and Ramey (2002), Francis, Owyang and Theodorou (2003), confirm Gali's results.

Some recent papers, however, questioned the robustness of the empirical results. Using long run restrictions as in Gali (1999), Christiano, Eichenbaum and Vigfusson (2003) show that the results are very sensitive to the stochastic specification of the hours worked series. If per capita hours worked is modelled as a difference stationary process, hours worked fall after a positive technology shock. But in case the system is estimated by using the level of the hours worked series, hours worked rise after a positive technology shock. In a different framework, by using medium-run identification of technology shocks, Uhlig (2004) shows also that hours worked slightly increases after a technology shock.

In this paper we challenge the empirical result of Gali (1999) from a different perspective. We provide evidence on this issue for the Euro Area, based on an alternative identification strategy in a structural vector autoregression. In contrast to Gali (1999) we do not rely on long-run restriction to identify technology shocks. First, given his set up, only technology shocks have a long-run impact on labor productivity. This assumption can be restrictive under some circumstances. For instance, in endogenous growth models, any shock may have a long-run effect on labor productivity. Moreover, Uhlig (2004) shows 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 without endogenous technological progress. In addition, Faust and Leeper (1997) show that by using long-run restrictions substantial distortions are possible due to small sample biases and measurement errors.

Our approach searches robust implications of theoretical models that hold given a range of sensible parametrizations and independent of the existence of nominal price rigidities. Once robust implications are discovered, they are used as sign restrictions to identify structural shocks in a VAR. Sign restrictions are introduced by Faust (1998), Uhlig (1999) and Canova and De Nicoló (2002) to identify monetary policy shocks. Recently, Peersman (2003) applies this method to a larger set of shocks. The advantage of this approach is that restrictions which are often used implicitly (by checking whether the impulse responses look "sensible") are used explicitly for identification. In our set up, we introduce a limited number of restrictions that are delivered by economic theory and are consistent with both New Keynesian sticky price and RBC models. Crucial is the fact that no restrictions on hours worked are imposed. Hence, the estimated reaction of hours worked in our VAR allows us to discriminate between both models. Another innovation of the paper is that we are the first to address this question using Euro Area data on hours worked.[1] [2]

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 result 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.

The paper is organized as follow. Section 2 describes our model based identification strategy. First, we set up a baseline RBC and sticky price model and use the model impulse responses to derive a minimal set of robust restrictions for our Euro Area VAR. Second, we check the robustness of our sign restrictions by using estimated posteriori distribution of structural parameters for the Euro Area. 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. Section 5 discusses the importance of technology shocks for the Euro Area business cycle and shows a historical decomposition of hours worked into the contribution of all identified shocks. Section 6 concludes.

2 Identification

In this section we discuss our model based identification strategy. Our first objective is to identify a technology shock in the Euro Area and disentangle it from a labor supply shock. We introduce a labor supply shock into the model since recent literature emphasizes the importance of labor supply shifts for business cycle fluctuation. Chang and Schorfheide (2003) show that labor supply shifts 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 described by labor supply shocks. We identify both shocks by searching for a minimum set of restrictions that are robust in both, RBC and sticky price models. As we will show, the crucial identifying

[1] Dedola and Neri (2004) also use an approach with sign restrictions to identify technology shocks in the US finding a positive effect on hours. We were not aware of this paper, written at the same time, while doing our research. In contrast to their work, we use Euro Area data and an empirical model with less variables and fewer restrictions.

[2] Gali (2004) finds a confirmation of his results for the Euro Area. His evidence, however, is based on the reaction of employment, while we use a series of hours worked.

assumption is that real wages increase after a technology shocks while decrease after a labor supply shock. In order to discriminate both shocks from demand and monetary policy shocks, we will introduce some additional conventional restrictions in section 2.3.

2.1 Real Business Cycle Model

In this section we derive a standard RBC model augmented by labor supply shocks. In our economy the representative agent is maximizing the expected utility function of the following form:

$$\max E_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\frac{1}{1-\sigma} C_t^{1-\sigma} - \epsilon_t^{ls} \frac{N_t^{1+\eta}}{1+\eta} \right) \right] \tag{1}$$

where C_t is consumption, N_t is labor supply and ϵ_t^{ls} represents a shock to leisure/labor in the utility function. Therefore, labor supply shocks are modelled as shocks to preferences, i.e. a positive labor supply shocks is considered as a negative shock to the weight of leisure in the utility function. As usual, β stands for the time preference rate and η for the inverse of the elasticity of labor supply. The maximization problem of the agent is constrainted by the equations describing the production function, the capital accumulation process and the aggregate resource constraint. The production function of the economy has the standard Cobb Douglas form:

$$Y_t = (A_t N_t)^{\alpha} K_t^{1-\alpha} \tag{2}$$

where Y_t is output, A_t is technology, K_t is capital and N_t is labor input. The capital accumulation process is described by the following function:

$$K_{t+1} = (1-\delta) K_t + I_t \tag{3}$$

And the aggregate resource constraint has the following form:

$$Y_t = C_t + I_t \tag{4}$$

Optimization and log-linearization of the equilibrium conditions leads to a system of dynamic equations. First, we have the standard Euler condition:

$$c_t = E(c_{t+1}) - \frac{1}{\sigma} E(r_{t+1}) \tag{5}$$

where small letters characterize percentage deviations form the steady state. The linearized production function has the form:

$$y_t = \alpha a_t + \alpha n_t + (1-\alpha)k_t \tag{6}$$

The log-linearized capital accumulation follows:

$$k_{t+1} = (1-\delta)k_t + \delta i_t \tag{7}$$

The labor supply curve is described by :

$$w_t = \eta n_t + \epsilon_t^{ls} + \sigma c_t \tag{8}$$

where w_t is the real wage. We specify the technology and the labor supply shocks to follow an AR(1) process.

$$a_t = \rho_a a_{t-1} + \varepsilon_t^a \tag{9}$$

$$\epsilon_t^{ls} = \rho_{\epsilon^{ls}} \epsilon_{t-1}^{ls} + \varepsilon_t^{ls} \tag{10}$$

In order to calculate the theoretical impulse responses to both shocks, we use the parameter values as reported in Table 1. We will discuss the robustness of the predictions with respect to the a range of sensible parameter values in section 2.3. In line with the majority of the RBC literature, we specify the intertemporal elasticity of substitution and the inverse of elasticity of hours worked to the real wage to be one (i.e. a log utility specification). The discount factor, β, is calibrated to be 0.99, which implies an annual steady state real interest rate of 4 percent. The depreciation rate, δ, is set to equal to 0.025. The steady state share of capital income in total output, α, is set to 0.7. The AR(1) term of the labor supply shock is calibrated to be 0.89 while for the technology shock 0.93 (see also section 2.3).

