Juha Tarkka – Mika Kortelainen

International economic spillovers and the liquidity trap

SUOMEN PANKKI • FINLANDS BANK •
EUROJÄRJESTELMÄ
EUROSYSTEMET

Bank of Finland Research
Discussion Papers
18 • 2005

Suomen Pankki
Bank of Finland
P.O.Box 160
FI-00101 HELSINKI
Finland
☎ + 358 10 8311

http://www.bof.fi

Bank of Finland Research
Discussion Papers
18 • 2005

Juha Tarkka – Mika Kortelainen

International economic spillovers and the liquidity trap

A preliminary version of this paper was presented at the Central Bank Workshop on Macroeconomic Modelling hosted by the Bank of Japan in Tokyo, 27–28 May 2004. The authors thank the participants of the conference for their comments.

http://www.bof.fi

ISBN 952-462-227-0
ISSN 0785-3572
(print)

ISBN 952-462-228-9
ISSN 1456-6184
(online)

Multiprint Oy
Helsinki 2005

International economic spillovers and the liquidity trap

Bank of Finland Research
Discussion Papers 18/2005

Juha Tarkka – Mika Kortelainen
Monetary Policy and Research Department

Abstract

We study the effect of the zero bound constraint of interest rates on international transmission of economic policy and supply shocks. After some preliminary analysis with a simple theoretical model, we apply a rich two-country simulation model to the problem. The model framework consists of EDGE, Bank of Finland's dynamic equilibrium model for the euro area, linked to a similar model calibrated to resemble the US economy. The models have new Keynesian properties because of price rigidities and forward-looking pricing, consumption and investment behaviour. We assume freely floating exchange rates. Monetary policies are modelled with Taylor type policy rules, taking into account the zero bound constraint for interest rates. We find that effects of policy and supply side shocks differ significantly from the 'normal' situation if one of the countries is in the 'liquidity trap', ie if the interest rate is constrained by the zero bound. Being in the liquidity trap amplifies the domestic effects of fiscal policy, but mitigates its spillover to abroad. Changing the long run inflation target, which does not have international spillovers in the normal case, does have effects abroad if the country where the target is changed is in a temporary liquidity trap. The effects of supply shocks are also very different in the liquidity trap case compared to the normal case.

Key words: zero bound, liquidity trap, international spillovers, edge

JEL classification numbers: F42, F47

Kansainväliset taloudelliset riippuvuudet ja likviditeettiloukku

Suomen Pankin tutkimus
Keskustelualoitteita 18/2005

Juha Tarkka – Mika Kortelainen
Rahapolitiikka- ja tutkimusosasto

Tiivistelmä

Tämä tutkimus käsittelee korkojen nollarajoitteen vaikutusta talouspoliittisten impulssien ja tarjontasokkien kansainväliseen välittymiseen. Yksinkertaisella teoreettisella mallilla suoritettujen valmistavien tarkastelujen jälkeen tutkimusongelmaan tartutaan monipuolisella kahden maan simulointimallilla. Tämä koostuu EDGE-mallista, joka on Suomen Pankissa kehitetty euroalueen taloutta kuvaava tasapainomalli, sekä siihen kytketystä samantapaisesta Yhdysvaltojen taloutta kuvaavasta mallista. Malleilla on uuskeynesiläiset ominaisuudet hintajäykkyyksien ja odotusperusteisten hinnoittelun, kulutuksen ja investointikäyttäytymisen vuoksi. Valuuttakurssi oletetaan vapaasti kelluvaksi. Rahapolitiikka mallitetaan Taylor-säännön mukaisesti ottaen kuitenkin huomioon korkojen nollaraja. Tulosten mukaan talouspoliittisten impulssien ja tarjontasokkien vaikutukset poikkeavat merkittävästi ”normaalista” tapauksesta, jos jompikumpi maista on ”likviditeettiloukussa” siten, että nollaraja rajoittaa korkotason määräytymistä. Likviditeettiloukku vahvistaa finanssipolitiikan kotimaisia vaikutuksia, mutta vähentää sen vaikutuksia ulkomailla. Inflaatiotavoitteen muuttaminen, jolla ei normaalioloissa ole kansainvälisiä vaikutuksia, vaikuttaa ulkomailla, jos maa, jossa inflaatiotavoitetta muutetaan, on likviditeettiloukussa. Myös tarjontahäiriöiden vaikutukset ovat hyvin erilaisia likviditeettiloukun oloissa verrattuna normaaliin tapaukseen.

Avainsanat: korkojen nollaraja, likviditeettiloukku, kansainväliset riippuvuudet, EDGE

JEL-luokittelu: F42, F47

Contents

Abstract 3
Tiivistelmä (abstract in Finnish) 4

1 Introduction 7

2 Some theoretical considerations 9
2.1 A simple two-country macroeconomic model 9
2.2 Case 1: Neither of the economies constrained by the zero bound 11
2.3 Case 2: One of the economies is constrainted by the zero bound 14
2.4 Case 3: Both economies are constrained by the zero bound 17

3 The two-country simulation model 19
3.1 A review of EDGE 19
3.2 Linking the two models 22
3.3 Data and calibration 24

4 International economic spillovers 25
4.1 Baselines and shocks 25
4.2 The results: the interest rate shock 28
4.3 The results: the fiscal policy shock 31
4.4 The results: changing the inflation target 34
4.5 The results: supply shock 37

5 Some tentative conclusions 40

References 42

Appendix 1 A preliminary detour: The closed-economy case 44
Appendix 2 Derivation of the aggregate demand function for the small analytical model 46
Appendix 3 Simulation results in table form 48
Appendix 4 The list of equations of the two-country DGE model 56
Appendix 5 Parameters of the two-country DGE model 82
Appendix 6 Data sources of the two-country DGE model 84

1 Introduction

Interest rates have recently been exceptionally low in all major currency areas of the world. After decades of high inflation and high interest rates throughout the world, the new situation has caused a debate among researchers about the implications of very low interest rates for the conduct and effects of monetary policy. This debate has been caused by the recognition of the fact that there exists a floor below which nominal short-term interest rates cannot fall. This floor is usually thought to be zero, even though in reality storage costs of currency and other factors may imply a slightly different numerical value for the interest rate floor. The existence of the zero bound results from the possibility to use currency as an investment asset. Economic agents can always substitute currency for other assets in their portfolios, and currency is seen as a secure asset which yields zero nominal interest. Therefore, it is argued, the interest on other assets cannot fall below zero.

The recent debate has to a large extent revolved around the question whether the zero bound for nominal interest rates implies a serious threat to the ability of monetary policy to stabilize prices or inflation. The fact that the current mainstream of macroeconomic analysis models monetary policy specifically as control of the (short-term) interest rate is probably one of the reasons why the consequences of the zero bound have been seen so important. If monetary control would mean just controlling the current level of the short-term rate of interest, the economy might become more volatile at very low levels of inflation. It has also been pointed out that, in principle, hitting the zero lower bound of interest rates might create a possibility of the economy going into a deflationary spiral where real interest rates would rise (without limit) and fuel more and more deflation, see Yates (2002).

Most of this debate and analysis took originally place in the context of models of closed economies. There, the basic questions have been whether the zero bound makes monetary policy that operates through the short-term rate of interest ineffective, and if so, what could replace the rate of interest as the main instrument of monetary policy in such a situation. Candidates for alternative instrument have been long-term interest rates, prices of other assets than bonds, direct injections of cash into the economy, and fiscal policies, see Bernanke (2003). It has also been argued that credible commitments regarding future inflation may be used to control the economy if it hits the interest rate floor (Svensson, 2003). Another related research problem, more geared to the study of the implications of the zero bound for the design of policy in normal circumstances, has been to estimate the probability of hitting the zero bound at different average levels of inflation.

Recently, more attention has been given to the problems of open economies. In that literature, the mainstream models use two 'monetary conditions' variables and two potential instruments of monetary policy – the interest rate and the exchange rate. The main issue in the case of open economies has been whether foreign exchange interventions and exchange rate management could provide a way to escape the liquidity trap, this meaning the situation where an economy is saturated with liquidity and the interest rate has hit the zero bound (see McCallum, 2000 and Svensson, 2003). This analysis has focused almost exclusively on models of small open economies, however. In reality of course, there is no justification to assuming a priori that international repercussions of monetary policy are insignificant. It seems therefore natural to explore the consequences of the zero bound of interest rates for the international effects of economic policy.

In this paper, we use a calibrated, dynamic general equilibrium model of a two-country world economy to study the possible implications of the zero bound constraint for the international transmission of some shocks, emanating from economic policy on the one hand and from productivity developments on the other. The two-country model used in this study is constructed on the basis of EDGE, Bank of Finland's dynamic equilibrium model of the Euro area. The structure of EDGE duplicated in another model calibrated to approximately fit US data, and the two models, seen as a 'European' and a 'US' model are linked with trade equations, and the uncovered interest parity condition reflecting perfect capital mobility. The exchange rate is assumed to be flexible. Monetary policies are modelled as following the conventional Taylor rules in both countries. The zero bound constraint of interest rates is taken into account.

Using this model, we compare the behaviour of the two-country world economy in the case when the zero bound does not constrain the interest rates, to cases when it is temporarily binding in at least one of the countries. We find that according to our model, demand shocks generally have only small international spillovers, thus confirming the results by Wieland and Coenen (2002). The presence of the liquidity trap modifies the domestic and international effects of policy and supply shocks in several respects, however. In particular, the effects of supply shocks and of changes in the inflation target in the country which is in the liquidity trap situation are very different from the normal case.

One conclusion supported by the simulation experiments is that a temporary bindingness of the zero bound constraint in a country seems to make that country more sensitive to shocks which change the equilibrium nominal interest rate. Another result is that the bindingness of the zero bound constraint increases the effectiveness of fiscal policy quite dramatically in the country where the policy is implemented. The international spillover effects of fiscal policy on economic activity in the other country remain weak even when that country is at the zero bound, however.

The rest of this paper is organised as follows. In the next section we analyse the effect of the zero bound on international transmission with a very simple two-country model without capital and without persistence. With the preliminary insights acquired from this simple example we turn to the more complex and hopefully realistic case of simulating the full two-country dynamic general equilibrium model. In section three we first explain the assumptions on which the model is based, and then describe briefly the structure of the model, its data and calibration of parameters. In the fourth section we apply the two-country version of EDGE to analyse the international economic spillovers when the zero bound constraint on monetary policy is binding. Some conclusions are developed in the final section.

2 Some theoretical considerations

2.1 A simple two-country macroeconomic model

A useful starting point to the study of the impact of the zero bound on the effects of monetary (and fiscal) policy is the standard New Keynesian model. Let us consider a simple model which consists of a forward looking aggregate demand equation (2.1), the conventional New Keynesian Phillips curve (2.2), a definition for the real interest rate (2.3) and a Taylor rule (2.4). These equations are specified for each country. We also need the uncovered interest rate parity condition (2.5), written in real terms, to link the countries together.

Now the whole model for one country is

$$y_t - E_t y_{t+1} = \alpha_1(\rho - r_t) + \alpha_2(g_t - E_t g_{t+1}) + \alpha_3(y_t^f - E_t y_{t+1}^f) + \alpha_4(q_t - E_t q_{t+1}) \quad (2.1)$$

$$\pi_t = \beta E_t \pi_{t+1} + \lambda y_t + \varepsilon_t \quad (2.2)$$

$$r_t = i_t - E_t \pi_{t+1} \quad (2.3)$$

$$i_t = \max\left[0, \rho + \bar{\pi} + \omega(\pi_t - \bar{\pi}) + \theta y_t + \eta_t\right] \quad (2.4)$$

$$r_t = r_t^f + E_t q_{t+1} - q_t \quad (2.5)$$

Here, the variables y, y^f, g and q denote logs of domestic and foreign output, government consumption and the real exchange rate, respectively. r, I, π and $\bar{\pi}$ are the real and nominal interest rate, the rate of inflation and the central bank's inflation objective, respectively. ρ is the equilibrium real interest rate in the steady state. ε and η are a cost push shock and an interest rate shock, respectively. The parameters α_1, α_2, α_3 and α_4 are functions of the underlying 'deep' parameters of the model, as shown in Appendix 2 where the derivation of the aggregate demand equation is presented.

The model for the other country is assumed to be similar to the one above, as will be seen below.

We now proceed to solve the model. For simplicity, we restrict the analysis to the case in which the zero bound constraint on the interest rate will neither be binding on period t+1 nor anytime thereafter. We also assume that $\beta = 1$. These assumptions allow us to solve the model in a very straightforward manner.

To solve for the expected values of the variables we lead the whole model by one period and take expectations

$$E_t(y_{t+1} - y_{t+2}) = \alpha_1(\rho - E_t r_{t+1}) + \alpha_2 E_t(g_{t+1} - g_{t+2}) + \alpha_3 E_t(y^f_{t+1} - y^f_{t+2}) + \alpha_4 E_t(q_{t+1} - q_{t+2})$$

$$E_t\pi_{t+1} = E_t\pi_{t+2} + \lambda E_t y_{t+1}$$

$$E_t r_{t+1} = E_t r^f_{t+1} + E_t(q_{t+2} - q_{t+1})$$

$$E_t r_{t+1} = E_t i_{t+1} - E_t\pi_{t+2}$$

$$E_t i_{t+1} = \rho + \overline{\pi} + \omega E_t\pi_{t+1} - \omega\overline{\pi} + \theta E_t y_{t+1}$$

Under the assumption of unchanged g_j and y^f_j for j > t, the above set of equations is satisfied by the following steady state solution

$$E_t y_{t+1} = E_t y_{t+2} = 0$$

$$E_t y^f_{t+1} = E_t y^f_{t+2} = 0$$

$$E_t q_{t+1} = E_t q_{t+2} = \overline{q}$$

$$E_t r_{t+1} = E_t r^f_{t+1} = \rho$$

$$E_t\pi_{t+1} = \overline{\pi}$$

$$E_t i_{t+1} = \rho + \overline{\pi}$$

$$E_t\varepsilon_{t+1} = 0$$

$$E_t\eta_{t+1} = 0$$

The assumption of constant expected foreign activity is now justified by symmetry. Without loss of generality for the analysis of transitory shocks, we can normalize the steady state value of the real exchange rate so that $\bar{q} = 0$. We see that the rational expectations are very simple and correspond to the steady state values because this model has no persistence. Plugging the steady state expectations back into the original model we get

$$y_t = \alpha_1(\rho - r_t) + \alpha_2 g_t + \alpha_3 y_t^f + \alpha_4 q_t \tag{2.6}$$

$$\pi_t = \bar{\pi} + \lambda y_t + \varepsilon_t \tag{2.7}$$

$$r_t = \max\left[0, \rho + \bar{\pi} + (\omega\lambda + \theta)y_t + \eta_t\right] - \bar{\pi} \tag{2.8}$$

$$r_t = r_t^f - q_t \tag{2.9}$$

By symmetry, we have for the other country,

$$y_t^f = \alpha_1(\rho - r_t^f) + \alpha_2 g_t^f + \alpha_3 y_t - \alpha_4 q_t \tag{2.10}$$

$$\pi_t^f = \bar{\pi}^f + \lambda y_t^f + \varepsilon_t^f \tag{2.11}$$

$$r_t^f = \max\left[0, \rho + \bar{\pi}^f + (\omega\lambda + \theta)y_t^f + \eta_t^f\right] - \bar{\pi}^f \tag{2.12}$$

We now proceed to scrutinize the properties of this simple model with and without the zero bound constraint binding.[1]

2.2 Case 1: Neither of the economies constrained by the zero bound

We start with the most conventional benchmark case. When the zero bound is assumed to be not relevant, the model is linear in the above defined variables and can be written simply as follows

$$y_t = \alpha_1(\rho - r_t) + \alpha_2 g_t + \alpha_3 y_t^f + \alpha_4 q_t \tag{2.6'}$$

[1] For comparison we present the even simpler closed economy case in Appendix 1.

$$\pi_t = \overline{\pi} + \lambda y_t + \varepsilon_t \tag{2.7'}$$

$$r_t = \rho + (\omega\lambda + \theta) y_t + \eta_t \tag{2.8'}$$

$$r_t = r_t^f - q_t \tag{2.9'}$$

$$y_t^f = \alpha_1 (\rho - r_t^f) + \alpha_2 g_t^f + \alpha_3 y_t - \alpha_4 q_t \tag{2.10'}$$

$$\pi_t^f = \overline{\pi}^f + \lambda y_t^f + \varepsilon_t^f \tag{2.11'}$$

$$r_t^f = \rho + (\omega\lambda + \theta) y_t^f + \eta_t^f \tag{2.12'}$$

Solving for domestic output in terms of the exogenous shocks, we get

$$\begin{aligned} y_t = {} & \frac{(\gamma_1 + \gamma_3\gamma_4)}{(1-\gamma_3^2)}\eta_t + \frac{\gamma_2}{(1-\gamma_3^2)} g_t + \frac{(\gamma_1\gamma_3 + \gamma_4)}{(1-\gamma_3^2)}\eta_t^f + \frac{\gamma_2\,\gamma_3}{(1-\gamma_3^2)} g_t^f \\ & + \frac{(\gamma_1\gamma_3 + \gamma_4)(1+\omega)}{(1-\gamma_3^2)}\varepsilon_t^f + \frac{(\gamma_1 + \gamma_3\gamma_4)(1+\omega)}{(1-\gamma_3^2)}\varepsilon_t \end{aligned} \tag{2.13}$$

where

$$\gamma_1 = -\frac{(\alpha_1 + \alpha_4)}{(1 + (\alpha_1 + \alpha_4)((1+\omega)\lambda + \theta))} \qquad \gamma_2 = \frac{\alpha_2}{(1 + (\alpha_1 + \alpha_4)((1+\omega)\lambda + \theta))}$$

$$\gamma_3 = \frac{(\alpha_3 + \alpha_4((1+\omega)\lambda + \theta))}{(1 + (\alpha_1 + \alpha_4)((1+\omega)\lambda + \theta))} \qquad \gamma_4 = \frac{\alpha_4}{(1 + (\alpha_1 + \alpha_4)((1+\omega)\lambda + \theta))}$$

The rest of the solution proceeds in a trivial way. The expression for foreign output is symmetrical to (2.13). There is no simultaneity in the rest of the model so inflation rates and interest rates for both countries as well as the real exchange rate can be solved in a straightforward recursive way, by substituting the expressions for domestic and foreign output to the respective equations for inflation rates, these in turn to the equations for real interest rates, and, finally, the resulting real interest rates to the equation for the real exchange rate.

