Monetary Policy under Rule of Thumb Consumers and External Habits: An International Comparison

Giovanni Di Bartolomeo (University of Rome *La Sapienza*)
Lorenza Rossi (University of Rome *Tor Vergata*)
Massimiliano Tancioni (University of Rome *La Sapienza*)

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Abstract. In this paper we build a simple New Keynesian Stochastic Dynamic General Equilibrium model with rule of thumb consumers and external habits in line with the recent developments of the monetary policy literature. We use our framework to study and underline the properties of these kinks of models. We stress the relevance of the demand regimes in explaining the model properties. In addition we test empirically our framework by comparing the outcomes of estimations based on the VAR and Bayesians techniques. We consider and compare the G7 countries, differently from the current studies we consider them separately and stress the cross country heterogeneity.

Keywords: Price puzzle, monetary policy transmission, New Keynesian Stochastic Dynamic General Equilibrium model, monetary policy, VAR and Bayesian estimations.

1. Introduction

Campbell and Mankiw (1989, 1990, 1991) provide compelling evidence for the existence of heterogeneous consumers: households who can smooth consumption (*Savers* or Ricardian consumers) and agents whose current consumption equals current income (*Spenders* or Non-Ricardian consumers), which represent a strong violation of the permanent income theory.[1]

Recently, spenders have been introduced, to study monetary policy, in a New Keynesian framework (Amato and Laubach, 2003; Galì *et al*., 2003; Bilbiie, 2004).[2] The presence of Spenders' behavior may alter dramatically the properties of these models and overturn some of the conventional results found in the literature.

[1] Spenders' behavior can be interpreted in various ways. One can view their behavior as resulting from consumers who face binding borrowing constraints. Alternatively, myopic deviations from the assumption of fully rational expectations should be assumed (rule-of-thumb), i.e. consumers naively extrapolate their current income into the future, or weigh their current income too heavily when looking ahead to their future income because current income is the most salient piece of information available. See Mankiw (2000) and references therein.

[2] Moreover, Christiano *et al*. (2001) investigate the effects of a rule-of-thumb behavior in firms' decisions. Mankiw (2000) and Muscatelli *et al*. (2003) consider fiscal policy.

Amato and Laubach (2003) explore the optimal monetary rule with rule-of thumb households and firms. By modeling consumers' rule-of-thumb behavior as a consumption habit, households' decisions today mimic yesterday behavior of all agents (including optimizing agents). The authors discover that, while the monetary policy implications of rule-of-thumb firms are minimal, the interest rate is more sensitive to the presence of rule-of-thumb consumers; in fact, as their fraction increases higher inertial monetary policy is required.

By contrast, Galì *et al*. (2003) show how the Taylor principle becomes a too weak criterion for stability when the proportion of rule-of-thumb consumers is large. However, the presence of Spenders cannot in itself overturn the conventional result on the sufficiency of the Taylor principle. By contrast, in the case of forward-looking interest rate rules, they show that the conditions for a unique equilibrium are somewhat different from those in a contemporaneous one. In particular, they show that when the share of Spenders is sufficiently large it may not be possible to guarantee a (locally) unique equilibrium or, if it is possible, it may require that interest rates respond less than one-for-one to changes in expected inflation.

The aim of this paper is twofold. First of all, we aim to illustrate both the properties of a model including rule-of-thumb consumers as Galì *et al*. (2003) augmented with savers' consumption external habits *à la* Smets and Wouters (2003). By considering a simple setup without capital accumulation, we obtain a closed-form solution of the model. By doing that we can discriminate between two different demand regimes (i.e. two IS-curves) characterized by different signs in the correlation between expected consumption growth and real interest rate. The existence of different regimes plays a crucial role on the discussion about monetary policy efficacy and equilibrium determinacy as discussed in Bijbiie (2005 and 2005) and Di Bartolomeo and Rossi (2005). In particular, if the correlation between expected consumption growth and real interest rate is positive, monetary policy efficacy increases in the fraction of Spenders (as Amato and Laubach, 2003). A reverse result is obtained if the correlation between expected consumption growth and real interest rate is negative. Regarding determinacy, we find that in the case of a positive correlation, standard results hold, i.e. if monetary policy follows a standard Taylor rule and determinacy is always associated with the satisfaction of the Taylor principle. By contrast, if the correlation is negative, we find different requirements for stability conditional on the magnitude of the effects of interest rate changes on the real output. Hence the non-conventional results stressed by Galì *et al*. (2003) hold only if the correlation between expected consumption growth and real interest rate is negative.

The introduction of Spenders into the DSGE New Keynesian model thus may explain the negative correlation between expected consumption growth and real interest rate sometimes found in the empirical literature. In fact, this correlation has been found to be low and sometimes negative across many of the industrialized countries (see Ahmad, 2004, Canzoneri *et al*. (2002)).

The assessment of the aspects outlined above is particularly important for analyzing the potentially heterogeneous effects of monetary policy. Anyway, the empirical relevance of the different theoretical predictions for real world economies is still ambiguous. First of all, to the best of our knowledge, there are only few studies that have addressed the effects of deviations from Hall's benchmark consumption equations for the IS relation, i.e. in a New Keynesian framework. Moreover, even when the problem has been explicitly or implicitly considered, the results obtained were weak and substantially inconclusive. In a recent paper, Fuhrer and Olivei (2004) give empirical evidence for the pseudo-structural parameters of an IS equation, defined in a standard NK model augmented with habits. The estimated income monetary multiplier resulted weakly negative or statistically meaningless. Bilbiie (2005) explicitly deal with the question of the monetary policy implications of the presence of relevant liquidity constraints in consumption behaviour. Even if the paper addresses some specific issues concerning the empirical relevance of the liquidity constraints, the evidence cannot be considered conclusive. First, the main purpose of the work is to give an evaluation of the monetary policy conduct in the pre-Volker and pre-financial liberalisation period in the view of the presence of rule of thumbs behaviour, and not to obtain a point estimate of the structural parameters of the model. Second, even if the analysis is based on empirical results, these results cannot be considered particularly informative for our purposes. They are circumscribed to the IS relation alone, which estimated coefficients are only a convolution of the (structural) parameters of interest. Moreover, their empirical relevance is potentially flawed, since they are obtained employing a GMM estimator, which small sample performances have been shown to be dramatically poor. Moreover, given our theoretical framework including habits and rule of thumb consumption, the chances of finding a theoretically consistent instrumentation for the moment conditions are strongly reduced.

In our empirical investigation we are mainly interested to the empirical assessment of the dynamic properties of the NK model, augmented with both rule of thumb consumers and habits persistence. In particular, we evaluate the sensitivity of the efficacy of the monetary policy to different parameterizations of the consumption equation. Since we aim at employing different parameterizations possibly having strong empirical grounds, the strategies of analysis that we develop are mainly econometric. The empirical scrutiny is implemented in two steps.

In a first step, we simulate the theoretical structure in order to evaluate its dynamic properties. The values of the deep parameters will not be calibrated or fixed on the basis of previous evidence, as in the standard practice: our strong empirical stance suggests of estimating the potentially heterogeneous structural coefficients employing the relevant data of the seven major economies

(G7).
The complexity and the nonlinearity of the resulting parameters structure of the model require the implementation of a Bayesian Monte-Carlo Markov Chain estimation procedure (MCMC). Because of the particular methodology, the calibrations or empirical results from previous studies will be employed as a basis for the definition of prior distributions for the structural coefficients and the shocks. Once the different sets of structural parameters are obtained on a single country perspective, the resulting structures will be simulated in order to appreciate the different responses to typical shocks, in particular to monetary policy shocks. As it will be stressed with more detail in the following, our analysis is close in spirit to the strategy proposed by Smets and Wouters (2003) (SW) for the estimation of their NK model. The main differences respect to their analysis is that we don't consider capital accumulation and that we introduce the role played by Non-Ricardian consumers. Moreover, we develop a single country analysis, while their estimates are circumscribed to aggregate data for the Euro area.
In a second step, the empirical performances of the model will also be evaluated on the basis of the results of country-specific VAR-based impulse responses analyses. Respect to the standard practice established by Sims (1992) and Christiano, Eichenbaum and Evans (1999) (CEE), our strategy of analysis is somewhat original. The standard stationary SVAR representation of the monetary system is substituted by a SVECM in which the cointegration relation is identified as a Fisher Interest Parity (FIP).
The comparison of the DSGE simulations and the SVECM impulse responses provides a rich set of theoretical and empirical results that are of particularly relevance for discussing some issues that are currently debated in the literature. In particular, we will address the question of the heterogeneous effects of monetary policies potentially emerging when different consumption equations are assumed. An important byproduct of our analysis is that it can address a number of limitations and problems that have emerged in the literature concerning the theoretical predictions of NK-like models. First, the analysis is repeated for seven countries and also it focuses mainly on the slope of the IS curve. Both aspects have received only a minor attention in previous analyses, as they have been mainly directed at the evaluation of the model respect to the US experience or, more recently, to the aggregate Euro-area (Coenen and Straub 2005) and to the estimation of the aggregate consumption function. Second, from the DSGE and the VAR analysis we also show how it is possible to address the problematic result of a positive response of output and inflation to a policy shock - the so-called "price puzzle" (Eichenbaum, 1992) – irrespective of considerations on the particular conduct of the monetary policy or on the particular empirical information set employed. The price-puzzle emerged in a number of analyses on the monetary policy transmission channels

and has been addressed as being the result of both weak identification of VARs (Sims, 1992, Bernanke, 2004)[3] and of a passive monetary policy conduct characterizing the central bank's pre-inflation targeting regimes (Clarida, Galì and Gertler, 2000, Cogley and Sargent, 2005, Castelnuovo and Sarico, 2005).[4]

On the basis of the simulation of the theoretical model and of the SVECMs, we will show that the "puzzling" VAR-based impulse responses to policy shocks are presumably due to the use of stationary VAR representations for Co-Integrated (CI) non-stationary variables, even if in principle they are theoretically consistent with a model involving a relevant fraction of rule of thumb consumers.

The sample employed for our estimations is composed of quarterly time series for the variables of interest observed in the period 1963:1 to 2003:2. In the benchmark formulations, we employ short term nominal interest rate definitions such as the Federal Funds Rate for US, the Overnight Rate (OR) for Canada and the UK and the Money Call Rate (MCR) for the remaining countries. In order to check for robustness, we also re-run the estimations by substituting the reference short-term rates with the three months Treasury Bill Rate (TBR) and the 10-years Government Bonds Rate (10yGBR). Data are all drawn from the IMF International Financial Statistics (IFS) data base.

The rest of the paper is organized as follows. Section 2 outlines the basic framework and describes the two demand regimes implied by the presence of Spenders and Savers habits persistence. Section 3 presents an empirical examination of the model employing the relevant data of the seven major economies (G7) and is organized as follows. The first part contains the model calibration and the Bayesian MCMC estimation of the structural parameters of the model. The second part considers the VAR analysis. Section 4 concludes.

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[3] A commodity price index correction of VARs resulted capable of resolving the price puzzle (Sims, 1992). This correction has been justified as being a proxy for time-varying inflation expectations.

[4] Castelnuovo and Sarico (2005) have shown that the weak identification and the passive policy explanations are not mutually alternative, as in the presence of a passive policy, indeterminacy is related to the emergence of an *omitted variable bias,* which in turn leads to high persistence in inflation, which is the ultimate responsible of the puzzle. Our SVECM approach addresses this problem as it takes into account the inflation persistence in a model which is specifically designed for I(1) processes. Furthermore, employing long-run restrictions only, we obtain an unrestricted contemporaneous structure which is consistent with the simultaneities present in the theoretical model.

2. The basic theoretical framework

2.1. The model

We consider a simple New Keynesian model augmented with Non-Ricardian consumers and habits formation. In order to simplify the analysis and highlight the demand-side effects of spenders' behavior we do not consider the capital accumulation process. We assume a continuum of infinitely-lived heterogeneous agents normalized to one. A fraction $1-\lambda$ of them consumes and accumulates wealth as in the standard setup (*Savers*). The remaining fraction λ is composed by agents who do not own any asset, cannot smooth consumption, and therefore, consume all their current disposable income (*Spenders*). We also assume that savers consumption at time $t+i$ depends on habits inherited from past consumption, i.e. on a fraction γ of lagged aggregate consumption. Representative consumers are indexed by R (*Ricardian or Savers*) and N (*Non-Ricardian or Spenders*). At the date zero, they maximize the following functions:

$$(1) \qquad E_t \sum_{i=0}^{\infty} \beta^i u\left(C_{t+i}^j, M_{t+i}^j P_{t+i}^{-1}, N_{t+i}^j, \phi^j\right) \quad j \in \{R, N\}$$

where $\beta \in (0,1)$ is the discount factor, C_t represents household consumption at time t, while $\frac{M_{t+i}}{P_{t+i}}, N_t$ are, respectively, real money balances and labor supply. ϕ^j is a binary variable such that when $j = R$, $\phi^R = 1$ and when $j = N$, $\phi^N = 0$. For sake of simplicity, we use a logarithmic period utility function, which allows us to obtain a closed-form solution of the model. Thus we assume the following instantaneous utility, $u(.) = \ln\left(C_{t+i}^j - \gamma\phi^j C_{t+i-1}^{\gamma}\right) - \kappa \ln\left(1 - N_t^j\right) + \phi^j \chi \ln\left(M_{t+i}^j P_{t+i}^{-1}\right)$ with $\chi > 0$ and $\varepsilon > 0$. In addition, the following budget constraints hold:

$$(2) \qquad C_t^j = \frac{W_t}{P_t} N_t^j + \phi^j \left[\Pi_t^j - \frac{M_t^j - M_{t-1}^j}{P_t} - \frac{B_t^j - (1+i_{t-1})B_{t-1}^j}{P_t}\right]$$

where W_t is the nominal wage at time t, Π_t is profit sharing. Real wages are the only source of spenders' disposable income, therefore they are subject to a static budget constraint, while savers face the standard dynamic constraint. In fact, since spenders do not save, they consume all their current income and the amount of money they hold at the end of period t is zero.