Table 1: Parameter values for RBC model

Description	**Symbol**	**Value**
Intertemporal elasticity of substitution	σ^{-1}	1
Inverse of elasticity of N with respect W/P	η	1
Discount factor	β	0.99
Capital depreciation rate	δ	0.025
Steady state share of capital income	α	0.7
AR(1) term labor supply	ρ^{ls}	0.89
AR(1) term technology	ρ^a	0.93

The theoretical impulse responses based on the above parameter values are shown in the first two columns of Figure 1 for a technology shock and labor supply shock respectively. After a positive technology shock, output, real wages, hours worked and the real interest rate increase. Given the persistence of technology shocks, all variables return to baseline approximately after 20 quarters. These results are consistent with expectations. The second column shows the responses after a positive labor supply shock. We observe an increase in output, interest rate and hours worked, while real wages decrease on impact. The asymmetric response of real wages is the only difference between both shocks concerning the sign of the impulse responses.

2.2 Sticky Price Model

The sticky price model presented in this section is based on the model by Ireland (2002). The representative agent follows the same utility function as in the RBC model:

$$\max E_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\frac{1}{1-\sigma} C_t^{1-\sigma} - \epsilon_t^{ls} \frac{N_t^{1+\eta}}{1+\eta} \right) \right] \tag{11}$$

subject to to the budget constraint

$$P_t C_t + \frac{B_{t+1}}{R_t} = W_t N_t + B_t \tag{12}$$

Monopolistic competitive firms in the intermediate good sector have a linear production function in labor and technology:

$$Y_t(i) = A_t N_t(i) \tag{13}$$

The final good is produced by aggregating the output in the intermediate good sector using constant returns to scale technology.

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}} \tag{14}$$

Sticky prices are introduced by assuming quadratic cost of nominal price adjustment a la Rotemberg (1982):

$$\frac{\phi}{2} \left[\frac{P_t(i)}{\pi P_{t-1}(i)} - 1 \right]^2 Y_t \tag{15}$$

Optimization and log-linearization lead to the following standard equilibrium conditions. The New Keynesian IS-Curve has the standard form:

$$y_t = E(y_{t+1}) - \frac{1}{\sigma}(r_t - E(\pi_{t+1})) \tag{16}$$

The pricing decision of the firm under the Rotemberg-type of nominal adjustment delivers the following forward looking equation for inflation:

$$\pi_t = \beta E(\pi_{t+1}) + \frac{\theta - 1}{\phi\theta}\left[(\sigma + \eta)y_t + \epsilon_t^{ls} - (\eta + 1)a_t\right] \tag{17}$$

The labor supply curve is described by :

$$w_t = (\sigma + \eta)y_t + \epsilon_t^{ls} - \eta a_t \tag{18}$$

As before, we specify technology and labor supply shocks to follow an AR(1) process.

$$a_t = \rho_a a_{t-1} + \varepsilon_t^a$$

$$\epsilon_t^{ls} = \rho_{\epsilon^{ls}} \epsilon_{t-1}^{ls} + \varepsilon_t^{ls}$$

Finally, monetary policy is described by a standard Taylor rule:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)\left(\phi^y y_t^{gap} + \phi^\pi \pi_t\right) \tag{19}$$

In order to derive the theoretical impulse response functions, we use the parameter values as shown in Table 2. Most of the coefficients are taken from a study about Euro Area structural parameters by Rabanal and Rubio-Ramirez (2003).[3] In addition, we set the price adjustment costs at $\phi = 50$, which implies that 95% of the price has adjusted 4 periods after a shock. The elasticity of demand for the intermediate good θ is set to 6. Finally, we impose the coefficients of the Taylor rule to be respectively 0.26, 1.30 and 0.73

[3] See section 2.3 for details and the robustness with respect to alternative parameter values.

for ϕ^y, ϕ^π and ρ^a.

Table 2: Parameter values for sticky price model

Description	Symbol	Value
Intertemporal elasticity of substitution	σ^{-1}	0.19
Inverse of elasticity of N with respect W/P	η	0.95
Discount factor	β	0.99
AR(1) term labor supply	ρ^{ls}	0.89
AR(1) term technology	ρ^a	0.93
Price adjustment costs	ϕ	50
Elasticity of demand for intermediate good	θ	6
Taylor rule/ reaction to outputgap	ϕ^y	0.26
Taylor rule/ reaction to inflation	ϕ^π	1.30
Taylor rule/ smoothing term	ρ_r	0.73

The third and fourth column of Figure 1 show the theoretical impulse responses for the sticky price model. As in the RBC model, output and real wages increase after a positive technology shock. However, as expected in contrast to the results of the RBC model hours worked decrease after a positive technology shock. In addition, there is a fall in the real interest rate. The last column of Figure 1 shows the responses after a positive labor supply shock. The predictions for output, hours and real wages are in line with the results of the RBC model. Specifically, output and hours worked increase while real wages decrease. We also find an immediate fall in the real interest rate. Notice that after both technology and labor supply shock, the price level decreases on impact in the sticky price model.

2.3 Sign Restrictions and Robustness Analysis

In this section we introduce a minimal number of sign restrictions which are necessary to do the estimations. We only impose restrictions that are robust across both theoretical models. From Figure 1, it is clear that a positive technology shock has a positive effect on output and real wages in both models. On the other hand, we find a consistent positive impact on output and hours worked and a negative effect on real wages after a labor supply shock. For all other variables, we do not find robust signs of the impulse response functions across both models. The well known controversy between both models is the increase of hours worked after a technology shock in the RBC model, while hours fall in the sticky price model. In addition, we find a positive effect on the real interest rate of both shocks in the RBC model whilst this effect is negative in the sticky price model. In order to disentangle a technology shock from labor supply shocks, we could therefore potentially impose in our empirical analysis the restriction that real wages rise after a positive technology shock but fall after an exogenous shock to labor supply. These restrictions on the signs of the impulse responses are sufficient to uniquely discriminate between both shocks. We do not have to impose restrictions on hours worked or the real interest rate. The data can determine the reaction of these variables. The restrictions on output and real wages for both shocks are shown in the first and fifth column of Table 3 respectively.

Table 3: Sign restrictions

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

However these results are potentially sensitive to the parameterization of the models. Since our goal was to derive robust restrictions for our SVAR analysis, we discuss the identifying conditions in more detail. Specifically, we analyse the robustness of the restrictions if we consider a range of sensible values for the parameters. To do so, we borrow estimation results for Euro Area structural parameters from the recently developed literature on Bayesian estimation. This literature combines priors and the likelihood function to obtain the posterior distribution of the structural parameters. Generally, the Kalman Filter is used to evaluate the likelihood function of a linear approximation of the model and a numerical algorithm (the Metropolis-Hastings algorithm) to draw from the posterior distribution. Recently, Smets and Wouters (2003) and Rabanal and Rubio-Ramirez (2003) applied the Bayesian approach to estimate structural parameters and the performance of structural models for the Euro Area.

The paper by Smets and Wouters (2003) compares the performance of a large scale New Keynesian Model with habit persistence, price and wage rigidities, capital utilization, price and wage indexation with nontheoretical VARs. Rabanal and Rubio-Ramirez (2003) estimate a baseline sticky price model and three extensions of the model using Euro

Area data. The models are then compared by using the marginal likelihood as a model comparison device. Since the production and preference structure of our model is similar to the basic sticky price model estimated by Rabanal and Rubio-Ramirez (2003) and the comparison of the marginal likelihoods show that the baseline model is not significantly worse in explaining the data than the extension with sticky wages, we use its estimation results for simulations in this section.