Despite of the simplicity of the model, the clusters of parameters in these expressions are rather complicated and are not reproduced here. Instead, it is instructive to assign numerical values for key parameters and see how the multipliers might turn out. Under conventional assumptions, the coefficients of the model obtain following values (see Appendix 2 for details)

$\alpha_1 = 0.25$, $\alpha_2 = 1.667$, $\alpha_3 = 1.667$, $\alpha_4 = 0.50$, $\lambda = 0.15$, $\omega = 0.5$, $\theta = 0.5$

This gives the following solution (with some rounding)

$$\begin{aligned} y_t \approx\ & 0.122 * g_t + 0.041 * g_t^f - 0.424 * \eta_t + 0.178 * \eta_t^f - 0.637 * \varepsilon_t \\ & + 0.267 * \varepsilon_t^f \end{aligned} \tag{2.14}$$

$$\begin{aligned} \pi_t \approx\ & \overline{\pi} + 0.018 * g_t + 0.006 * g_t^f - 0.063 * \eta_t + 0.026 * \eta_t^f + 0.904 * \varepsilon_t \\ & + 0.040 * \varepsilon_t^f \end{aligned} \tag{2.15}$$

$$\begin{aligned} r_t \approx\ & \rho + 0.088 * g_t + 0.030 * g_t^f + 0.692 * \eta_t + 0.129 * \eta_t^f + 1.038 * \varepsilon_t \\ & + 0.193 * \varepsilon_t^f \end{aligned} \tag{2.16}$$

$$\begin{aligned} q_t \approx\ & 0.058 * g_t^f - 0.058 * g_t + 0.562 * \eta_t^f - 0.562 * \eta_t + 0.844 * \varepsilon_t^f \\ & - 0.844 * \varepsilon_t \end{aligned} \tag{2.17}$$

$$\begin{aligned} y_t^f \approx\ & 0.122 * g_t^f + 0.041 * g_t - 0.424 * \eta_t^f + 0.178 * \eta_t - 0.637 * \varepsilon_t^f \\ & + 0.267 * \varepsilon_t \end{aligned} \tag{2.18}$$

$$\begin{aligned} \pi_t^f \approx\ & \overline{\pi}^f + 0.018 * g_f^f + 0.006 * g_t - 0.063 * \eta_t^f + 0.026 * \eta_t + 0.904 * \varepsilon_t^f \\ & + 0.040 * \varepsilon_t \end{aligned} \tag{2.19}$$

$$\begin{aligned} r_t^f \approx\ & \rho + 0.088 * g_t^f + 0.030 * g_t + 0.692 * \eta_t^f + 0.129 * \eta_t + 1.038 * \varepsilon_t^f \\ & + 0.193 * \varepsilon_t \end{aligned} \tag{2.20}$$

We see that, in this example, the effects of policy and other shocks are quite conventional, resembling the behaviour of the textbook Mundell-Fleming model: fiscal policy which temporarily increases government consumption has an expansionary effect on both domestic and foreign output, even though the effect on foreign output is weaker than at home. The currency of the country engaging in the expansionary policy will appreciate. The monetary policy shock (meaning a temporary interest rate increase relative to the Taylor rule) has a negative effect on the domestic output but a positive effect on foreign output. Asymmetric cost shocks (negative supply shocks) have a negative effect on the economy where they emanate but a positive effect on the other country. These asymmetries result from the adjustment of the real exchange rate, of course. Interest rate increases and cost-push shocks appreciate the currency and improve the competitiveness of the other country.

2.3 Case 2: One of the economies is constrained by the zero bound

Turning next to analyse the effect of the zero bound constraint, we assume that the foreign rate of interest hits the zero bound for one period, but is unconstrained and positive thereafter. This can be thought to have happened as a result of a large negative cost shock (or a positive supply shock). Starting from a 'normal' situation such as described in the previous case, a large enough negative shock in variable ε_t^f can bring the foreign interest rate to zero.

In such a state the model can be written as

$$y_t = \alpha_1(\rho - r_t) + \alpha_2 g_t + \alpha_3 y_t^f + \alpha_4 q_t \tag{2.6'}$$

$$\pi_t = \overline{\pi} + \lambda y_t + \varepsilon_t \tag{2.7'}$$

$$r_t = \rho + (\omega\lambda + \theta) y_t + \eta_t \tag{2.8'}$$

$$q_t = r_t^f - r_t \tag{2.9'}$$

$$y_t^f = \alpha_1(\rho - r_t^f) + \alpha_2 g_t^f + \alpha_3 y_t - \alpha_4 q_t \tag{2.10'}$$

$$\pi_t^f = \overline{\pi}^f + \lambda y_t^f + \varepsilon_t^f \tag{2.11'}$$

$$r_t^f = -\overline{\pi}^f \tag{2.12'}$$

Note that the linear version of model as written above describes the behaviour of the economies in this state only locally: if the shocks are such that they lift the foreign economy out of the liquidity trap, or that they drive the domestic economy into the trap the linear model consisting of (2.6')–(2.12') does no longer apply, of course.

We now proceed to solve the model. Obviously, the symmetry of the previous case does not apply any more when the foreign country is in the liquidity trap but the domestic on is not. Solving for domestic output gives

$$y_t = \gamma_5((1+\omega)\varepsilon_t + \eta_t) + \gamma_6 g_t + \gamma_7(\rho + \overline{\pi}^f) + \gamma_8 g_t^f \tag{2.21}$$

where

$$\gamma_5 = \frac{(\alpha_3 \alpha_4 - (\alpha_1 + \alpha_4))}{(1 + (\alpha_1 + (1 - \alpha_3)\alpha_4)((1 + \omega)\lambda + \theta) - \alpha_3^2)}$$

$$\gamma_6 = \frac{\alpha_2}{(1 + /(\alpha_1 + (1 - \alpha_3)\alpha_4)((1 + \omega)\lambda + \theta) - \alpha_3^2)}$$

$$\gamma_7 = \frac{(\alpha_3 (\alpha_1 + \alpha_4) - \alpha_4)}{(1 + (\alpha_1 + (1 - \alpha_3)\alpha_4)((1 + \omega)\lambda + \theta) - \alpha_3^2)}$$

$$\gamma_8 = \frac{\alpha_2 \alpha_3}{(1 + (\alpha_1 + (1 - \alpha_3)\alpha_4)((1 + \omega)\lambda + \theta) - \alpha_3^2)}$$

The expression for foreign output is, in turn,

$$y_t^f = \gamma_9 (\rho + \overline{\pi}^f) + \gamma_{10} g_t^f + \gamma_{11}((1 + \omega)\varepsilon_t + \eta_t) + \gamma_{12} g_t \qquad (2.22)$$

where

$$\gamma_9 = \left[(\alpha_1 + \alpha_4) + (\alpha_3 + \alpha_4((1 + \omega)\lambda + \theta))\gamma_7\right]$$

$$\gamma_{10} = \left[\alpha_2 + (\alpha_3 + \alpha_4((1 + \omega)\lambda + \theta))\gamma_8\right]$$

$$\gamma_{11} = \left[(\alpha_3 + \alpha_4((1 + \omega)\lambda + \theta))\gamma_5 + \alpha_4\right]$$

$$\gamma_{12} = (\alpha_3 + \alpha_4((1 + \omega)\lambda + \theta))\gamma_6$$

Again, the rest of the solution is very straightforward because of the recursive nature of the rest of the model. The expressions for outputs need to be substituted in the respective equations for inflation rates and the domestic output and inflation to the equation for the domestic real interest rate. Finally, the real exchange rate is determined simply on the basis of real interest rates.

As before, the parameter clusters in these equations are far too complicated to be really transparent. Using again the same parameter values as in the first case yields the following numerical example of the solution for this state of the economies

$$y_t \approx 0.114 * g_t + 0.019 * g_t^f - 0.687 * \varepsilon_t - 0.458 * \eta_t - 0.257 * (\rho + \overline{\pi}^f) \qquad (2.23)$$

$$\pi_t \approx \overline{\pi} + 0.017 * g_t + 0.002 * g_t^f + 0.896 * \varepsilon_t - 0.068 * \eta_t - 0.038 * (\rho + \overline{\pi}^f) \qquad (2.24)$$

$$r_t \approx \rho + 0.083 * g_t + 0.013 * g_t^f + \varepsilon_t + 0.667 * \eta_t - 0.186 * (\rho + \bar{\pi}^f) \qquad (2.25)$$

$$q_t \approx -0.083 * g_t - 0.013 * g_t^f - \varepsilon_t - 0.667 * \eta_t - 0.813 * (\rho + \bar{\pi}^f) \qquad (2.26)$$

$$y_t^f \approx 0.176 * g_t^f + 0.060 * g_t + 0.386 * \varepsilon_t + 0.257 * \eta_t + 0.613 * (\rho + \bar{\pi}^f) \qquad (2.27)$$

$$\pi_t^f \approx 1.092 * \bar{\pi}^f + 0.026 * g_t^f + 0.009 * g_t + \varepsilon_t^f + 0.057 * \varepsilon_t + 0.038 * \eta_t + 0.092 * \rho \qquad (2.28)$$

$$r_t^f = -\bar{\pi}^f \qquad (2.29)$$

The effects of policy and other shocks are now quite different from the normal case of no binding zero bound constraints. The most important differences are the following.

The effects of demand shocks (like temporary increases in government consumption) are amplified in the country where the zero bound constraint binds.

The real effects of supply side (cost-push) shocks occurring in the country where the zero bound constraint binds disappear altogether.

Also, changes in the long-run inflation target of the country where the zero bound constraint is effective now have real effects. This is because the inflation target determines inflation expectations and hence has an impact on the expected real rate of interest, when the nominal rate is temporarily constrained by the zero bound.

Two important qualitative differences emerge with regard to the transmission of shocks to abroad from the country where the zero bound constraint binds. They are both related to the way the zero floor modifies the effects of shocks in the country where the floor is effective.

First, the supply (cost-push) shock occurring in the country where the zero bound is binding no longer has any foreign real effects. In normal circumstances, temporary cost push shocks on a country benefit the other country, because the interest rate reaction to these shocks appreciates the currency where the cost push shock occurs. Then the other country benefits from this. However, when the zero bound is effective, and inflation expectations are governed by the inflation target, the expected real interest rate is decoupled from temporary cost shocks in the country where the zero bound is effective. Because the expected real interest rate is the channel through which the temporary cost shocks are transmitted internationally (in this simple model at least), this decoupling is sufficient to prevent the international transmission of these shocks.

Second, the inflation expectations prevailing in the country where the zero bound constraint is effective now have real effects abroad, something which does not happen in normal circumstances. The reason for this is the effect of the inflation target on the expected real rate of interest and hence on the real exchange rate. The higher is the inflation target in the country where the zero bound is effective, the more the exchange rate of this country depreciates, worsening the competitiveness of the other country.

2.4 Case 3: Both economies are constrained by the zero bound

Finally, we can consider the case in which both countries are in the liquidity trap. The local linear version of the model applicable to such a case can be written as follows

$$y_t = \alpha_1(\rho - r_t) + \alpha_2 g_t + \alpha_3 y_t^f + \alpha_4 q_t \tag{2.6''}$$

$$\pi_t = \overline{\pi} + \lambda y_t + \varepsilon_t \tag{2.7''}$$

$$r_t = -\overline{\pi} \tag{2.8''}$$

$$q_t = r_t^f - r_t \tag{2.9''}$$

$$y_t^f = \alpha_1(\rho - r_t^f) + \alpha_2 g_t^f + \alpha_3 y_t - \alpha_4 q_t \tag{2.10''}$$

$$\pi_t^f = \overline{\pi}^f + \lambda y_t^f + \varepsilon_t^f \tag{2.11''}$$

$$r_t^f = -\overline{\pi}^f \tag{2.12''}$$

The model is now in a sense less simultaneous than in the above cases, and consequently the solution looks a bit simpler. Solving for the activity levels in the two countries gives

$$y_t = \frac{(1+\alpha_3)\alpha_1}{(1-\alpha_3^2)}(\rho + \overline{\pi}) + \frac{\alpha_2}{(1-\alpha_3^2)} g_t + \frac{\alpha_3\alpha_2}{(1-\alpha_3^2)} g_t^f + \frac{[\alpha_4 - \alpha_3(\alpha_1 + \alpha_4)]}{(1-\alpha_3^2)}(\overline{\pi} - \overline{\pi}^f)$$

$$y_t^f = \frac{(1+\alpha_3)\alpha_1}{(1-\alpha_3^2)}(\rho + \overline{\pi}^f) + \frac{\alpha_2}{(1-\alpha_3^2)} g_t^f + \frac{\alpha_3\alpha_2}{(1-\alpha_3^2)} g_t - \frac{[\alpha_4 - \alpha_3(\alpha_1 + \alpha_4)]}{(1-\alpha_3^2)}(\overline{\pi} - \overline{\pi}^f)$$

Given y and y^f, the inflation rates can be solved from the following

$$\pi_t = \overline{\pi} + \lambda y_t + \varepsilon_t$$

$$\pi_t^f = \overline{\pi}^f + \lambda y_t^f + \varepsilon_t^f$$

Simplifying,

$$y_t = \gamma_{13}(\rho + \overline{\pi}) + \gamma_{14}\, g_t + \gamma_{15}\, g_t^f + \gamma_{16}(\overline{\pi} - \overline{\pi}^f) \tag{2.30}$$

where

$$\gamma_{13} = \frac{(1+\alpha_3)\alpha_1}{(1-\alpha_3^2)},\ \gamma_{14} = \frac{\alpha_2}{(1-\alpha_3^2)},\ \gamma_{15} = \frac{\alpha_3\alpha_2}{(1-\alpha_3^2)},\ \gamma_{16} = \frac{[\alpha_4 - \alpha_3(\alpha_1+\alpha_4)]}{(1-\alpha_3^2)}$$

In this case, the countries are similar in the sense that symmetry applies.

Assigning the above specified values for parameters yields the following solution for the model in this case

$$y_t \approx 0.171 * g_t + 0.028 * g_t^f + 0.685 * \overline{\pi} - 0.385 * \overline{\pi}^f + 0.3 * \rho \tag{2.31}$$

$$\pi_t \approx 0.025 * g_t + 0.004 * g_t^f + 1.102 * \overline{\pi} - 0.057 * \overline{\pi}^f + 0.045 * \rho + \varepsilon_t \tag{2.32}$$

$$r_t = -\overline{\pi} \tag{2.33}$$

$$q_t = \overline{\pi}_t - \overline{\pi}_t^f \tag{2.34}$$

$$y_t^f \approx 0.17 * g_t^f + 0.028 * g_t + 0.685 * \overline{\pi}^f - 0.385 * \overline{\pi} + 0.3 * \rho \tag{2.35}$$

$$\pi_t^f \approx 0.025 * g_t^f + 0.004 * g_t + 1.102 * \overline{\pi}^f - 0.057 * \overline{\pi} + 0.045 * \rho + \varepsilon_t^f \tag{2.36}$$

$$r_t^f = -\overline{\pi}^f \tag{2.37}$$

The solution of the model in the case when both countries are in the liquidity trap displays features which were already visible in the previous case.

The inflation expectations (here governed by the inflation targets) now have real effects both at home and abroad. The effects are such that higher inflation expectations in one country boost activity at home but depress it in the other country. The negative effect abroad is weaker than the expansionary effect at home, and consequently a parallel upward shift in inflation expectations in both countries is expansionary for both countries.

The absence of real effects from negative supply shocks occurs is now in both countries. As in case 2, this can be explained by the observation that, in this model, temporary supply shocks do not affect inflation expectations. Because the nominal interest rate is constrained to zero, there is no effect on the real rate of interest and hence none on aggregate demand either.

A curious property of this simple model is that if both countries are in the liquidity trap, the real exchange rate is dependent only on the relative inflation expectations in the two countries.

It is obvious that the simple model used above is useful mainly to fix ideas of how one could think about the international implications of liquidity traps in a multicountry context. The model is too stylized to claim much realism. In particular, its dynamics are too simplistic, as it does not display any persistence in the effect of shocks to the real economy nor on inflation. Because of this, expectations do not react at all to shocks, which is of course analytically convenient but probably disregards some effects relevant in economies which seem to display a lot of persistence in practice. Therefore, it is necessary to complement the above analysis with more complicated models. In practice, numerical simulations are probably the only realistic alternative to do this, because the analytics get intractable very quickly as dynamics of the model are made richer than above.

3 The two-country simulation model

We now turn to analyse the international transmission of shocks under liquidity traps with a rich simulation model. The model we use consists of EDGE, Bank of Finland's dynamic equilibrium model for the euro area, see Tarkka and Kortelainen (2001), and a similar model calibrated to resemble the US economy. The microeconomics behind the model are presented in detail in Kortelainen (2002). Here, we discuss the key assumptions of the model, data and calibration, and describe the linking of the two models to form a framework suitable for the study of policy interaction.

3.1 A review of EDGE

The Euro area Dynamic General Equilibrium (EDGE) -model of the Bank of Finland was built in order to analyse the effects of monetary policy credibility in Europe. The underlying principles of the model are the inclusion of micro-foundations through optimisation behaviour of representative agents, and the explicit treatment of expectations. We usually use the assumption of rational expectations, but the model can be used to analyse heterogeneous expectations, too, for example in the context of less than perfect monetary policy credibility. A simplification which has been made in constructing the model is that the derivation of the equations is done under the certainty equivalence assumption, with some risk premia added later ad hoc in the arbitrage equations in the model. The model has nominal rigidities in the short-run, which allow monetary policy to have real effects. Hence, the model can be characterised as following the New Keynesian approach and it displays many Keynesian short-run properties but the long run is quite neoclassical at least in the rational expectations mode, due to forward-looking expectations and long-run market clearing.

EDGE is a quarterly model and is coded and used in Troll simulation software environment. It contains about 40 equations 11 of which are key behavioural equations and rest contains technical equations, identities and policy rules. The parameters are calibrated on the basis of publicly available Euro area data. The model is disaggregated to household, corporate, government and foreign sectors. The government sector is treated as a single entity even though the model is intended to describe the euro area.

The microeconomics of the EDGE-model include consumption/saving decisions according to Blanchard's stochastic lifetime approach, the valuation of private financial wealth according to the present value of capital income, overlapping Calvo wage contracts in the labour market, and a neoclassical supply side. Also producer prices are rigid in the short run following the Rotenberg approach. The exchange rate is determined by the uncovered interest rate parity.

The key behavioural equations that establish the core of the EDGE-model are derived from the optimisation problems of households and firms. The consumption is derived from the household maximisation problem with no liquidity constraints, myopic behaviour or habit persistence assumption. A closed form solution for the consumption is derived using logarithmic utility function. The Blanchard (1985) approach which we use assumes consumers who face a positive hazard of dying, p, each period. Also, each period a new cohort is born with zero wealth. An exogenous birth rate determines the population growth rate in the model. The model assumes that there is a competitive life insurance market which distributes in each period the wealth of the dying individuals to the survivors. The financial wealth is calculated by the present value method, applying an exogenous equity premium in addition to the real rate of interest to all capital income incurred by the private sector.

The problem of the firm is solved to obtain investment demand, labour demand and inventory demand equations as well as the price of the value added. The production function of value added is assumed to be Cobb-Douglas. In their labour demand and pricing decisions, firms incur adjustment costs à la Rotemberg (1982). The capital stock is endogenous and is accumulated from investments. In analysing the firm's problem we assume that the adjustment problems mentioned above are separable. Households and firms together determine wages as overlapping Calvo contracts, see Calvo (1983), in the labour market. Labour supply is exogenous, but employment and labour income are demand-determined in the short run because of nominal wage rigidities. In the longer run, employment converges towards the level determined by the size of the labour force and the exogenous equilibrium rate of unemployment (NAIRU).

Private consumption, government consumption, fixed investment and exports are assumed to be CES aggregates of domestic value added and imported goods. This approach allows the derivation of price indices for the demand components consistent with the demand functions for imports (and, implicitly, the domestic value added), see Kollman (1999) for an exposition. Below, we will discuss the trade equations in some more detail.

The economic policy part of the EDGE model contains the budget constraint of the government sector and two policy rules: a budget closure rule of the fiscal authority and a monetary policy rule of the monetary authority. The fiscal policy rule is imposed to guarantee that the dynamic budget constraint is met. We usually apply an income tax rule. Following this type of rule, the government always balances its budget in the long run through tax changes. As target variables in this fiscal rule both the debt/GDP and budget deficit/GDP ratios are applied in parallel. The monetary policy rule is used to pin down the growth rate of the undetermined price level. Taylor-rule type of monetary policy rule is applied here, see Taylor (1993).

In addition to the above dynamic model we have also derived a companion steady-state model, which is derived from and is consistent with the dynamic model. This steady-state model is used to obtain the necessary terminal points for the solution of the dynamic model. In principle, the steady-state model could be used separately to analyse the long-run properties of the economy, too. The steady-state model is also helpful in stock-flow considerations since it defines explicitly the stock equilibrium for private financial assets, capital stock, government debt and net foreign assets. The short-run flow equilibria of consumption, investment, government net lending and current account are described by the dynamic model. In this flow equilibrium the stock equilibrium may still be incomplete but in the long-run even stocks of assets will adjust fully to the steady-state stock equilibrium.

The simulation properties of the model (under the single country, small open economy assumption) are reported in Tarkka and Kortelainen (2001), Kortelainen (2002) and Kortelainen and Mayes (2004), so we do not need to go into these here. The results reveal, however, that the model has very little persistence of inflation or employment in its response to permanent shocks. This has probably a lot to do with the fact that there is no inflation persistence imposed in the model, only price level rigidities (in prices and wages). Similarly, the convergence of the unemployment rate to NAIRU is usually very quick (when the model is used in the rational expectations mode).

3.2 Linking the two models

In the two-country model we use EDGE and a similar model calibrated for US data (see Appendix 4 for the model code). In order to link the euro area and US model we employ some additional assumptions.