By solving the inter-temporal optimization problems of Savers and Spenders, aggregating and then log-linearizing, we obtain the following description of the demand side of the economy:

(3) $$c_t = -\frac{1-\varpi-\lambda\zeta^N}{1+\varpi}\left(i_t - E_t\pi_{t+1}\right) + \frac{\varpi}{1+\varpi}c_{t-1} + \frac{1}{1+\varpi}c_{t+1} - \frac{\lambda\zeta^N}{1+\varpi}\Delta\left(w_{t+1} - p_{t+1}\right)$$

(4) $$w_t - p_t = \upsilon n_t + \left(1-\varpi\right)c_t - \varpi\left(1-\varpi\right)c_{t-1}$$

where c_t is consumption, i_t is the nominal interest rate, π_t is the inflation rate and $w_t - p_t$ is the real wage. Concerning parameters, $\varpi = \gamma\left(1-\lambda\right)$ is the habit coefficient in aggregate term (given that only Ricardian consumers have consumption habits); $\upsilon = N\left(1-N\right)^{-1} = \theta\kappa^{-1}\left(1-\varpi\right)^{-1}$ is the inverse Frish elasticity, where $\theta = \left(\eta-1\right)\eta^{-1} \in \left(0,1\right)$ depends on the elasticity of substitution of intermediate goods η, thus on firms mark-up, and κ is labor disutility. The parameter $\zeta^N = \kappa\left(1+\kappa\right)^{-1}\left(1+\upsilon\right)\left(1-\varpi\right)$ is the steady state share of Spenders' consumption, which is a function of labor supply elasticity κ, of the habits parameter γ and of the proportion of Ricardian consumers $1-\lambda$. Equation (3) represents a modified version of the standard consumption Euler equation, Equation (4) is the consumers' aggregate labor supply.

Our Euler equation differs from the standard equation with habits formation, in which the last term of the right hand side of equation (3) is absent. This is due to the presence of Savers, which establish a link between the demand for goods and the real wage (see equation (4)).

Considering the economy production function, $y_t = a_t + n_t$, the economy resource constraint, $y_t = c_t$ and equation (4), equation (3) can be expressed as a modified IS-curve:

(5) $$y_t = \frac{1-\lambda\zeta^N\left[\left(1+\upsilon\right)+\varpi\right]}{1+\varpi-\lambda\zeta^N\left(1+\upsilon-\varpi^2\right)}E_t y_{t+1} + \frac{\varpi\left[1-\left(1+\varpi\right)\lambda\zeta^N\right]}{1+\varpi-\lambda\zeta^N\left(1+\upsilon-\varpi^2\right)}y_{t-1} +$$
$$-\frac{\left(1-\varpi-\lambda\zeta^N\right)}{1+\varpi-\lambda\zeta^N\left(1+\upsilon-\varpi^2\right)}\left(i_t - E_t\pi_{t+1}\right) + \frac{\lambda\zeta^N\upsilon}{1+\varpi-\lambda\zeta^N\left(1+\upsilon-\varpi^2\right)}\Delta E_t a_{t+1}$$

As in the standard New-Keynesian framework, the supply side of the economy can be represented by a continuum of firms producing differentiated intermediate goods for a perfectly competitive final goods market.

The forward-looking Phillips curve is the following:

(6) $$\pi_t = \beta E_t\pi_{t+1} + \tau mc_t,$$

in which $\tau = (1-\varphi)(1-\beta\varphi)\varphi^{-1}$. The parameter φ defines price staggering, i.e. the fraction of firms maintaining their price fixed each period. Equation (6) is a forward looking equation for inflation, which links movements of current inflation to contemporaneous movements in real marginal cost and expected inflation. Given the model assumptions, sticky-price equilibrium real marginal costs are given by:

(7) $$mc_t = \frac{1+\upsilon(1-\varpi)}{1-\varpi} y_t - \frac{\varpi}{1-\varpi} y_{t-1} - (1+\upsilon) a_t .$$

Since markup is constant at the steady-state, under flexible price equilibrium real marginal costs are equal to zero. Substituting this relation in (5) and solving for y_t we can give an expression for the natural rate of output, which is the output under flexible price equilibrium y_t^f,

(8) $$y_t^f = \frac{(1+\upsilon)(1-\varpi)}{1+\upsilon(1-\varpi)} a_t + \frac{\varpi}{1+\upsilon(1-\varpi)} y_{t-1}^f .$$

The flexible price equilibrium output is a weighted average of technology and of its past value. Equation (8) shows that the inertial component is increasing in ϖ, hence in the aggregate habits stock and decreasing in the inverse Frish elasticity. Given the definition of ϖ, the introduction of rule-of-thumb consumers reduces the role played by the inertial component in the natural rate of output adjustment process. If habits persistence is not present, equation (8) collapses to the standard natural output equation, in which the technological component alone drives the evolution of the natural output process. Considering the equations above, we finally find that (6) can be rewritten as:

(9) $$\pi_t = \beta E_t \pi_{t+1} + \frac{\tau(\kappa+\theta)}{\kappa(1-\varpi)} \left(y_t - y_t^f \right).$$

Notice that if we assume nonzero habits persistence in consumption, the fraction of Non-Ricardian consumers affects the coefficient for the inflation response to the output gap, otherwise it has no role.

An interesting result is that neither γ nor λ can change the sign of the correlation between inflation and output gap. In the next section we will show that the qualitative irrelevance result of the two modifications for consumption does not hold when considering the monetary multiplier in the equation defining the demand side of the economy.

2.2. Demand regimes and monetary policy

The dynamics of our model is summarized by equations (5), (8) and (9), which respectively describe the IS curve, the flexible-price real output adjustment and the Phillips curve.

The model is close in spirit to that proposed by the New-Keynesian literature. However, the existence of spenders has serious implications for the impact of the interest rate - thus of monetary policy - on aggregate demand, from both a quantitative and a qualitative point of view. Other things equal, by increasing the fraction of rule of thumb consumers we can in fact generate an inversion in the sign of the monetary income multiplier. According to the sign of the income multiplier, equation (5) can in fact individuate two different regimes:

1. A standard regime - i.e. a negatively sloped IS curve - holds if the income monetary multiplier is positive. Such a regime is dominated by the hypothesis of life-cycle permanent income and thus by the consumption smoothing theory.
2. An inverse regime – i.e. a positively sloped IS curve - holds if the income monetary multiplier is negative. In other terms, the demand regime is dominated by the liquidity-constraint effect, for which an increase in real interest rates is expansionary and interest rate cuts imply demand contractions since many consumers cannot access to financial markets and saving.

The income elasticity of consumption is increasing in the share of spenders - who are insensitive to interest rate movements - and in the extent to which labor supply is inelastic, because small variations in hours (and output) are associated to large variations in the real wage and hence in the spenders’ consumption. Hence, if spenders are many and/or the inverse of the Frisch elasticity is high, the income elasticity can become greater than one and the income monetary multiplier becomes negative, so that an increase in the interest rates can lead to an increase in output and aggregate consumption

We first discuss the case without habits, i.e. $\gamma = 0$ or $\varpi = 0$. The model in this case is described by the following equations:

(10) $$y_t = E_t y_{t+1} - \frac{1-\lambda\zeta^N}{1-\lambda\zeta^N\left(1+\upsilon\right)}\left(i_t - E_t\pi_{t+1}\right)$$

(11) $$\pi_t = \beta E_t\pi_{t+1} + \tau\left(1+\upsilon\right)\left(y_t - a_t\right).$$

Notice that ζ^N and υ are in this case independent of the Non-Ricardian consumer' fraction and that $y_t^f = a_t$.

Formally, the two regimes depend on a threshold value of λ. The traditional regime holds for:

(12) $$\lambda < \lambda^* = \frac{1}{\zeta_N\left(1+\upsilon\right)} = \frac{\kappa\left(1+\kappa\right)}{\left(\kappa+\theta\right)^2},$$

otherwise we are in the liquidity-constrained regime. For relatively low values of θ and high values of κ, the threshold value is greater than one ($\lambda^* > 1$). In such a case, only the standard regime occurs since $\lambda \in [0,1]$. In other terms, the inverse Frish elasticity is smaller than one. For relatively high values of θ and low values of κ, the liquidity-constrained regime can emerge. In addition, if θ is greater than 0.5, λ^* is always smaller than one. Thus, in such a case, the liquidity-constraint regime always holds for a value of λ sufficiently great.

The simplified framework briefly analyzed above is still incomplete for deriving tight predictions on the model outcomes. First of all, we have to consider that the threshold value of λ^* only shows the critical fraction of rule of thumb in consumption above which an inversion in the sign of the income monetary multiplier emerges, and not for getting clear indications on the effects of, say, a monetary policy shock. These effects can be obtained only after considering the full set of equations and parameters of the monetary DSGE model.[5]

Moreover, when considering habits formation, the monetary multiplier becomes highly non linear in λ since ζ^N and υ are not independent of it. Thus, regimes are more difficult to be analytically determined. An implicit condition can be easily derived:

(13) $$\lambda < \frac{\left(1-\varpi^2\right)\kappa\left(1+\kappa\right)}{\left[\kappa\left(1-\varpi\right)\left(1-\varpi^2\right)+\theta\right]\left[\kappa\left(1-\varpi\right)+\theta\right]}$$

[5] In particular, we have to consider the expectation-consistent Phillips relation and the monetary policy rule. If we substitute into (5) equation (11) and a Taylor-like reaction function for monetary authorities, we can see that the contemporaneous response of y_t to a positive policy shock is still deflationary for given values of the monetary policy coefficients, irrespective of λ being above the threshold. This result is particularly interesting for the conduct of monetary policy, as outcomes depend strongly on policy parameters.

From the expression above it is clear that as θ increases the inverse regime is more likely to be observed. The effects of κ are more ambiguous; numerical simulations (partially reported below) show that for high values of κ the inverse regime is never observed. The joint effect of λ and γ on the regime is also ambiguous. Figure A1 shows the results from sensitivity analysis simulations, obtained employing a reasonable set of parameters values.[6] Dark areas represent the combination of γ and λ where the standard regime holds.

Numerical simulations show that, other things equal, by augmenting the parameter defining habits persistence the threshold value of λ needed to observe the regime inversion tends to increase.

3. Empirical evaluation of the model

3.1 Bayesian MCMC estimation of the structural parameters of the model

On the basis of the derivations made in section 2, for the purpose of estimation and simulation we consider the log-linear system defined by equations 5 to 8 augmented with a Taylor-like monetary policy reaction function, an output gap definition and five structural shocks. For the monetary policy reaction function we assume autoregressive interest rate smoothing, which intensity is defined by the parameter ρ_i, and that the authorities respond to deviations from targeted inflation π_t^* (assumed to be zero at the beginning of the simulation) and to the output gap x_t. The structural shocks hitting the economy are: *i)* a preference shock ε_t^{IS}, *ii)* a technology shock ε_t^{a}, *iii)* a cost-push shock ε_t^{cp}, *iv)* a monetary policy shock ε_t^{i} and *v)* a shock on the monetary policy objective, i.e. on targeted inflation, $\varepsilon_t^{\pi^*}$. We also assume that the preference, the technology and the monetary policy objective shocks are persistent, giving rise to autoregressive stationary processes governing preferences, technology and targeted inflation. The other shocks are defined by serially uncorrelated *iid* perturbations. This characterization of the shocks is needed in order to render the persistence and hump-shaped responses found in the data and it represents a quite weak assumption from a theoretical point of view. It is in fact commonly accepted that technology shocks, as well as preference shocks have generally long-lasting effects, while the permanence of the monetary policy objective can be justified on the grounds that, once convinced and committed on a given target,

[6] Without loss of generality, we plot the case of *k* between 0.1 and 1.5 and *q* between 0.3 and 0.6 (corresponding to an elasticity of substation between 1.4 and 2.5). Further plots, available upon request, do not show different qualitative paths.

authorities change their mind slowly.