Intuitively, the restrictions imposed to identify a labor supply shock (namely a positive output and negative inflation and real wages response) are not sensitive to the chosen value of the structural parameters in both models. Therefore we will focus in the following on the identification procedure of the technology shock. The impact effect on real wages in the RBC model after a technology shock is also unambiguous. A positive technology shock generates a wealth effect in labor supply. At the same time the shock raises productivity and labor demand. Therefore, the wages increase at impact regardless of the parameter values as the labor demand and supply effects work in the same direction.

This is not the case in the sticky price model. The effect of the technology shock on labor demand is for most of the parameter values negative. The reason is that, though all firms will experience a decline in their marginal cost, they will adjust the price downwards only partially in the short run. Accordingly, aggregate demand will rise less than proportionally to the increase in productivity. Under these circumstances real wages only increase if we have a very strong wealth effect and therefore the labour supply shift is dominating the labor demand effect.

Consequently we check the robustness of the presented results by using the posterior distribution of the structural parameters estimated in Rabanal and Rubio-Ramirez (2003). The results for the relevant parameters are depicted in Table 4. Notice that the value of the price adjustment costs is adjusted to be $\phi = 100$ to be approximately in line with the Calvo parameter estimated in Rabanal and Rubio-Ramirez (2003)[4]. Since the standard

[4]Note that in the empirical literature the degree of price stickyness is estimated to be rather high. For example Smets and Wouters (2004) estimate that the average duration of price contracts is two and half years in the Euro Area. The results of Rubio and Rabanal (2003) indicate a price duration of six and half quarters. One possibility why the degree of price stickyness is potentially overestimated lies in the specification of the marginal cost curve. While the marginal disutility of labor is upward sloping the marginal cost curve for the firms is usually assumed to be flat due to constant returns to scale production functions. Gali, Gertler and Lopez-Salido (2001) show that by assuming decreasing returns to scale and an upward sloping marginal cost curve the degree of price stickyness decrease significantly.

deviation, i.e. the uncertainty around the parameters $\rho^a, \phi^y, \phi^\pi, \rho_r, \phi$ are relatively low, we will focus on the impact response of output, inflation and real wages by varying σ^{-1} (the intertemporal elasticity of substitution) and η (inverse of the elasticity of hours worked with respect to the real wage). We use two standard deviations from the posteriori mean as a sensible range for our simulation exercise. We emphasize that the variation of the remaining parameters according to the same principle would not significantly alter the results. The impact responses of output, prices, real wages and hours worked are presented in Figure 2.

Table 4: Posterior Distribution of Estimated Structural Parameters for the Euro Area

Parameter	**Mean**	**Standard Deviation**
σ^{-1}	0.19	0.08
η	0.95	0.20
ρ^a	0.93	0.01
ϕ^y	0.26	0.06
ϕ^π	1.30	0.12
ρ_r	0.73	0.03

source: Rabanal and Rubio-Ramirez (2003)

Given the posterior distribution of structural parameters for the Euro Area in Rabanal and Rubio-Ramirez (2003), the results confirm that after a technology shock for a wide range of parameters output and real wages increase on impact, while prices and hours decrease. There is, however, one exception. If at the same time $\eta > 1.30$ and $\sigma > 30.60$ ($\sigma^{-1} < 0.03$), then we find a contemporaneous negative effect on real wages. This joint probability is, however, smaller than 0.001. We therefore consider our imposed conditions as robust restrictions depending on the parameters. These restrictions are also consistent with the empirical evidence on the reaction of real wages to shocks. Specifically, Francis and Ramey (2002) and Fleischmann (1999) find a positive effect of technology shocks and a negative effect of labor supply shocks on hours worked using an identification strategy in the spirit of Gali (1999).

So far, we have only disentangled technology from labor supply shocks. For a proper identification, we also have to distinguish both shocks from demand side shocks. Specifically, in the empirical part, we also estimate the effects of monetary policy shocks and aggregate demand shocks. To do so, we introduce some generally accepted sign conditions in Table 3 that are based on a typical aggregate supply and demand diagram which are also consistent with a large class of general equilibrium models. We assume that after both, an expansionary monetary policy and positive demand shock, the responses of output and prices are positive. In contrast, prices fall after a technology and labor supply shock. To disentangle between a monetary policy and an aggregate demand shock, we assume further that a positive demand shock generates an increase in the nominal interest rate whilst an expansionary monetary policy shock a fall of the same.[5] This strategy is in line with the method applied in Faust (1998), Uhlig (1999) and Peersman (2003). All sign restrictions are summarized in Table 3.

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:

$$Y_t = c + \sum_{i=1}^{n} A_i Y_{t-i} + B\varepsilon_t \tag{20}$$

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

[5] Notice that the response of the nominal interest rate after a monetary policy shock in a micro founded New Keynesian model depends crucially on the monetary policy rule. However in contrast to sticky price models, in a standard RBC model monetary policy has no real effects. Therefore by assumption, we do not have the possibiliy to impose restrictions that are robust in both models. Consequently, we stick to the identification scheme derived directly from the AD/AS framework. Note, however, that we also allow for a possible zero impact of monetary policy shocks in our empirical approach, because restrictions are imposed as $\geqslant$ or $\leqslant$. Our identification scheme for a demand shock (modelled e.g. as a government consumption shock in structural model) is robust in both sticky and flexible price models.

parameters (Sims et. al., 1990).[6] Within this VAR, we identify four types of underlying disturbances, a monetary policy, aggregate demand, technology and labor supply shock respectively. In order to identify these shocks, we use the restrictions reported in Table 3. For the implementation of these restrictions, we refer to Peersman (2003) or the appendix of this paper. All restrictions are imposed as $\leq$ or $\geq$. This means that a restrictive monetary policy shock is identified as a shock which has a positive effect on the interest rate and a negative (or zero) impact on output and prices. After a positive demand shock, output, prices and the interest rate do not fall. 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. In contrast, an unexpected increase in labor supply has not a negative impact on output, not a positive effect on prices and there is not an increase in real wages. These limited number of restrictions allow us to compare the estimated impulse responses of the other variables with the expectations from the theoretical models. In particular the responses of hours to all the shocks. No restrictions are imposed for the latter, which allows us to compare the theoretical responses with the data. For all variables except the interest rate, the time period over which the sign restriction is binding is set equal to four quarters. The response of the interest rate is only restricted for one quarter. We only select decompositions which produce impulse responses that are consistent with the restrictions of all four shocks. Specifically, the responses of four identified shocks should be consistent with a monetary policy, aggregate demand, technology and labor supply shock. Decompositions that match only the criteria of three or less shocks are rejected. Impulse responses and error bands are computed based on Monte Carlo integration with 1000 draws from the posterior. In all figures, we report the median of the responses together with 84th and 16th percentiles error bands.