Export price is defined as the minimum cost of producing one unit of exports

$$PX = ((nux)(P)^{1-mux} + (1-nux)(PM)^{1-mux})^{\frac{1}{1-mux}}$$

where P and PM are the deflators for domestic value added goods and imported goods respectively. nux is the share of domestic value added goods in exports. mux is the substitution elasticity between domestic value added good and imports in exports.

Imports are obtained by adding up aggregate demand for imported goods

$$M = (1-nuc)\left(\frac{PM}{PC}\right)^{-muc} C + (1-nucg)\left(\frac{PM}{PCG}\right)^{-mucg} CG + (1-nui)\left(\frac{PM}{PI}\right)^{-mui} ITOT + (1-nux)\left(\frac{PM}{PX}\right)^{-mux} X$$

Euro area import prices are defined by foreign export prices and the exchange rate. US imports and exports deflators are indexed to 1996=1. Thus, we have euro area import prices as follows

$$PM = ((PM)(e))_{96}\left(\frac{PX^{*}}{e}\right)$$

where $((PM)(e))_{96} = 1.33508$ is the average of euro area import prices in dollars in year 1996.

Exports are defined by foreign imports. When constructing US import and export series we apply euro area exports and imports and convert these to US equivalents as follows

variable/country	**Linkage of the model**	
	euro area	USA
Imports	$M = (1-nuc)\left(\frac{PM}{PC}\right)^{-muc} C + (1-nucg)\left(\frac{PM}{PCG}\right)^{-mucg} CG + (1-nui)\left(\frac{PM}{PI}\right)^{-mui} ITOT + (1-nux)\left(\frac{PM}{PX}\right)^{-mux} X$	$M^* = (1-nuc^*)\left(\frac{PM^*}{PC^*}\right)^{-muc^*} C^* + (1-nucg^*)\left(\frac{PM^*}{PCG^*}\right)^{-mucg^*} CG^* + (1-nui^*)\left(\frac{PM^*}{PI^*}\right)^{-mui^*} ITOT^* + (1-nux^*)\left(\frac{PM^*}{PX^*}\right)^{-mux^*} X^*$
Import price	$PM = 1.33508\frac{PX^*}{e}$	$PM^* = e\frac{PX}{1.33762}$
Exports	$X = (M^*)/1.33762$	$X^* = 1.33508(M)$
Export price	$PX = ((nux)(P)^{1-mux} + (1-nux)(PM)^{1-mux})^{\frac{1}{1-mux}}$	$PX^* = ((nux^*)(P^*)^{1-mux^*} + (1-nux^*)(PM^*)^{1-mux^*})^{\frac{1}{1-mux^*}}$
Trade balance	$TB = PX(X) - PM(M)$	$TB^* = PX^*(X^*) - PM^*(M^*)$
Current account	$CA = TB + NFN$	$CA^* = TB^* + NFN^*$
Net factor income	$NFN = -\frac{NFN^*}{e}$	$NFN^* = R^*/400\left(NFA^*_{-1}\right)$
Net foreign assets	$NFAR = -\left(\frac{NFAR^*}{Q}\right)\left(\frac{PF^*}{PF}\right)\left(\frac{PC}{PC^*}\right)$	$NFAR^* = \frac{NFAR^*_{-1}}{1+INFD^*} + \frac{CA^*}{PF^*}$

$$X = ((PX)(e))_{96}(M^{*})$$

where $((PX)(e))_{96} = 1.33762$ is the average of euro area export prices in dollars in year 1996. We use similar export and import volumes for USA and recalculate the national accounting identity by using inventories as residual.

An additional assumption is that net foreign assets sum to zero; another is that the current accounts must do likewise. These two assumptions are fulfilled by determining euro area net foreign assets and net factor income as opposite variables of equivalent US figures.

The exchange rate is endogenised via uncovered interest rate parity. Thus, real interest rates can differ only if the real exchange rate changes. Net foreign assets are accumulated through the current account surpluses. The net factor income is accrued as interest on US denominated short-term debt.

3.3 Data and calibration

Euro area and US data are described in Appendix 6. We assemble data for period up to the end of 2001. In our simulations we start steady-state simulations from 2002 onwards. All dynamic simulations are set to run starting from 2100 onwards. Thus, our dynamic simulations are run from an artificial database, which can only be loosely connected with the actual data.

In calibrating the structural parameters of the model we try to apply values which are close to the conventional values used in the literature. At the moment we apply no formal method for fitting our model to data.

In calibration, we set the capital share of income in the Cobb-Douglas production function to 0.4. This is slightly more than the secular growth (1/3) in output per worker due to changes in capital as calculated by Solow, see Cooley (1995). The depreciation rate is set to 6% per annum, which means roughly that the capital is fully amortised in about 16 years after the instalment. Equity premium is set at 6% per annum, which is somewhat higher than 3.25% per annum suggested by the US data for years 1800–1990, see Siegel (1992).

The NAIRU levels as well as indirect tax rates are set to correspond to the last observed values in the respective data. The constant probability of death in the Blanchard's model is calibrated to equal 1/80. This means that an average consumer/worker can expect to live 80 more periods making the average planning horizon 20 years. On average the total life of a consumer/worker is 160 periods, which corresponds to 40 years. We assume that the rate of time preference is roughly 0.01 which yields a subjective discount rate of 0.99.

Calvo probability is set at 0.125, which corresponds roughly to two year long wage contracts. The parameter defining the deviations of the optimal real wage from the marginal product of labour is set to one. The adjustment cost parameter in the menu cost pricing is set at 0.1.

Translog adjustment cost parameters a_1 ('level' of adjustment costs) and a_2 (cost of changing 'the rate in capital accumulation') in the fixed investments are set at 250 and 0.25 respectively. In the inventory demand the target level of inventories relative to output is set to one for euro area and at 0.5 for USA. The adjustment cost parameter with respect to quadratic changes in the level of inventories is set at 0.25.

Inflation target and the real growth rate are calibrated to generate a chosen baseline. The rest of the calibration results are shown in Appendix 5.

4 International economic spillovers

In this section, we analyse the behaviour of the two-country model which was described above. The specific focus is on the international economic spillovers, both in 'normal' circumstances of positive interest rates, and in the especially interesting case of the liquidity trap.

4.1 Baselines and shocks

For the purposes of the comparative simulation study, we created two baseline scenarios with the two-country model, each scenario 50 years long. They can be briefly described as follows.

1. The standard baseline scenario (we call this baseline 1) is one where neither of the countries in the model is in the liquidity trap, so that nominal interest rates are positive in both countries. In order for this scenario to be not too far from the liquidity trap scenarios however, it has been calibrated so that the nominal interest rate is relatively low, namely 1 per cent. This has been achieved by setting the inflation targets of both central banks to zero, and by slowing down the total factor productivity growth in both countries so that the economies grow only at the rate of 0.4 per cent per annum. As a result of these changes, the real interest rate is also only 1 per cent. Baseline 1 is a smooth growth scenario in which all variables evolve smoothly along their calibrated steady state growth paths.

2. The asymmetric liquidity trap scenario (we call it baseline 2) is one in which the 'US economy' in the model is temporarily in a deflationary liquidity trap with the short term interest rate equal to zero. The duration of the liquidity trap is four years, starting from the beginning of the scenario. This situation is achieved

through switching off the Taylor rule for four years and keeping the nominal interest rate in 'the US' zero instead. (this means that the real interest rate is temporarily higher than in the long run). After the imposed liquidity trap in 'the US' economy ends, the model returns to a steady growth paths so that all real variables, the interest rate, and the growth rates of other nominal variables evolve along paths similar to baseline 1.

These two baseline scenarios are used to scrutinize the impact of four different of shocks, three demand shocks and one supply shock. The shocks are chosen so that the results could be usefully compared with the analysis of the theoretical model in section 2 above. We describe these shocks and their effects each in turn.

Demand shock 1

The first shock is a monetary policy experiment, done over both baselines 1 and 2, consisting of a temporary tightening of monetary policy. This shock is selected in order to study the impact of the liquidity trap on how a pure monetary policy shock is transmitted from a country in a normal monetary regime to another where deflation and the liquidity trap are prevailing. In the experiment, the 'European' short term interest rate is increased by 50 basis points for a period of one year. The shock is implemented through an additive term to the euro area interest rate rule, with duration of one year. The standard Taylor rule takes over thereafter. In the US, the Taylor rule is in force throughout in when the experiment is performed over baseline 1, but in the other experiment, over baseline 2, zero bound prevents the movement of the US interest rate for the initial four-year period. The shock is assumed to come as a surprise to the agents in the model, but after they observe it, they also know that it is going to vanish after one year (as if the return to the Taylor rule policy after 4 quarters were announced simultaneously with the shock).

Demand shock 2

This shock is a fiscal policy experiment, consisting of a one-year increase in government consumption in 'the US' of one per cent of GDP. It is conducted over both of the baselines in order to see how different monetary conditions modify the transmission of this kind of policy shock to abroad. The shock is assumed to come as a surprise to the agents in the two economies, but the duration of the shock is known as soon as the shock occurs, as if there was a credible announcement that the increase in government consumption would last only one year. The financing of the increase in government expenditure happens according to the tax rule operating in the model: the income tax rate reacts to deviations of the government deficit and of the government debt from their target levels. Because the tax rule is quite gradual, the increase in government consumption will initially be mostly bond financed. However, the addition to debt will be repaid in about five years' time due to the operation of the tax rule. Note that the supply side effects of the income tax rate on labour supply are not present in this model since labour supply decisions of households are exogenous and the tax rate has no direct effects on the nominal wage behaviour either in the model.

Demand shock 3

The third demand shock consists of a permanent upward shift in the inflation target in the US The inflation target is increased by 50 basis points permanently. This shock is also performed over both baseline cases. Performed over baseline 1, with no liquidity traps, this shock will test for the 'superneutrality' of the model as well as the effective degree of persistence in the adjustment of the model to higher inflation. Performed over baseline 2, it helps us to check whether we find support for the prediction of the theoretical model, that there should be large real effects from changing the long-run inflation target when a temporary liquidity trap prevails. Note that in the case of baseline 2, the inflation target is announced right in the beginning of the experiment, although it takes four years before it affects the actual interest rate decisions. The effects through expectations start immediately, however.

The supply shock

The fourth shock is an asymmetric, negative supply shock occurring in 'the US' and its effects are studied over both scenarios. This shock consists of an increase of one percentage point in the US equilibrium unemployment rate, for the period of one year. As in the previous temporary shocks, the duration of this shock is assumed to be known and incorporated to expectations as soon as the shock occurs in the beginning of the experiment. On the basis of the theoretical analysis in section 2, it was thought that it would be interesting to test whether the effects of the supply shocks indeed vanish in the liquidity trap case also in our rich simulation model as they did in the small analytical model.

4.2 The results: the interest rate shock

The results of the contractive monetary policy shock in ‘Europe’ (a temporary increase in the short-term interest rate by 50 bp) are presented in Figures 1–2 and in Tables A1–A2 in the Appendix 3.

Let us consider first the case of no liquidity traps. The effects of the interest rate increase in this case are presented in Figure 1 and in Table A1 in the Appendix 3. The interest rate increase causes a corresponding appreciation on the euro, by 0.35 per cent in real terms. This tightening in monetary conditions generates a strong negative reaction in all demand components in ‘Europe’: consumption, investment and exports all decline between 0.14 and 0.4 per cent in the short run. As a result, real GDP declines also by 0.25 per cent below the baseline scenario. Inflation decelerates only a little and the unemployment rate increases also a little. All these effects vanish quickly. The rapidity of the reactions in ‘Europe’ reflects the features of the model that there is no ‘additional’ or ad hoc persistence built in the consumption and wage/price behaviour and the forward looking behaviour dominates the temporary shocks.

The effects on the ‘US economy’ are very small, almost negligible. At first, as the result of the surprise change in the European interest rate, the US short term interest rate increases by almost half of the European interest rate increase and the US currency depreciates. The US interest rate moves back down in the second quarter after the shock, however. The reaction of the exchange rate, reflected also in the real exchange rate, is sufficient to shield the domestic economy from any great impact from European monetary policy. As predicted by our small analytical model, there is a small positive activity effect in the US from the temporary tightening of European monetary policy, but here the effects are really quite small.

The results are not markedly different in the case where the US is in a temporary deflationary trap (see Figure 2 and Table A2 in the Appendix 3). The small activity effects to abroad are now even slightly smaller. The finding that when the exchange rates can adjust freely, the presence (or not) of a temporary liquidity trap does not much alter the country’s response to demand shocks from abroad, is confirmed by the next experiment where we consider a fiscal policy impulse.

Figure 1. **Temporary (1Y) 0.5%-pt increase in euro area short-term interest rates with baseline 1**
(Deviation from control)

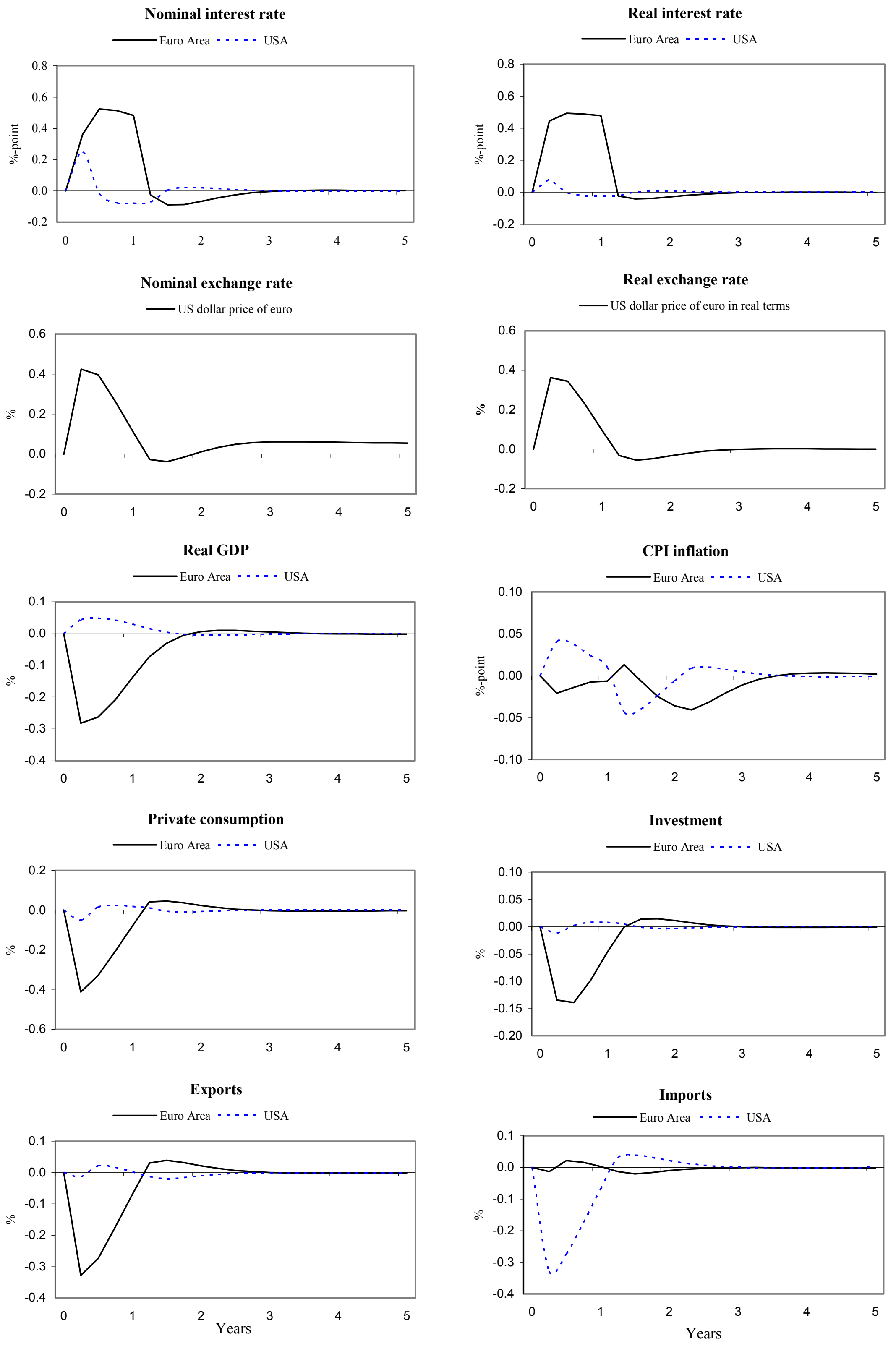
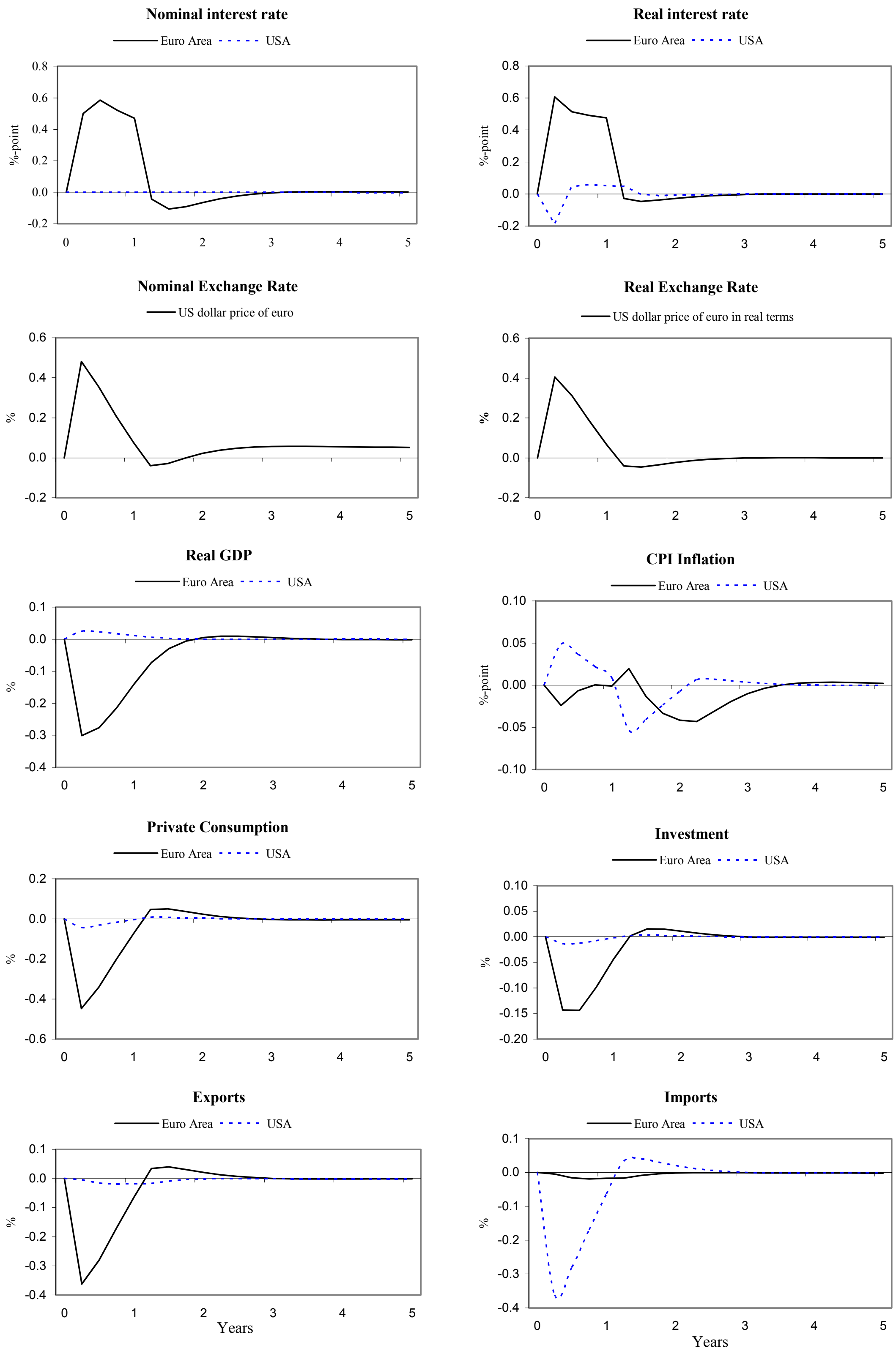


Figure 2. **Temporary (1Y) 0.5%-pt increase in euro area short-term interest rates with baseline 2**
(Deviation from control)



4.3 The results: the fiscal policy shock

The results of the expansionary fiscal policy shock in 'the US' are presented in Figures 3–4 and in Tables A3–A4 in the Appendix 3.