The operational structure is thus the following:

$$(14)\qquad \begin{cases} y_t = \Omega_1 E_t y_{t+1} + \Omega_2 y_{t-1} - \Omega_3\left(i_t - E_t \pi_{t+1} - \mu_t^{IS} + E_t \mu_{t+1}^{IS}\right) + \Omega_4 E_t \Delta a_{t+1} \\ \pi_t = \beta E_t \pi_{t+1} + \tau mc_t \\ i_t = \rho_i i_{t-1} + (1-\rho_i)\left[\pi_t^* + \psi_\pi\left(\pi_t - \pi_t^*\right) + \psi_x x_t\right] + \varepsilon_t^i \\ mc_t = \dfrac{1+\upsilon(1-\varpi)}{1-\varpi} y_t + \dfrac{\varpi}{1-\varpi} y_{t-1} - (1+\upsilon) a_t + \varepsilon_t^{cp} \\ x_t = y_t - y_t^f \\ y_t^f = \dfrac{(1+\upsilon)(1-\varpi)}{1+\upsilon(1-\varpi)} a_t + \dfrac{\varpi}{1+\upsilon(1-\varpi)} y_{t-1}^f \\ \pi_t^* = \rho_{\pi^*} \pi_{t-1}^* + \varepsilon_t^{\pi^*} \\ a_t = \rho_a a_{t-1} + \varepsilon_t^a \\ \mu_t^{IS} = \rho_{IS} \mu_{t-1}^{IS} + \varepsilon_t^{IS} \end{cases},$$

where the first equation is the IS relation, in which the four parameters Ω_i, i = 1,…,4, represent the corresponding parameters in equation (5), the second equation is the expectation-augmented Phillips curve and the third equation is a Taylor-like rule in the spirit of that employed by SM (2003). The fourth equation is the marginal costs definition under rule of thumbs and habits persistence, the fifth the output gap definition and the sixth defines the process for natural output. The last three equations define the autoregressive processes for the three permanent components of our model.

Since we are interested at the estimation of the structural parameters, the resulting computational task is somewhat complicated, as the strong nonlinearities in model parameters may significantly affect the performances of the numerical methods for Full Information Maximum Likelihood (FIML) estimation.[7] A viable solution would be to restrict the parameters to assume values that are restricted to a defined range that we deem as "reasonable".

The restricted FIML estimation is close in spirit to the Bayesian approach that we adopt here.[8] Instead of employing interval restrictions on FIML estimated parameters, we use a procedure which nests a formalized *a priori* on parameters expected values and distributions with the conditional

[7] See Ireland, 1999, for some reference applications of the methodology.

[8] In our applications we will follow thus follow the Bayesian strategy adopted in SM (2003), which in turn draws on Geweke (1998), Landon-Lane (2000), Otrok (2001), Fernandez-Villaverde and Rubio-Ramirez (2001) and Schorfheide (2002).

distributions - i.e. with the likelihood function - in order to obtain a posterior density that we will consider as the reference for our parameters estimates, that will be obtained employing the Metropolis-Hastings MCMC procedure (M-H) implemented in Dynare for Matlab (Juillard, 2004).

The posterior density will result from a weighted average of the prior distributions and of the likelihood function (i.e. the empirical information), with weights inversely related to the variance of the prior and sample information ("precisions.") The bigger the informative power of the likelihood (i.e. the lesser the variances of the likelihood-based parameters), the closer the posterior will be to the conditional distribution. In the limiting case in which the data allow a perfect knowledge of parameter values, the posterior density collapses to the conditional distribution. Contrary, if empirical information is poor, the priors will have more weight in the estimation. Formalizing a tight prior will result in highly constrained estimation, while assuming a diffuse prior will result in weakly constrained estimation.

Formally, our procedure requires of nesting the prior distribution $P(\boldsymbol{\theta})$ for the parameter vector $\boldsymbol{\theta} \in \boldsymbol{\Theta}$ and the conditional distribution (or likelihood)[9] $P(Y_T \mid \boldsymbol{\theta})$, $Y_T = \{y_t\}_{t=1}^{T}$ to get the posterior distribution $P(\boldsymbol{\theta} \mid Y_T)$. This is obtained employing the Bayes theorem, i.e.

$$(15) \qquad P(\boldsymbol{\theta} \mid Y_T) = \frac{L(Y_T \mid \boldsymbol{\theta}) P(\boldsymbol{\theta})}{P(Y_T)},$$

where $P(Y_T)$ is the marginal distribution. Once the posterior distribution is obtained, it will be employed as the "proposal density" to initialize the M-H MCMC sampling method,[10] which substantially produces a large number of random draws from the posterior density in order to obtain a Monte-Carlo estimate of the parameters expected values and distributions.

Operationally, the proposed model (14) is estimated employing four observable variables, log real private output, logs of first differences of the implicit GDP deflator, the quarterly nominal interest rate and a measure of the log real output gap, obtained as the difference between log real output and its nonlinear trend, in turn obtained with Hodrick-Prescott filtering. Following SM (2003), real output is detrended assuming a linear trend while inflation and the nominal interest rate are detrended by the linear component in inflation, on the basis of their co-trending behavior.

[9] The conditional distribution is obtained employing the Kalman filter (Sargent, 1989).

[10] More precisely, the algorithm employs the mode and the Hessian evaluated at the mode for the initialisation of the M-H procedure.

The subjective component: prior distributions

The shape of prior distributions is chosen according to the following rules: we assume, as in SM (2003), that the reference distribution for structural shocks is the inverted gamma distribution with two degrees of freedom, which is consistent with a diffuse prior on perturbations and positive variances; for parameters theoretically defined in a 0-1 range, we adopt a beta distribution, while for the other parameters we adopt a normal distribution. The means and standard deviations are defined on the basis of the empirical reliability of the information obtainable from other studies or from the results of our GMM or ML average estimates conducted for the seven countries.

Since in our log-linear formulation of utility the parameterization is substantially reduced, differently from SM (2003), and with the exception of the discount factor β fixed at 0.995 (this is consistent with a steady state real rate of 2%), we do not employ fixed parameters values. Anyway, we adopt tight priors for the elasticity of substitution across intermediate goods η and for labor disutility κ (i.e. small prior standard deviations).

As a result of the model assumptions described above, we have to estimate 16 parameters, of which 5 define the distribution of structural shocks and 3 their persistence.

Concerning prior mean values, in line with in Galì *et al.* (2003), the expected elasticity of substitution across intermediate goods η is set to 6, which is consistent with a steady-state mark-up of 0.2. The mean of the labor disutility parameter κ, set to 3, is chosen on the basis of the ratio between hours spent at work and total available time. For both parameters we assume a relatively small prior variability of, respectively, 0.3 and 0.15, consistent with a 5% coefficient of variation and a normal prior shape. Concerning the Taylor rule parameters, we assume that the mean of the distribution of the parameter on expected inflation is 1.5 and that of the parameter on output gap is 0.125. Prior standard deviations are, respectively 0.15 and 0.05 and the prior shape is again the normal. The prior variability implies a moderately diffuse prior for the first parameter and a very diffuse prior for the second parameter. These values are also consistent with the average ML estimates of the Taylor rule parameters conducted for the seven countries included in the analysis. The prior mean of the interest rate smoothness parameter is 0.8, coherent with the average ML estimate, while for the prior variability we assume a prior of 0.10, which can be considered relatively large respect to the empirical standard deviations commonly found with the ML estimates. The prior shape for the distribution for the interest rate smoothness is the beta distribution.

For the fraction of firms maintaining the price fixed φ we assume a prior mean of 0.75, consistent with the results of Galì, Gertler and Lopez-Salido (2001) signaling an average duration of the price contracts of approximately one year, and a rather small prior variability, consistent with a range between 3 and 6 quarters.

For the parameters defining the persistence of shocks, following SM (2003), we presume a common mean value of 0.85 and a prior variability of 0.10. The choice of a relatively concentrated prior for the persistence parameters is justified on the grounds of the need of having a tight separation between persistent and transitory shocks, which enhances the identification of the two shocks entering the interest rate equation. The prior shape is the beta distribution.

For the habits persistence parameter we assume a prior mean value of 0.7 associated with a moderately diffuse prior variability of 0.1. The shape of the prior distribution is again the beta distribution. Prior mean and variability are chosen on the basis of the evidence emerged in a number of previous studies[11] and on the basis of the average results of our GMM estimates of the parameters of an Euler equation for consumption modified in order to take account of habits persistence.

For the rule of thumb parameter we set a prior mean of 0.5 and a prior S.D. of 0.10, while the reference distributional shape is again the beta. These prior values are consistent with the findings of Campbell and Mankiw (1989) and with the average result from our GMM estimates for the seven major economies.

For the structural shocks we basically adopt a parameterization which is similar to that employed by SM (2003). Apart from the large interval implied by the assumption of 2 degrees of freedom for the inverted gamma distribution, the prior mean values are obtained from previous estimations conducted with very diffuse priors.

The table below reassumes the prior distributions for the structural parameters considered in the analysis.

For a better understanding of the dynamical properties of the model under the parameterization established by the priors discussed above, the model is solved numerically and simulated. Impulse responses are reported in figures A2-A6 in the appendix.

Table 1. Prior distributions for the structural parameters

[11] E.g. Fuhrer (2000) finds that about one-fourth of income accruing to rule of thumb consumers in the United States. Muscatelli *et al*. (2003) find an even larger proportion. They suggest that about 37% of consumers are rule of thumb consumers, whilst 84% of total consumption in steady state is given by optimizing consumers. Rule of thumb consumers account for about 59% of total employment. Additional evidence is provided by Jappelli (1990), Shea (1995), Parker (1999), Souleles (1999), Fuhrer and Rudebusch (2003), and Ahmad (2004).

Parameter	Definition	Prior shape	Prior mean	Prior S.D.
sigma_*e* _*a*	Structural technology shock	inv_gamma	0.090	2
sigma_*e* _*IS*	Structural technology shock	inv_gamma	0.220	2
sigma_*e* _*pi*	Structural technology shock	inv_gamma	0.010	2
sigma_*e* _*i*	Structural technology shock	inv_gamma	0.012	2
sigma_*e* _*dP*	Structural technology shock	inv_gamma	0.050	2
rho_*a*	Persistence parameter for tech. shock	beta	0.850	0.10
rho_*IS*	Persistence parameter for tech. shock	beta	0.850	0.10
rho_*pi*	Persistence parameter for tech. shock	beta	0.850	0.10
rho_*i*	Smoothness parameter for nominal interest	beta	0.800	0.10
beta	Discount factor	-	0.995	0
eta	Elasticity of substitution among intermediate goods	normal	6.000	0.30
k	Labor disutility	normal	3.000	0.15
psi_*pi*	Taylor rule parameter on inflation	normal	1.500	0.15
psi_*x*	Taylor rule parameter on output gap	normal	0.125	0.05
phi	Calvo parameter	beta	0.750	0.10
gamma	Habits persistence parameter	beta	0.700	0.10
lambda	Fraction of rule of thumb consumers	beta	0.500	0.10

Note: for the inverted gamma distribution the degrees of freedom are indicated

The prior calibration and simulation of the model gives encouraging results. The simulated first two moments are close to the empirical ones for the US and the impulse responses show qualitative coherence of results respect to the theoretical expectations. The typical hump-shaped behavior of the impulse responses obtained with estimated structures such as the VAR are well reproduced both in the extent and in the duration of the empirical deviations from steady-state equilibrium.

It is interesting to highlight that, other things equal, when the habits parameter is increased above 0.8, the price puzzle emerges even assuming values of the inflation parameter in the Taylor rule that are well above the standard prescription for determinacy.[12] If we set the Taylor rule inflation parameter at 1.2, the same result can be obtained by augmenting the fraction of rule of thumb consumers above 0.58. The price puzzle also emerges increasing the fraction of rule of thumb consumers above 0.7, irrespective of the values for the habits and Taylor rule inflation parameters.

Indeterminacy emerges for parameters values above 0.85, while a regime inversion can be obtained, under this parameterization, solely by increasing the rule of thumb parameter at values that are well above the indeterminacy threshold.

This means that, as long as the parameterization employed is credible, the occurrence of a demand regime shift has a weak probability, as it requires a very high percentage of Non-Ricardian consumers. Such percentage is hardly sustainable, both in the light of the standard theory and of the empirical evidence produced so far in the literature. Conversely, the price puzzle is an empirical result that can be considered being consistent with the dynamic model properties when there are substantial but “reasonable” deviations from Hall’s consumption behavior and/or a not particularly

[12] The price puzzle is in this case observed for a Taylor rule inflation parameter equal to 1.2.

tight conduct of monetary policy.

Parameter estimates

The following table describes the MCMC estimates of the structural parameters, the posterior distribution of the parameters obtained through the Metropolis-Hastings sampling algorithm. We find relevant heterogeneity across countries regarding the impact of rule of thumb fraction and the habit parameter, which seem to be the parameters that drive differences in the compared countries. In fact the other parameters show a lower cross-country variability. Italy has the highest degree of habits, while Germany shows the lowest. The fraction of rule of thumb in Italy, Germany and Japan is relatively low, while it is high in Canada, United States and United Kingdom. In the latter group of countries financial markets are rather developed thus it seems that international differences on the consumers' behaviors may be more likely to be founded on the psychological and cultural factors rather than financial markets development. Although habits are significant, estimates also show a considerable degree of Calvo price stickiness.