Figure 3 shows the results. After a restrictive monetary policy shock, we find a significant negative response of output and prices. Output returns to baseline after five years whilst the effect on prices is more persistent. These monetary policy effects are qualitative similar to the results of Peersman and Smets (2001). We observe a significant decrease in hours worked and real wages. Both variables seem to be pro-cyclical after a monetary policy shock. Following an aggregate demand shock, we find a positive response of output up to 12 quarters. The effect on prices is also more persistent and the interest rate returns

[6] In Section 4.1, we check the robustness of our results when we use a first differences specification of the VAR. We can, however, not reject the hypothesis of the existence of a cointegration relation in the level specification.

to baseline together with output. Hours worked and real wages react pro-cyclical, but the uncertainty around the estimates are relatively high for the latter. The third row of Figure 3 presents the results for a technology shock. Striking is the positive and significant reaction on impact of hours worked. Notice that the variable hours worked is unrestricted in our set up. The results are in favor of the RBC model and stand in contrast to the results of Gali (1999) and others for the US. The last row depicts the results after a labor supply shock. As expected the response of hours worked is positive and very significant.[7]

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.

4.1 Difference specification

Christiano, Eichenbaum and Vigfusson (2003) show that the results of Gali (1999) are highly sensitive to the stochastic specification of the VAR. The negative response of hours worked of Gali (1999) are obtained with a VAR in first difference specification. If the model is estimated in levels, the results do not longer hold. 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. Indeed, we cannot reject the hypothesis of the existence of a cointegration relation in the level specification using the procedure of Johansen and Juselius in CATS. Nevertheless, we run this exercise as a robustness check. All variables included in the VAR are now measured as first differences. The impulse response function are reported in Figure 4. Results are very similar at first sight. However, there are some differences for technology and labor supply shocks. We now find a permanent effect of both shocks on the level of output and prices. This is not surprising given the stochastic specification of the VAR.

[7] Notice that the response of output returns to baseline in the long-run after a technology and labor-supply shock. This finding is not surprising given our de-trended level specification.

There is also a puzzling permanent effect of both shocks on the level of the nominal interest rate. However, we still find a positive (and permanent) effect of a technology shock on hours worked. The reaction of the latter variable to all shocks is also still pro-cyclical. The results show that the positive response of hours worked after a technology shock is independent of 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 differences model with employment included instead of hours worked. The latter was also done by Gali (1999). Results are reported in Figures 5 and 6. 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.

5 How important are technology shocks for aggregate fluctuations?

In Figure 7, we report the contribution of technology shocks to the forecast error variance of output and hours worked series for the two specifications. In contrast to the work of Gali (1999), who finds almost no role for technology shocks in explaining business cycle fluctuations, we find a substantial impact on the output and hours worked series. 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 et al. (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 8, we plot the actual time series of hours worked and employment, together with the contribution of all shocks to hours worked as percentage points deviations from baseline. This means that hours worked can be written as the sum of a deterministic component (baseline) and the contribution of current and past shocks. For reasons of legibility, we only show the median estimates. 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 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 (2003) who finds an important role for negative aggregate supply shocks in explaining the early millennium slowdown.

It is interesting to mention that the significant rise in hours worked between 1995 and 2001, often also called the New Economy period, is also mainly the result of positive labor supply shocks. This effect is even more pronounced for the differences specification. The positive labor supply shocks are actually the only significant source of the rise until 1999. In addition, we also find a positive effect of demand shocks between 1987 and 1991 and in 2000. The contribution is negative between approximately 1991 and 1997. Monetary policy shocks, on the other hand, made a negative contribution in 1992 and 1993, after which there was a slight upward effect until 2001.

6 Conclusions

This paper has provided empirical evidence for the effects of technology, labor supply, monetary policy and aggregate spending shocks on hours worked in the Euro Area economy. 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 sticky price 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 increases 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. This finding is in contrast to the results of Gali (1999) and others who find a negative reaction of hours worked to a technology shock in the US, but is consistent with Christiano et al. (2003) and Uhlig (2004) who use an alternative strategy.

However, this finding does not necessarily imply that sticky price models are not a good representation of reality. The shocks are identified at a fairly aggregated level. Identifying more shocks, like price and wage mark-up shocks, can provide additional information. If the impulse responses of structural shocks like price and wage mark up shocks are qualitatively equivalent to the impulse response functions following a technology shock for the parameters in our empirical model, then it might be worthwhile to pose the question how important price and wage markup shocks are for the Euro Area. Indeed, in further work (see Peersman and Straub, 2004), we identify a larger set of shocks in a Euro Area SVAR, and find an important role for price mark-up shocks.

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 (2003). Consider equation (20) in section 3. Since the shocks are mutually orthogonal, $E(\varepsilon_t \varepsilon_t^{'}) = I$, the variance-covariance matrix of equation (20) 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, i.e. $QQ' = I$. 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 (2003), 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:

$$Q_{m,n}(\theta) = \begin{bmatrix} 1 & \cdots & 0 & \cdots & 0 & \cdots & 0 \\ \cdots & \ddots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & \cdots & \cos(\theta) & ... & -\sin(\theta) & \cdots & 0 \\ \vdots & \vdots & \vdots & 1 & \vdots & \vdots & \vdots \\ 0 & \cdots & \sin(\theta) & \cdots & \cos(\theta) & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \ddots & \cdots \\ 0 & \cdots & 0 & \cdots & 0 & \cdots & 1 \end{bmatrix} \tag{21}$$

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 (21). 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:

$$R_{j,t+k} = A(L)^{-1} B_j \varepsilon_t \tag{22}$$

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:

$$R^{pq}_{j,t+k} \gtrless 0 \tag{23}$$

Following Uhlig (1999) and Peersman (2003), we use a Bayesian approach for estimation and inference. Our prior and posterior belong to the Normal-Wishart family used in the RATS manual fro 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 draw 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 of the four different shocks are satisfied, we keep the draw. Decompositions that match only the criteria of three or less shocks are rejected. This means that these draws receive zero prior weight. Based on the draws 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