As a benchmark, let us first consider the case in which the "US' fiscal expansion is applied in normal monetary conditions (of no liquidity traps, baseline 1) prevailing in both countries of the model. These results are in Figure 3 and Table A3 in the Appendix 3. The first thing to note is that the temporary increase in government consumption has a clear expansionary effect on the economic activity in the country where the policy is enacted. There is also a clear spillover to the other country, but the order of magnitude is small, reflecting of course the share of trade in the countries' aggregate demand and supply. The currency of the expanding country appreciates in the standard Mundell-Fleming fashion. Regarding the response of inflation to the fiscal policy shock, it is interesting to note that even our model (despite of the forward looking nature of the price and wage equations) displays the 'price puzzle' behaviour often encountered in macroeconomic models: in the very short run, inflation reacts negatively to fiscal expansion (in the country where the expansionary policy is applied). This can probably be explained by the currency appreciation, which reduces the cost of imports. In the medium run, the effect on inflation is clearly positive, however.

Turning to consider the effects of fiscal policy under liquidity trap conditions (baseline 2), we see that the activity effects of fiscal policy are dramatically increased by the immobility of the interest rate. In our simulation experiment, the effects are doubled compared to normal conditions, if fiscal expansion is done under the conditions of liquidity trap. Another significant difference is that now the currency of the expanding country depreciates, whereas under normal conditions it appreciated. Because of the difference in the reaction of the exchange rate, the international spillover of the fiscal policy diminishes and in fact practically disappears when the expanding country is in the liquidity trap.

Figure 3. **Temporary (1Y) increase of 1% of real GDP in public consumption in USA with baseline 1**
(Deviation from control)

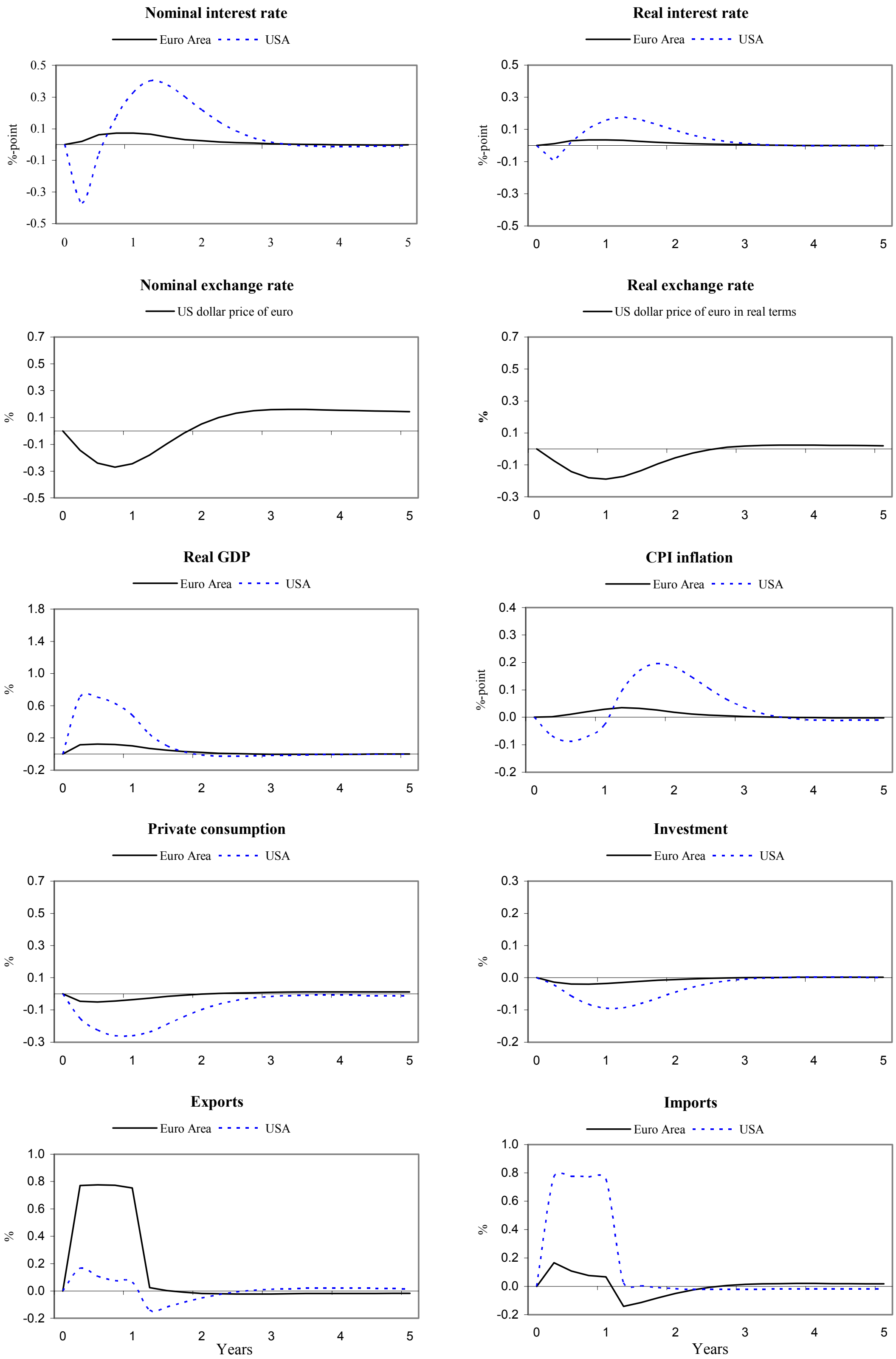
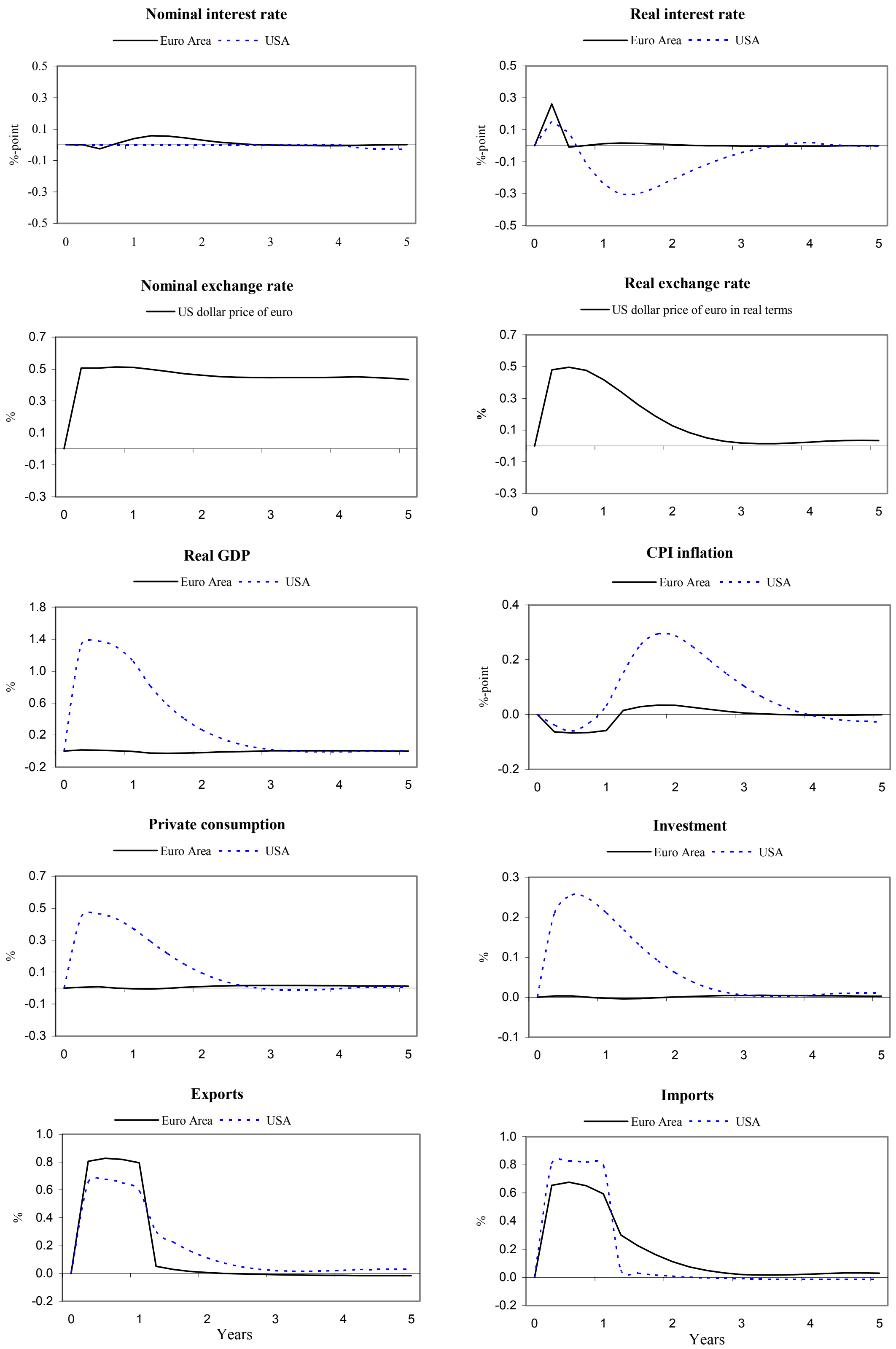


Figure 4. **Temporary (1Y) increase of 1% of real GDP in public consumption in USA with baseline 2**
(Deviation from control)



4.4 The results: changing the inflation target

The results of the inflation target experiment are depicted in Figures 5–6 and in Tables A5–A6 in the Appendix 3.

When the US inflation target is increased under normal conditions (ie on baseline 1, in which there is no liquidity trap), inflation reacts immediately, following the target with no delay (the figure shows a gradual increase of the inflation rate spread over one year, but that is a result of calculation the inflation rate on a year-on-year basis). Also the nominal interest rate adapts quickly to the new conditions of higher inflation.

The EDGE model is very nearly, but not completely superneutral, ie the real economy is almost completely insensitive to changes in inflation. It is typical for models of the New Keynesian variety to have a slightly upward sloping Phillips curve, but our simulation experiment shows that the real effects are totally negligible in the EDGE model. Also international spillovers are insignificant. The only international effect is the gradual depreciation of the US currency which leaves the real exchange rate unchanged, however.

Things are very different under the liquidity trap conditions. Even though the inflation target affects actual monetary policy only after the liquidity trap regime is over, ie after four years, increasing the inflation target has effects through inflation expectations immediately when the policy change is announced. Inflation accelerates a lot (in the medium run, as much as three times more than the change in the inflation target) and reduces the real rate of interest for the four-year duration of the liquidity trap. At the same time, the US currency depreciates strongly. Both of these channels together cause a large increase in economic activity in the US The spillover to ‘Europe’ is negative as predicted by the small analytical model of section 2, both in terms of real activity and inflation, but the effects are not nearly as large as those generated in the US economy.

Figure 5. **Permanent 0.5%-pt increase in US inflation target with baseline 1**
(Deviation from control)

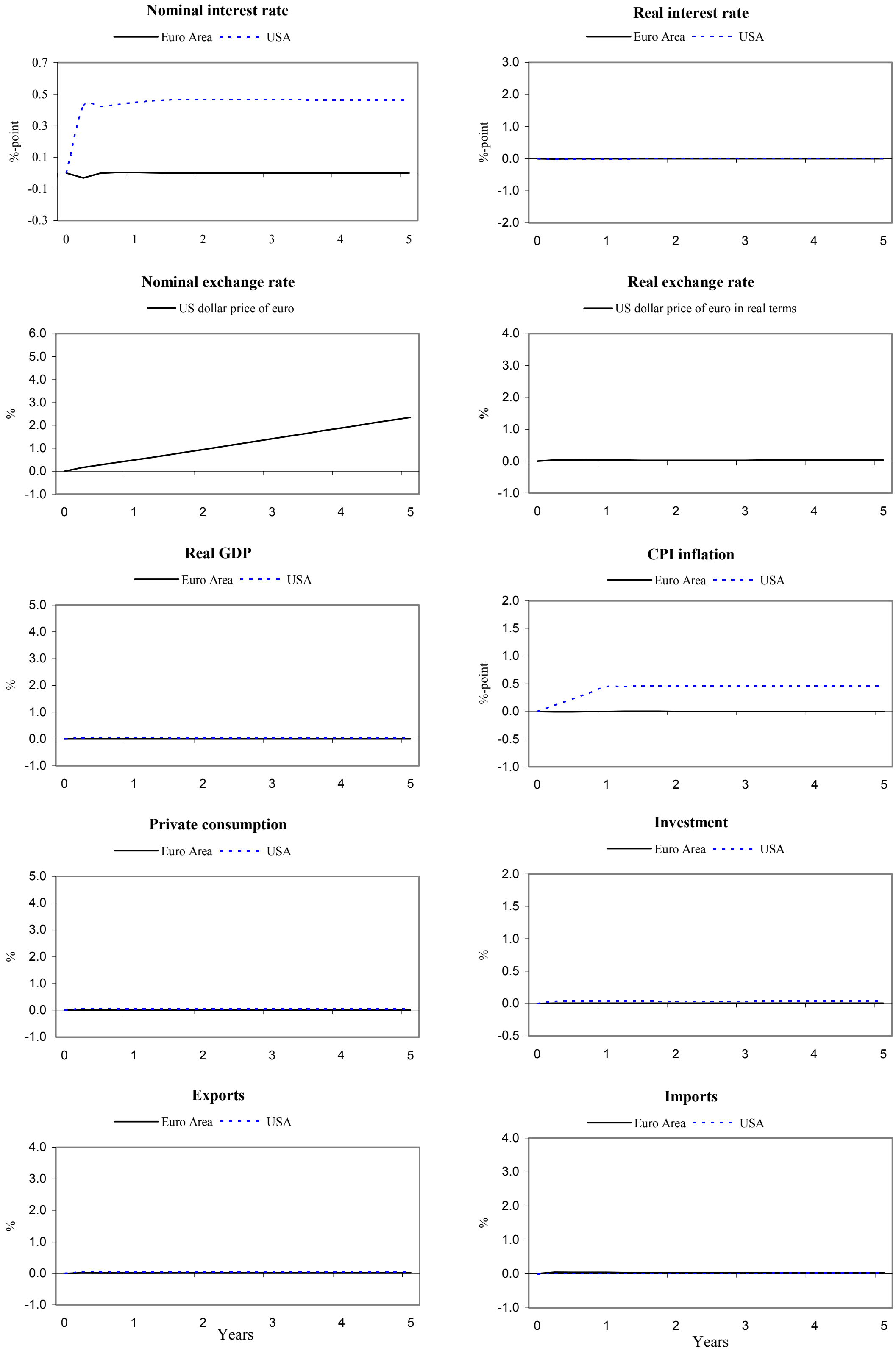
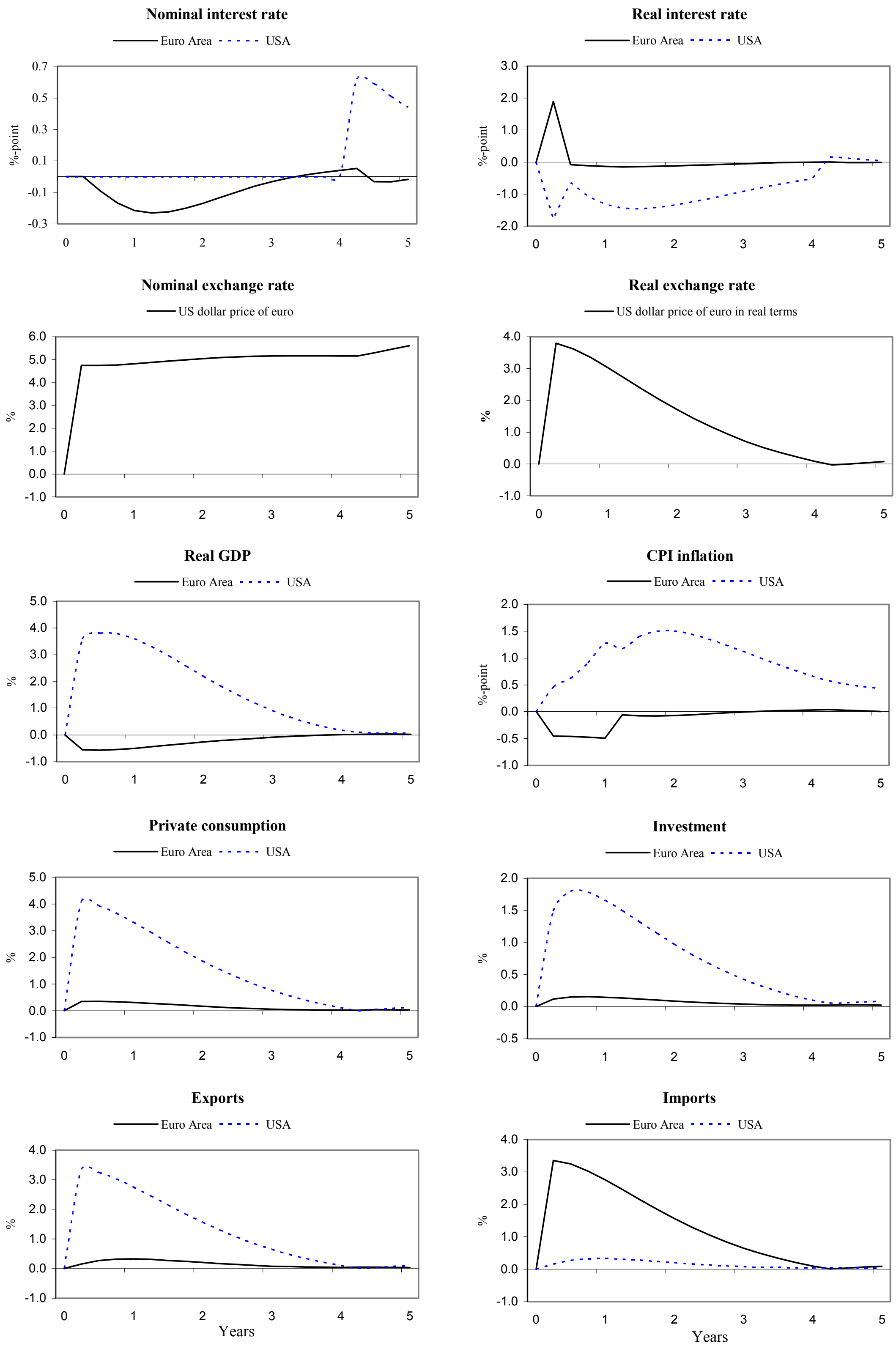


Figure 6. **Permanent 0.5%-pt increase in US inflation target with baseline 2**
(Deviation from control)



4.5 The results: supply shock

We now turn to consider the last pair of simulations, describing the effects of a temporary reduction of labour supply in the US operationalised as an increase in the NAIRU in ‘USA’. The results of these experiments are presented in Figures 7–8 and in Tables A7–A8 in the Appendix 3.

When neither of the countries is in the liquidity trap, this temporary negative supply shock in the US decreases US real output and labour productivity and increases inflation. The effects are significant in size, even if the hike in the NAIRU is assumed to be reversed in one year’s time, as done here. The real exchange rate of the US appreciates, the real interest rate of that country increases and all demand components there contract sharply. International spillovers to the ‘European’ output are positive, as predicted by our small analytical model, but not very large.

The results are very different from the above when the US economy is in a liquidity trap. Now the US interest rate does not increase even though inflation accelerates as the result of the decrease in the supply of labour. Therefore, the real interest rate is decreased in that country, and there is a strong boost in aggregate demand and output. This is reinforced by a real depreciation of the US currency.

