Putting the New Keynesian Model to a Test: An SVAR Analysis with DSGE Priors*

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Abstract

This paper shows how the popular New Keynesian DSGE model can be used to derive sign restrictions for the identification of several shocks in a structural vector autoregression (SVAR) for the Euro Area. The impact is first estimated for respectively monetary policy, preferences, government spending, investment, price mark-up, technology and labor supply shocks. In a second step, the restrictions from the DSGE model are significantly relaxed and the SVAR is re-estimated with a minimum set of more general constraints. The data can then provide more information about the validity of the DSGE model. It is shown that most of the responses remain consistent with the New Keynesian model, including the controversial negative effects of a government spending shock on private consumption and investment. Some interesting differences, however, emerge. In contrast to the theoretical model, a positive effect of a technology shock on employment, and a positive impact of a preferences and investment shock on respectively investment and consumption are found.

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*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 workhorse in today's theoretical macroeconomics is a dynamic stochastic general equilibrium (DSGE) model with sticky prices, habit formation, capital adjustment costs, variable capacity utilization and other frictions introduced to capture empirical fluctuations in macroeconomic data.[1] In addition, these type of models are also used for policy purposes in practise[2]. On the other hand, since the seminal work of Sims (1980), structural vector autoregressions (SVARs) are frequently used as a tool in empirical macroeconomic analysis. This technique is convenient to implement and can provide clear answers to policy relevant questions such as: "What are the effects of monetary and fiscal policy shocks?", "What shocks drive the business cycle?" and "Which underlying disturbances caused recent output and inflation fluctuations?" using respectively impulse response functions, variance decompositions and historical decompositions. The results of a VAR analysis are also frequently used to evaluate the outcome of theoretical models. Gali (1992) checks whether the IS-LM model is able to fit postwar US data. Blanchard and Perotti (2002) and Fatás and Mihov (2001) use the outcome of a government spending shock from an SVAR model to assess New Keynesian (NK) and Real Business Cycle (RBC) models. Gali (1999) estimates the effects of technology shocks on hours worked to discriminate between both theoretical models. Canova (2002) compares a limited participation monetary model and a sticky price monopolistic competition model with a VAR analysis. In this study, we first show how the popular NK DSGE model can be used to derive restrictions for the identification of a large set of shocks in a structural vector autoregression (SVAR) for the Euro Area. In a second step, we significantly relax the restrictions from the DSGE model and re-estimate the SVAR in order to evaluate the outcome of the theoretical model. So to say, we put the conditional properties of the large scale NK model to a test.

A crucial aspect in the SVAR literature is the identification of structural shocks. In order to identify these shocks, a number of zero restrictions on the immediate or long-

[1] Examples are Christiano, Eichenbaum and Evans (2005) for the US and Smets and Wouters (2003) for the Euro Area.

[2] See for example the GEM model of the IMF, the SIGMA model of the FED and the TOTEM model of the Bank of Canada.

run impact of the shocks are typically introduced.[3] A problem, however, is that the implementation of zero restrictions could be very arbitrary and misleading if a lot of variables are included in the system. That is why a majority of the empirical papers only focus on one type of shock, such as monetary or fiscal policy shocks. In that case it is only necessary to make assumptions to estimate the monetary or fiscal policy rule. Even if additional shocks are identified, this is still at a relative aggregate level. Examples are aggregate supply or aggregate spending shocks. Identifying more shocks at a disaggregated level is not possible because it involves using economic theory to introduce additional zero restrictions in the short or long-run to disentangle the shocks from each other.[4] Unfortunately, these restrictions are not always available or are very stringent, which can significantly affect the results.

In this paper, we consider many shocks simultaneously at a more disaggregate level which is a first contribution of the paper. We identify monetary policy, preferences, government spending, investment, price mark-up, technology and labor supply shocks in the Euro Area economy. In order to identify the shocks, we use sign restrictions. The latter are used by Faust (1998), Uhlig (1999) and Canova and de Nicoló (2003) to identify monetary policy shocks and extended by Peersman (2005) to oil price, aggregate supply and aggregate demand shocks. The advantage of this procedure is that no zero constraints have to be imposed. The restrictions are much more general and easier to implement when economic theory only provides qualitative rather than quantitative information about the effects of shocks. As a consequence, it is possible to identify more shocks. In this paper we use a standard DSGE model to derive the sign restrictions for our empirical analysis. Specifically, we first calibrate a NK DSGE model with sticky prices, habit formation, capital adjustment costs and variable capacity utilization which provides us theoretical

[3]Several alternative strategies are used to do this. For instance, Christiano et. al. (1998) and Sims (1990) assume a short-run recursive ordering of the variables in the system. This means that the shocks are orthogonal to the variables ordered before the shock. Bernanke (1986), Sims (1986) and Bernanke and Mihov (1998) abandon the recursiveness assumption and introduce a broader set of short-run relations based on economic theory. Blanchard and Quah (1989), King et al. (1989) and Gali (1992) also use long-run restrictions to identify the shocks.

[4]Blanchard (1993) estimates a VAR on the components of GDP, but does not identify structural disturbances.

impulse response functions for a number of macroeconomic variables. From these impulse response functions, we select a set of sign conditions which are robust with respect to the parameterization of the model. We then estimate a seven-variables VAR for output, prices, employment, real wages, consumption, investment and the short-run interest rate for the Euro Area. The data can then determine the magnitudes of the responses, the contribution to the variances of the variables and the historical contribution of the shocks to all variables.

When we consider the theoretical DSGE model into more detail, some of the constraints and responses are however not consistent with existing empirical evidence or other alternative theoretical models. For instance, Blanchard and Perotti (2002), Fatás and Mihov (2001) and Gali et. al. (2003) find a rise in private consumption after a government spending shock which is ad odds with the DSGE model.[5] On the other hand, standard RBC models predict a positive impact of technology shocks on employment whilst this effect is always negative in a NK model. As a result, restricting the latter two responses to be negative with sign conditions can be questioned. We therefore significantly relax the imposed conditions in a second step. The SVAR is re-estimated with a minimum set of less stringent more general constraints from the NK model that are consistent with a broader class of models and less controversial. Accordingly, it is possible to evaluate the DSGE model and compare it with other empirical evidence which is the second contribution of the paper. We show that most of the responses remain consistent with the NK DSGE model, including the negative impact of government spending shocks on private consumption and investment. Some interesting differences, however, emerge. We find a positive effect of a technology shock on employment, and a positive impact of a preferences and investment shock on respectively investment and consumption, which was not predicted by the model.

This methodology implies that we use the outcome of a DSGE model as a prior for SVARs. There are also other papers using DSGE priors. DeJong et al. (1993) and Ingram and Whiteman (1994) use a DSGE model as a prior to estimate a bayesian VAR used for

[5]Gali et. al. (2003) extend the standard New Keynesian model with rule-of-thumb consumers and show that the interaction of the latter with sticky prices and deficit financing can account for the existing evidence on the effects of government spending in specific circumstances.

forecasting purposes. However, they do not identify structural shocks in their analysis. Del Negro and Schorfheide (2003), in contrast, utilize the priors from the theoretical model to estimate a three-variables bayesian VAR and to do the identification of a monetary policy shock, which seems to be a very promising method. The disadvantage of these approaches is that the modelling of the dynamics of the DSGE model is relative important, which can have a substantial impact on the results. Misspecification can lead to biased results and wrong conclusions. In contrast to these studies, our VAR is more extended and includes much more shocks. In addition, we only use the DSGE model to derive the sign constraints to do the identification of the structural shocks. Moreover, these conditions are robust for several parameterizations of the model. This implies that the construction of the dynamics of the theoretical model is rather limited for the estimation results.[6]

The rest of the paper is structured as follows. In Section 2, we develop a New Keynesian DSGE model for the Euro Area and show the theoretical impulse response functions. The sign conditions for the identification are derived from this model. Section 3 shows the estimation results of the SVAR-model for the Euro Area with the DSGE priors for the sign restrictions. In Section 4, we substantially relax the imposed restrictions in order to evaluate the NK results. Finally, Section 5 concludes.