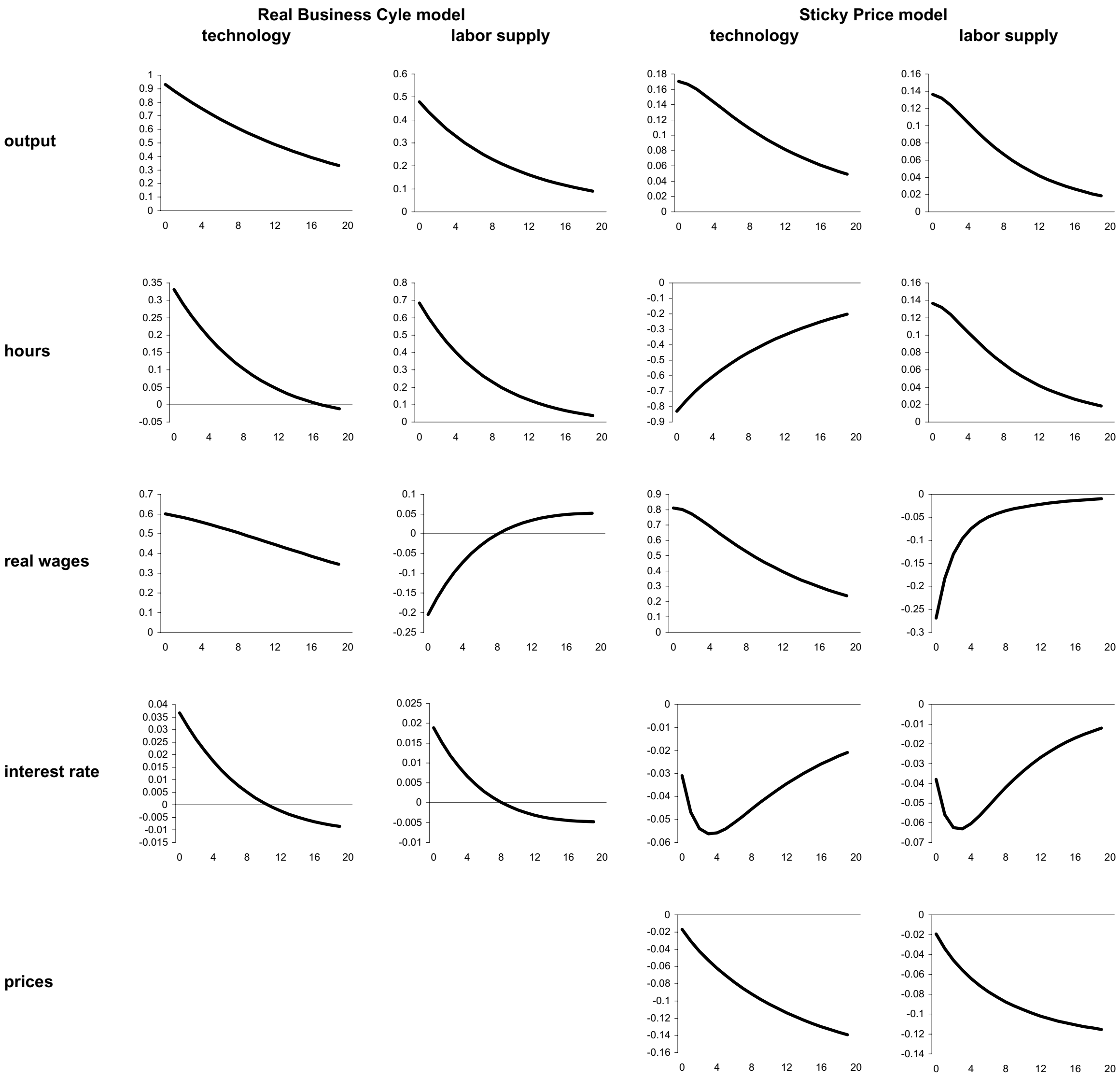


Figure 2 - Responses on impact in the Sticky Price model after a technology shock

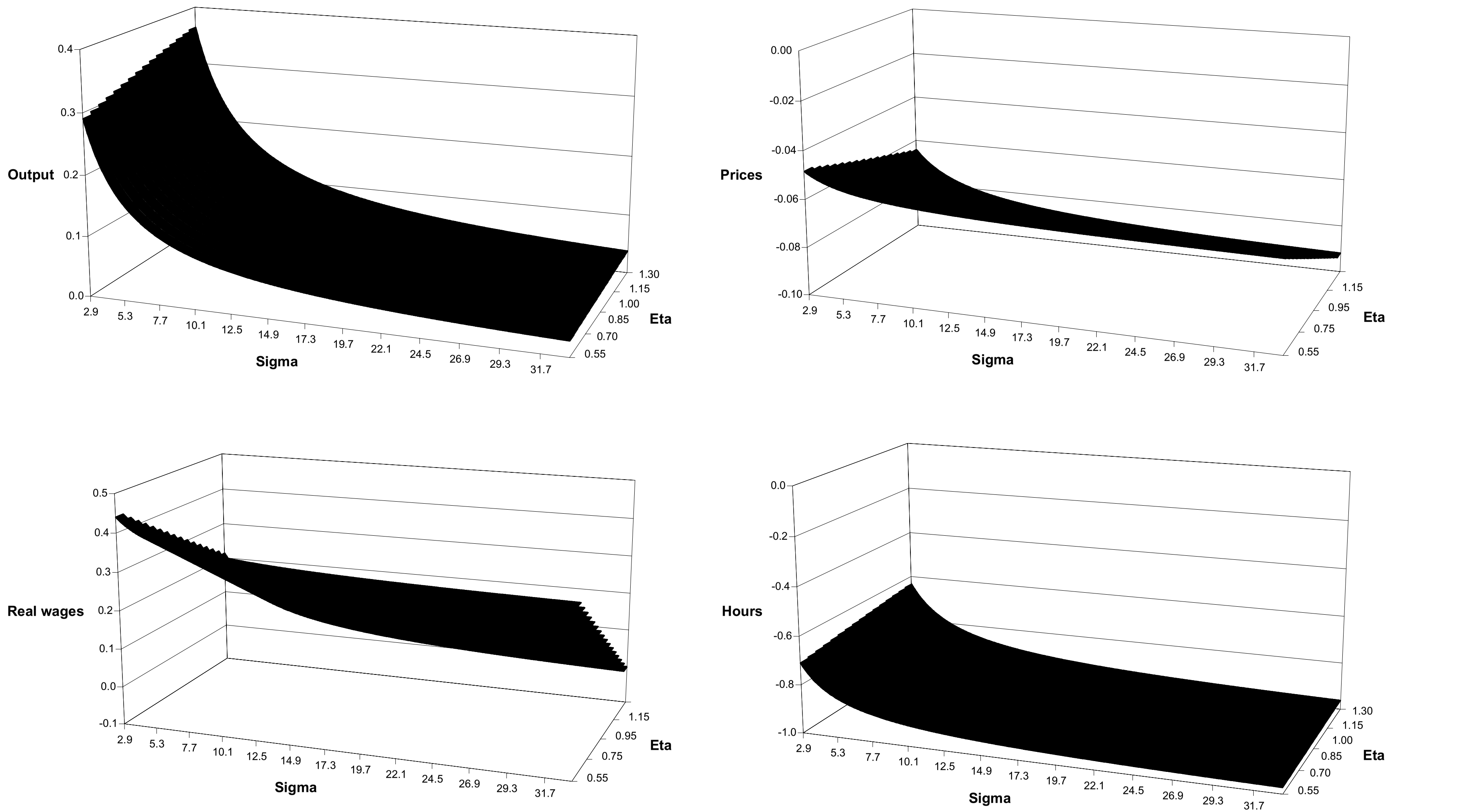
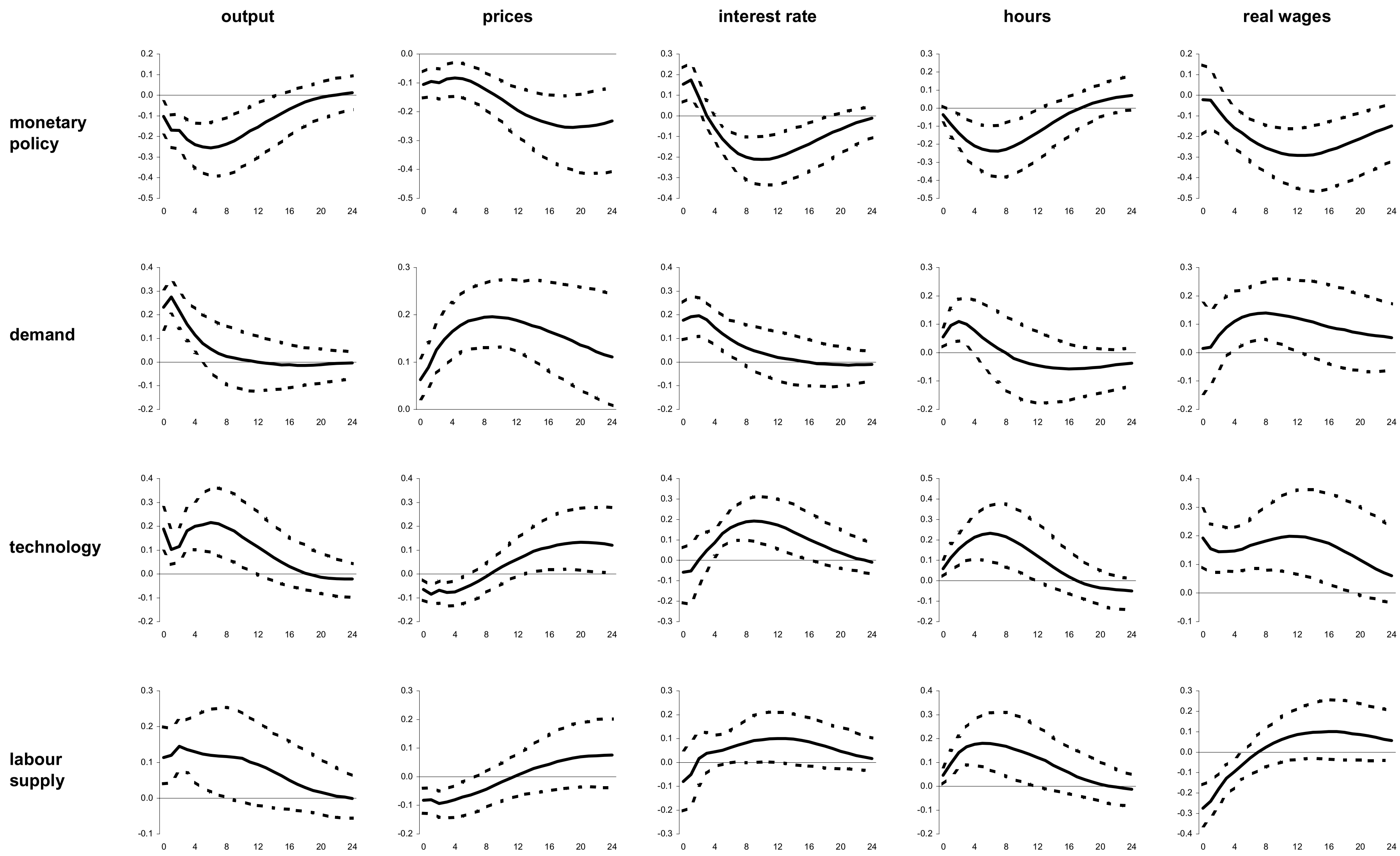