This effect is in contrast with the predictions form the small analytical model of section 2. In that model, the temporary increase in costs does not feed into the expected real interest rate because inflation expectations are anchored by the inflation target. Therefore, there is no effect of the real activity either. In the EDGE model, however, the effect of the negative supply shock on inflation shows enough persistence to reduce the expected real interest rate for a while. In EDGE, the persistence does not come from the inflation process as such (no inflation persistence is imposed in the price or wage equations) but instead from the distributed impact of costs on prices.

The international spillovers of the negative US supply shock are also changed when the US economy is in the liquidity trap. The European currency appreciates and the European real interest rate does not change (not much at least). These results are in line with the predictions form the small analytical model of section 2. The effects on the European economic activity are now slightly negative (not positive as in the case of no liquidity trap). This is in contrast with the prediction of the small analytical model in which the effects of temporary supply shocks vanish altogether when they occur under the conditions of a liquidity trap. The reason for this is difficult to trace but it is probably linked to the positive activity effect in the US

Figure 7. **Temporary (1Y) 1%-pt increase in NAIRU in USA with baseline 1**
(Deviation from control)

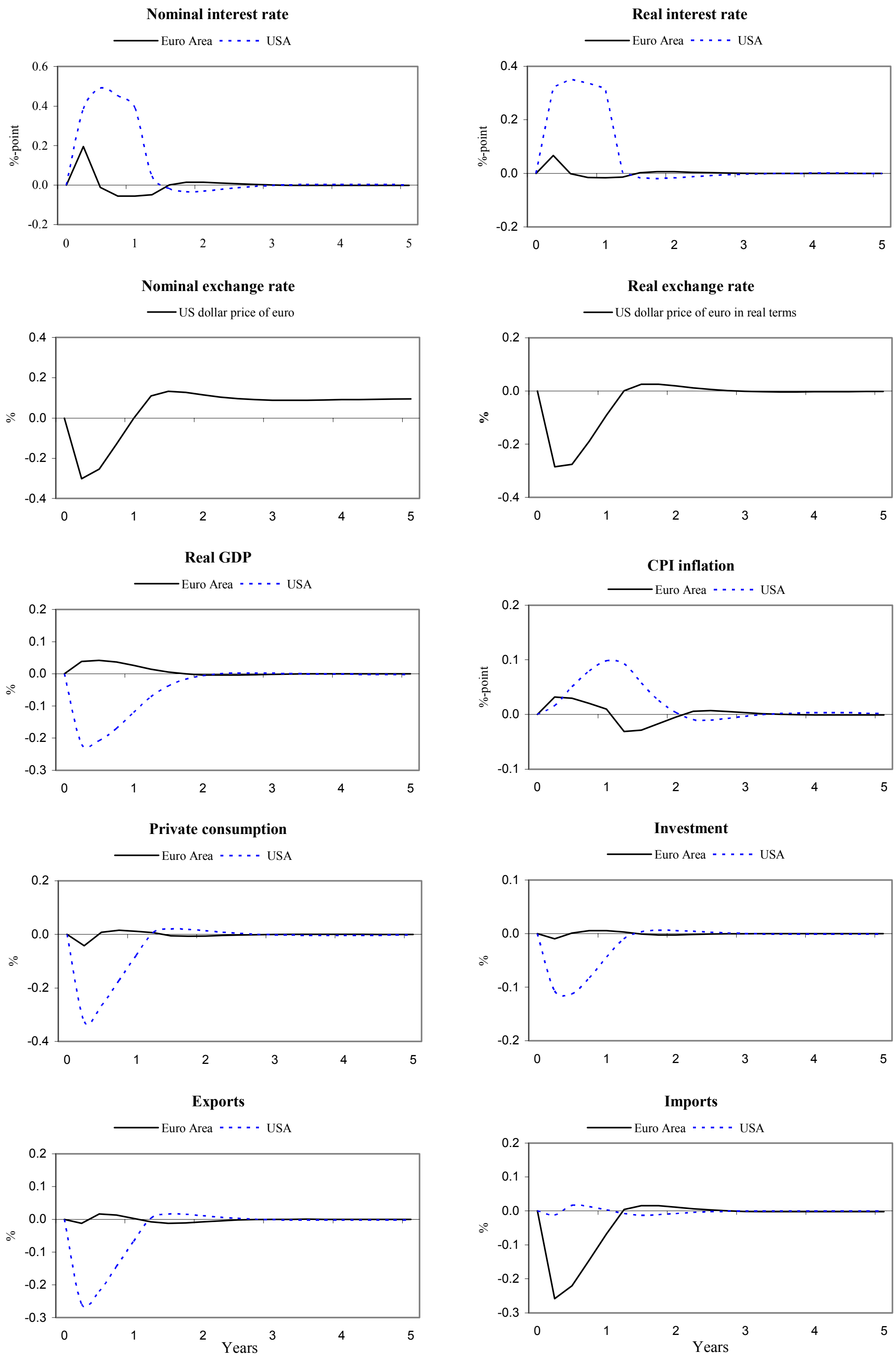
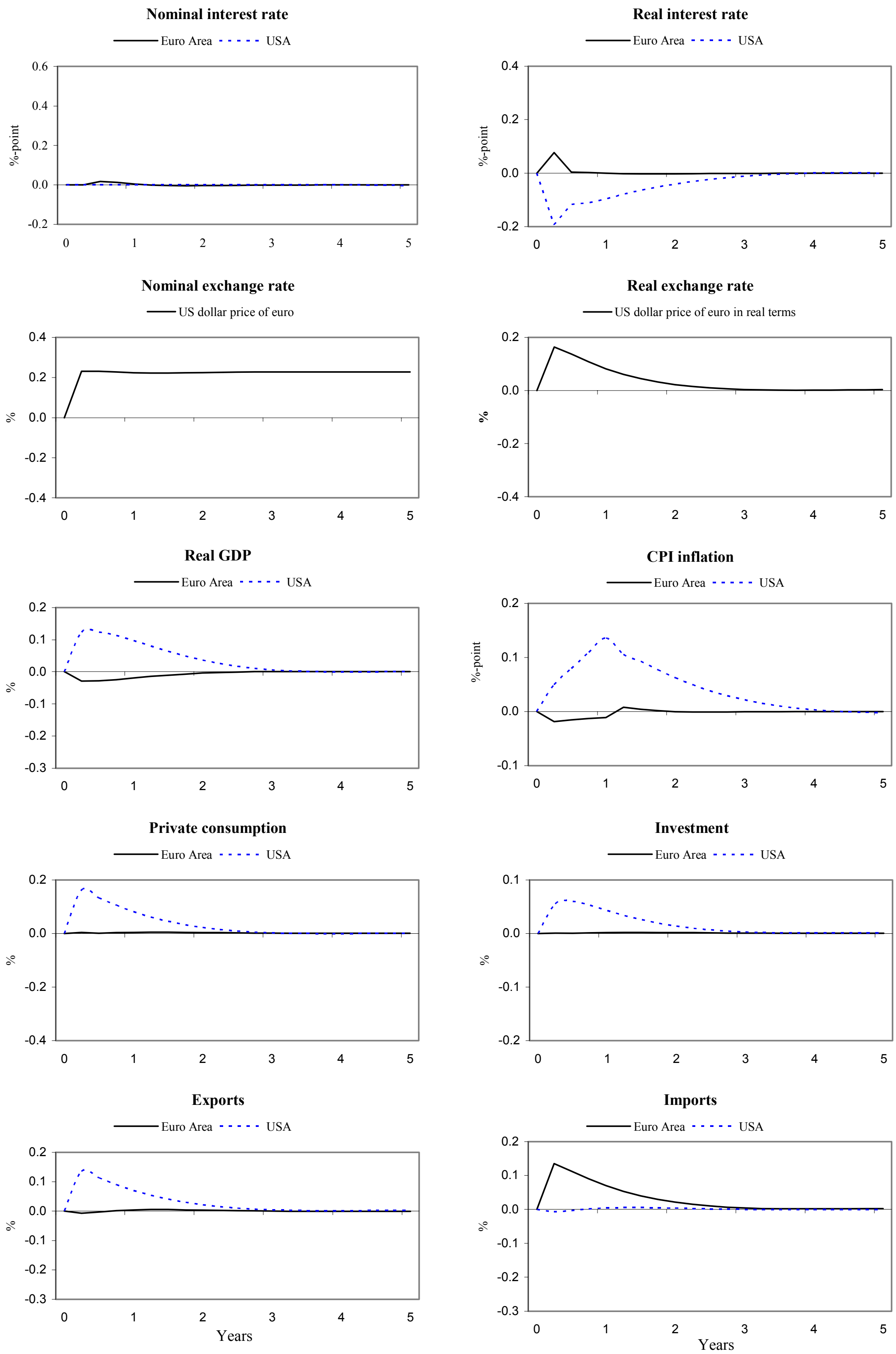


Figure 8. **Temporary (1Y) 1%-pt increase in NAIRU in USA with baseline 2**

(Deviation from control)



5 Some tentative conclusions

We have used a two-country DGE model to study international transmission of economic shocks when there may be a liquidity trap prevailing in one of the countries. The model we used is a calibrated, forward looking New Keynesian model with endogenous capital stock and price rigidities, but no additional persistence in inflation or consumer behaviour. It was developed on the basis of the EDGE model for the Euro area economy used at the Bank of Finland.

The experiments and results of this paper tell primarily something of the properties of the DGE model used in the analysis. We know that the properties of models like EDGE or the two-country model constructed on its basis are very sensitive to particular calibrations of the model, as well as on some specification choices made when constructing the model.

These caveats notwithstanding, it can be hoped that the findings here can shed some light on the effect of liquidity traps on international economic transmission. Economic intuition and the interpretation of the simulation results is further enhanced by the results we derive form a simple analytical model on the key effects of policy and shocks in states with and without liquidity traps. Certainly, more work is required on this very complex topic. This work, preferably with both simple theoretical models and more realistic but complicated numerical models can then corroborate or possibly refute the following observations from the simulation experiments reported in this study.

First, the presence of liquidity traps in either country does not appear to alter the basic feature of the DGE models, that the usual aggregate demand shocks are not transmitted internationally to a very large degree. It is obvious that this property is conditional on the openness of the economies, on the degree of flexibility of the exchange rate, and the independence of the monetary policy rule on the exchange rate or any foreign variables.

Second, being in the liquidity trap amplifies the domestic impact of fiscal policy a lot. This is, however, relative to the basic DGE model properties of rather weak fiscal policy effects when the zero bound on the nominal interest rate is not binding.

Third, the liquidity trap changes a lot the effects of supply shocks, because the reaction of monetary policy to these shocks is prevented or at least reduced. (In the normal state of the economy, anti-inflationary monetary policy tends to aggravate the effects of supply shocks.) Our theoretical exercise suggests that if there is no effect on inflation expectations, temporary supply shocks may even become irrelevant for the aggregate demand and real activity. The simulation results are less extreme in this regard, but the effects of supply shocks are nevertheless quite different under the liquidity trap conditions. For example, if inflation expectations react, cost push shocks can reduce the real interest rate and stimulate aggregate demand. In the model simulations, the reaction of the exchange rate to temporary supply shocks is reversed in the liquidity trap case.

Fourth, the liquidity trap destroys the otherwise neutrality of the inflation target for real economic developments. For a country in a liquidity trap, the commitment to higher inflation in the future is shown to be a way to stimulate the economy, but this stimulus has negative activity effects abroad.

References

Bernanke, B. (2003) **An Unwelcome Fall in Inflation?** The Federal Reserve Board, Remarks by Governor B.S. Bernanke Before the Economics Roundtable, University of California, www.federalreserve.gov/boarddocs/speeches/2003/20030723/default.htm.

Blanchard, O. (1985) **Debt, Deficits, and Finite Horizons.** Journal of Political Economy, Vol. 93, No. 2, 223–247.

Calvo, G.A. (1983) **Staggered Prices in a Utility-Maximizing Framework.** Journal of Monetary Economics, 12, No. 3.

Coenen G. – Wieland, V. (2002) **Inflation dynamics and international linkages: a model of the United States, the euro area and Japan.** September 2002, ECB Working Paper No. 181.

Cooley T.F. (ed.) (1995) **Frontiers of Business Cycle Research.** Princeton, NJ, Princeton University Press.

Kollman, R. (1999) **Explaining International Comovements of Output and Asset Returns: The Role of Money and Nominal Rigidities.** IMF WP/99/84.

Kortelainen, M. (2002) **EDGE: a model of the euro area with applications to monetary policy.** Bank of Finland Studies E:23.

Kortelainen, Mika – Mayes, D.G. (2004) **Using EDGE – A Dynamic General Equilibrium Model of the Euro Area.** In S.G. Hall, U. Heilemann, and P. Pauly eds., Macroeconometric Models and European Monetary Union, RWI Essen, Dunker & Humblot, Berlin, 41–78.

McCallum, B. (2000) **Theoretical analysis regarding a zero lower bound on nominal interest rates.** NBER working paper No. 7677.

Rotemberg, J.J. (1982) **Monopolistic Price Adjustment and Aggregate Output.** Review of Economic Studies, October, 49.

Siegel, J. (1992) **The real rate of interest from 1800–1990.** Journal of Monetary Economics, Vol. 29, No. 2, 227–252.

Svensson, L. (2003) **Escaping from the liquidity trap and deflation: The foolproof way and others.** Journal of Economic Perspectives (forthcoming).

Tarkka, J. – Kortelainen, M. (2001) **Analysing Monetary Policy Credibility with a Model of the Euro Area.** Bank of Finland Bulletin, September 2001, Vol. 75, No. 3, 18–23.

Taylor, J.B. (1993) **Discretion versus policy rules in practice.** Carnegie-Rochester Conference Series on Public Policy, 39.

Yates, T. (2002) **Monetary policy and the zero bound to interest rates: a review.** October 2002, ECB Working Paper No. 19. A two-country two-period model.

Appendix 1

A preliminary detour: The closed-economy case

$$y_t - E_t y_{t+1} = \alpha_1(\rho - r_t) + \alpha_2(g_t - E_t g_{t+1})$$

$$p_t - p_{t-1} = \beta(E_t p_{t+1} - p_t) + \lambda y_t + \varepsilon_t$$

$$r_t = i_t - (E_t p_{t+1} - p_t)$$

$$i_t = \max\left[0, \rho + \overline{\pi} + \omega(p_t - p_{t-1} - \overline{\pi}) + \theta y_t + \eta_t\right]$$

Leading one period and taking expectations

$$E_t(y_{t+1} - y_{t+2}) = \alpha_1(\rho - E_t r_{t+1})$$

$$E_t r_{t+1} = E_t i_{t+1} - E_t \pi_{t+2}$$

$$E_t i_{t+1} = \max\left[0, \rho + \overline{\pi} + \omega(E_t \pi_{t+1} - \overline{\pi}) + \theta E_t y_{t+1}\right]$$

Under the simplifying assumption that β = 1, the solution for the above is

$$E_t y_{t+1} = E_t y_{t+2} = 0$$

$$E_t r_{t+1} = \rho$$

$$E_t \pi_{t+1} = E_t \pi_{t+2} = \overline{\pi}$$

$$E_t i_{t+1} = \rho + \overline{\pi}$$

Hence the model becomes simply

$$y_t = \alpha_1(\rho - r_t) + \alpha_2 g_t$$

$$\pi_t = \overline{\pi} + \lambda y_t + \varepsilon_t$$

$$r_t = i_t - \overline{\pi}$$

$$i_t = \max\left[0, \rho + \overline{\pi} + \omega(\pi_t - \overline{\pi}) + \theta y_t + \eta_t\right]$$

Now let us consider the case in which the zero bound is binding for one period but not thereafter

$$y_t = \alpha_1(\rho + \bar{\pi}) + \alpha_2 g_t$$

$$\pi_t = \lambda\alpha_1\rho + (1 + \lambda\alpha_1)\bar{\pi} + \lambda\alpha_2 g_t + \varepsilon_t$$

Appendix 2

Derivation of the aggregate demand function for the small analytical model

Start from the following

$$Y_t = C_t + G_t + X_t - M_t$$

In log changes, this is approximately

$$\begin{aligned} y_t - y_{t-1} = {} & (\overline{C}/\overline{Y})(c_t - c_{t-1}) + (\overline{G}/\overline{Y})(g_t - g_{t-1}) + (\overline{X}/\overline{Y})(x_t - x_{t-1}) \\ & - (\overline{M}/\overline{Y})(m_t - m_{t-1}) \end{aligned}$$

Leading forward and taking expectations

$$\begin{aligned} y_t - E_t y_{t+1} = {} & (\overline{C}/\overline{Y})(c_t - E_t c_{t+1}) + (\overline{G}/\overline{Y})(g_t - E_t g_{t+1}) + (\overline{X}/\overline{Y})(x_t - E_t x_{t+1}) \\ & - (\overline{M}/\overline{Y})(m_t - E_t m_{t+1}) \end{aligned}$$

The consumer's Euler equation is

$$c_t = E_t c_{t+1} - \sigma(r_t - \rho)$$

Exports are determined by international demand and the real exchange rate

$$x_t = A + y_t^f + (\phi/2) q_t$$

so that

$$x_t - E_t x_{t+1} = y_t^f - E_t y_{t+1}^f + (\phi/2)(q_t - E_t q_{t+1}^f)$$

Analogously, for imports

$$m_t = B + y_t - (\phi/2) q_t$$

so that, in difference terms

$$m_t - E_t m_{t+1} = y_t - E_t y_{t+1} - (\phi/2)(q_t - E_t q_{t+1})$$

Now, we combine the above to yield

$$y_t - E_t y_{t+1} = (\overline{C}/\overline{Y})\sigma(\rho - r_t) + (\overline{G}/\overline{Y})(g_t - E_t g_{t+1}) + (\overline{X}/\overline{Y})(y_t^f - E_t y_{t+1}^f)$$
$$- (\overline{M}/\overline{Y})(y_t - E_t y_{t+1}) + \phi(\overline{X}/\overline{Y} + \overline{M}/\overline{Y})(q_t - E_t q_{t+1})$$

Rearranging and simplifying we get

$$y_t - E_t y_{t+1} = \alpha_1(\rho - r_t) + \alpha_2(g_t - E_t g_{t+1}) + \alpha_3(y_t^f - E_t y_{t+1}^f) + \alpha_4(q_t - E_t q_{t+1})$$

where

$$\alpha_1 = \frac{(\overline{C}/\overline{Y})\sigma}{(1 + \overline{M}/\overline{Y})} \qquad \alpha_2 = \frac{(\overline{G}/\overline{Y})}{(1 + \overline{M}/\overline{Y})}$$

$$\alpha_3 = \frac{(\overline{X}/\overline{Y})}{(1 + \overline{M}/\overline{Y})} \qquad \alpha_4 = \frac{(\overline{X}/\overline{Y} + \overline{M}/\overline{Y})\phi}{(1 + \overline{M}/\overline{Y})}$$

We choose the following values for the parameters of the model

$(\overline{C}/\overline{Y}) = 0.6$, $(\overline{M}/\overline{Y}) = 0.2$, $(\overline{X}/\overline{Y}) = 0.2$, $(\overline{G}/\overline{Y}) = 0.2$, $\sigma = 0.5$, $\phi = 1.5$,
$\omega = 0.5$, $\lambda = 0.15$, $\theta = 0.5$

Appendix 3

Simulation results in table form

Table A1. **Temporary (1Y) 0.5%-pt increase in euro area short-term interest rates with baseline 1**
(Deviation from control)