2 The DSGE Priors

The DSGE model and the corresponding discussion in this section draws heavily on Smets and Wouters (2003) and Coenen and Straub (2005).[7] The paper by Smets and Wouters has garnered much attention because it demonstrates that large scale DSGE models are able to fit data as well as a conventional atheoretical VAR. The empirical success lies in the introduction of numerous dynamic extensions into the 'workhorse' New Keynesian

[6] This approach is somewhat similar to Canova (2002). He evaluates two DSGE models of money, i.e. a limited participation economy and a sticky price monopolistic competitive economy against the data. Specifically, he derives robust restrictions for the cross correlations of some macroeconomic variables from both models and implement them in a VAR. In contrast, we only restrict the sign of the responses and we analyse a large set of structural shocks while Canova (2002) only focuses on monetary and technology shocks.

[7] See also Christiano et. al. (2005), the GEM and Sigma model.

model to capture the persistence in the macro data. Large scale DSGE models exhibit both sticky prices and wages, partial indexation, external habit formation in consumption, capital adjustment costs and variable capital utilization. Additionally, several structural shocks are identified and can be estimated within the model framework. These features make them sufficiently rich to capture the stochastics and dynamics in the data and a valuable tool for policy analysis in an empirically plausible set-up. In the following we will focus on the log-linearized version of the model. For the description of the full non-linear model and derivation of the equilibrium conditions, the interested reader is referred to the papers cited above. We first briefly describe the model in Section 2.1. The sign restrictions obtained from this model and implemented in our empirical analysis are discussed in Section 2.2.

2.1 Description of the model

The model consists of a continuum of households who value consumption and leisure and are subject to habit persistence. The preferences are subject to two type of preference shocks. Households supply a differentiated labor in a imperfectly competitive labor market and trade bonds in a complete market to allocate consumption over time. The equation governing the evolution of consumption can be summarized by:

$$C_t = \frac{\gamma_c}{1+\gamma_c} C_{t-1} + \frac{1}{1+\gamma_c} E_t C_{t+1} - \frac{1-\gamma_c}{(1+\gamma_c)\sigma}(r_t - E_t \pi_{t+1}) + \frac{1-\gamma_c}{(1+\gamma_c)\sigma}(\varepsilon_t^b - E_t \varepsilon_{t+1}^b) \quad (1)$$

where C_t is consumption, γ_c is the parameter determining the degree of habit persistence, σ is the coefficient of risk aversion, r_t is the nominal interest rate, π_t is the inflation rate and ε_t^b is a AR(1) shock to the intertemporal elasticity of substitution. As households have market power, they act as wage setters in the labor market. But households face nominal wage rigidity a la Calvo (1983) and are only able to reset wages with probability $(1 - \xi_w)$. If they are not able to re-optimize, the nominal wage will grow at a rate equal partially to the nominal price inflation. As a result, the optimal wage setting of households leads to the following real wage equation:

$$\begin{aligned} w_t \;=\; & \frac{\beta}{(1+\beta)} w_{t+1} + \frac{1}{(1+\beta)} w_{t-1} + \frac{\beta}{(1+\beta)} \pi_{t+1} - \frac{(1+\beta\gamma_w)}{(1+\beta))} \pi_t - \frac{\gamma_w}{(1+\beta))} \pi_{t-1} \quad (2) \\ & - \frac{1}{(1+\beta)} \frac{(1-\beta\xi_w)(1-\xi_w)}{(\xi_w(1+\frac{1+\lambda_w}{\lambda_w}\zeta)} (w_t - \xi_w n_t + \lambda_t + \varepsilon_t^n) \end{aligned}$$

where w_t is the real wage, β is the discount factor, γ_w is the partial wage indexation, ζ a coefficient determining the disutility of labor while ε_t^n stand for an AR(1) shock to labor supply. Households own capital and rent to firms at rental rate r_t^k. Capital used in production can be modified by either changing the utilization rate or through investment. Adjusting both generates adjustment costs which are incurred by the households. As adjustment costs are only of second order, they are assumed to be zero in steady state. As a results the optimal investment i_t is determined by:

$$i_t = \frac{\beta}{(1+\beta)} E_t i_{t+1} + \frac{1}{(1+\beta)} i_{t-1} + \frac{(1+\beta)}{\Upsilon_t} q_t + \frac{\beta E_t \varepsilon_{t+1}^i - \varepsilon_t^i}{1+\beta}$$

while the linearized capital accumulation is given by:

$$k_t = (1-\delta)k_{t-1} + \delta i_t \tag{3}$$

where Υ_t is the inverse of the capital adjustment costs, δ is the capital depreciation rate, ε_t^i is an AR(1) shock to the investment adjustment cost function, henceforth for simplicity labelled as an investment shock, while q_t is the real value of capital and follows:

$$q_t = (1-\delta)\beta q_{t+1} + \beta R^k E_t r_{t+1}^k - (r_t - \pi_{t+1}) \tag{4}$$

There is a continuum of intermediate goods producer facing imperfect competition. Cost minimization of firms leads to the following equilibrium conditions, determining the evolution of the capital-labor ratio and the marginal cost function mc_t:

$$n_t = w_t + k_{t-1} + (1+\Psi))\, r_t^k \tag{5}$$

$$mc_t = \alpha r_t^k + (1-\alpha) w_t - \varepsilon_t^a \tag{6}$$

where Ψ is the inverse of the elasticity of the capital utilization cost function and α is a technology determining partly the evolution of the log-linearized production function:

$$y_t = \alpha k_{t-1} + \alpha z_t + (1+\alpha) n_t + \varepsilon_t^a \tag{7}$$

Notice that ε_t^a is an AR(1) technology shock common to all firms. Firms face Calvo-type of nominal price rigidity with partial indexation and the degree of competition is subject to the AR(1) shock ε_t^p. This leads to the following generalized New Keynesian Phillipscurve:

$$\pi_t = \frac{\beta}{(1+\beta\gamma_p)}\pi_{t+1} + \frac{\gamma_p}{(1+\beta\gamma_p)}\pi_{t-1} + \frac{(1-\beta\xi_p)(1-\xi_p)}{(1+\beta\gamma_p)\,\xi_p}(mc_t + \varepsilon_t^p) \tag{8}$$

where γ_p is the degree of price indexation and $(1-\xi_p)$ is the probability to reset prices in the actual period. As in Smets and Wouters (2003), we assume that hours worked determines employment e_t according to the following equation:

$$e_t = \beta e_{t+1} + \frac{(1-\beta\xi_e)(1-\xi_e)}{\xi_e}(n_t - e_t) \tag{9}$$

The parameter $(1-\xi_e)$ determines the share of firms that are able to adjust employment in any given period. We assume that fiscal policy is Ricardian and variations in government spending-output share g_t are governed by an AR (1) process. As a result, equilibrium in the goods market is determined by the following equation:

$$y_t = \frac{C}{Y}c_t + \frac{I}{Y}i_t + g_t + R^K\frac{K}{Y}\Psi r_t^k \tag{10}$$

Notice that $\frac{C}{Y}, \frac{I}{Y}, \frac{K}{Y}$ are the corresponding steady state ratios of consumption, investment and capital to output. Finally, the model is closed by an empirically motivated policy rule, where $\bar{\pi}$ is the inflation targeting and η_t^r an i.i.d. policy shock.

$$\begin{aligned} r_t \;=\; & \phi_r r_{t-1} + (1-\phi_r)\left(\bar{\pi}_t + \phi_\pi(\pi_{t-1} - \bar{\pi}_t) + \phi_y(y_t - y_t^*)\right) \\ & + \phi_{\Delta\pi}(\pi_t - \pi_{t-1}) + \phi_{\Delta y}(y_t - y_t^* - (y_{t-1} - y_{t-1}^*)) + \eta_t^r, \end{aligned} \tag{11}$$

In the next section, we discuss the conditional impulse response functions of the model after a monetary policy, preferences, government spending, investment, price mark-up, technology and labor supply shock. The signs of these responses will be used as identifying restrictions in Section 4.