Figure 3 - Impulse responses for VAR with levels (hours)



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

Figure 4 - Impulse responses for VAR with first differences (hours)

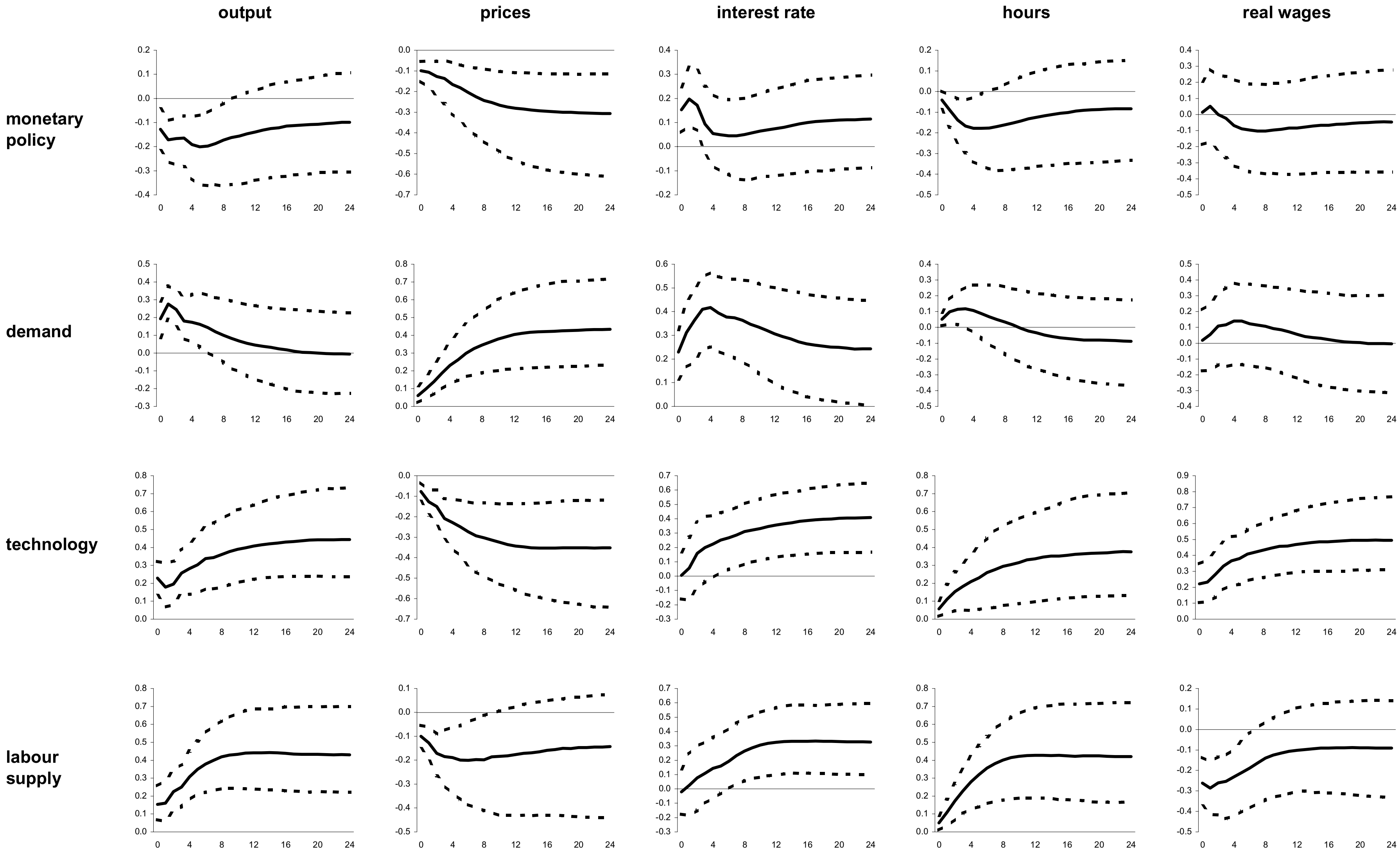


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Figure 5 - Impulse responses for VAR with levels (employment)