	USA								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	0.03	-0.03	0.01	0.00	0.00	0.04	0.04	0.02	0.01
GDP and components									
GDP, %	0.04	0.00	0.00	0.00	0.00	0.04	0.05	0.04	0.03
Private consumption, %	0.00	0.00	0.00	0.00	0.00	-0.05	0.01	0.02	0.02
Private fixed investment, %	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.01	0.01
Imports, %	-0.21	0.03	0.01	0.00	0.00	-0.33	-0.27	-0.17	-0.07
Exports, %	0.01	-0.01	0.00	0.00	0.00	-0.01	0.02	0.02	0.00
Labour market									
Unemployment rate, %-pts	-0.01	-0.01	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01
Financial variables									
Nominal interest rate, %-pts	0.02	-0.01	0.01	0.00	0.00	0.25	-0.02	-0.08	-0.08
Long-term interest rate, %-pts	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00
	euro area								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	-0.01	-0.01	-0.03	0.00	0.00	-0.02	-0.01	-0.01	-0.01
GDP and components									
GDP, %	-0.22	-0.03	0.01	0.00	0.00	-0.28	-0.26	-0.21	-0.14
Private consumption, %	-0.26	0.04	0.00	0.00	0.00	-0.41	-0.33	-0.21	-0.08
Private fixed investment, %	-0.10	0.01	0.00	0.00	0.00	-0.13	-0.14	-0.10	-0.05
Imports, %	0.01	-0.01	0.00	0.00	0.00	-0.01	0.02	0.02	0.00
Exports, %	-0.21	0.03	0.01	0.00	0.00	-0.33	-0.27	-0.17	-0.07
Labour market									
Unemployment rate, %-pts	0.07	0.05	0.01	0.00	0.00	0.04	0.07	0.08	0.07
Financial variables									
Nominal interest rate, %-pts	0.47	-0.07	-0.02	0.00	0.00	0.36	0.52	0.51	0.48
Long-term interest rate, %-pts	0.03	-0.01	0.00	0.00	0.00	0.05	0.04	0.02	0.01
Exchange rates									
Nominal exchange rate, %	0.30	-0.02	0.05	0.06	0.06	0.42	0.40	0.26	0.11
Real exchange rate, %	0.26	-0.04	-0.01	0.00	0.00	0.36	0.34	0.23	0.10

Table A2. **Temporary (1Y) 0.5%-pt increase in euro area short-term interest rates with baseline 2**
(Deviation from control)

	USA								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	0.03	-0.03	0.01	0.00	0.00	0.05	0.04	0.02	0.01
GDP and components									
GDP, %	0.02	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.01
Private consumption, %	-0.02	0.01	0.00	0.00	0.00	-0.04	-0.03	-0.02	0.00
Private fixed investment, %	-0.01	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	0.00
Imports, %	-0.22	0.03	0.01	0.00	0.00	-0.36	-0.28	-0.17	-0.06
Exports, %	-0.01	-0.01	0.00	0.00	0.00	0.00	-0.02	-0.02	-0.02
Labour market									
Unemployment rate, %-pts	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00
Financial variables									
Nominal interest rate, %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Long-term interest rate, %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	euro area								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	-0.01	-0.02	-0.03	0.00	0.00	-0.02	-0.01	0.00	0.00
GDP and components									
GDP, %	-0.23	-0.03	0.01	0.00	0.00	-0.30	-0.28	-0.21	-0.14
Private consumption, %	-0.27	0.04	0.00	0.00	0.00	-0.45	-0.34	-0.20	-0.07
Private fixed investment, %	-0.11	0.01	0.00	0.00	0.00	-0.14	-0.14	-0.10	-0.04
Imports, %	-0.01	-0.01	0.00	0.00	0.00	0.00	-0.02	-0.02	-0.02
Exports, %	-0.22	0.03	0.01	0.00	0.00	-0.36	-0.28	-0.17	-0.06
Labour market									
Unemployment rate, %-pts	0.07	0.05	0.02	0.00	0.00	0.05	0.07	0.08	0.08
Financial variables									
Nominal interest rate, %-pts	0.52	-0.08	-0.02	0.00	0.00	0.50	0.59	0.52	0.47
Long-term interest rate, %-pts	0.03	-0.01	0.00	0.00	0.00	0.06	0.04	0.02	0.00
Exchange rates									
Nominal exchange rate, %	0.28	-0.01	0.05	0.06	0.05	0.48	0.35	0.21	0.08
Real exchange rate, %	0.24	-0.04	-0.01	0.00	0.00	0.41	0.31	0.19	0.07

Table A3. **Temporary (1Y) increase of 1% of real GDP in public consumption in USA with baseline 1**
(Deviation from control)

	USA								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	-0.06	0.16	0.09	0.00	-0.01	-0.07	-0.09	-0.07	-0.03
GDP and components									
GDP, %	0.63	0.09	-0.03	-0.01	0.00	0.71	0.70	0.63	0.48
Private consumption, %	-0.23	-0.17	-0.04	-0.01	-0.01	-0.15	-0.23	-0.26	-0.26
Private fixed investment, %	-0.06	-0.07	-0.02	0.00	0.00	-0.02	-0.06	-0.08	-0.09
Imports, %	0.77	0.00	-0.02	-0.02	-0.02	0.77	0.78	0.77	0.75
Exports, %	0.10	-0.10	0.00	0.02	0.02	0.17	0.11	0.08	0.06
Labour market									
Unemployment rate, %-pts	-0.21	-0.16	-0.06	-0.02	-0.01	-0.13	-0.21	-0.25	-0.24
Financial variables									
Nominal interest rate, %-pts	0.02	0.32	0.07	-0.01	-0.01	-0.37	-0.06	0.17	0.33
Long-term interest rate, %-pts	0.05	0.03	0.00	0.00	0.00	0.04	0.06	0.06	0.06
	euro area								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	0.02	0.03	0.01	0.00	0.00	0.00	0.01	0.02	0.03
GDP and components									
GDP, %	0.11	0.04	0.00	0.00	0.00	0.11	0.12	0.12	0.10
Private consumption, %	-0.04	-0.01	0.01	0.01	0.01	-0.05	-0.05	-0.04	-0.04
Private fixed investment, %	-0.02	-0.01	0.00	0.00	0.00	-0.01	-0.02	-0.02	-0.02
Imports, %	0.10	-0.10	0.00	0.02	0.02	0.17	0.11	0.08	0.06
Exports, %	0.77	0.00	-0.02	-0.02	-0.02	0.77	0.78	0.77	0.75
Labour market									
Unemployment rate, %-pts	-0.04	-0.04	-0.02	-0.01	0.00	-0.02	-0.04	-0.05	-0.05
Financial variables									
Nominal interest rate, %-pts	0.06	0.04	0.01	0.00	0.00	0.02	0.06	0.07	0.07
Long-term interest rate, %-pts	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Exchange rates									
Nominal exchange rate, %	-0.23	-0.06	0.14	0.16	0.15	-0.14	-0.24	-0.27	-0.25
Real exchange rate, %	-0.15	-0.11	0.00	0.02	0.02	-0.07	-0.14	-0.18	-0.19

Table A4. **Temporary (1Y) increase of 1% of real GDP in public consumption in USA with baseline 2**
(Deviation from control)

	USA								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	-0.02	0.25	0.17	0.03	-0.02	-0.04	-0.06	-0.03	0.03
GDP and components									
GDP, %	1.28	0.52	0.08	-0.01	0.00	1.33	1.38	1.31	1.12
Private consumption, %	0.43	0.19	0.02	-0.01	0.00	0.45	0.46	0.43	0.37
Private fixed investment, %	0.23	0.11	0.02	0.00	0.01	0.21	0.26	0.25	0.21
Imports, %	0.81	0.03	0.00	-0.01	-0.02	0.81	0.83	0.82	0.80
Exports, %	0.64	0.20	0.04	0.02	0.03	0.65	0.68	0.65	0.59
Labour market									
Unemployment rate, %-pts	-0.18	0.00	-0.15	-0.13	-0.05	-0.34	-0.40	0.00	0.00
Financial variables									
Nominal interest rate, %-pts	0.00	0.00	0.00	0.00	-0.02	0.00	0.00	0.00	0.00
Long-term interest rate, %-pts	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	-0.01	-0.01	-0.01
	euro area								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	-0.06	0.03	0.02	0.00	0.00	-0.06	-0.07	-0.07	-0.06
GDP and components									
GDP, %	0.01	-0.02	-0.01	0.00	0.00	0.01	0.01	0.00	-0.01
Private consumption, %	0.00	0.00	0.02	0.02	0.01	0.00	0.01	0.00	-0.01
Private fixed investment, %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imports, %	0.64	0.20	0.04	0.02	0.03	0.65	0.68	0.65	0.59
Exports, %	0.81	0.03	0.00	-0.01	-0.02	0.81	0.83	0.82	0.80
Labour market									
Unemployment rate, %-pts	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01
Financial variables									
Nominal interest rate, %-pts	0.01	0.05	0.01	0.00	0.00	0.00	-0.03	0.01	0.04
Long-term interest rate, %-pts	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Exchange rates									
Nominal exchange rate, %	0.51	0.48	0.45	0.45	0.44	0.51	0.51	0.51	0.51
Real exchange rate, %	0.47	0.23	0.05	0.02	0.03	0.48	0.50	0.48	0.42

Table A5. **Permanent 0.5%-pt increase in US inflation target with baseline 1**
(Deviation from control)

	USA								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	0.28	0.46	0.47	0.46	0.46	0.11	0.22	0.34	0.45
GDP and components									
GDP, %	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05
Private consumption, %	0.05	0.04	0.04	0.04	0.04	0.06	0.05	0.05	0.04
Private fixed investment, %	0.04	0.04	0.04	0.04	0.04	0.03	0.04	0.04	0.04
Imports, %	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Exports, %	0.04	0.03	0.03	0.03	0.03	0.05	0.05	0.04	0.04
Labour market									
Unemployment rate, %-pts	-0.03	-0.06	-0.06	-0.07	-0.07	-0.02	-0.03	-0.04	-0.05
Financial variables									
Nominal interest rate, %-pts	0.43	0.46	0.47	0.46	0.46	0.43	0.42	0.44	0.45
Long-term interest rate, %-pts	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46

	euro area								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00	0.00
GDP and components									
GDP, %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Private consumption, %	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
Private fixed investment, %	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Imports, %	0.04	0.03	0.03	0.03	0.03	0.05	0.05	0.04	0.04
Exports, %	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Labour market									
Unemployment rate, %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Financial variables									
Nominal interest rate, %-pts	-0.01	0.00	0.00	0.00	0.00	-0.03	0.00	0.01	0.00
Long-term interest rate, %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exchange rates									
Nominal exchange rate, %	0.33	0.77	1.24	1.71	2.18	0.16	0.27	0.38	0.49
Real exchange rate, %	0.04	0.03	0.03	0.03	0.03	0.04	0.05	0.04	0.04

Table A6. **Permanent 0.5%-pt increase in US inflation target with baseline 2**
(Deviation from control)

	USA								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	0.82	1.40	1.29	0.83	0.50	0.46	0.63	0.91	1.27
GDP and components									
GDP, %	3.69	2.75	1.35	0.40	0.07	3.57	3.80	3.78	3.59
Private consumption, %	3.75	2.39	1.14	0.33	0.06	4.10	3.93	3.66	3.32
Private fixed investment, %	1.68	1.23	0.61	0.21	0.07	1.49	1.80	1.78	1.66
Imports, %	0.27	0.26	0.12	0.05	0.04	0.16	0.28	0.32	0.32
Exports, %	3.10	2.00	0.96	0.28	0.05	3.35	3.25	3.03	2.75
Labour market									
Unemployment rate, %-pts	-0.38	0.00	-0.64	-1.08	-0.47	-1.11	-0.40	0.00	0.00
Financial variables									
Nominal interest rate, %-pts	0.00	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.00
Long-term interest rate, %-pts	0.27	0.31	0.36	0.41	0.44	0.26	0.27	0.28	0.29

	euro area								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	-0.47	-0.07	-0.03	0.02	0.02	-0.46	-0.46	-0.47	-0.49
GDP and components									
GDP, %	-0.55	-0.35	-0.15	-0.02	0.02	-0.56	-0.58	-0.55	-0.51
Private consumption, %	0.34	0.23	0.10	0.03	0.03	0.34	0.35	0.34	0.32
Private fixed investment, %	0.14	0.11	0.05	0.02	0.02	0.12	0.15	0.15	0.15
Imports, %	3.10	2.00	0.96	0.28	0.05	3.35	3.25	3.03	2.75
Exports, %	0.27	0.26	0.12	0.05	0.04	0.16	0.28	0.32	0.32
Labour market									
Unemployment rate, %-pts	0.24	0.33	0.23	0.11	0.04	0.13	0.22	0.29	0.32
Financial variables									
Nominal interest rate, %-pts	-0.12	-0.21	-0.08	0.02	-0.01	0.00	-0.09	-0.17	-0.21
Long-term interest rate, %-pts	-0.04	-0.02	0.00	0.00	0.00	-0.04	-0.05	-0.04	-0.04
Exchange rates									
Nominal exchange rate, %	4.77	4.96	5.13	5.17	5.38	4.75	4.75	4.77	4.82
Real exchange rate, %	3.45	2.19	1.06	0.30	0.02	3.79	3.62	3.35	3.03

Table A7. **Temporary (1Y) 1%-pt increase in NAIRU in USA with baseline 1**
(Deviation from control)

	USA								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	0.06	0.04	-0.01	0.00	0.00	0.02	0.05	0.08	0.10
GDP and components									
GDP, %	-0.18	-0.03	0.00	0.00	0.00	-0.22	-0.21	-0.17	-0.12
Private consumption, %	-0.21	0.01	0.00	0.00	0.00	-0.33	-0.27	-0.17	-0.08
Private fixed investment, %	-0.09	0.00	0.00	0.00	0.00	-0.11	-0.11	-0.08	-0.04
Imports, %	0.00	-0.01	0.00	0.00	0.00	-0.01	0.02	0.01	0.00
Exports, %	-0.17	0.01	0.00	0.00	0.00	-0.26	-0.22	-0.14	-0.07
Labour market									
Unemployment rate, %-pts	0.06	0.05	0.02	0.01	0.00	0.04	0.06	0.07	0.07
Financial variables									
Nominal interest rate, %-pts	0.43	-0.01	-0.01	0.00	0.00	0.39	0.49	0.45	0.39
Long-term interest rate, %-pts	0.03	0.00	0.00	0.00	0.00	0.05	0.04	0.03	0.01

	euro area								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	0.02	-0.02	0.01	0.00	0.00	0.03	0.03	0.02	0.01
GDP and components									
GDP, %	0.04	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.03
Private consumption, %	0.00	0.00	0.00	0.00	0.00	-0.04	0.01	0.02	0.01
Private fixed investment, %	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.01	0.01
Imports, %	-0.17	0.01	0.00	0.00	0.00	-0.26	-0.22	-0.14	-0.07
Exports, %	0.00	-0.01	0.00	0.00	0.00	-0.01	0.02	0.01	0.00
Labour market									
Unemployment rate, %-pts	-0.01	-0.01	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01
Financial variables									
Nominal interest rate, %-pts	0.02	0.00	0.01	0.00	0.00	0.20	-0.01	-0.06	-0.06
Long-term interest rate, %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exchange rates									
Nominal exchange rate, %	-0.17	0.12	0.10	0.09	0.09	-0.30	-0.25	-0.13	0.00
Real exchange rate, %	-0.21	0.02	0.00	0.00	0.00	-0.29	-0.28	-0.19	-0.09

Table A8. **Temporary (1Y) 1%-pt increase in NAIRU in USA with baseline 2**
(Deviation from control)

	USA								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	0.09	0.08	0.03	0.01	0.00	0.05	0.08	0.11	0.14
GDP and components									
GDP, %	0.11	0.06	0.01	0.00	0.00	0.12	0.12	0.11	0.10
Private consumption, %	0.12	0.04	0.01	0.00	0.00	0.16	0.13	0.11	0.08
Private fixed investment, %	0.05	0.02	0.01	0.00	0.00	0.06	0.06	0.05	0.04
Imports, %	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00
Exports, %	0.10	0.04	0.01	0.00	0.00	0.14	0.11	0.09	0.07
Labour market									
Unemployment rate, %-pts	-0.02	0.00	-0.02	-0.01	-0.01	-0.03	-0.05	0.00	0.00
Financial variables									
Nominal interest rate, %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Long-term interest rate, %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	euro area								
Year/Quarter	Y1	Y2	Y3	Y4	Y5	Y1Q1	Y1Q2	Y1Q3	Y1Q4
Inflation									
Inflation, consumpt.defl., %-pts	-0.01	0.00	0.00	0.00	0.00	-0.02	-0.02	-0.01	-0.01
GDP and components									
GDP, %	-0.03	-0.01	0.00	0.00	0.00	-0.03	-0.03	-0.02	-0.02
Private consumption, %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Private fixed investment, %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imports, %	0.10	0.04	0.01	0.00	0.00	0.14	0.11	0.09	0.07
Exports, %	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00
Labour market									
Unemployment rate, %-pts	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Financial variables									
Nominal interest rate, %-pts	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00
Long-term interest rate, %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exchange rates									
Nominal exchange rate, %	0.23	0.22	0.23	0.23	0.23	0.23	0.23	0.23	0.22
Real exchange rate, %	0.12	0.04	0.01	0.00	0.00	0.16	0.14	0.11	0.08

Appendix 4

The list of equations of the two-county DGE model

Dynamic model

Population growth rate, euro area

$$1+n=(1-p)(1+\beta)$$

Population, euro area

$$N=(1+n)N_{-1}$$

Labour force, euro area

$$F=(1+n)F_{-1}$$

Total factor productivity, euro area

$$TFP/TFP_{-1}=(1+\varepsilon)$$

Real growth rate, euro area

$$g=\frac{\varepsilon}{1-\alpha}+n$$

Labour demand, euro area

$$L=\text{lnn.lead}(L_{+1})+\text{lnn.lag}(L_{-1})+\text{lnn.funda}\left(\frac{Y}{TFP(K)^{\alpha}}\right)^{\frac{1}{1-\alpha}}$$

Fixed investment, euro area

$$\log\left(\frac{K}{K_{-1}}\right)=\text{ksr.lead2}\left(\log\left(\frac{K_{+2}}{K_{+1}}\right)\right)+\text{ksr.lead}\left(\log\left(\frac{K_{+1}}{K}\right)\right)+\text{ksr.lag}\left(\log\left(\frac{K_{-1}}{K_{-2}}\right)\right)$$
$$+\text{ksr.funda}\left(\alpha\frac{Y}{K}\frac{PF}{PC}-\frac{r+\delta+\chi}{1+r+\chi}\frac{PI}{PC}\right)$$

Real wages, euro area

$$\frac{WR}{L} = \text{win.lead}\left(\frac{WR_{+1}(1+INFD_{+1})}{L_{+1}}\right) + \text{win.lag}\left(\frac{WR_{-1}}{L_{-1}(1+INFD_{-1})}\right)$$
$$+ \text{win.funda}\left(\frac{(1-\alpha)Y}{L}(1-\text{win.ugap}(U-\overline{U}))\right)$$

Nominal wages, euro area

$$\frac{W}{PF} = WR$$

GDP deflator, euro area

$$1 + INFD = \frac{P}{P_{-1}}$$

Inflation, GDP deflator, euro area

$$INFD = \text{yed.lag} - 1 + \text{yed.lead}(1+INFD_{+1})(1+INFD)$$
$$+ \text{yed.funda}\left(\frac{WR}{(1-\alpha)Y}\right)(1+INFD)$$

Private consumption, euro area

$$C = \text{pcr.lead}\left(\frac{C_{+1}}{1+r+\chi}\right) + \text{pcr.funda}\left((1+WFG)(1+\pi)\frac{A_{-1}}{PC} + \frac{YDN}{PC}\right)$$

Windfall gain, euro area

$$WFG = \frac{A}{A_{-1}(1+\pi)} - 1 - \frac{YDN - C(PC)}{A_{-1}(1+\pi)}$$

Nominal value of private assets, euro area

$$\frac{A}{PF} = ASTR$$

Nominal value of net foreign assets, euro area

$$\frac{\text{NFA}}{\text{PF}} = \text{NFAR}$$

Nominal value of public debt, euro area

$$\frac{\text{GDN}}{\text{PF}} = \text{GDNR}$$

Real value of private wealth, euro area

$$\begin{aligned}\text{ASTR} = {} & \frac{(\text{ASTR}_{+1} - \text{NFAR}_{+1} - \text{GDNR}_{+1})(1 + \text{INFD}_{+1})}{(1 + \text{R}/400 + \chi)} \\ & + \left(\text{Y} - \frac{\text{W}}{\text{PF}} - \delta \frac{\text{PI}}{\text{PF}} \text{K}_{-1} \right) + \frac{\text{NFA} + \text{GDN}}{\text{PF}}\end{aligned}$$