2.2 Sign restrictions

In order to derive the sign restrictions utilized later in the VAR analysis, we calculate the impulse response functions from the DSGE model. We focus on the conditional responses of output, prices, interest rate, employment, real wages, consumption and investment following a monetary policy, preferences, government spending, investment, price mark-up, technology and labor supply shock because these will be used in our empirical estimations. To do so, we first calibrate the DSGE model for a range of sensible values for the parameters that are frequently used in the literature. For some of these values, we also borrow estimation results for Euro Area structural parameters from the recently developed literature such as Smets and Wouters (2003). More specifically, for each parameter, we draw a value from an interval and generate the corresponding impulse response functions. The intervals for the parameter values are reported in Table 1.[8] This exercise is repeated for 10000 simulations. The 20th and 80th percentiles of all these conditional simulations are shown in Figure 1 for our 7 variables (dotted lines). In this figure, we also include the median of the posterior (full line) for the Smets and Wouters (2003) model to check consistency of these two exercises. Except for the real wage reaction to an investment shock, the sign of all responses are the same for both exercises.[9] The corresponding sign restrictions for our empirical analysis are presented in Table 2.

Consider first demand and policy shocks. A temporary expansionary monetary policy shock reflected by a fall in the nominal interest rate implies a rise in consumption, investment and output respectively. Also prices, employment and real wages rise. Preferences, government spending and investment shocks all have a positive effect on output, prices, the nominal interest rate, employment and real wages. A shock in preferences, while increasing consumption and output, has a negative effect on investment. In contrast, an investment boom generated by a temporary reduction in the cost of installing capital, crowds out consumption on impact. A government spending shock generates the expected negative wealth effect that has a negative impact on consumption and investment while

[8] Notice that ρ^{shock} is the AR(1) coefficient for the corresponding shocks and g/y is the share of government spending to output.

[9] Note that for some shocks, the scaling is somewhat different for both exercises. Since we are only interested in the signs of the responses, this is irrelevant for our analysis.

rising employment, i.e. the so-called crowding-out effects of government spending. All these responses generated by the NK DSGE model turn out to be very consistent over a sensible range of parameter values. In addition, the signs are also consistent with the Smets and Wouters (2003) estimation results for the Euro Area.

Table 1: Parameter ranges for DSGE simulations

β	0.99
σ	$[0.1 - 2]$
γ_c	$[0.4 - 0.8]$
ζ	$[0.5 - 4]$
α	0.3
δ	0.025
Υ	$[5 - 9]$
Ψ	$[0 - 0.3]$
ξ_p	$[0.6 - 0.99]$
ξ_w	$[0.6 - 0.9]$
γ_p	$[0.3 - 0.7]$
γ_w	$[0.6 - 0.9]$
ξ_e	$[0.5 - 0.7]$
ϕ_r	$[0.5 - 0.95]$
ϕ_y	$[0 - 0.2]$
ϕ_π	$[1 - 2.5]$
$\phi_{\Delta y}$	$[0 - 0.2]$
$\phi_{\Delta \pi}$	$[0.9 - 1]$
ρ^{shock}	$[0.7 - 0.95]$
g/y	0.18

Concerning supply side shocks, favorable price mark-up, technology and labor supply shocks all have a robust positive effect on output, consumption and investment, whilst the impact on prices and interest rate is negative for all sensible parameter values. A jump in productivity (technology shock) has a negative impact on marginal costs, but as prices are sticky, aggregate demand rises less than supply so employment falls despite the positive response of output and there is a rise in real wages. Notice that if monetary policy is accommodative enough, the NK model is also able to generate a positive response of employment. On the other hand, a positive labor supply shock leads unambigiously to an increase in employment and a fall in the equilibrium real wage. As discussed in detailed in Peersman and Straub (2004), the fall in real wages along with the positive correlation between output and employment is the most significant and robust qualitative difference between the conditional responses following a technology and labor supply shock. The impact of price-mark up shocks on output, consumption, investment and inflation are similar to the previous shocks, but the model predicts different impact responses of real wages and employment compared to labor supply shocks and technology shocks respectively.

Table 2: Signs of theoretical impulse response functions

	Y	P	S	E	$\frac{W}{P}$	C	I
monetary policy	↑	↑	↓	↑	↑	↑	↑
preferences	↑	↑	↑	↑	↑	↑	↓
government spending	↑	↑	↑	↑	↑	↓	↓
investment	↑	↑	↑	↑	↑	↓	↑
price mark-up	↑	↓	↓	↑	↑	↑	↑
technology	↑	↓	↓	↓	↑	↑	↑
labor supply	↑	↓	↓	↑	↓	↑	↑

In sum, we can consider the signs of the impulse responses reported in Table 2 as being more or less robust restrictions obtained from a NK DSGE model that can be used for empirical identification in Section 3. Although all conditional responses are robust with respect to a sensible range of parameter values from the NK model, some of the results are subject to ongoing controversy. For example, the conditional response of employment following a technology shock is for a wide range of parameters negative in the NK model. In contrast, RBC models predict a positive effect of technology shocks, which is confirmed by evidence of Christiano et. al. (2003), Uhlig (2003) and Peersman and Straub (2004) among others. But the empirical results are not unanimous (see for example Gali and Rabanal, 2005). The crowding-out of private consumption following a government spending shock is similarly controversial. The majority of the empirical literature predicts a positive or insignificant impact of government spending on private consumption. See the empirical work by Blanchard and Perotti (2002), Fatás and Mihov (2001) among others. On the basis of this evidence, Gali, López-Salido and Vallés (2004) extend the standard New Keynesian model to allow for the presence of non-Ricardian, rule-of-thumb households and show that the interaction of the latter with sticky prices and deficit financing can account for the existing empirical evidence. However, as argued in Bilbiie and Straub (2004), the result relies on a sharp response of real wages following government spending shocks which stands in contrast with the observed a-cyclical pattern of real wages in the data. Coenen and Straub (2005) argue utilizing an estimated DSGE model with non-Ricardian agents for the Euro Area that, although the presence of non-Ricardian households is in general conducive to raising the level of private aggregate consumption in response to government spending shocks; as a practical matter, however, there is only a fairly low probability for this to happen. The results show that the estimated share of non-Ricardian households is quite low, but also that the large negative wealth effect induced by the highly persistent nature of the estimated government spending shocks crowds out consumption of the Ricardian agents significantly. Finally the lack of empirical evidence on the responses of preference and investment shocks give rise to caution in implementing the full set of conditional responses for identification.

Despite the lack of agreement in the empirical and theoretical literature with respect to some of the impact responses, we first estimate our VAR using the complete set of restrictions depicted in Table 2 to provide a benchmark for our later results. Using the estimation results, we can check whether there exist decompositions in the data that are consistent with all restrictions from the theoretical DSGE model in the first place. Moreover, it provides us information how easy it is to find these decompositions in the data. If one fully believes the derived restrictions from the New Keynesian model, the results of the estimations can also be used to evaluate the magnitudes of the impulse responses and analyze variance and historical decompositions. In Section 4, we will then significantly reduce the number of restrictions by utilizing only a minimum set of robust sign restrictions that are more general and less controversial. Accordingly, it is possible to check the robustness of the conditional responses and accompanying contributions to variances and historical fluctuations. So to say: we put the conditional properties of the large scale New Keynesian model to a test.

3 An SVAR-model for the Euro Area with DSGE priors

In this section we present the results of the standard SVAR-model using Euro Area quarterly data for the sample period 1980-2003. All data are taken from the area-wide model of the ECB (Fagan et. al., 2001). We first describe the specification and identification strategy of the SVAR in Section 3.1. Results for impulse response analysis and variance decompositions are presented in Section 3.2.

3.1 Methodology

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

$$Y_t = c + \sum_{i=1}^{n} A_i Y_{t-i} + B\varepsilon_t \tag{12}$$

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 (s_t), employment (e_t), real wages ($\frac{w_t}{p_t}$), consumption (c_t) and investment (i_t). All variables are logs, except the interest rate which is in percentages. 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).