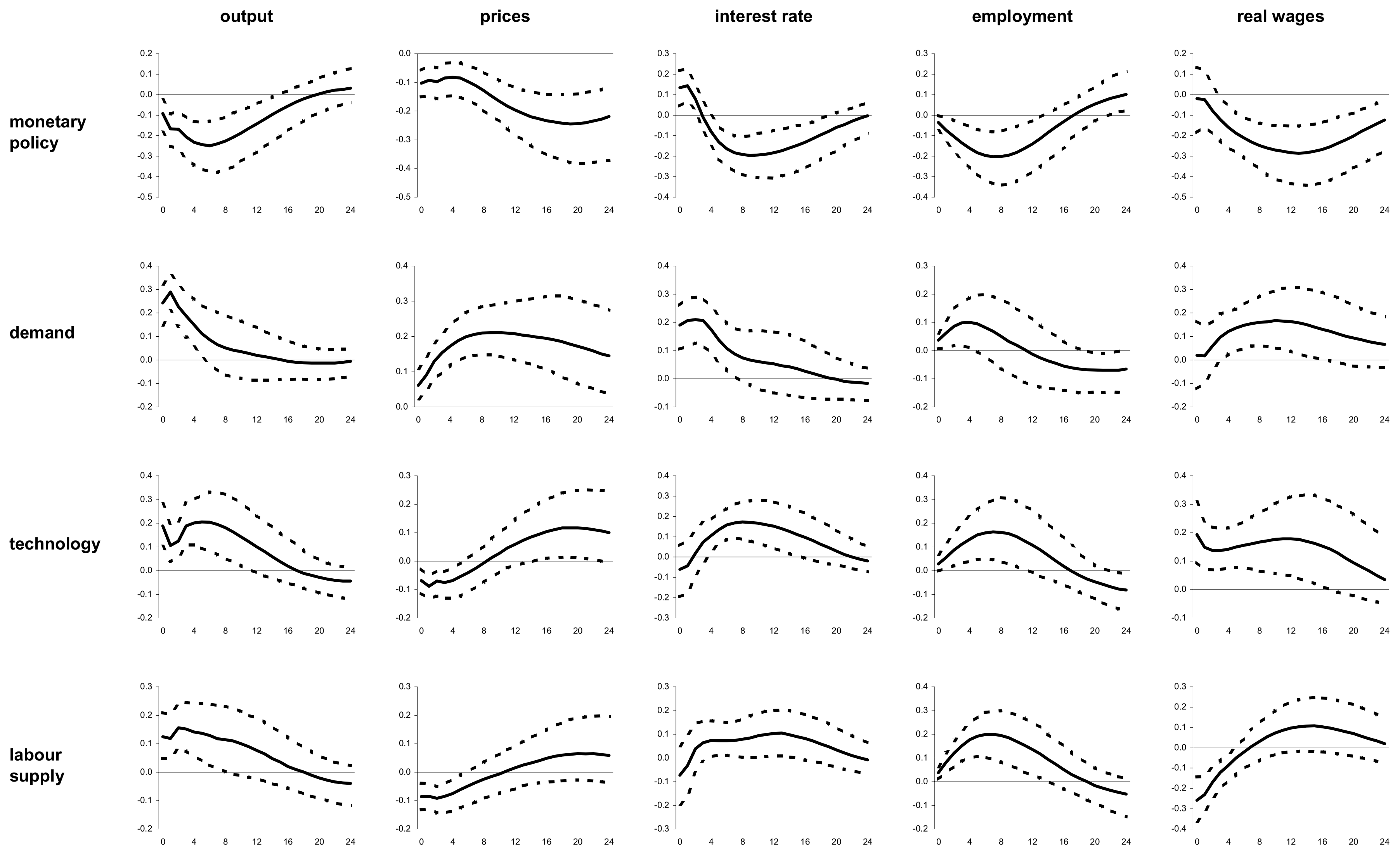

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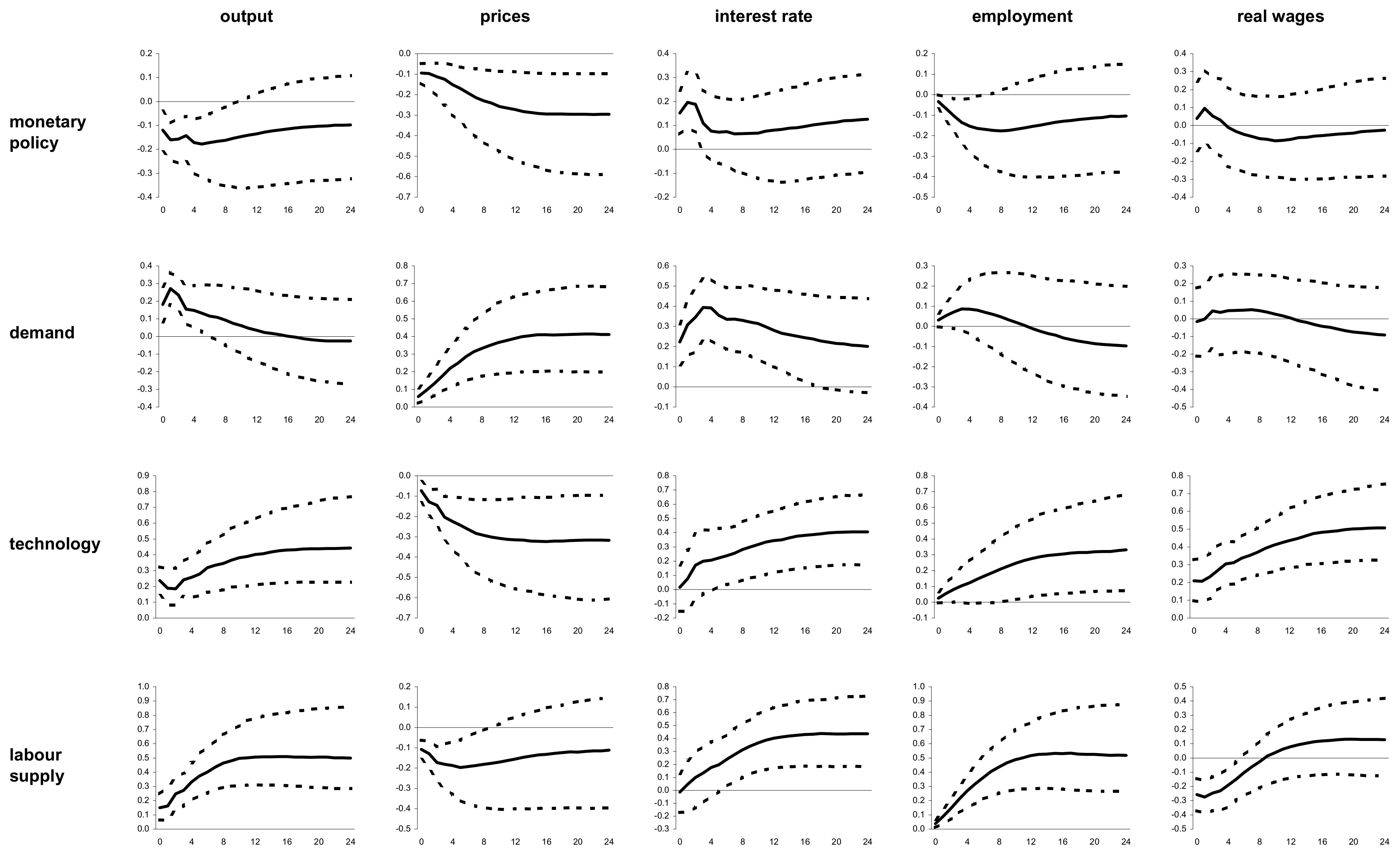
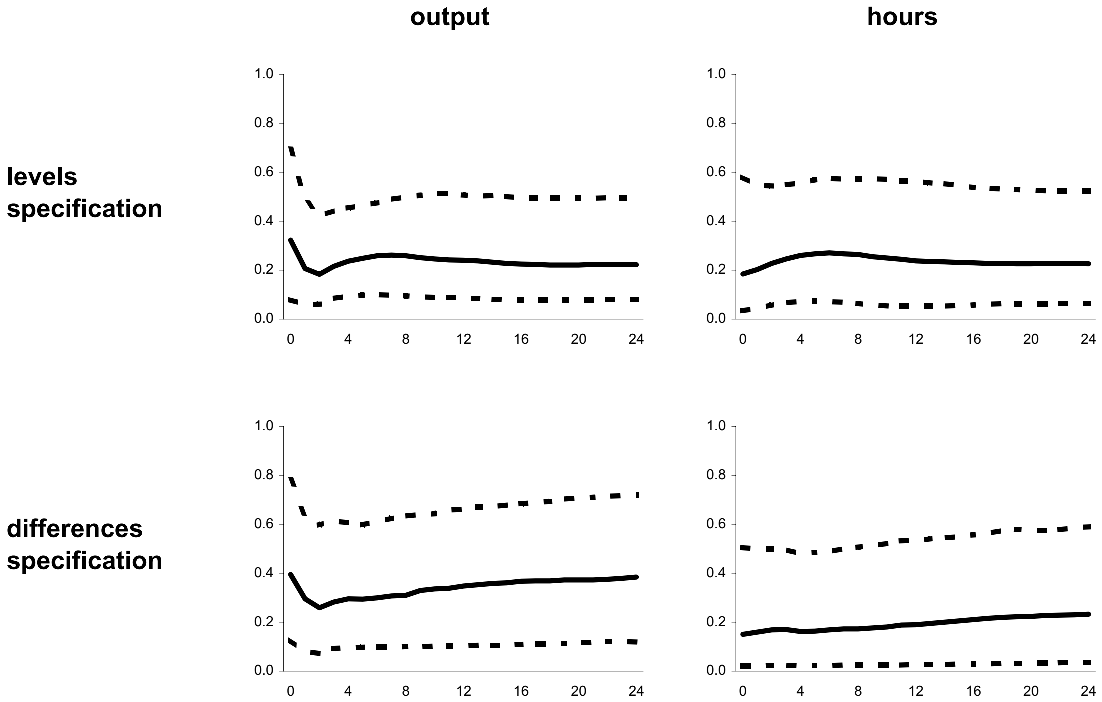
Figure 6 - Impulse responses for VAR with first differences (employment)