Table 2. MCMC estimates of the structural parameters. G7 countries

	USA			JAP			GER			FRA		
Parameter	Mean	inf	sup	Mean	inf	sup	Mean	inf	sup	Mean	inf	sup
sigma_e _a	0.048	0.048	0.048	0.048	0.048	0.048	0.346	0.294	0.358	0.048	0.048	0.048
sigma_e _IS	0.125	0.113	0.123	0.086	0.090	0.097	0.041	0.043	0.045	0.128	0.122	0.135
sigma_e _pi	0.008	0.005	0.012	0.006	0.004	0.008	0.017	0.015	0.018	0.020	0.016	0.024
sigma_e _i	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
sigma_e _dP	0.162	0.159	0.175	0.241	0.227	0.251	0.238	0.229	0.247	0.156	0.133	0.163
rho_a	0.767	0.735	0.767	0.780	0.737	0.757	0.828	0.815	0.839	0.709	0.695	0.718
rho_IS	0.948	0.946	0.949	0.935	0.934	0.938	0.826	0.827	0.830	0.881	0.866	0.882
rho_pi	0.746	0.744	0.763	0.970	0.967	0.976	0.840	0.841	0.844	0.933	0.932	0.933
rho_i	0.801	0.801	0.803	0.861	0.858	0.863	0.821	0.821	0.822	0.876	0.876	0.878
beta	0.995	-	0.995	-	0.995	-	0.995	-	0.995	-	0.995	-
eta	5.895	5.810	5.917	6.055	6.096	6.186	5.977	6.001	6.059	5.958	5.865	6.008
k	3.128	3.143	3.250	3.032	2.977	3.018	3.075	3.036	3.116	3.009	3.009	3.055
psi_pi	1.491	1.493	1.502	1.498	1.518	1.587	1.507	1.474	1.496	1.494	1.494	1.495
psi_x	0.204	0.195	0.263	0.131	0.117	0.144	0.114	0.126	0.130	0.133	0.133	0.134
phi	0.837	0.833	0.846	0.823	0.817	0.825	0.865	0.864	0.865	0.854	0.854	0.854
gamma	0.710	0.687	0.714	0.729	0.729	0.756	0.610	0.610	0.612	0.685	0.684	0.685
lambda	0.372	0.298	0.409	0.087	0.065	0.126	0.077	0.049	0.102	0.442	0.441	0.443

	UK			ITA			CAN			G7		
	Mean	inf	sup	Mean	inf	sup	Mean	inf	sup	Mean	inf	sup
sigma_e _a	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.090	0.083	0.092
sigma_e _IS	0.056	0.060	0.066	0.105	0.109	0.143	0.111	0.079	0.099	0.093	0.088	0.101
sigma_e _pi	0.009	0.005	0.008	0.006	0.005	0.006	0.006	0.005	0.006	0.010	0.008	0.012
sigma_e _i	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
sigma_e _dP	0.200	0.182	0.214	0.300	0.287	0.364	0.288	0.204	0.281	0.226	0.203	0.242
rho_a	0.779	0.674	0.802	0.853	0.825	0.881	0.829	0.778	0.846	0.792	0.751	0.801
rho_IS	0.856	0.876	0.896	0.928	0.909	0.943	0.909	0.899	0.908	0.897	0.894	0.906
rho_pi	0.969	0.966	0.990	0.979	0.970	0.992	0.990	0.978	0.998	0.918	0.914	0.928
rho_i	0.879	0.876	0.883	0.864	0.846	0.879	0.849	0.827	0.847	0.850	0.843	0.853
beta	0.995	-	0.995	-	0.995	-	0.995	-	0.995	-	0.995	-
eta	6.070	5.930	5.999	5.971	5.861	6.029	5.971	5.896	6.022	5.985	5.923	6.031
k	3.095	2.995	3.136	3.168	3.060	3.173	3.049	3.039	3.139	3.079	3.037	3.126
psi_pi	1.507	1.504	1.514	1.496	1.429	1.614	1.454	1.399	1.452	1.492	1.473	1.523
psi_x	0.136	0.140	0.145	0.192	0.199	0.285	0.166	0.129	0.156	0.154	0.148	0.180
phi	0.806	0.804	0.805	0.846	0.837	0.869	0.877	0.852	0.884	0.844	0.837	0.850
gamma	0.646	0.641	0.644	0.818	0.804	0.859	0.753	0.723	0.735	0.707	0.697	0.715
lambda	0.422	0.427	0.439	0.090	0.062	0.119	0.314	0.301	0.377	0.258	0.235	0.288

Computations obtained with Dynare for Matlab

Regarding monetary policy, we find a significant positive central bank's short-term reaction to the current change in inflation and the output gap. Our estimation delivers plausible parameters for the long and short-run reaction function of the monetary authorities for all the central banks, broadly in line with Taylor (1993). The parameter of the inflation response is rather stable across countries. In agreement with the large literature on estimated interest rate rules, we also find evidence of a substantial degree of interest rate smoothing, which in addition is also rather stable across countries.

3.2 VAR analysis

In this section the results obtained from the Bayesian MCMC estimation of the model are confronted with the outcomes obtainable with the simulation of a weakly-identified VAR structure.

The common practice with monetary VARs has been to estimate and simulate stationary structural representations.[13] The choice for a stationary representation is made possible by the use of pre-filtered or detrended variables, while the structural representation is generally obtained via orthogonalisation of the shocks and exclusion restrictions on the contemporaneous effects matrix of the VMA representation. The stationary SVAR approach in fact basically relies on identification schemes based on orthonormalisations of the variance-covariance matrix of errors and on exclusion restrictions on the contemporaneous impact matrix. In a three-variable stationary VAR representation in output, inflation and nominal interest rate $\mathbf{x}_t' = [y_t, \pi_t, i_t]$, the structural identification is obtained, given the particular ordering of variables defined above, by imposing a triangular structure to the impact multipliers, i.e. by employing a Cholesky decomposition.

We criticize this approach from two points of view. First, we argue that, as long as we deal with non-stationary variables, the stationary VAR representation is potentially badly specified, as Co-integration (CI) may emerge between the levels of the variables entered in the VAR. In such a case, the VECM is the appropriate structure. Second, even if the triangular structure defined by the Cholesky decomposition allows the identification of shocks as "original", the resulting contemporaneous structure is not model-consistent.

In other terms, the stationary triangular SVAR representation is unsatisfactory for being unable to render, on the one hand, a statistically appropriate representation of the data as it omits the potential error-correction dynamics implied by CI and, on the other hand, a model consistent contemporaneous structure.[14]

The SVECM approach that we employ is convenient in both respects. In particular, the presence of CI entails a reduction of the number of contemporaneous restrictions needed for the exact identification of the system. We will show that, with a three variables system and in the case of the presence of only one cointegrating vector (CV),[15] we can just-identify the VECM by imposing the orthonormalisation of errors and only one restriction on the long-run response matrix; in this case no restrictions are required on the contemporaneous effects matrix.

Operationally, an important intermediate step for the use of the VECM representation is thus the assessment of the order of integration of the series and of the presence of CI. On the basis of the

[13] The works of Sims (1992) and Christiano, Eichenbaum and Evans (1999) can be considered the benchmark for the standard practice.

[14] We have shown that the model outcomes strongly depend on the *whole* contemporaneous structure of the model, hence the recursive specification implied by the triangular contemporaneous structure assumption is not model consistent, irrespective of the ordering of the variables.

[15] The number of CVs is established via the Johansen test.

indications from the ACFs and from standard DF-ADF tests we can assume that all the series employed in the analysis are I(1),[16] hence the VECM is a viable representation. From the Johansen LR tests we also obtain that a CI relation is present for all the specifications when a 90% statistical criterion is adopted. Results do not change significantly when employing bootstrapped distributions for the CI test.

Coherently with the commonly accepted theoretical indication of a long-run relationship between the nominal interest rate and the price dynamics, we assume that the CV is the Fisher Interest Parity (FIP).[17]

Formally, given the VECM in structural form $\mathbf{A}_0 \Delta \mathbf{y}_t = \mathbf{H}\mathbf{y}_{t-l} + \sum_{l=1}^{p-1} \mathbf{A}_l \Delta \mathbf{y}_{t-l} + \boldsymbol{\varepsilon}_t$ and its reduced form $\Delta \mathbf{y}_t = \boldsymbol{\Pi}\mathbf{y}_{t-l} + \sum_{l=1}^{p-1} \boldsymbol{\Gamma}_l \Delta \mathbf{y}_{t-l} + \mathbf{v}_t$, where $\boldsymbol{\Pi} = \mathbf{A}_0^{-1}\mathbf{H}$, $\boldsymbol{\Gamma}_l = \mathbf{A}_0^{-1}\mathbf{A}_l$, $\mathbf{v}_t = \mathbf{A}_0^{-1}\boldsymbol{\varepsilon}_t$, $\mathbf{v}_t \sim (\mathbf{0}, \boldsymbol{\Omega})$, $\boldsymbol{\Omega} = \mathbf{A}_0^{-1}\boldsymbol{\Sigma}\mathbf{A}_0^{-1}{}'$, $\mathbf{H} = \boldsymbol{\eta}\boldsymbol{\beta}'$ and $\boldsymbol{\Pi} = \boldsymbol{\alpha}\boldsymbol{\beta}'$, the identification of the long-run relation with the FIP implies that $\boldsymbol{\beta} = [0, -b, 1]$. The VMA representation of the reduced-form VECM is the following (Johansen, 1995):

$$(16) \qquad \mathbf{y}_t = \mathbf{C}(1)\sum_{i=1}^{t} \mathbf{v}_{t-l} + \mathbf{C}^*(L)\mathbf{v}_t + \mathbf{y}_0,$$

where $\mathbf{y}_0$ depends on initial conditions and $\mathbf{C}^*(L) = \sum_{j=0}^{\infty} \mathbf{C}_j^* L^j$ is a polynomial with elements converging to zero as j goes to infinity. In other terms, $\mathbf{C}^*(L)$ is the transitory effects matrix and $\mathbf{C}_j^*$ contains the contemporaneous impact effects. The long-run effects matrix $\mathbf{C}(1)$ contains the unit roots of the model and, because of cointegration, it has a reduced rank $k = m - r$, where r is the number of long-run relations.

Since the relationship between the reduced form and the structural errors of the VECM is $\mathbf{v}_t = \mathbf{A}_0^{-1}\boldsymbol{\varepsilon}_t$, the structural VMA representation can be written as:

$$(17) \qquad \mathbf{y}_t = \mathbf{C}(1)\mathbf{A}_0^{-1}\sum_{i=1}^{t} \boldsymbol{\varepsilon}_{t-l} + \mathbf{C}^*(L)\mathbf{A}_0^{-1}\boldsymbol{\varepsilon}_t + \mathbf{y}_0.$$

The exact identification of the system requires m^2 restrictions, of which $m(m+1)/2$ are given by

[16] This implies that the price level is I(2).

[17] The idea of employing the FIP as a theory-based identifying long-run relation is quite common in the empirical literature for monetary models. See, for an application, Garratt *et al.*, 2003.

the usual hypothesis of orthonormality[18] of the structural errors, i.e. by the assumption that $E(\boldsymbol{\varepsilon}_t \boldsymbol{\varepsilon}_t^{'}) = \mathbf{A}_0 \boldsymbol{\Omega} \mathbf{A}_0^{'} = \mathbf{I}_m$, thus leaving $m(m-1)/2$ restrictions for the identification of the model.
Since the system is cointegrated, the number restrictions needed for exact identification is reduced. $(m-r)(m-r-1)/2$[19] restrictions must be imposed on the permanent shocks and $r(r-1)/2$ restrictions on the transitory shocks. In our specific case with m = 3 and r = 1, the model is identifiable with only one restriction on the permanent effect matrix $\mathbf{C}(1)$.
For the identification of the long-run response matrix we adopt the hypothesis that only technology shocks can have permanent effects on output, i.e.:

(18) $$\mathbf{C}(1) = \begin{bmatrix} C_{1,1} & C_{1,2} & 0 \\ C_{2,1} & C_{2,2} & 0 \\ C_{3,1} & C_{3,2} & 0 \end{bmatrix}, \ C_{1,2} = 0 .$$

The exclusion that we impose is equivalent to the restriction introduced by Blanchard and Quah (1989) in their influential paper on the assessment of the respective role of "demand" and supply shocks over the business cycle. The unique difference is that we operate the restriction in a non-stationary VAR framework.
Once the system is identified, the SVMA (17) can be estimated and stochastically simulated, thus the results can be confronted with those obtained from the simulation of the estimated DSGE structure.
Results from impulse response analysis are reported in figures A9-A15.

4. Conclusions

[18] The structural shocks are assumed to be independent and of unit variance.

[19] The cointegration relations are identifying in that they impose the shocks to have no long-run effects on CVs.