Within this VAR, the seven types of shocks from the NK model are identified: a monetary policy, preferences, government spending, investment, price mark-up, technology and labor supply shock respectively. In order to identify these shocks, we use the sign restrictions as shown in Table 2. The restrictions are sufficient to uniquely disentangle all seven shocks. Specifically, for each shock the sign of the response of at least one variable is different from the sign of the response to another shock. For the implementation of these restrictions, we refer to Peersman (2005). All restrictions are imposed as $\leqslant$ or $\geqslant$. For all variables, the time period over which the sign constraints are binding is set equal to four quarters, except for the interest rate where this time period is two quarters.[10] 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 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 on the responses are satisfied, we keep the draw. If the decomposition does not match the criteria, the draw is rejected. This means that these draws receive zero prior weight. Based on the draws left, we calculate statistics and report the median responses, together with 84th and 16th percentiles error bands. We do not require the restrictions of all shocks to hold simultaneously. Specifically, if the impulse responses to an individual shock are consistent with the imposed conditions for this shock, the results for the specific shock are accepted. This implies that even if some restrictions for a certain shock are debatable, this has no effect on the estimation of the other shocks.[11] Impulse responses and error bands are computed with a minimum of 1000 solutions for each shock.

3.2 Results

Figure 2 shows the results for the impulse response analysis. By construction, the signs of all responses are consistent with the theoretical model. The fact that we do find empirical results for all shocks, however, already indicates that the DSGE model conditions exist in the data. The monetary policy effects in the Euro Area are comparable to the results of Peersman and Smets (2001), although we also find a considerable contemporaneous impact

[10] Note that since the response of the interest rate to an investment shock is only significant at lag 2 in our theoretical analysis, we only introduce this restriction for the second lag after the investment shock.

[11] This enables us also to evaluate for all individual shocks how easy it is to find an admissible decomposition in the data, i.e. an acceptance rate of each shock.

on output, which is restricted to be zero in Peersman and Smets (2001). Output returns to baseline after five years whilst the effect on prices is permanent. In addition, we also find a hump-shaped effect on employment, real wages, consumption and investment. A shock in preferences also has a temporary effect on output and more persistent price effects. As discussed in Section 2, the DSGE model predicts a negative impact on investment as a result of crowding-out effects. This assumption will be abandoned in the next section. The data can then determine the exact response of this variable. It is already interesting to note that it is very hard to find solutions for the preferences shock that match all the restrictions. On average only 1 solution out of 140000 draws is consistent with all conditions of a preferences shock. All other draws from the posterior are rejected for this shock. For comparison, the acceptance is 1 out of 8 draws for a monetary policy shock. This might already be an indication that the restrictions from the NK DSGE model are too stringent for a preferences shock. The same is true for a government spending and investment shock. For these shocks we find a solution consistent with the NK priors for respectively each 23000 and 70000 draws. On the other hand, noticeable is that a few quarters after a technology shock, the impact on employment becomes insignificant and highly uncertain. The imposed negative effect on this variable is seriously questioned by standard RBC-models and will also be tested in the next section. Also for this shock we only accept on average one solution out of each 168 draws. In contrast, the responses to a price mark-up and labor supply shock are more accepted by the data. The acceptance rate is 1/9 for the former and 1/17 for the latter.

If one believes the theoretical DSGE model presented in Section 2 its accompanying restrictions for the responses, the empirical results can also be used to do variance and historical decompositions. The former decomposes the forecast error variance of the variables into the part due to each of the innovation processes, the latter decomposes the historical values of these variables into a deterministic component and the accumulated effects of current and past innovations.

Table 3: Variance decomposition of output in the Euro Area - all restrictions

	0 quarters			4 quarters			20 quarters		
	low	med	up	low	med	up	low	med	up
monetary policy	4	23	50	17	33	52	16	30	50
preferences	0	3	12	1	3	8	1	3	6
government spending	0	2	7	2	5	9	2	6	13
investment	3	10	22	9	18	27	4	10	19
price mark-up	9	27	51	10	22	39	13	27	44
technology	9	20	35	4	9	15	4	8	15
labor supply	3	13	29	9	18	33	12	23	38

Table 3 contains the variance decompositions for output in the Euro Area at respectively 0, 4 and 20 quarters, together with 84th and 16th percentiles error bands.[12] As usual, the width of the error bands is relatively large. We therefore focus on the median of the estimations. The contribution of monetary policy shocks is relatively high compared to traditional VAR studies, being around 30 percent in the long-run. This result is similar to Canova and de Nicoló (2003) who also apply sign restrictions, and the bayesian estimations of Smets and Wouters (2003). Also the contributions of the other shocks are mostly comparable to the results of Smets and Wouters (2003) such as a considerable impact of labor supply shocks. In contrast to them, however, we only find a very small immediate contribution of preferences and government spending shocks. Moreover, we find a substantial impact of price mark-up shocks. The median of the estimates is 27 percent for the contemporaneous and long run impact, whilst this is negligible in Smets and Wouters (2003). In the next section, we analyze whether these results still hold if we significantly relax the restrictions obtained from the standard DSGE model.

Historical contribution of all shocks to output are presented in Figure 2. For reasons of legibility, we only show the median of the estimates. Consider, for instance, the New Economy period between 1996 and 2000. All shocks made a positive contribution to

[12] Full results for all horizons and other variables included in the VAR are not reported but available on request.

this period of high growth. The two most important shocks, however, turn out to be labor supply and price mark-up shocks. The former is also found by Smets and Wouters (2003) and Peersman and Straub (2004), the latter is rather surprising. Also investment, monetary and fiscal policy shocks made a favorable contribution, whilst the positive effects of preferences and technology shocks were much more limited. On the other hand, the slowdown at the beginning of the century was mainly caused by negative labor supply and price mark-up shocks and too restrictive monetary policy. This result is more or less consistent with the findings of Peersman (2005).

4 A more general SVAR-model with DSGE priors

If one fully believes that the restrictions of the NK DSGE model of Section 2 are a true representation of reality, the results presented above should be accepted. Some constraints and responses are, however, not consistent with other theoretical and empirical evidence. The theoretical DSGE model predicts a negative effect of government spending shocks on private consumption and investment whilst Blanchard and Perotti (2002), Fatás and Mihov (2001) and Gali et. al. (2003) among others find evidence in favour of a rise in private consumption; and Mountford and Uhlig (2004) find an insignificant reaction of consumption. Also the reaction of investment to a shock in government spending is not robust across empirical studies. For instance Blanchard and Perotti (2002) find a fall in investment while Edelberg et. al. (1999) find the opposite. Only the former is consistent with our sign restriction from the DSGE model. In addition, the reaction of employment to technology shocks is restricted to be negative in the above presented empirical analysis. In contrast, RBC models predict a positive effect of technology shocks, which is confirmed by evidence of Christiano et. al. (2003), Uhlig (2003) and Peersman and Straub (2004). As a result, some of the restrictions we have imposed are questionable. In this section, we further evaluate and test the NK DSGE model. Specifically, we significantly relax the sign restrictions obtained from the theoretical model and make them more general in order to check whether the responses are still consistent with the model and, as such, test the NK model. We first discuss the more general restrictions in Section 4.1. New empirical results are presented in Section 4.2.

4.1 Relaxed restrictions

Since some of the restrictions that come out of the popular NK DSGE model are at odds with alternative theoretical models or with the existing empirical evidence, it is an interesting exercise to exclude a number of constraints that are not necessary to uniquely disentangle the shocks. A specific shock is identifiable with sign restrictions if at least one sign of the responses is different from another shock. Accordingly, we can already significantly reduce the number of restrictions in a first step and still identify all shocks. This does, however, not mean that all controversial restrictions are avoided. For instance, the only restriction to differentiate a price mark-up shock from a technology shock is the opposite sign of the reaction of employment. The latter reaction, however, is exactly at the core of the debate between NK and RBC adherents. In order to solve this problem, we also introduce some restrictions on the signs of relative responses obtained from the DSGE model that are less stringent and less questionable than the restrictions on the responses themselves. This enables us to identify shocks with more commonly accepted and therefore more robust sign restrictions and evaluate the DSGE model predictions for all unconstraint conditional responses. All relaxed restrictions used for the empirical evidence in Section 4.2 are presented in Table 4.