Inventories, euro area

$$\begin{aligned}\text{KI} = {} & \text{lsr.prod}(\text{TFP}(\text{K})^{\alpha}(\text{L})^{1-\alpha}) + \text{lsr.dprod}(\text{Y} - \text{TFP}(\text{K})^{\alpha}(\text{L})^{1-\alpha}) \\ & + \text{lsr.dprodlead}(\text{Y}_{+1} - \text{TFP}_{+1}(\text{K}_{+1})^{\alpha}(\text{L}_{+1})^{1-\alpha})\end{aligned}$$

Exports, euro area

$$\text{X} = (\text{M}^{*})/1.33762$$

Imports, euro area

$$\begin{aligned}\text{M} = {} & (1 - \text{nuc})\left(\frac{\text{PM}}{\text{PC}}\right)^{-\text{muc}} \text{C} + (1 - \text{nucg})\left(\frac{\text{PM}}{\text{PCG}}\right)^{-\text{mucg}} \text{CG} \\ & + (1 - \text{nui})\left(\frac{\text{PM}}{\text{PI}}\right)^{-\text{mui}} \text{ITOT} + (1 - \text{nux})\left(\frac{\text{PM}}{\text{PX}}\right)^{-\text{mux}} \text{X}\end{aligned}$$

Export prices, euro area

$$\text{PX} = ((\text{nux})(\text{P})^{1-\text{mux}} + (1 - \text{nux})(\text{PM})^{1-\text{mux}})^{\frac{1}{1-\text{mux}}}$$

Import prices, euro area

$$PM = 1.33508 \frac{PX^*}{e}$$

Long-term nominal interest rate, euro area

$$LTN = ltn.stn(R) + (1 - ltn.stn)(LTN_{+1}) + ltn.rp$$

Private nominal disposable income, euro area

$$YDN = YFN - TAX + INN + TRN + NFN - GOY - \delta(PI)K_{-1}$$

GDP identity, euro area

$$Y = C + CG + ITOT + X - M + KI - KI_{-1}$$

Capital accumulation, euro area

$$I = K - (1 - \delta)K_{-1}$$

Total investment, euro area

$$ITOT = I + \frac{GIN}{PI}$$

Indirect taxes, euro area

$$TIN = \tau^{indirect}(YEN)$$

Direct taxes, euro area

$$TAX = \tau^{direct}(YEN)$$

Public disposable income, euro area

$$GYN = TAX + TIN + GOY - TRN - INN$$

Public interest outlays, euro area

$$INN = R/400(GDN_{-1})$$

Real value of net foreign assets, euro area

$$\text{NFAR} = -\left(\frac{\text{NFAR}^*}{\text{Q}}\right)\left(\frac{\text{PF}^*}{\text{PF}}\right)\left(\frac{\text{PC}}{\text{PC}^*}\right)$$

Net factor income from abroad, euro area

$$\text{NFN} = -\frac{\text{NFN}^*}{\text{e}}$$

Nominal current account, euro area

$$\text{CA} = \text{PX(X)} - \text{PM(M)} + \text{NFN}$$

Real value of public debt, euro area

$$\text{GDNR} = \frac{\text{GDNR}_{-1}}{(1 + \text{INFD})} - \frac{\text{GLN}}{\text{PF}}$$

Public net lending, euro area

$$\text{GLN} = -\text{GCN} - \text{GIN} + \text{GYN}$$

Nominal GDP at factor cost, euro area

$$\text{YFN} = \text{PF(Y)}$$

Nominal GDP, euro area

$$\text{YEN} = \text{P(Y)}$$

GDP deflator at the factor price, euro area

$$\text{PF} = \text{P}(1 - \tau^{\text{indirect}})$$

Inflation, consumer prices, euro area

$$1 + \pi = \frac{\text{PC}}{\text{PC}_{-1}}$$

Real interest rate, euro area

$$1 + r = \frac{1 + R/400}{1 + \pi_{+1}}$$

Private consumption price deflator, euro area

$$PC = ((nuc)(P)^{1-muc} + (1 - nuc)(PM)^{1-muc})^{\frac{1}{1-muc}}$$

Investment price deflator, euro area

$$PI = ((nui)(P)^{1-mui} + (1 - nui)(PM)^{1-mui})^{\frac{1}{1-mui}}$$

Public consumption price deflator, euro area

$$PCG = ((nucg)(P)^{1-mucg} + (1 - nucg)(PM)^{1-mucg})^{\frac{1}{1-mucg}}$$

Nominal value of public consumption, euro area

$$GCN = PCG(CG)$$

Real value of public consumption, euro area

$$CG = b_1(Y)$$

Nominal value of public investment, euro area

$$GIN = b_2(PI)Y$$

Unemployment rate, euro area

$$U = \frac{F - L}{F}$$

Nominal value of public other income, euro area

$$GOY = B_4(YEN)$$

Nominal value of public transfers, euro area

$$\mathrm{TRN} = (\mathrm{trnyen.urx}(\mathrm{U}) + \mathrm{trnyen.cst})\mathrm{YEN}$$

Direct tax rate, euro area

$$\tau^{\mathrm{direct}} = \tau^{\mathrm{direct}}_{-1} - \tau_1\left(\frac{\mathrm{GLN}}{\mathrm{YEN}} + 4\mathrm{b}_3\frac{(1+\mathrm{g})(1+\bar{\pi})-1}{(1+\mathrm{g})(1+\bar{\pi})}\right) + \tau_2\left(\frac{\mathrm{GDN}}{\mathrm{YEN}} - 4\mathrm{b}_3\right)$$

Short-term nominal interest rate, euro area

$$\begin{aligned}\mathrm{R}/400 = {} & (1-\lambda_1)\left[\mathrm{R}_{-1}/400\right] \\ & + \lambda_1\left[\frac{\mathrm{PC}}{\mathrm{PC}_{-1}}(1+\bar{\mathrm{r}}) - 1 + \lambda_2\left\{\frac{\mathrm{PC}}{\mathrm{PC}_{-1}} - 1 - \bar{\pi}\right\} - \lambda_3(1-\alpha)\left\{\mathrm{U} - \bar{\mathrm{U}}\right\}\right]\end{aligned}$$

Equilibrium real interest rate

$$\bar{\mathrm{r}} = \bar{\mathrm{r}}_{+1}$$

Population growth rate, USA

$$1 + \mathrm{n}^* = (1 - \mathrm{p}^*)(1 + \beta^*)$$

Population, USA

$$\mathrm{N}^* = (1 + \mathrm{n}^*)\mathrm{N}^*_{-1}$$

Labour force, USA

$$\mathrm{F}^* = (1 + \mathrm{n}^*)\mathrm{F}^*_{-1}$$

Total factor productivity, USA

$$\mathrm{TFP}^*/\mathrm{TFP}^*_{-1} = (1 + \varepsilon^*)$$

Real growth rate, USA

$$\mathrm{g}^* = \frac{\varepsilon^*}{1 - \alpha^*} + \mathrm{n}^*$$

Labour demand, USA

$$L^* = \text{lnn.lead}^*(L^*_{+1}) + \text{lnn.lag}^*(L^*_{-1}) + \text{lnn.funda}^*\left(\frac{Y^*}{TFP^*(K^*)^{\alpha^*}}\right)^{\frac{1}{1-\alpha^*}}$$

Fixed investment, USA

$$\log\left(\frac{K^*}{K^*_{-1}}\right) = \text{ksr.lead2}^*\left(\log\left(\frac{K^*_{+2}}{K^*_{+1}}\right)\right) + \text{ksr.lead}^*\left(\log\left(\frac{K^*_{+1}}{K^*}\right)\right) + \text{ksr.lag}^*\left(\log\left(\frac{K^*_{-1}}{K^*_{-2}}\right)\right)$$
$$+ \text{ksr.funda}^*\left(\alpha^*\frac{Y^*}{K^*}\frac{PF^*}{PC^*} - \frac{r^*+\delta^*+\chi^*}{1+r^*+\chi^*}\frac{PI^*}{PC^*}\right)$$

Real wages, USA

$$\frac{WR^*}{L^*} = \text{win.lead}^*\left(\frac{WR^*_{+1}(1+INFD^*_{+1})}{L^*_{+1}}\right) + \text{win.lag}^*\left(\frac{WR^*_{-1}}{L^*_{-1}(1+INFD^*_{-1})}\right)$$
$$+ \text{win.funda}^*\left(\frac{(1-\alpha^*)Y^*}{L^*}\left(1-\text{win.ugap}^*(U^*-\overline{U}^*)\right)\right)$$

Nominal wages, USA

$$\frac{W^*}{PF^*} = WR^*$$

GDP deflator, USA

$$1 + INFD^* = \frac{P^*}{P^*_{-1}}$$

Inflation, GDP deflator, USA

$$INFD^* = \text{yed.lag}^* - 1 + \text{yed.lead}^*(1+INFD^*_{+1})(1+INFD^*)$$
$$+ \text{yed.funda}^*\left(\frac{WR^*}{(1-\alpha^*)Y^*}\right)(1+INFD^*)$$

Private consumption, USA

$$C^* = pcr.lead^*\left(\frac{C^*_{+1}}{1+r^*+\chi^*}\right) + pcr.funda^*\left((1+WFG^*)(1+\pi^*)\frac{A^*_{-1}}{PC^*} + \frac{YDN^*}{PC^*}\right)$$

Windfall gain, USA

$$WFG^* = \frac{A^*}{A^*_{-1}(1+\pi^*)} - 1 - \frac{YDN^* - C^*(PC^*)}{A^*_{-1}(1+\pi^*)}$$

Nominal value of private assets, USA

$$\frac{A^*}{PF^*} = ASTR^*$$

Nominal value of net foreign assets, USA

$$\frac{NFA^*}{PF^*} = NFAR^*$$

Nominal value of public debt, USA

$$\frac{GDN^*}{PF^*} = GDNR^*$$

Real value of private wealth, USA

$$\begin{aligned} ASTR^* = {} & \frac{(ASTR^*_{+1} - NFAR^*_{+1} - GDNR^*_{+1})(1 + INFD^*_{+1})}{(1 + R^*/400 + \chi^*)} \\ & + \left(Y^* - \frac{W^*}{PF^*} - \delta^* \frac{PI^*}{PF^*} K^*_{-1}\right) + \frac{NFA^* + GDN^*}{PF^*} \end{aligned}$$

Inventories, USA

$$\begin{aligned} KI^* = {} & lsr.prod^*(TFP^*(K^*)^{\alpha^*}(L^*)^{1-\alpha^*}) + lsr.dprod^*(Y^* - TFP^*(K^*)^{\alpha^*}(L^*)^{1-\alpha^*}) \\ & + lsr.dprodlead^*\left(Y^*_{+1} - TFP^*_{+1}(K^*_{+1})^{\alpha^*}(L^*_{+1})^{1-\alpha^*}\right) \end{aligned}$$

Exports, USA

$$X^{*} = 1.33508(M)$$

Imports, USA

$$M^{*} = (1-nuc^{*})\left(\frac{PM^{*}}{PC^{*}}\right)^{-muc^{*}} C^{*} + (1-nucg^{*})\left(\frac{PM^{*}}{PCG^{*}}\right)^{-mucg^{*}} CG^{*}$$
$$+ (1-nui^{*})\left(\frac{PM^{*}}{PI^{*}}\right)^{-mui^{*}} ITOT^{*} + (1-nux^{*})\left(\frac{PM^{*}}{PX^{*}}\right)^{-mux^{*}} X^{*}$$

Export prices, USA

$$PX^{*} = ((nux^{*})(P^{*})^{1-mux^{*}} + (1-nux^{*})(PM^{*})^{1-mux^{*}})^{\frac{1}{1-mux^{*}}}$$

Import prices, USA

$$PM^{*} = e\frac{PX}{1.33762}$$

Long-term nominal interest rate, USA

$$LTN^{*} = ltn.stn^{*}(R^{*}) + (1-ltn.stn^{*})(LTN^{*}_{+1}) + ltn.rp^{*}$$

Private nominal disposable income, USA

$$YDN^{*} = YFN^{*} - TAX^{*} + INN^{*} + TRN^{*} + NFN^{*} - GOY^{*} - \delta^{*}(PI^{*})K^{*}_{-1}$$

GDP identity, USA

$$Y^{*} = C^{*} + CG^{*} + ITOT^{*} + X^{*} - M^{*} + KI^{*} - KI^{*}_{-1}$$

Capital accumulation, USA

$$I^{*} = K^{*} - (1-\delta^{*})K^{*}_{-1}$$

Total investment, USA

$$ITOT^{*} = I^{*} + \frac{GIN^{*}}{PI^{*}}$$

Indirect taxes, USA

$$TIN^{*} = \tau^{indirect*}(YEN^{*})$$

Direct taxes, USA

$$TAX^{*} = \tau^{direct*}(YEN^{*})$$

Public disposable income, USA

$$GYN^{*} = TAX^{*} + TIN^{*} + GOY^{*} - TRN^{*} - INN^{*}$$

Public interest outlays, USA

$$INN^{*} = R^{*}/400(GDN^{*}_{-1})$$

Real value of net foreign assets, USA

$$NFAR^{*} = \frac{NFAR^{*}_{-1}}{1 + INFD^{*}} + \frac{CA^{*}}{PF^{*}}$$

Net factor income from abroad, USA

$$NFN^{*} = R^{*}/400(NFA^{*}_{-1})$$

Nominal current account, USA

$$CA^{*} = PX^{*}(X^{*}) - PM^{*}(M^{*}) + NFN^{*}$$

Real value of public debt, USA

$$GDNR^{*} = \frac{GDNR^{*}_{-1}}{(1 + INFD^{*})} - \frac{GLN^{*}}{PF^{*}}$$

Public net lending, USA

$$GLN^{*} = - GCN^{*} - GIN^{*} + GYN^{*}$$

Nominal GDP at factor cost, USA

$$YFN^{*} = PF^{*}(Y^{*})$$

Nominal GDP, USA

$$YEN^{*} = P^{*}(Y^{*})$$

GDP deflator at the factor price, USA

$$PF^{*} = P^{*}(1 - \tau^{indirect*})$$

Inflation, consumer prices, USA

$$1 + \pi^{*} = \frac{PC^{*}}{PC^{*}_{-1}}$$

Real interest rate, USA

$$1 + r^{*} = \frac{1 + R^{*}/400}{1 + \pi^{*}_{+1}}$$

Nominal exchange rate

$$e = Q\frac{PC^{*}}{PC}$$

Real exchange rate

$$Q = Q_{+1}\frac{1 + r}{1 + r^{*}}$$

Private consumption price deflator, USA

$$PC^{*} = ((nuc^{*})(P^{*})^{1\text{-}muc^{*}} + (1 - nuc^{*})(PM^{*})^{1 - muc^{*}})^{\frac{1}{1 - muc^{*}}}$$

Investment price deflator, USA

$$PI^* = ((nui^*)(P^*)^{1-mui^*} + (1-nui^*)(PM^*)^{1-mui^*})^{\frac{1}{1-mui^*}}$$

Public consumption price deflator, USA

$$PCG^* = ((nucg^*)(P^*)^{1-mucg^*} + (1-nucg^*)(PM^*)^{1-mucg^*})^{\frac{1}{1-mucg^*}}$$

Nominal value of public consumption, USA

$$GCN^* = PCG^*(CG^*)$$

Real value of public consumption, USA

$$CG^* = b_1^*(Y^*)$$

Nominal value of public investment, USA

$$GIN^* = b_2^*(PI^*)Y^*$$

Unemployment rate, USA

$$U^* = \frac{F^* - L^*}{F^*}$$

Nominal value of public other income, USA

$$GOY^* = B_4^*(YEN^*)$$

Nominal value of public transfers, USA

$$TRN^* = (trnyen.urx^*(U^*) + trnyen.cst^*)YEN^*$$

Direct tax rate, USA

$$\tau^{direct*} = \tau_{-1}^{direct*} - \tau_1^*\left(\frac{GLN^*}{YEN^*} + 4b_3\frac{(1+g^*)(1+\bar{\pi}^*)-1}{(1+g^*)(1+\bar{\pi}^*)}\right) + \tau_2^*\left(\frac{GDN^*}{YEN^*} - 4b_3^*\right)$$

Short-term nominal interest rate, USA

$$R^*/400 = (1-\lambda_1^*)\left[R_{-1}^*/400\right] + \lambda_1^*\left[\frac{PC^*}{PC_{-1}^*}(1+\bar{r}) - 1 + \lambda_2^*\left\{\frac{PC^*}{PC_{-1}^*} - 1 - \bar{\pi}^*\right\} - \lambda_3^*(1-\alpha^*)\left\{U^* - \overline{U}^*\right\}\right]$$

Steady-state model

Population growth rate, euro area

$$1+n = (1-p)(1+\beta)$$

Population, euro area

$$N = (1+n)N_{-1}$$

Labour force, euro area

$$F = (1+n)F_{-1}$$

Total factor productivity, euro area

$$TFP/TFP_{-1} = (1+\varepsilon)$$

Real growth rate, euro area

$$g = \frac{\varepsilon}{1-\alpha} + n$$

Employment, euro area

$$L = F(1-\overline{U})$$

Capital stock, euro area

$$\alpha\frac{Y}{K}\frac{PF}{PC} = \frac{r+\delta+\chi}{1+r+\chi}\frac{PI}{PC}$$

Real wages, euro area

$$\frac{W}{PF} = WR$$

Nominal wages, euro area

$$\frac{W}{PF} = \frac{win.funda}{1 - win.lead(1+g)(1+\overline{\pi}) - win.lag/((1+g)(1+\overline{\pi}))}(1-\alpha)Y$$

Inflation, GDP deflator, euro area

$$INFD = \overline{\pi}$$

Inflation, consumer price deflator, euro area

$$\frac{PC}{PC_{-1}} = 1 + \overline{\pi}$$

Private consumption, euro area

$$C = pcr.lead\left(\frac{C(1+g)}{1+r+\chi}\right) + pcr.funda\left(\frac{(1+WFG)(1+\pi)}{(1+g)(1+\pi)}\frac{A}{PC} + \frac{YDN}{PC}\right)$$

Windfall gain, euro area

$$WFG = \frac{A}{A/(1+g)} - 1 - \frac{YDN - PC(C)}{A/(1+g)}$$

Real value of private assets, euro area

$$\frac{A}{PF} = ASTR$$

Real value of net foreign assets, euro area

$$\frac{NFA}{PF} = NFAR$$

Real value of public debt, euro area

$$\frac{GDN}{PF} = GDNR$$

Nominal value of private wealth, euro area

$$AST = \frac{(1 + R/400 + \chi)}{(R/400 + \chi - ((1+g)(1+\overline{\pi}) - 1))}(\alpha(PF)Y - \delta(PI)K/(1+g)) + NFA + GDN$$

Inventories, euro area

$$KI = lsr.prod(Y)$$

Exports, euro area

$$X = (M^{*})/1.33762$$

Imports, euro area

$$M = (1 - nuc)\left(\frac{PM}{PC}\right)^{-muc} C + (1 - nucg)\left(\frac{PM}{PCG}\right)^{-mucg} CG$$
$$+ (1 - nui)\left(\frac{PM}{PI}\right)^{-mui} ITOT + (1 - nux)\left(\frac{PM}{PX}\right)^{-mux} X$$

Export prices, euro area

$$PX = ((nux)(P)^{1-mux} + (1 - nux)(PM)^{1-mux})^{\frac{1}{1-mux}}$$

Import prices, euro area

$$PM = 1.33508\frac{PX^{*}}{e}$$

Long-term nominal interest rate, euro area

$$LTN = R$$

Private nominal disposable income, euro area

$$\mathrm{YDN} = \mathrm{YFN} - \mathrm{TAX} + \mathrm{INN} + \mathrm{TRN} + \mathrm{NFN} - \mathrm{GOY} - \delta(\mathrm{PI})\mathrm{K}/(1+\mathrm{g})$$

GDP identity, euro area

$$\mathrm{Y} = \mathrm{C} + \mathrm{CG} + \mathrm{ITOT} + \mathrm{X} - \mathrm{M} + \mathrm{KI} - \mathrm{KI}/(1+\mathrm{g})$$