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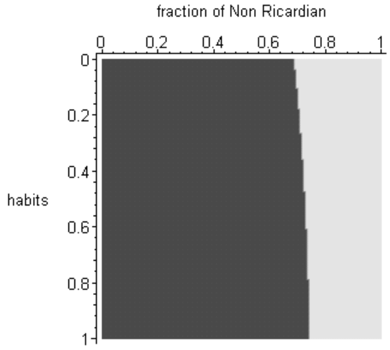
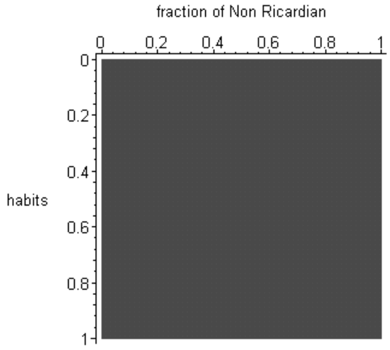
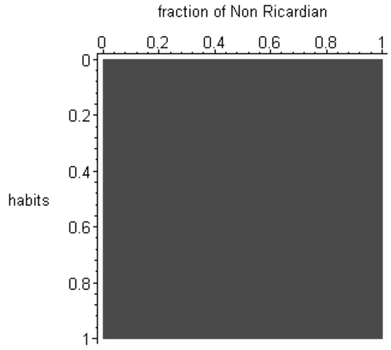
Figure A1 – Demand regimes, habits and Non Ricardian consumers



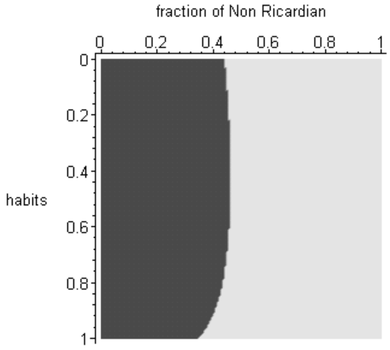
(a1) $\kappa = 0.1$ and $\theta = 0.3$



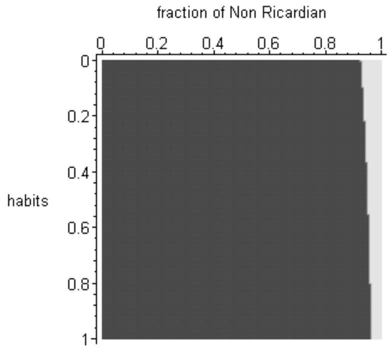
(a2) $\kappa = 0.5$ and $\theta = 0.3$



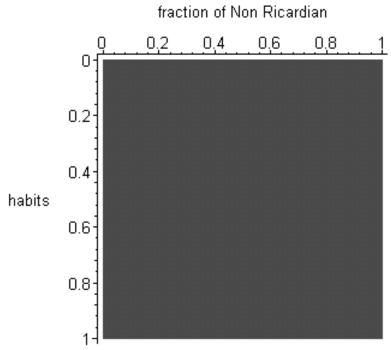
(a3) $\kappa = 1.5$ and $\theta = 0.3$



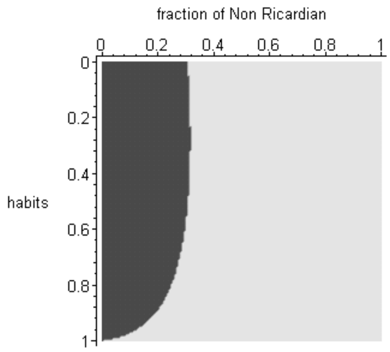
(b1) $\kappa = 0.1$ and $\theta = 0.4$



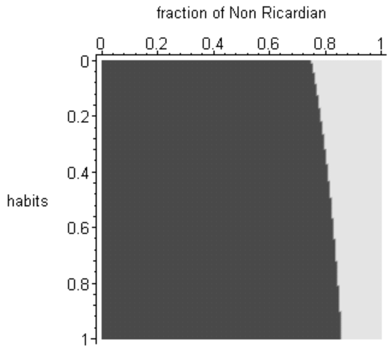
(b2) $\kappa = 0.5$ and $\theta = 0.4$



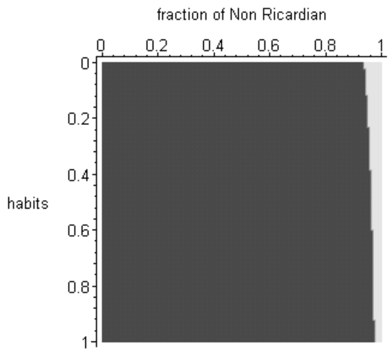
(b3) $\kappa = 1.5$ and $\theta = 0.4$



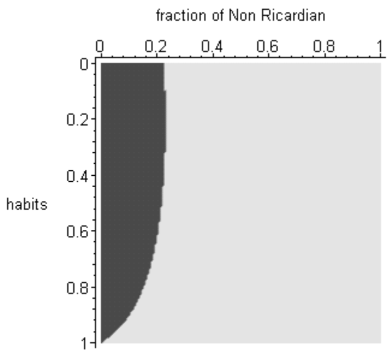
(c1) $\kappa = 0.1$ and $\theta = 0.5$



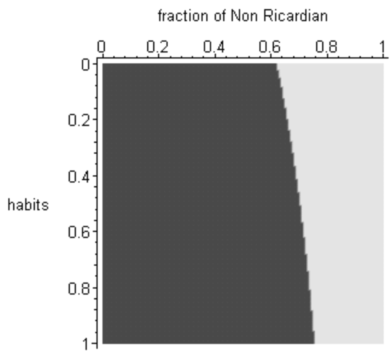
(c2) $\kappa = 0.5$ and $\theta = 0.5$



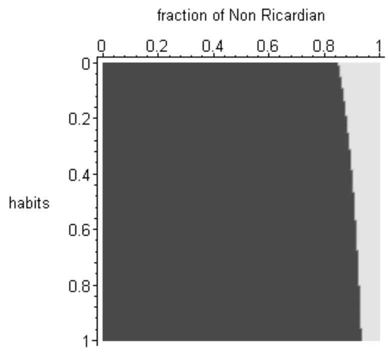
(c3) $\kappa = 1.5$ and $\theta = 0.5$



(d1) $\kappa = 0.1$ and $\theta = 0.6$

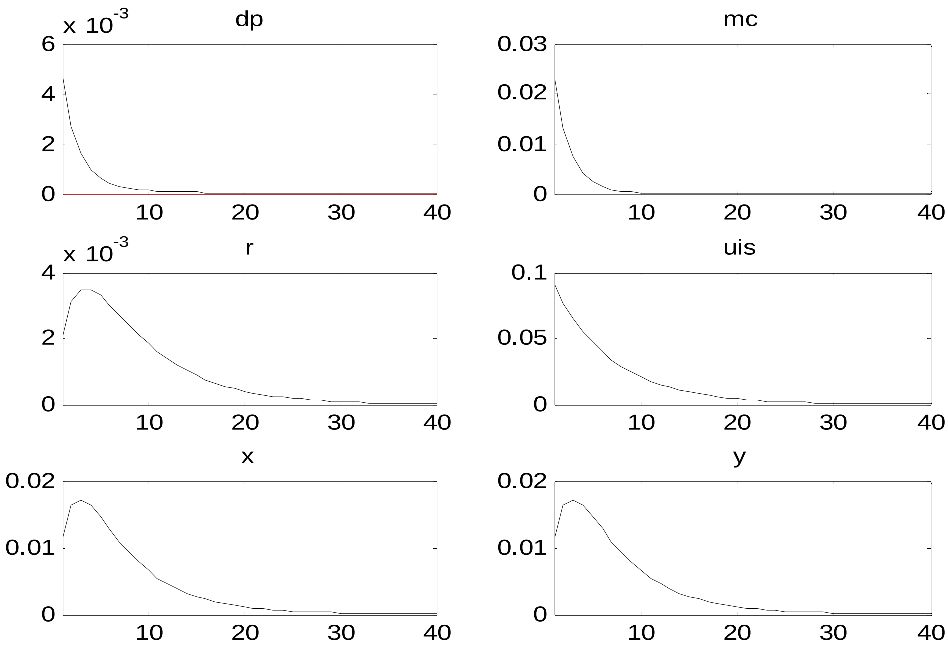


(d2) $\kappa = 0.5$ and $\theta = 0.6$



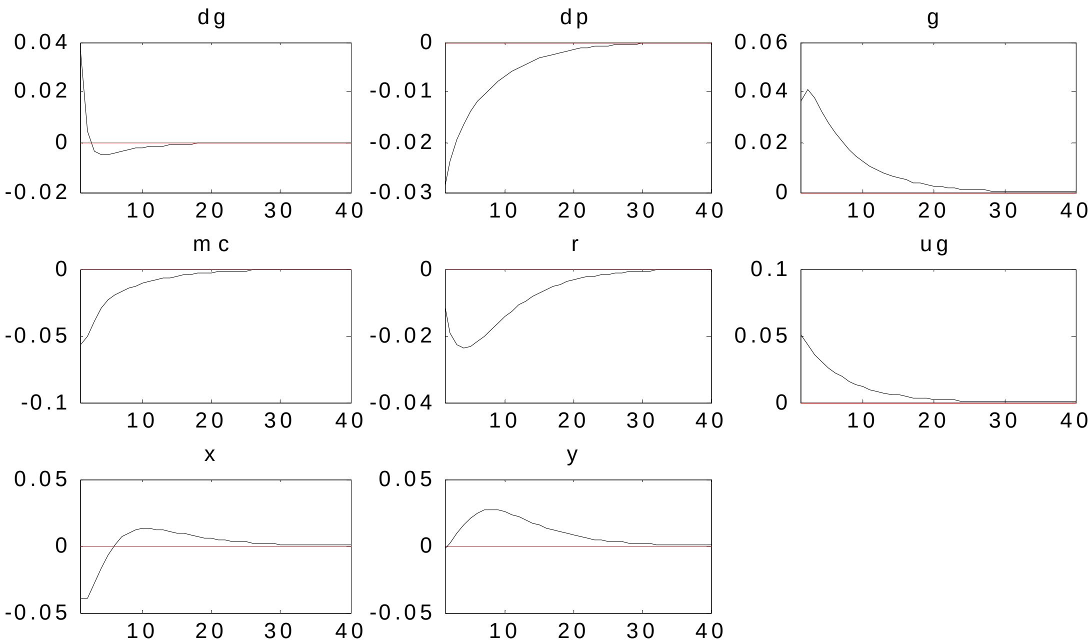
(d3) $\kappa = 1.5$ and $\theta = 0.6$

Figure A2. Impulse responses to a preference shock, parameterization based on priors



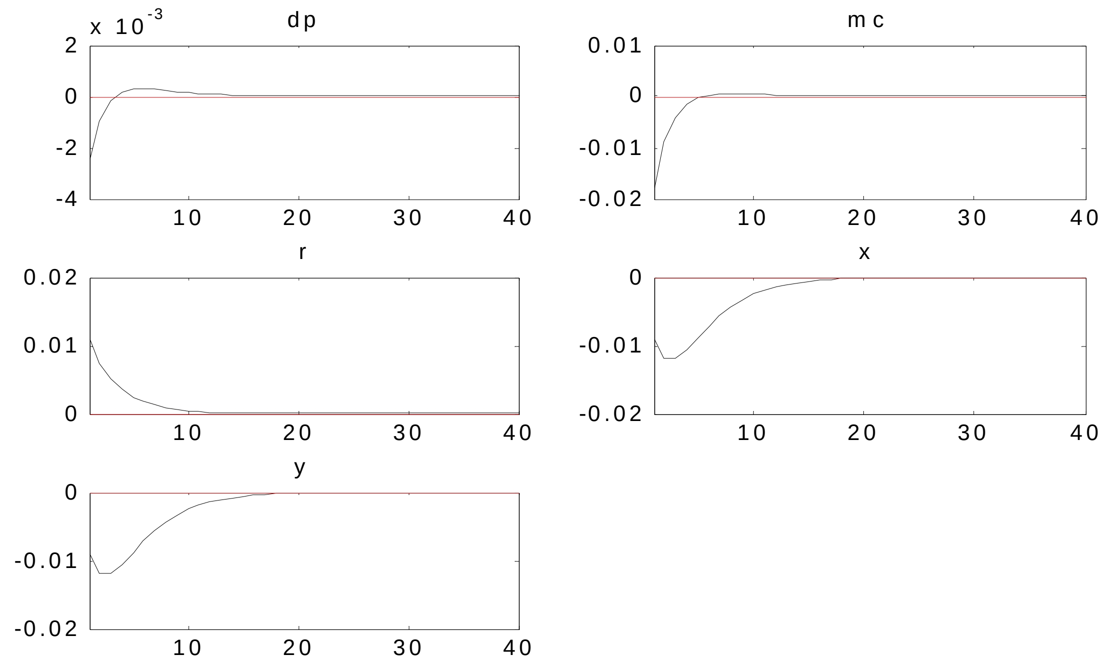
Computations obtained with Dynare for Matlab.