Table 4: Relaxed restrictions

	Y	P	S	E	$\frac{W}{P}$	C	I	$\frac{Y}{L}-\frac{W}{P}$	$C-Y$	$I-Y$
monetary policy	↑	↑	↓							
preferences	↑	↑	↑						↑	
govern. spending	↑	↑	↑						↓	↓
investment	↑	↑	↑						↓	↑
price mark-up	↑	↓			↑			↓		
technology	↑	↓			↑			↑		
labor supply	↑	↓			↓					

An expansionary monetary policy shock is identified as a shock that has a negative effect on the interest rate and a positive effect on output and prices. These restrictions from the DSGE model are generally accepted and sufficient to uniquely disentangle the shock from all other shocks. The data can then determine whether the other responses are still consistent with the DSGE model. All other shocks at the demand side of the economy, i.e. a preferences, government spending and investment cost shock are still assumed to have a positive impact on output, prices and the nominal interest rate. If we want to differentiate them from each other using the NK DSGE model and the standard responses of the variables, some restrictions on consumption and investment are required. Specifically, consumption increases and investment decreases following a shock in preferences. The opposite is true for an investment shock. On the other hand, both variables fall after a government spending shock. These responses derived from the DSGE model are the result of capacity constraints or so-called crowding-out effects. If one of the variables significantly rises, this is only possible if there is a fall in the other variables. There is, however, disagreement about these responses in the literature, in particular for government spending shocks.[13] Although also RBC models predict a fall in private consumption and investment after a positive government spending shock, this is mostly rejected in empirical evidence. Blanchard and Perotti (2002), Fatás and Mihov (2001) and Gali et. al. (2003) find an increase in private consumption after a favorable government spending shock. On the other hand, they do find crowding-out effects on investment. However, Edelberg et. al. (1999) find the opposite effects on investment and Perotti (2002) shows that the responses of both variables are often insignificant in many countries and even negative in the post-1980 period for the US. Gali et. al. (2003) even show that an extended NK DSGE model with rule-of-thumb consumers can account for a positive effect of government spending on consumption in specific circumstances. To avoid these controversial restrictions, we introduce some less stringent constraints on the responses of consumption and investment relative to output. The responses obtained from the DSGE model for consumption-output ratio and investment-output ratio are shown in respectively the second and third column of Figure 4. Consider a positive shock in preferences. Since the DSGE model predicts a rise in consumption and a fall in all other components of output, the reaction of the consumption-output ratio is obviously positive. On the other hand, for the same reason, the reaction

[13] We are not aware of theoretical or empirical papers questioning the mentioned effects of preferences and investment shocks because we are the first to evaluate these specific responses empirically. Smets and Wouters (2003, p 1156) do, however, describe the negative conditional responses as a potential problem in their underlying model.

of this ratio to a government spending and investment shock is negative (not surprisingly because the model predict for both shocks a rise in output and fall in consumption). More generally, preferences shocks, e.g. a shift in preferences towards consumption today, will cause in most of the generally accepted models a stronger response of consumption than output. We therefore introduce a positive restriction on the consumption-output ratio after a preferences shock and a negative restriction after a shock in government spending and investment costs. As a result, it is perfectly possible to have a rise in investment after a shock in preferences and a positive effect on private consumption after a government spending and investment shock, as long as this effect is smaller than the effect on total GDP.[14] We use the same reasoning to discriminate between the investment and government spending shock, i.e. the investment-output ratio rises after the former and falls after the latter in the short-run. These restrictions are much more general and less stringent. The data can now determine the exact sign of consumption, investment and all other responses.

At the supply side (shocks with a negative correlation between output and prices), a labor supply shock is identified as a shock with a negative effect on real wages whilst this effect is positive for a technology and price mark-up shock. Also this restriction is generally accepted in the theoretical and empirical literature. Peersman and Straub (2004) illustrate this for a large class of DSGE models, including RBC models. Moreover, Francis and Ramey (2002) and Fleischmann (1999) find a positive effect of technology shocks and a negative effect of labor supply shocks on employment using an identification strategy in the spirit of Gali (1999). To differentiate between a price mark-up and technology shock is much more difficult. Only one sign of the response functions in the DSGE model is different between these two shocks, i.e. employment rises after a price mark-up shock and falls after a technology shock. This restriction, however, is the well known controversy between RBC and New Keynesian sticky price models. The former expects a positive impact whilst the latter predicts a negative effect. Also the empirical evidence is mixed. Gali (1999), Shea (1998), Basu et. al. (1999), Francis and Ramey (2002), and Francis, Owyand and Theodorou (2003) find a negative effect and Christiano, Eichenbaum and Vigfusson (2003), Peersman and Straub (2004), Uhlig (2004), Dedola and Neri (2004) and,

[14] Note that these restrictions are only introduced the first four lags after a shock. Accordingly, it is perfectly possible to have a different sign in the long run.

Canova and Gambetti (2005) find a positive impact. We follow Dedola and Neri (2004) to discriminate between both shocks. The first column of Figure 4 shows the responses of the difference between labor productivity and real wages after both shocks obtained from our theoretical DSGE model. This difference is clearly negative following a price mark-up shock and positive after a technology shock for different parameterizations of the model, i.e. we assume that the impact of technology shocks on labor productivity is stronger than the one on real wages; a result again in line with both NK and RBC models. In contrast and again independent from the existence of nominal rigidities, a negative shock to the price mark-up will have, through the corresponding fall in prices, a stronger effect on the real wage than on labor productivity.[15] As a result, we use this restriction to disentangle both shocks. No additional restrictions are required and the empirical results, discussed in next section, can determine the signs of all unconstrained responses to evaluate the DSGE model.

4.2 Results

Impulse response functions for the SVAR with relaxed restrictions are shown in Figure 5. Due to the limited number of constraints, it was much easier to find solutions that match all the restrictions for each shock. The acceptance rate for a monetary policy, preferences, government spending, investment, price mark-up, technology and labor supply shock is respectively 1/4, 1/21, 1/42, 1/4, 1/11, 1/102 and 1/4 whilst this was only 1/8, 1/140000, 1/23000, 1/70000, 1/9, 1/168 and 1/17 for the SVAR with all DSGE restrictions. The results are nevertheless still very consistent with the theoretical DSGE model. Some interesting differences, however, emerge.

After a monetary policy shock, all conditional responses still have the same sign in line with the DSGE model. Restrictive monetary policy has a significant negative effect on output, prices, employment, real wages, consumption and investment. The responses to a government spending shock are also very comparable with the results of Section 3 and the theoretical DSGE model, although the impact on employment and real wages are insignificant now in the short-run. Remarkably is that we still find the crowding-out

[15] Dedola and Neri (2004) show that this restriction holds in a pure RBC model with flexible prices.

effects of fiscal policy, i.e. there is a fall in investment and private consumption after an expansionary government spending shock. The impact on the latter is, however, only significant during one quarter. This empirical finding is in contrast to many other studies using VAR-methods such as Blanchard and Perotti (2002), Fatás and Mihov (2001) and Gali et. al. (2003).

The conditional responses to preferences and investment shocks are also qualitatively similar to our previous results for respectively output, prices, interest rates, employment and real wages, although we now find a somewhat stronger quantitative effect on output. We do notice, however, a substantial difference with respect to the responses of investment and consumption after a preferences and investment cost shock respectively. A shift in preferences towards consumption today, i.e. a positive preferences shock, has a significant positive impact on investment. Similarly, a fall in investment costs has an upward effect on private consumption. Both effects are ad odds with theoretical New Keynesian DSGE models discussed in Section 2. We notice also the sharp increase in the acceptance rate of possible decompositions for both shocks. Only 21 and 4 draws are necessary to find a solution that match all imposed sign conditions for respectively a preferences and investment shock, while this was respectively 140000 and 70000 using all DSGE restrictions. Crowding-in effects of both shocks seems to be more accepted by the data.

Concerning supply side shocks, responses to price mark-up and labor supply shocks do also not change much when we impose only a limited number of restrictions. Notice that this is not the case for the conditional responses to a technology shock. From a quantitative point of view, we find a much larger impact of a rise in productivity on output being almost double the first years after the shock. This difference is mainly the result of a stronger impact on investment using less stringent restrictions. In addition, we now find a positive effect on employment whilst this response is restricted to be negative when we impose all constraints obtained from the NK model. The conditional response of employment to technology shocks is at the core of the debate between NK and RBC adherents. The former expect a negative effect while the latter expect the opposite. Our evidence is in favour of the RBC model. This positive effect on employment is also found by Christiano et. al. (2003), Uhlig (2003), Peersman and Straub (2004) and Canova and

Gambetti (2005).