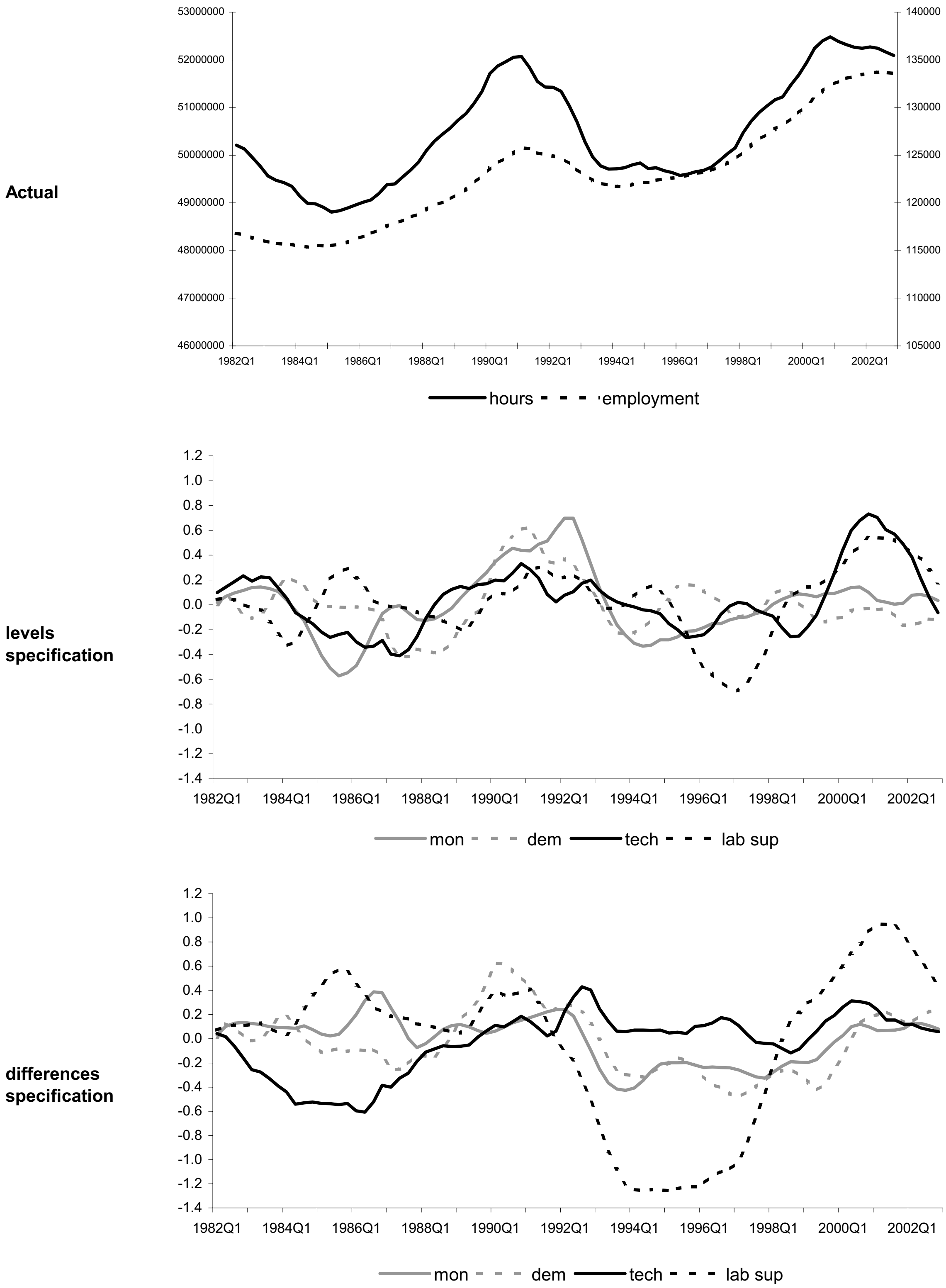
Note: median impulse responses with 84th and 16th percentiles error bands based on Monte Carlo integration, horizon is quarterly

Figure 7 - 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 8 - Historical contribution of shocks to hours worked in the Euro area



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

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