Figure A3. Impulse responses to a technology shock, parameterization based on priors



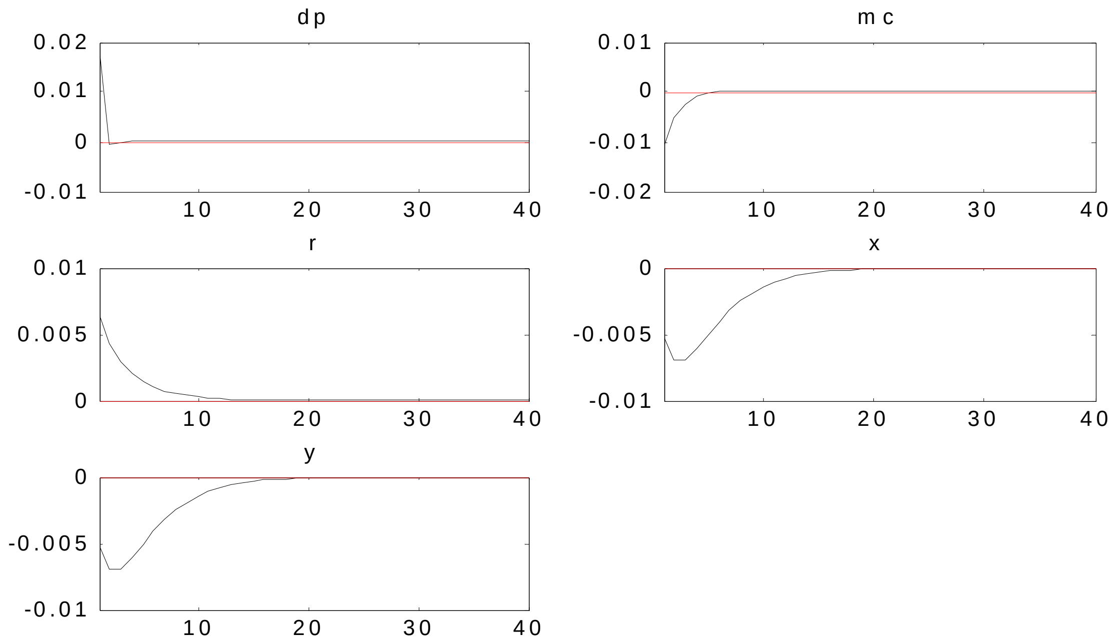
Computations obtained with Dynare for Matlab.

Figure A4. Impulse responses to a policy shock, parameterization based on priors



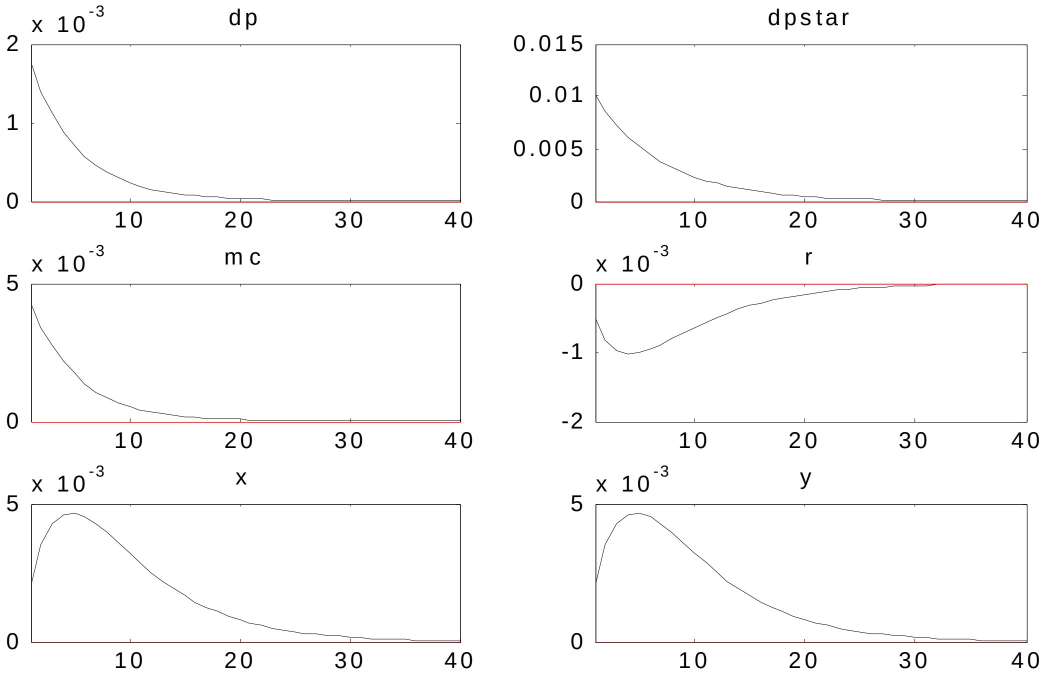
Computations obtained with Dynare for Matlab.

Figure A5. Impulse responses to a cost push shock, parameterization based on priors



Computations obtained with Dynare for Matlab.

Figure A6. Impulse responses to a policy-target shock, parameterization based on priors



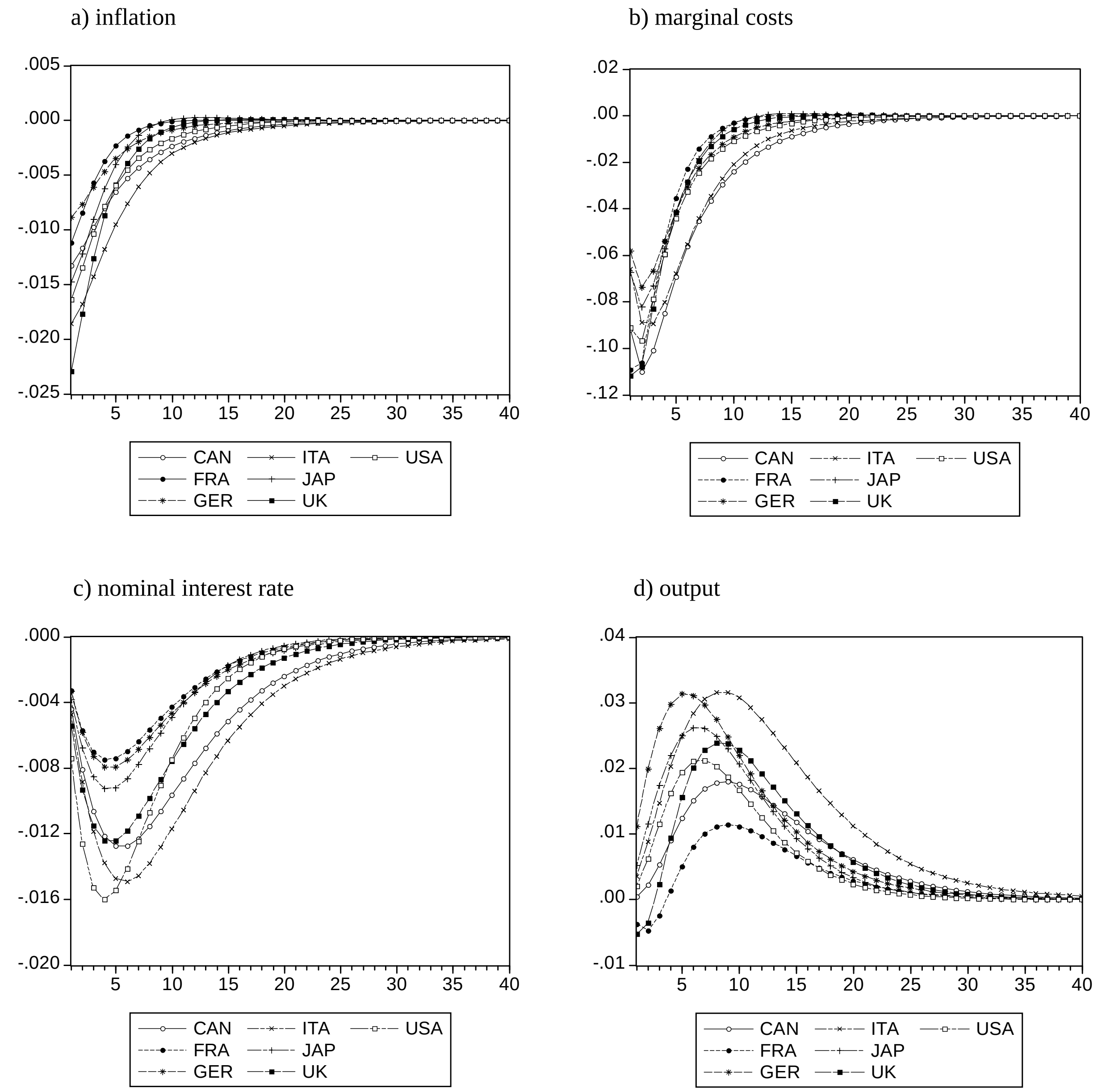
Computations obtained with Dynare for Matlab.

Table A1. Estimated posterior mode and S.D. (Hessian). Direct method

	USA		JAP		GER		FRA		UK		ITA		CAN	
Parameter	Mode	S.D.	Mode	S.D.	Mode	S.D.	Mode	S.D.	Mode	S.D.	Mode	S.D.	Mode	S.D.
sigma_e _*a*	0.048	0.000	0.048	0.000	0.411	0.033	0.048	0.000	0.048	0.000	0.048	0.000	0.048	0.000
sigma_e _*IS*	0.102	0.186	0.085	0.057	0.051	0.031	0.156	0.481	0.054	0.060	0.108	0.072	0.119	0.031
sigma_e _*pi*	0.019	0.269	0.011	0.056	0.021	0.141	0.062	0.972	0.013	0.039	0.004	0.001	0.007	0.004
sigma_e _*i*	0.012	0.000	0.012	0.000	0.012	0.079	0.012	0.000	0.012	0.000	0.015	0.005	0.012	0.000
sigma_e _*dP*	0.126	0.025	0.202	0.117	0.256	0.401	0.110	0.681	0.274	1.529	0.181	0.069	0.165	0.140
rho_*a*	0.773	0.230	0.712	0.034	0.762	0.467	0.745	0.041	0.783	1.235	0.758	0.277	0.701	0.440
rho_*IS*	0.954	0.021	0.943	0.071	0.825	0.017	0.883	0.082	0.881	0.055	0.949	0.079	0.914	0.031
rho_*pi*	0.754	0.144	0.969	0.082	0.839	0.033	0.933	0.019	0.911	1.390	0.981	0.124	0.951	0.187
rho_*i*	0.799	0.002	0.864	0.007	0.821	0.002	0.876	0.002	0.877	0.010	0.851	0.027	0.870	0.023
beta	0.995	-	0.995	-	0.995	-	0.995	-	0.995	-	0.995	-	0.995	-
eta	6.000	0.105	6.001	0.119	6.000	0.109	6.000	0.128	6.001	0.117	6.001	0.101	6.001	0.108
k	2.999	0.169	2.998	0.184	3.001	0.153	3.001	0.511	2.997	0.596	2.996	0.107	2.997	0.395
psi_*pi*	1.501	0.017	1.489	0.743	1.499	0.120	1.495	0.001	1.508	0.019	1.493	0.127	1.488	0.086
psi_*x*	0.126	0.191	0.143	0.143	0.095	0.029	0.133	0.002	0.138	0.011	0.128	0.179	0.131	0.063
phi	0.813	0.028	0.815	0.024	0.865	0.006	0.854	0.001	0.806	0.007	0.798	0.028	0.815	0.071
gamma	0.671	0.098	0.664	0.625	0.600	0.015	0.685	0.003	0.638	0.021	0.702	0.064	0.731	0.043
lambda	0.506	0.175	0.380	1.899	0.491	0.673	0.442	0.011	0.431	0.077	0.441	0.611	0.397	0.128