Table 5: Variance decomposition of output in the Euro Area - relaxed restrictions

	0 quarters			4 quarters			20 quarters		
	low	med	up	low	med	up	low	med	up
monetary policy	0	4	19	6	13	27	4	12	31
preferences	1	12	29	4	11	22	4	10	23
government spending	1	8	18	5	10	18	4	8	15
investment	8	29	56	16	31	52	6	14	27
price mark-up	0	8	24	3	8	17	4	12	29
technology	23	42	63	14	31	50	8	23	43
labor supply	2	11	28	4	12	26	4	11	27

We now check whether it matters a lot for variance and historical decompositions. Table 5 contains the variance decomposition of output in the Euro Area. Using more general restrictions clearly has an effect on the results. The relative importance of government spending and labor supply shocks has not changed a lot. Both shocks explain around 10 percent of output fluctuations. The relative importance of shocks in preferences is now also around 10 percent while this was negligible when we use all restrictions from the DSGE model. Although the impulse responses of monetary policy shocks are very similar with both approaches, the contribution to output variance is now less than one half of the results we obtained is Section 3, being slightly above 10 percent in the medium to long-run. This shift is mainly the result of a much larger contribution of investment and technology shocks using less stringent constraints. Both shocks now explain around 30 percent of output fluctuations after one year. For investment shocks this is rather surprising. Smets and Wouters (2003) find a value around 10 percent using Bayesian methods. The relative contribution of technology shocks is rather in line with the results of Christiano et. al. (2003) and Peersman and Straub (2004) being higher than results obtained by Gali (1999) and others. In contrast to the results presented in Section 3, the contribution of price mark-up shocks, less than 10 percent most of the time, are much more subdued. This is not surprising given that we previously restricted the response of employment to be negative for a technology shock and positive for a favorable price mark-up shock. Accordingly, part of the technology shocks were identified as price mark-up shocks.

These findings are also reflected in the historical decomposition of output fluctuations as shown in Figure 6. When we use less controversial restrictions, the impact of price mark-up shocks in explaining the long-lasting boom of the second half of the nineties, also often called the New Economy period, and the succeeding recession is much less. In contrast, we now find a substantial impact of positive and negative technology shocks in explaining both periods. Moreover, we now also find an important role for positive shocks in preferences between 1998 and 2001, turning negative afterwards which is in line with shifts in consumer confidence around that period following September 11. Finally, the more general approach also finds a role for unfavorable investment cost shocks in explaining the slowdown after the millennium shift. In sum, these results are not inconsistent with the general believe about the causes of the boom in the second half of the nineties and the early millennium slowdown.

5 Conclusions

In this paper we have shown how the popular New Keynesian DSGE model can be used to derive sign restrictions for the identification of a large set of structural shocks in the Euro Area economy using an SVAR methodology. For a sensible range of underlying parameter values, the DSGE model can deliver us sufficient restrictions to uniquely identify respectively monetary policy, preferences, government spending, investment, price mark-up, technology and labor supply shocks. Many of these shocks have not been identified before in SVARs and can be considered as a first contribution of the paper.

Some of the imposed conditions of the New Keynesian DSGE model are, however, not consistent with alternative theoretical models and existing empirical evidence. In a second step, we therefore significantly relax the restrictions from the DSGE model and re-estimate the VAR with a minimum set of more general constraints. The data can then provide more information about the validity of the DSGE model, in particular about the conditional responses of the model. As such, we put the New Keynesian model to a test.

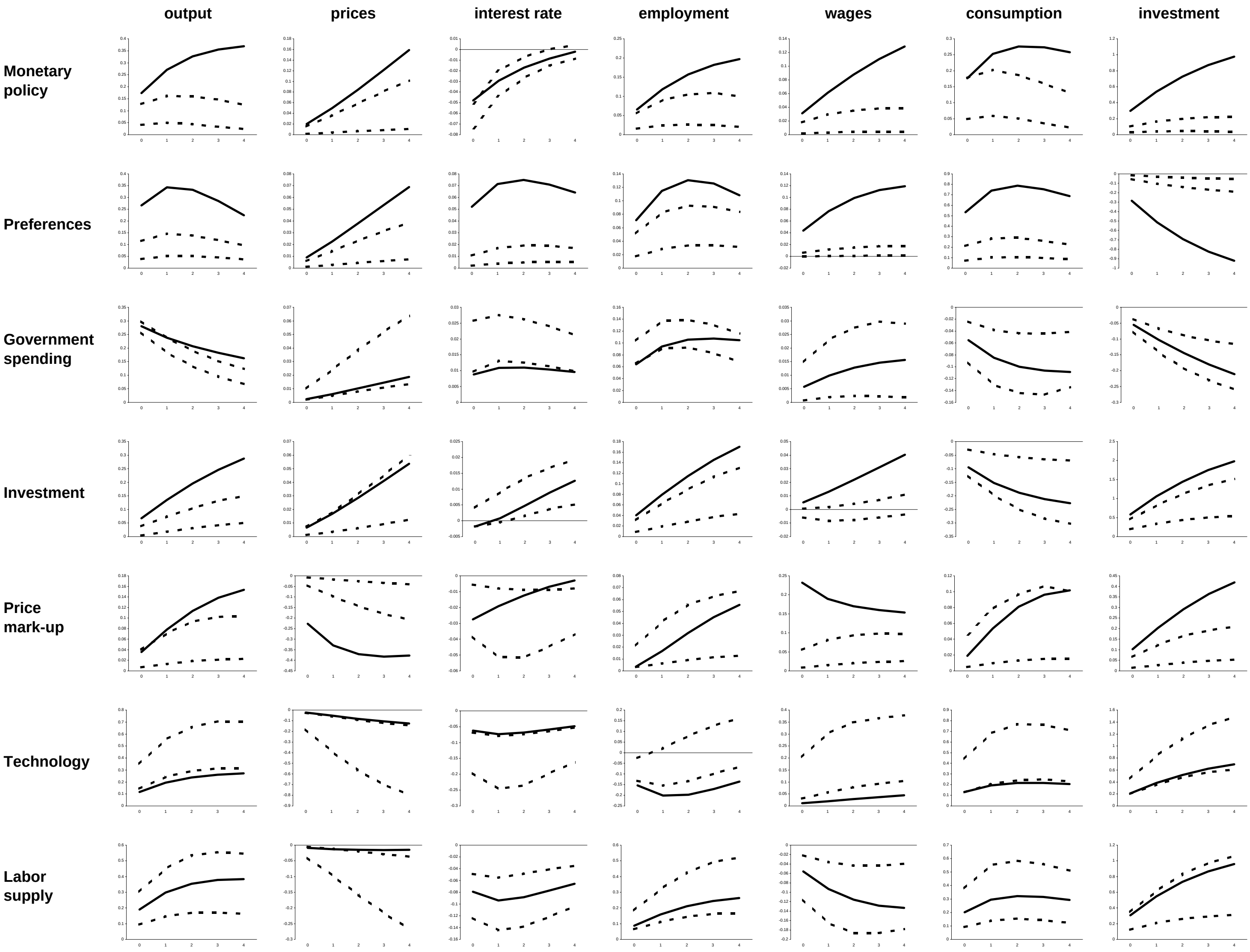
The empirical evidence shows that most of the responses remain consistent with the

New Keynesian DSGE model, including the controversial negative effects of a government spending shock on private consumption and investment, i.e. crowding-out effects of fiscal policy. We do find, however, some interesting differences. In contrast to the theoretical model, we find a positive impact of technology shocks on employment whilst New Keynesian models predict a negative effect. Our finding is more consistent with an RBC model in which technology shocks are the driving force of business cycles. In addition, we find a positive impact of shocks in preferences on investment and also private consumption rises after a negative shock in investment costs. The latter two conditional responses are not predicted by a theoretical New Keynesian DSGE model. Specifically, a standard feature of New Keynesian DSGE models is the so-called crowding-out effect. Empirical evidence, however, suggests that this is not consistent with the data, a finding which should be tried to be incorporated in future theoretical DSGE modelling.

References

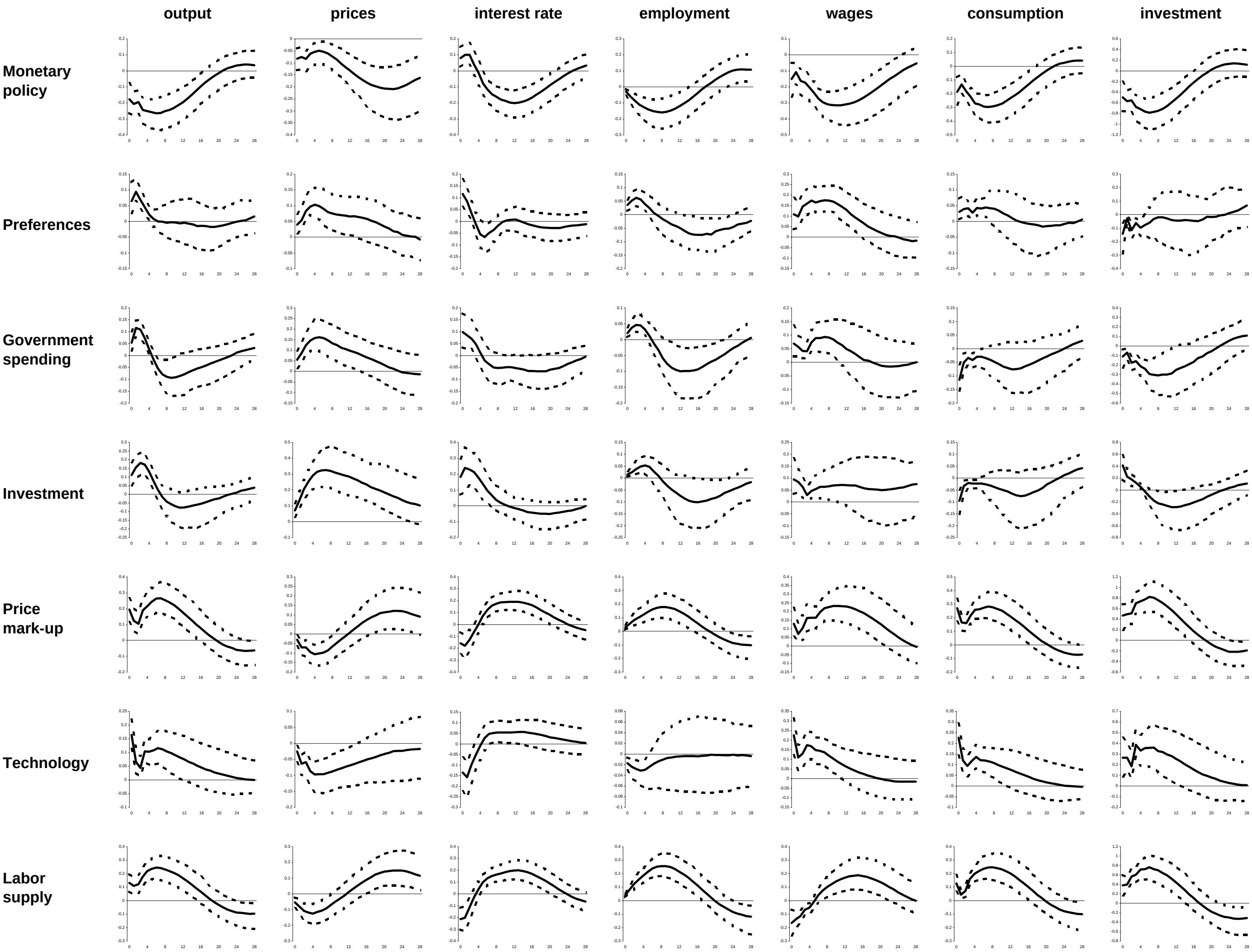
SIMS, C. (1980): "Macroeconomics and Reality," *Econometrica*, 48(1), 1–48.

Figure 1 - Theoretical impulse responses from DSGE model



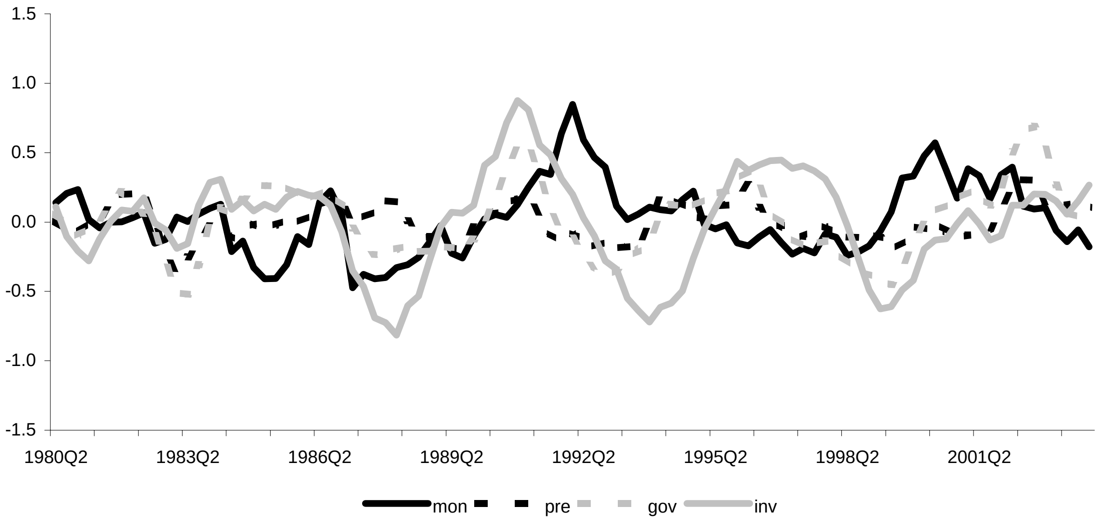
Note: dotted lines: interval for sensible range of parameter values; full lines are median of posterior of Smets and Wouters (2003)

Figure 2 - Impulse responses of VAR with all DSGE sign restrictions



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

Figure 3 - Historical contribution to output from VAR with all DSGE sign restrictions