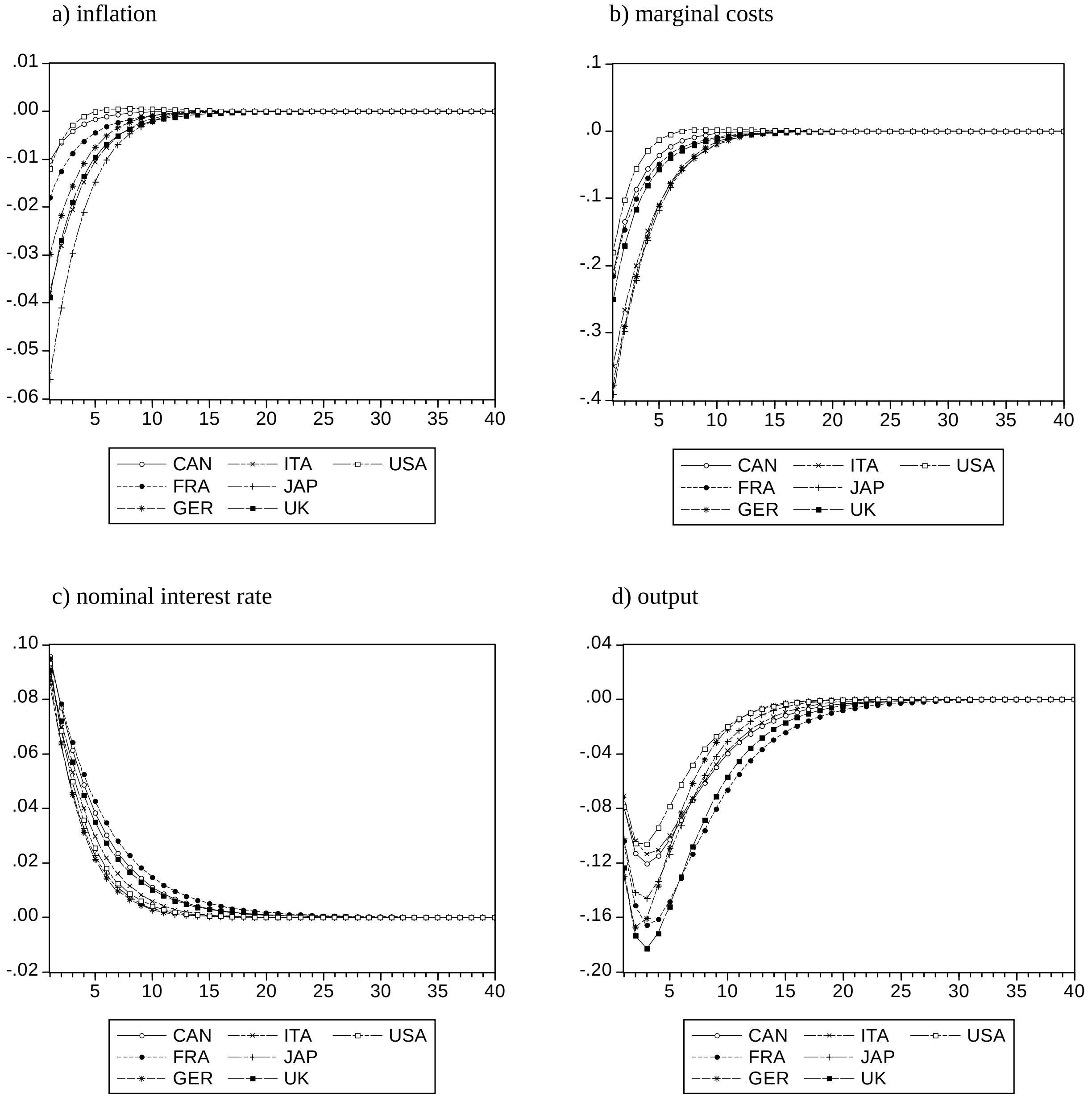
Computations obtained with Dynare for Matlab.

Figure A7. Impulse responses to a technology shock, G7 economies, M-H MCMC estimates



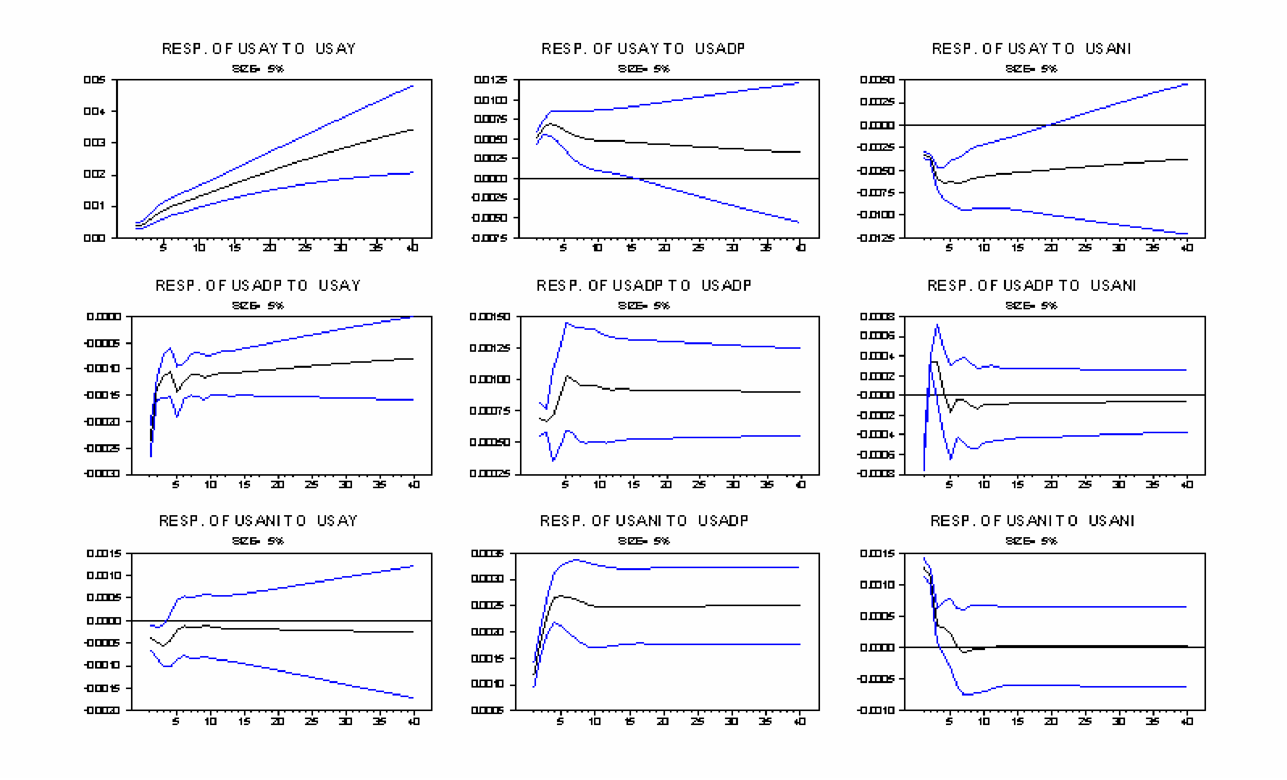
Computations obtained with Dynare for Matlab.

Figure A8. Impulse responses to a monetary policy shock, G7 economies, M-H MCMC estimates



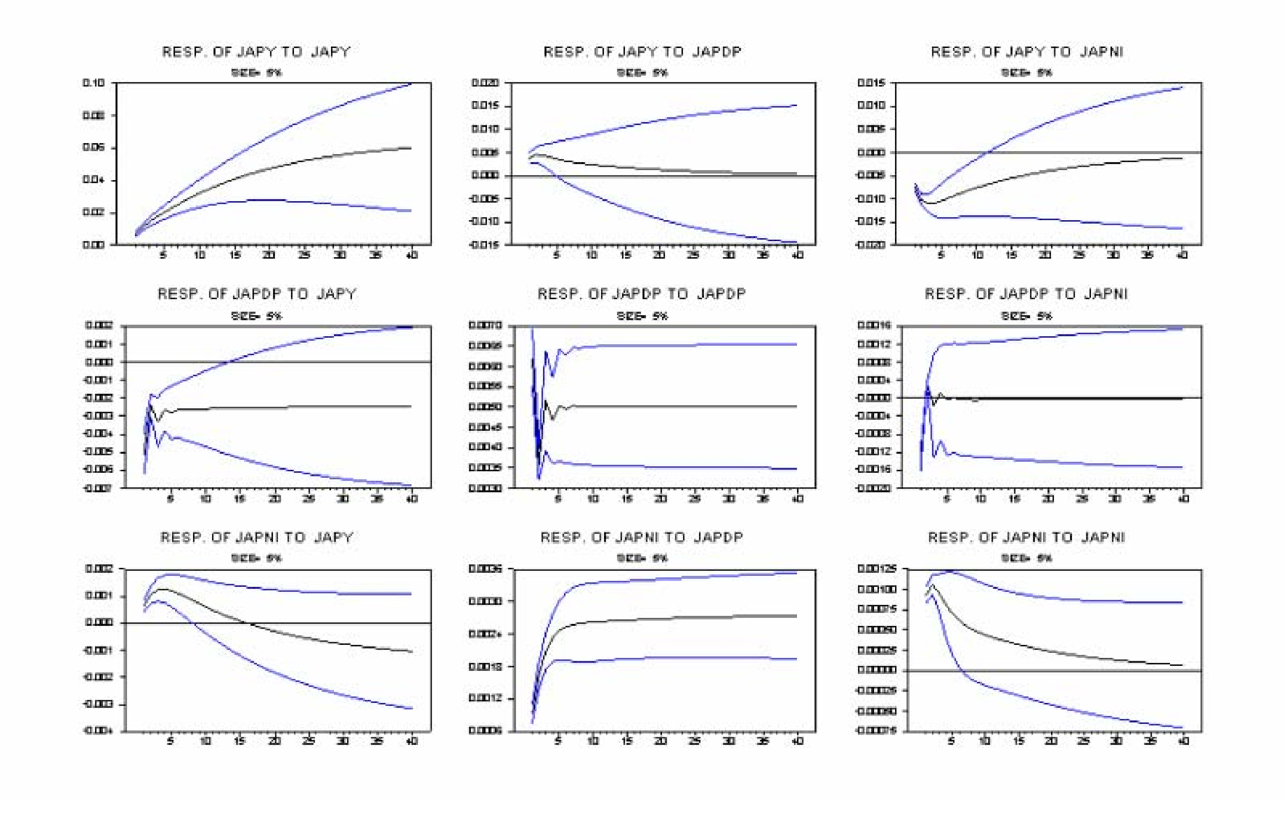
Computations obtained with Dynare for Matlab.

Figure A9. SVECM-based Impulse responses to structural shocks. USA



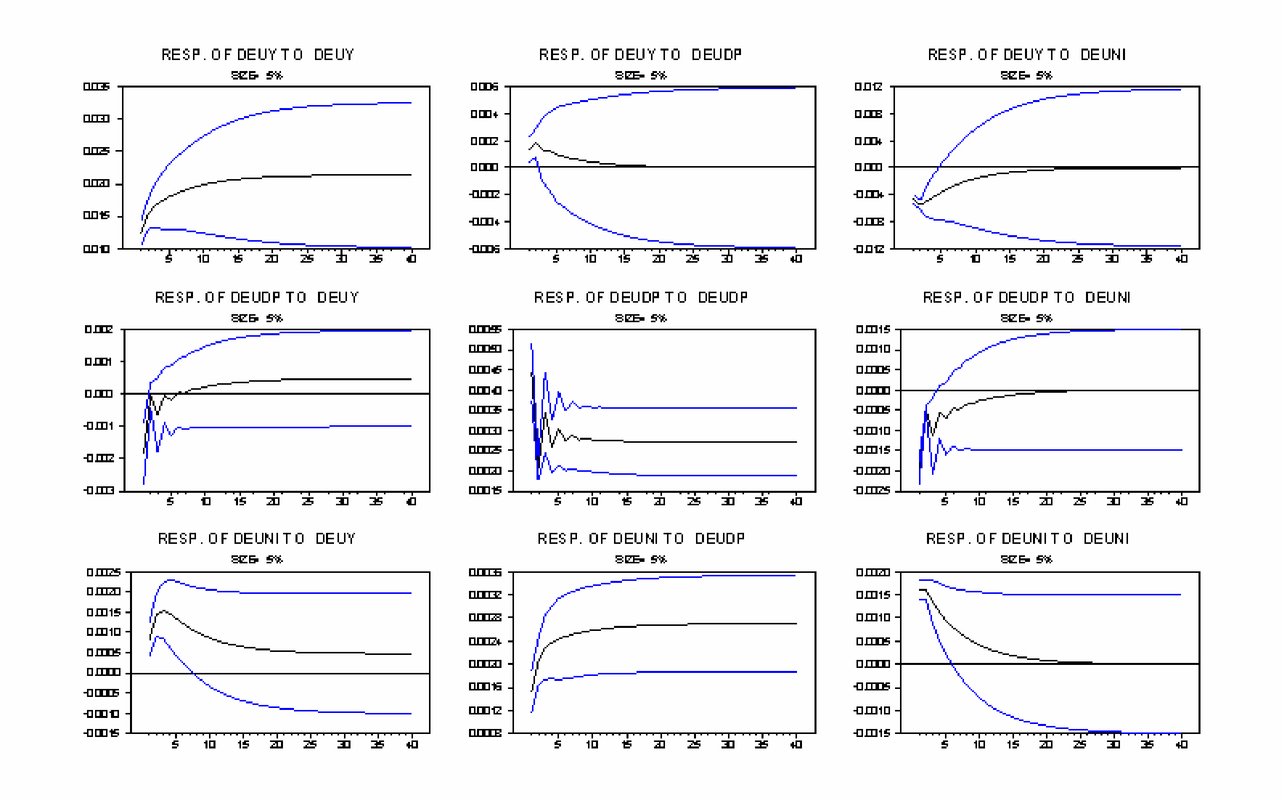
Computations executed with Malcolm 2.9 for Rats.