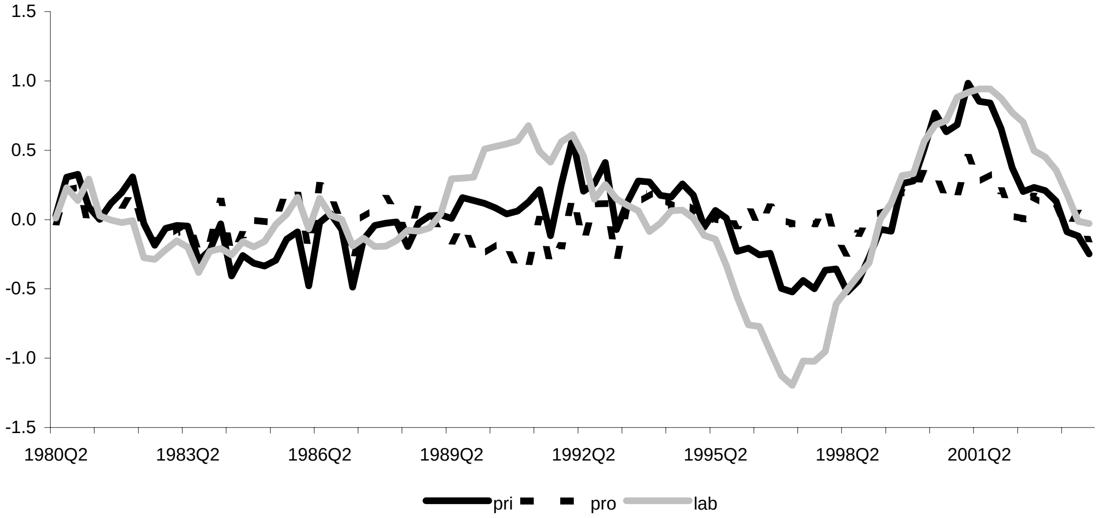
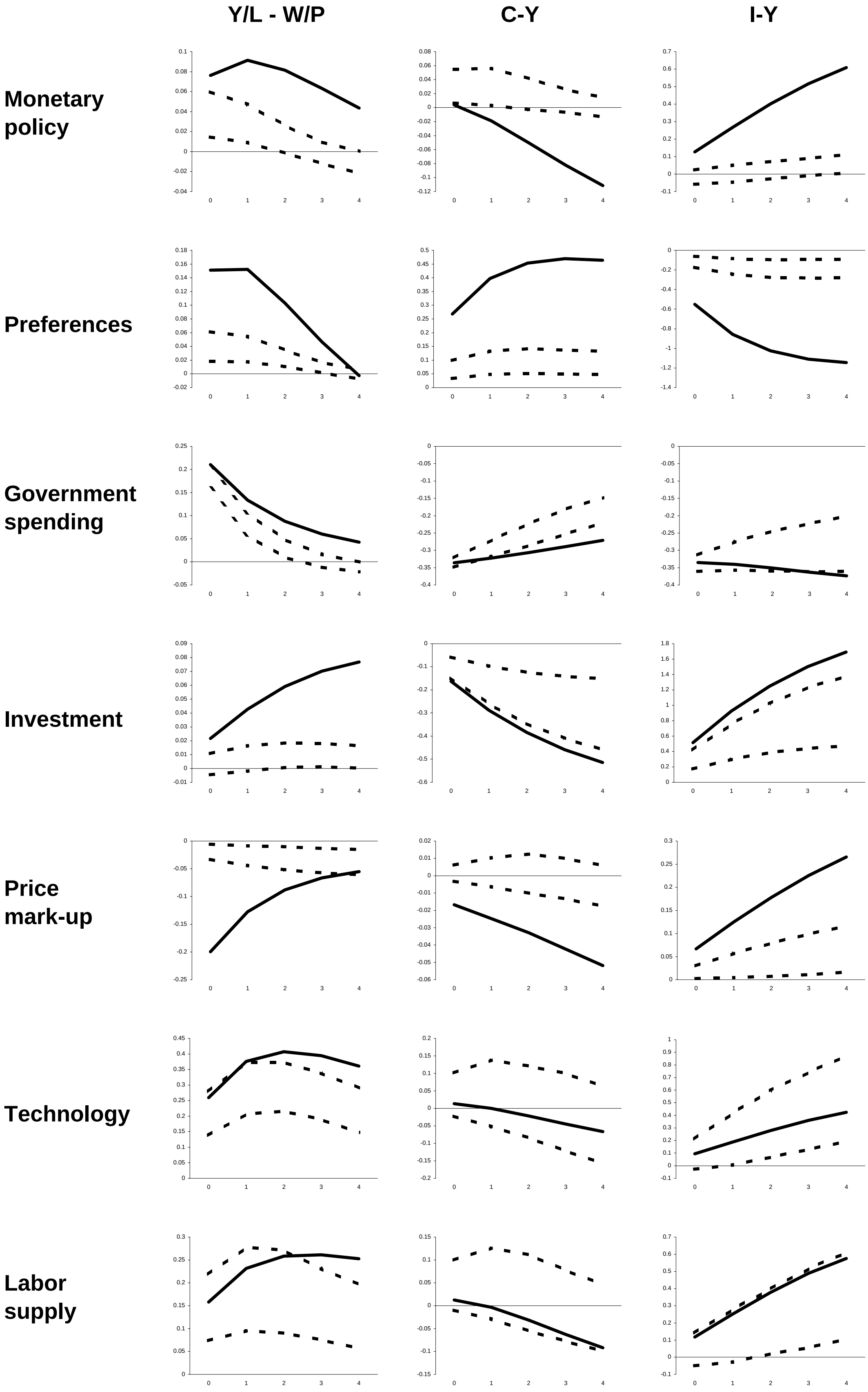
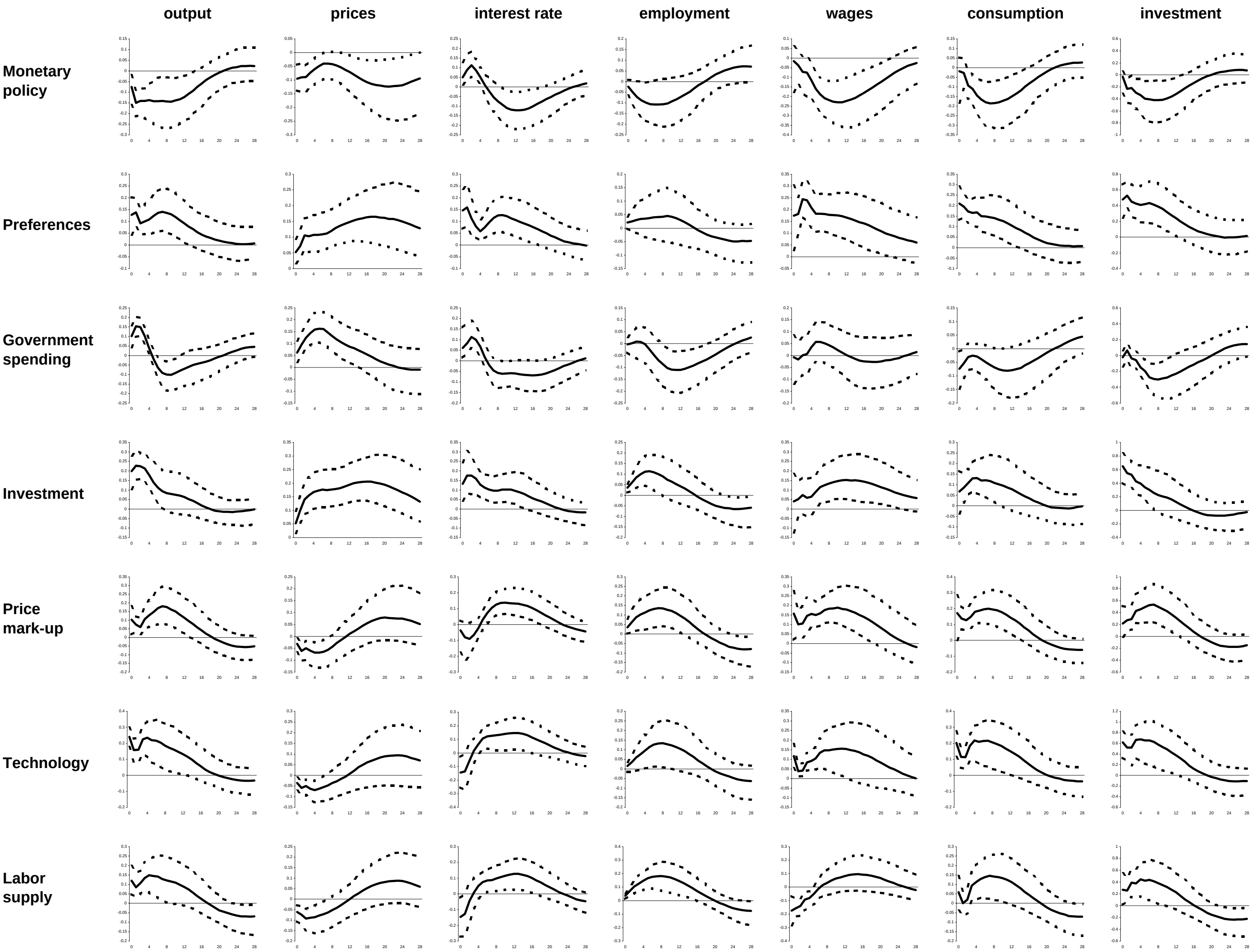


Figure 4 - Theoretical relative impulse responses from DSGE model



Note: dotted lines: interval for sensible range of parameter values; full lines are median of posterior of Smets and Wouters (2003)

Figure 5 - Impulse responses for VAR with relaxed restrictions



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

Figure 6 - Historical contribution to output for VAR with relaxed restrictions