Figure A10. SVECM-based Impulse responses to structural shocks. Japan



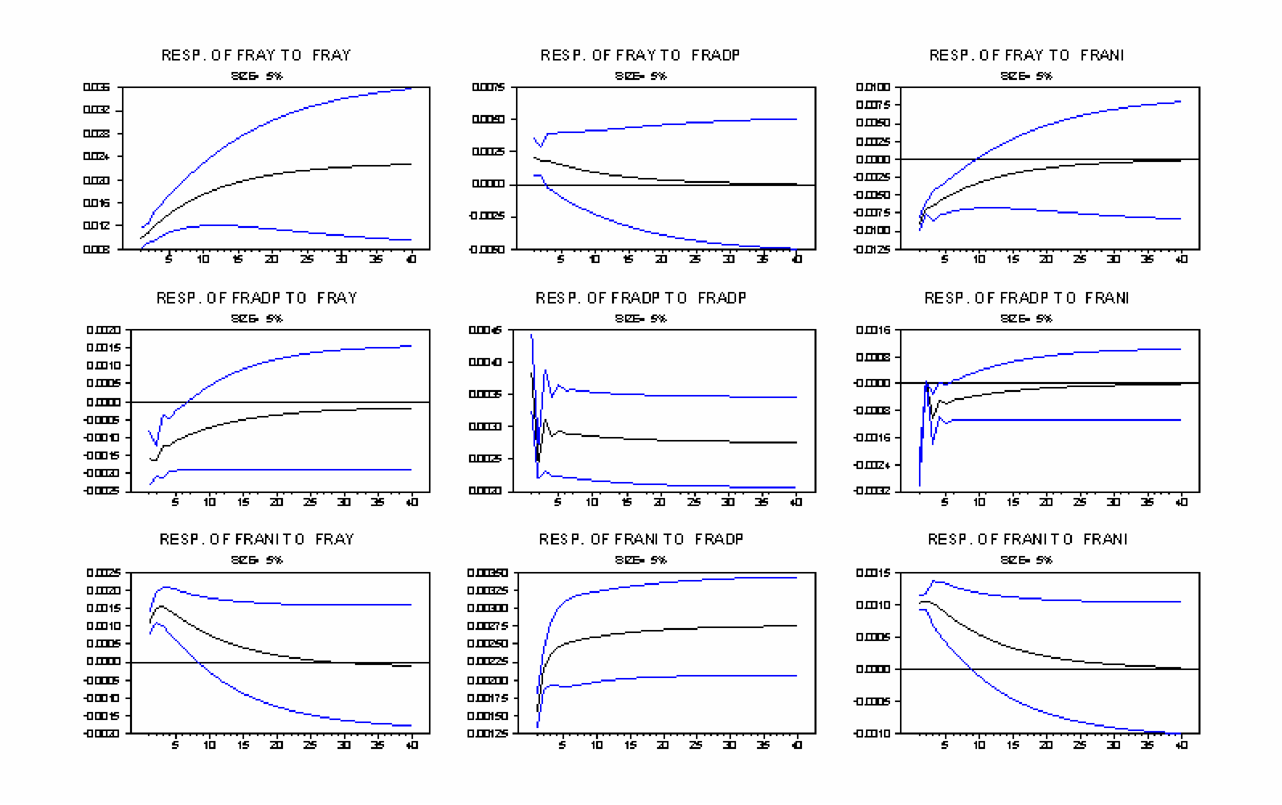
Computations executed with Malcolm 2.9 for Rats.

Figure A11. SVECM-based Impulse responses to structural shocks. Germany



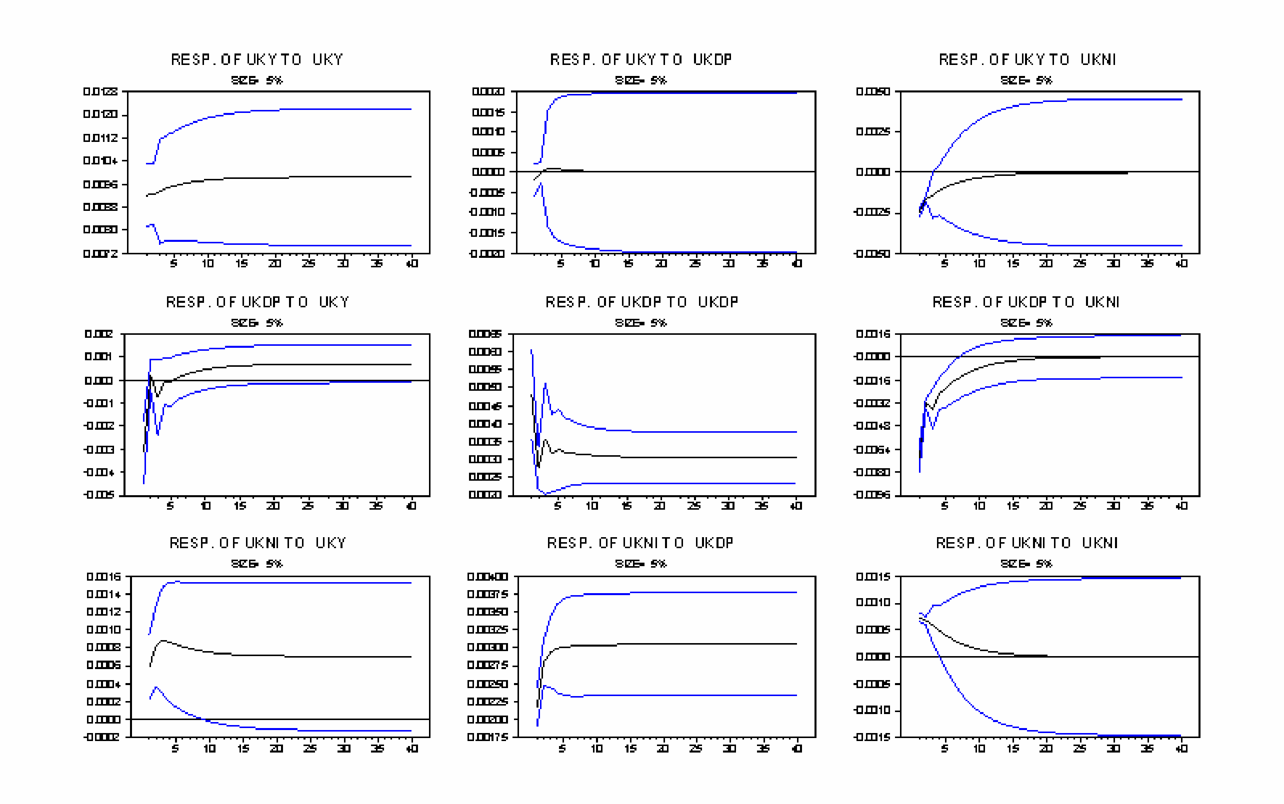
Computations executed with Malcolm 2.9 for Rats.

Figure A12. SVECM-based Impulse responses to structural shocks. France



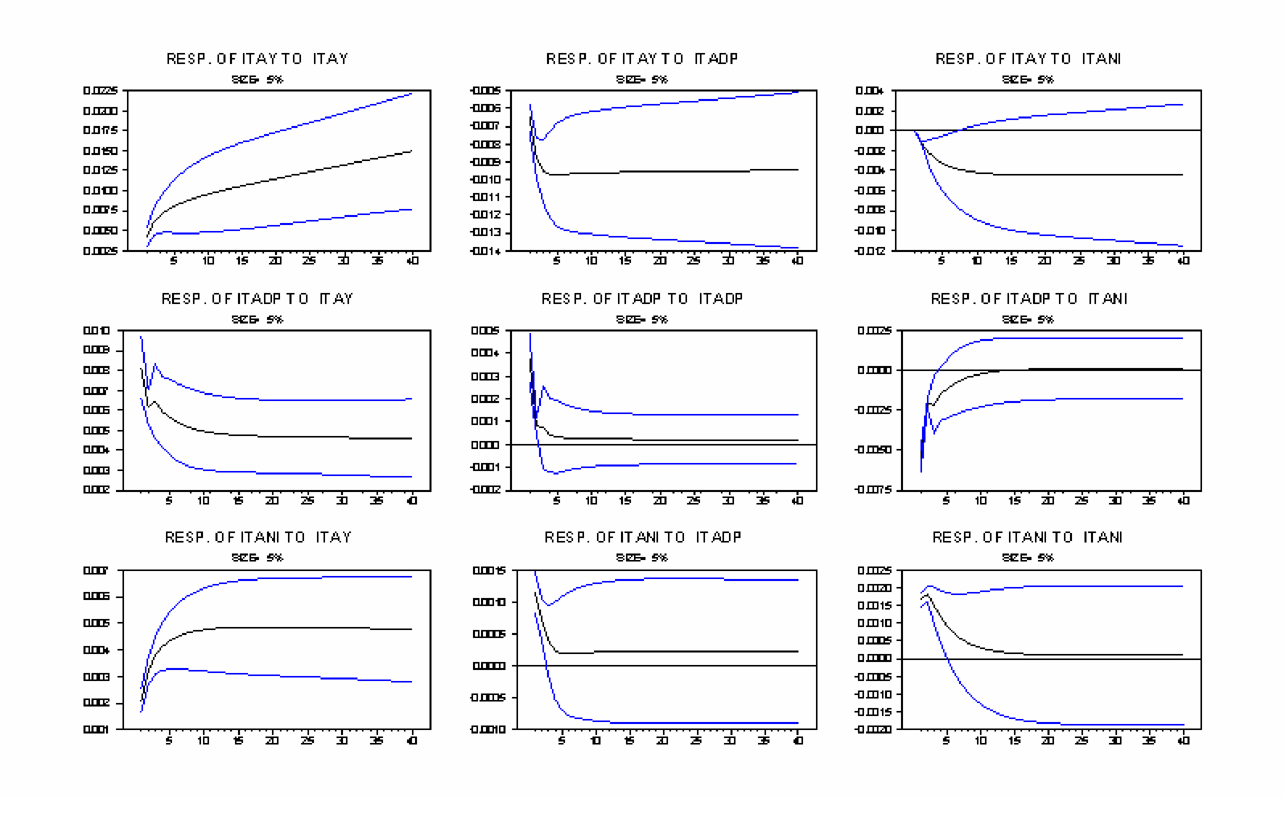
Computations executed with Malcolm 2.9 for Rats.

Figure A13. SVECM-based Impulse responses to structural shocks. United Kingdom



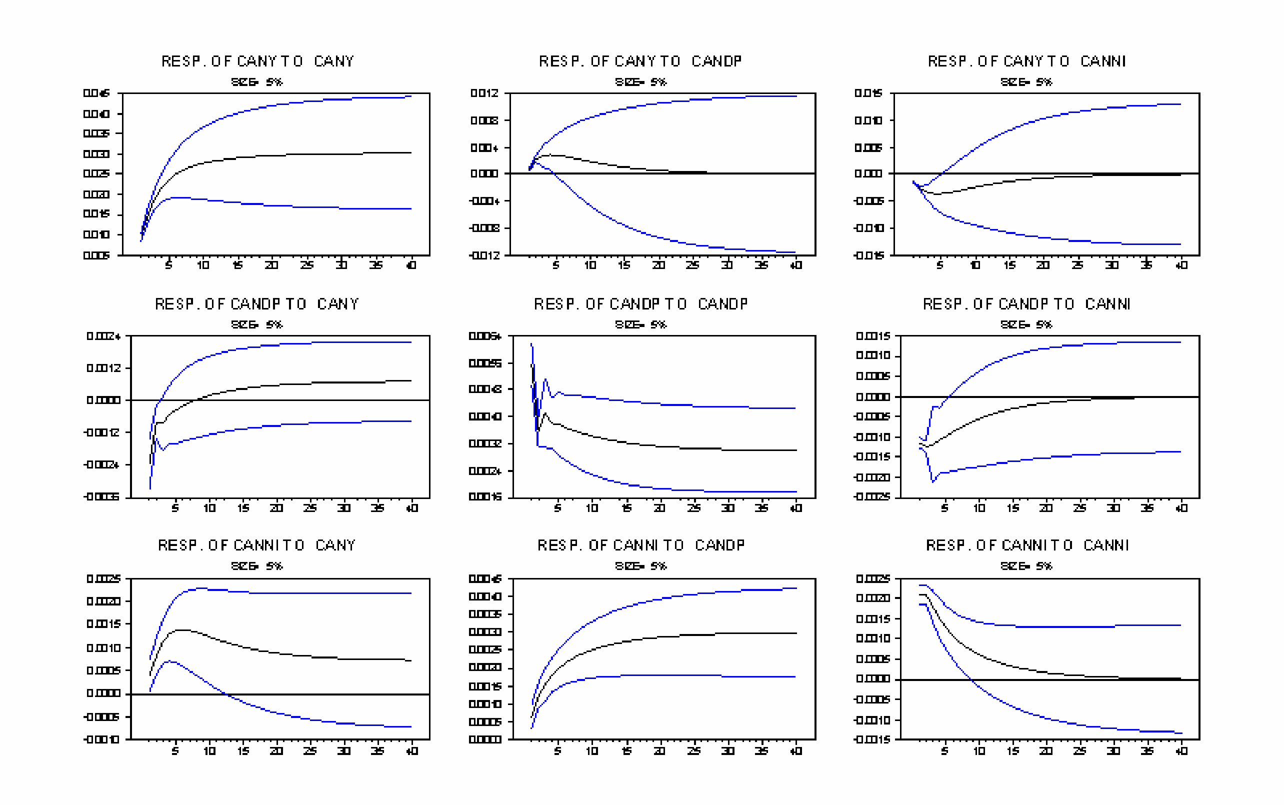
Computations executed with Malcolm 2.9 for Rats.

Figure A14. SVECM-based Impulse responses to structural shocks. Italy



Computations executed with Malcolm 2.9 for Rats.

Figure A15. SVECM-based Impulse responses to structural shocks. Canada



Computations executed with Malcolm 2.9 for Rats.