Capital accumulation, euro area

$$\mathrm{I} = \mathrm{K} - (1-\delta)\mathrm{K}/(1+\mathrm{g})$$

Total investment, euro area

$$\mathrm{ITOT} = \mathrm{I} + \frac{\mathrm{GIN}}{\mathrm{PI}}$$

Indirect taxes, euro area

$$\mathrm{TIN} = \tau^{\mathrm{indirect}}(\mathrm{YEN})$$

Direct taxes, euro area

$$\mathrm{TAX} = \tau^{\mathrm{direct}}(\mathrm{YEN})$$

Public disposable income, euro area

$$\mathrm{GYN} = \mathrm{TAX} + \mathrm{TIN} + \mathrm{GOY} - \mathrm{TRN} - \mathrm{INN}$$

Public interest outlays, euro area

$$\mathrm{INN} = \mathrm{R}/400(\mathrm{GDN}/((1+\mathrm{g})(1+\pi)))$$

Nominal value of net foreign assets, euro area

$$\mathrm{NFA} = -\left(\frac{\mathrm{NFA}^{*}}{\mathrm{e}}\right)$$

Net factor income from abroad, euro area

$$NFN = -\frac{NFN^{*}}{e}$$

Nominal current account, euro area

$$CA = PX(X) - PM(M) + NFN$$

Nominal value of public debt, euro area

$$GLN = -GDN\frac{(1+g)(1+\pi)-1}{(1+g)(1+\pi)}$$

Public net lending, euro area

$$GLN = -GCN - GIN + GYN$$

Nominal GDP at factor cost, euro area

$$YFN = PF(Y)$$

Nominal GDP, euro area

$$YEN = P(Y)$$

GDP deflator at the factor price, euro area

$$PF = P(1-\tau^{indirect})$$

Inflation, consumer prices, euro area

$$\pi = \overline{\pi}$$

Output, euro area

$$Y = TFP(K)^{\alpha}(L)^{1-\alpha}$$

Private consumption price deflator, euro area

$$PC = ((nuc)(P)^{1\text{-muc}} + (1 - nuc)(PM)^{1\text{-muc}})^{\frac{1}{1\text{-muc}}}$$

Investment price deflator, euro area

$$PI = ((nui)(P)^{1\text{-mui}} + (1 - nui)(PM)^{1\text{-mui}})^{\frac{1}{1\text{-mui}}}$$

Public consumption price deflator, euro area

$$PCG = ((nucg)(P)^{1\text{-mucg}} + (1 - nucg)(PM)^{1\text{-mucg}})^{\frac{1}{1\text{-mucg}}}$$

Nominal value of public consumption, euro area

$$GCN = PCG(CG)$$

Real value of public consumption, euro area

$$CG = b_1(Y)$$

Nominal value of public investment, euro area

$$GIN = b_2(PI)Y$$

Unemployment rate, euro area

$$U = \overline{U}$$

Nominal value of public other income, euro area

$$GOY = B_4(YEN)$$

Nominal value of public transfers, euro area

$$TRN = (trnyen.urx(U) + trnyen.cst)YEN$$

Direct tax rate, euro area

$$GDN = 4(b_3)YEN$$

Real interest rate, euro area

$$1 + r = (1 + R/400)/(1 + \overline{\pi})$$

Equilibrium real interest rate

$$\bar{r} = r$$

Population growth rate, USA

$$1 + n^* = (1 - p^*)(1 + \beta^*)$$

Population, USA

$$N^* = (1 + n^*)N^*_{-1}$$

Labour force, USA

$$F^* = (1 + n^*)F^*_{-1}$$

Total factor productivity, USA

$$TFP^*/TFP^*_{-1} = (1 + \varepsilon^*)$$

Real growth rate, USA

$$g^* = \frac{\varepsilon^*}{1 - \alpha^*} + n^*$$

Labour demand, USA

$$L^* = N^*(1 - \overline{U}^*)$$

Fixed investment, USA

$$\alpha^* \frac{Y^*}{K^*} \frac{PF^*}{PC^*} = \frac{r^* + \delta^* + \chi^*}{1 + r^* + \chi^*} \frac{PI^*}{PC^*}$$

Nominal wages, USA

$$W^* = \frac{\text{win.funda}^*}{(1-\text{win.lead}^*(1+g^*)(1+\pi^*)-\text{win.lag}^*/((1+g^*)(1+\pi^*)))}(1-\alpha^*)(PF^*)Y^*$$

Nominal wages, USA

$$\frac{W^*}{PF^*} = WR^*$$

GDP deflator, USA

$$INFD^* = \pi^*$$

Inflation, GDP deflator, USA

$$\frac{PC^*}{PC^*_{-1}} = 1+\pi^*$$

Private consumption, USA

$$C^* = \text{pcr.lead}^*\left(\frac{C^*(1+g^*)}{1+r^*+\chi^*}\right)+\text{pcr.funda}^*\left(\frac{(1+WFG^*)(1+\pi^*)}{(1+g^*)(1+\pi^*)}\frac{A^*}{PC^*}+\frac{YDN^*}{PC^*}\right)$$

Windfall gain, USA

$$WFG^* = \frac{A^*}{A^*/(1+g^*)}-1-\frac{YDN^*-C^*(PC^*)}{A^*/(1+g^*)}$$

Nominal value of private assets, USA

$$\frac{A^*}{PF^*} = ASTR^*$$

Nominal value of net foreign assets, USA

$$\frac{NFA^*}{PF^*} = NFAR^*$$

Nominal value of public debt, USA

$$\frac{GDN^*}{PF^*} = GDNR^*$$

Real value of private wealth, USA

$$AST^* = \frac{(1 + R^*/400 + \chi^*)}{(R^*/400 + \chi^* - ((1+g^*)(1+\pi^*) - 1))}((1-a^*)PF^*(Y^*) - \delta^*(PI^*)K^*/(1+g^*)) + NFA^* + GDN^*$$

Inventories, USA

$$KI^* = lsr.prod^*(Y^*)$$

Exports, USA

$$X^* = 1.33508(M)$$

Imports, USA

$$M^* = (1-nuc^*)\left(\frac{PM^*}{PC^*}\right)^{-muc^*} C^* + (1-nucg^*)\left(\frac{PM^*}{PCG^*}\right)^{-mucg^*} CG^* + (1-nui^*)\left(\frac{PM^*}{PI^*}\right)^{-mui^*} ITOT^* + (1-nux^*)\left(\frac{PM^*}{PX^*}\right)^{-mux^*} X^*$$

Export prices, USA

$$PX^* = ((nux^*)(P^*)^{1-mux^*} + (1-nux^*)(PM^*)^{1-mux^*})^{\frac{1}{1-mux^*}}$$

Import prices, USA

$$PM^* = e\frac{PX}{1.33762}$$

Long-term nominal interest rate, USA

$$LTN^* = R^*$$

Private nominal disposable income, USA

$$YDN^{*} = YFN^{*} - TAX^{*} + INN^{*} + TRN^{*} + NFN^{*} - GOY^{*} - \delta^{*}(PI^{*})K^{*}/(1+g^{*})$$

GDP identity, USA

$$Y^{*} = C^{*} + CG^{*} + ITOT^{*} + X^{*} - M^{*} + KI^{*} - KI^{*}/(1+g^{*})$$

Capital accumulation, USA

$$I^{*} = K^{*} - (1-\delta^{*})K^{*}/(1+g^{*})$$

Total investment, USA

$$ITOT^{*} = I^{*} + \frac{GIN^{*}}{PI^{*}}$$

Indirect taxes, USA

$$TIN^{*} = \tau^{indirect*}(YEN^{*})$$

Direct taxes, USA

$$TAX^{*} = \tau^{direct*}(YEN^{*})$$

Public disposable income, USA

$$GYN^{*} = TAX^{*} + TIN^{*} + GOY^{*} - TRN^{*} - INN^{*}$$

Public interest outlays, USA

$$INN^{*} = R^{*}/400\left(\frac{GDN^{*}}{(1+g^{*})(1+\pi^{*})}\right)$$

Real value of net foreign assets, USA

$$NFA^{*} = \frac{(1+g^{*})(1+\pi^{*})}{(1+g^{*})(1+\pi^{*})-1}CA^{*}$$

Net factor income from abroad, USA

$$NFN^{*} = R^{*}/400\left(\frac{NFA^{*}}{(1+g^{*})(1+\pi^{*})}\right)$$

Nominal current account, USA

$$CA^{*} = PX^{*}(X^{*}) - PM^{*}(M^{*}) + NFN^{*}$$

Real value of public debt, USA

$$GLN^{*} = -\frac{(1+g^{*})(1+\pi^{*})-1}{(1+g^{*})(1+\pi^{*})}GDN^{*}$$

Public net lending, USA

$$GLN^{*} = -GCN^{*} - GIN^{*} + GYN^{*}$$

Nominal GDP at factor cost, USA

$$YFN^{*} = PF^{*}(Y^{*})$$

Nominal GDP, USA

$$YEN^{*} = P^{*}(Y^{*})$$

GDP deflator at the factor price, USA

$$PF^{*} = P^{*}(1-\tau^{indirect*})$$

Inflation, consumer prices, USA

$$\pi^{*} = \overline{\pi}^{*}$$

Real interest rate, USA

$$r^{*} = r$$

Real exchange rate

$$e = Q\frac{PC^*}{PC}$$

Output, USA

$$Y^* = TFP^*(K^*)^{\alpha^*}(L^*)^{1-\alpha^*}$$

Private consumption price deflator, USA

$$PC^* = ((nuc^*)(P^*)^{1\text{-}muc^*} + (1-nuc^*)(PM^*)^{1\text{-}muc^*})^{\frac{1}{1\text{-}muc^*}}$$

Investment price deflator, USA

$$PI^* = ((nui^*)(P^*)^{1\text{-}mui^*} + (1-nui^*)(PM^*)^{1\text{-}mui^*})^{\frac{1}{1\text{-}mui^*}}$$

Public consumption price deflator, USA

$$PCG^* = ((nucg^*)(P^*)^{1\text{-}mucg^*} + (1-nucg^*)(PM^*)^{1\text{-}mucg^*})^{\frac{1}{1\text{-}mucg^*}}$$

Nominal value of public consumption, USA

$$GCN^* = PCG^*(CG^*)$$

Real value of public consumption, USA

$$CG^* = b_1^*(Y^*)$$

Nominal value of public investment, USA

$$GIN^* = b_2^*(PI^*)Y^*$$

Unemployment rate, USA

$$U^* = \overline{U}^*$$

Nominal value of public other income, USA

$$GOY^{*} = B_{4}^{*}(YEN^{*})$$

Nominal value of public transfers, USA

$$TRN^{*} = (trnyen.urx^{*}(U^{*}) + trnyen.cst^{*})YEN^{*}$$

Direct tax rate, USA

$$GDN^{*} = 4(b_{3}^{*})YEN^{*}$$

Short-term nominal interest rate, USA

$$1 + R^{*}/400 = (1 + r^{*})(1 + \pi^{*})$$

Appendix 5

Parameters of the two-country DGE model

	Parameters		
	Euro area	**USA**	**Description**
α	0.4	0.4	capital share of income
δ	0.015	0.015	depreciation rate
g	0.00066	0.00066	real growth rate
χ	0.015	0.015	equity premium
p	1/80	1/80	probability of death (20Y life expectancy)
β	1/78	1/78	birth rate
φ	0.01	0.01	rate of time preference
win.ugap	1	1	weight of unemployment gap
qp	0.125	0.125	expected length of Calvo contracts (1/qp quarters)
arothm	0.1	0.1	adjustment cost parameter in menu cost pricing
brothm	0.05	0.05	adjustment cost parameter in labour demand
a_1	250	250	adjustment cost parameter in 'level' of capital stock
a_2	0.25	0.25	adjustment cost parameter in 'change' of capital stock
kq	1	0.5	target level of inventories relative to output
ω	0.25	0.25	adjustment cost parameter in inventory demand
nuc	0.87	0.87	share of domestic value added good in private consumption
nucg	0.87	0.87	share of domestic value added good in public consumption
nui	0.8	0.8	share of domestic value added good in investment
nux	0.7	0.7	share of domestic value added good in exports
muc	1.1	1.1	substitution elasticity between domestic value added good and imports in private consumption
mucg	1.1	1.1	substitution elasticity between domestic value added good and imports in public consumption
mui	1.1	1.1	substitution elasticity between domestic value added good and imports in investment
mux	1.1	1.1	substitution elasticity between domestic value added good and imports in exports
tnyen.urx	0	0	steady-state government transfers elasticity to unemployment rate
tnyen.cst	0.227	0.096	steady-state level of government transfers
b_1	0.199542	0.1463	steady-state government real consumption to GDP ratio
b_2	0.026023	0.034594	steady-state government nominal investments to GDP ratio
b_3	0.691877	0.587292	steady-state government debt to nominal GDP ratio
b_4	0.205432	0.071391	steady-state government other income to GDP ratio
τ_1	0.1	0.1	tax rule weight on deviation of deficit
τ_2	0.005	0.005	tax rule weight on deviation of debt
λ_1	1	1	interest rate smoothing (1 = no smoothing)
λ_2	0.5	0.5	Taylor-rule weight on inflation gap
λ_3	0.5	0.5	Taylor-rule weight on unemployment gap
ltn.stn	1/29	1/29	1/(1+duration)
ltn.rp	1/29*0.01	1/29*0.01	risk premium in long term nominal interest rate

	Exogenous variables		
	Euro area	**USA**	**Description**
$\bar{U}$	0.08104	0.0561	NAIRU
$\bar{\pi}$	0	0	inflation target
$\tau^{indirect}$	0.138494	0.076815	indirect tax rate

	Coefficients	
	Euro area/USA	**Description**
WIN.LEAD	$\frac{(1-qp)(1/(1+\varphi+\bar{\pi})}{1+(1-qp)^2(1/(1+\varphi+\bar{\pi})}$	lead in wage equation
WIN.LAG	$\frac{(1-qp)}{1+(1-qp)^2(1/(1+\varphi+\bar{\pi})}$	lag in wage equation
WIN.FUNDA	1-WIN.LEAD-WIN.LAG	fundamental in wage equation
YED.LEAD	$\frac{1/(1+\varphi+\bar{\pi})}{1+arothm+(1/(1+\varphi+\bar{\pi})}$	lead in price equation
YED.LAG	$\frac{1}{1+arothm+(1/(1+\varphi+\bar{\pi})}$	lag in price equation
YED.FUNDA	1-YED.LEAD-YED.LAG	fundamental in price equation
LNN.LEAD	$\frac{1/(1+\varphi)}{1+brothm+(1/(1+\varphi)}$	lead in labour demand equation
LNN.LAG	$\frac{1}{1+brothm+(1/(1+\varphi)}$	lag in labour demand equation
LNN.FUNDA	1-LNN.LEAD-LNN.LAG	fundamental in labour demand equation
KSR.LEAD2	$\frac{-a_2(1/(1+\varphi+\chi))^2}{1/(1+\varphi+\chi)a_2(1+a_2)+1)}$	2nd lead in fixed investment equation
KSR.LEAD	$\frac{a_2^2(1/(1+\varphi+\chi))^2+(1/(1+\varphi+\chi))(1+a_2)}{1/(1+\varphi+\chi)a_2(1+a_2)+1)}$	lead in fixed investment equation
KSR.LAG	1-KSR.LEAD2-KSR.LEAD	lag in fixed investment equation
KSR.FUNDA	$\frac{1}{a_1(1/(1+\varphi+\chi)a_2(1+a_2)+1)}$	fundamental in fixed investment equation
PCR.LEAD	$\frac{(1-p)}{1-(1-p)(1-(1-p)(1/(1+\varphi)))}$	lead in consumption equation
PCR.FUNDA	$pcr.lead*\frac{p(1-(1-p)(1/(1+\varphi)))}{1-p}$	fundamental in consumption equation
LSR.DPROD	$\frac{1}{\omega}$	level in inventories equation
LSR.DPROD LEAD	$\frac{\omega}{(1+\varphi)}$	difference in inventories equation

Appendix 6

Data sources of the two-country DGE model

	euro area data		
Symbol	**Description**	**Unit**	**Source**
Y	Gross domestic product	95-EUR mill.	Eurostat
C	Private consumption	95-EUR mill.	Eurostat
CG	Public consumption	95-EUR mill.	Eurostat
I	Gross private investment	95-EUR mill.	European Central Bank
IG	Gross public investment	95-EUR mill.	European Central Bank
KI	Change in inventories	95-EUR mill.	See Appendix 4
X	Extra euro area exports of goods (fob)	95-EUR mill.	European Central Bank
M	Extra euro area imports of goods (cif)	95-EUR mill.	European Central Bank
YEN	Gross domestic product	EUR mill.	Eurostat
PCN	Private consumption	EUR mill.	Eurostat
GCN	Public consumption	EUR mill.	Eurostat
ITN	Gross private investment	EUR mill.	European Central Bank
GIN	Gross public investment	EUR mill.	European Central Bank
XN	Exports	EUR mill.	European Central Bank
MN	Imports	EUR mill.	European Central Bank
P	Private consumption prices	1995=1	Eurostat
PC	Private consumption prices	1995=1	Eurostat
PG	Private consumption prices	1995=1	Eurostat
PI	Gorss private investment prices	1995=1	Eurostat, aggregate investment prices
PX	Export prices	1995=1	European Central Bank
PM	Import prices	1995=1	European Central Bank
ITOT	Total gross investment	95-EUR mill.	See Appandix 4
CA	Current account	EUR mill.	European Central Bank
NFN	Net factor income	EUR mill.	European Central Bank
NFA	Net foreign assets	EUR mill.	See Appendix 4
WIN	Compensation of employees	EUR mill.	Eurostat
π	Quarterly inflation rate	%	See Appendix 4
$\bar{\pi}$	Quarterly inflation rate target	%	Calibrated
R	3 month Euribor-Interbank offered rate	%	Reuters
LR	10 years government bond yield rate	%	Eurostat
r	3 month real interest rate	%	See Appendix 4
GDN	General government EMU-debt	EUR mill.	European Central Bank
GLN	General government: deficit (-)/ surplus(+)	EUR mill.	European Central Bank
TAX	Personal and profit tax	EUR mill.	European Central Bank
TIN	Indirect business tax and non-tax accruals	EUR mill.	European Central Bank
GOY	Contributions for social insurance	EUR mill.	European Central Bank
INN	General government net interest paid	EUR mill.	European Central Bank
TRN	General government: transfer	EUR mill.	European Central Bank

GYN	General government disposable income	EUR mill.	See Appendix 4
TAR	Direct tax rate	%	See Appendix 4
TIR	Indirect tax rate	%	See Appendix 4
L	Total employment	1000 pers.	European Central Bank
F	Labour force	1000 pers.	See Appendix 4
N	Working age population	1000 pers.	OECD Economic Outlook
U	Unemployment rate	%	Eurostat
$\bar{U}$	NAIRU	%	Calibrated
A	Value of private asset wealth	EUR mill.	See Appendix 4
ASTR	Real private asset wealth	95-EUR mill.	See Appendix 4
K	Fixed capital stock	95-EUR mill.	See Appendix 4
KI	Inventories	95-EUR mill.	See Appendix 4
TFP	Total factor productivity	Index	See Appendix 4
WFG	Windfall gain	%	See Appendix 4
YDN	Private disposable assets	EUR mill.	See Appendix 4
YFN	GDP at the factor cost	EUR mill.	See Appendix 4
YFD	GDP deflator at factor price	Index	See Appendix 4
e	USD price of euro	USD/EUR	European Central Bank
q	Real USD price of euro	USD/EUR	See Appendix 4

	US data		
Symbol	**Description**	**Unit**	**Source**
Y*	Gross domestic product	96-USD mill.	Bureau of Economic Analysis
C*	Private consumption	96-USD mill.	Bureau of Economic Analysis
CG*	Public consumption	96-USD mill.	Bureau of Economic Analysis
I*	Gross private investment	96-USD mill.	Bureau of Economic Analysis
IG*	Gross public investment	96-USD mill.	Bureau of Economic Analysis
KI*	Change in inventories	96-USD mill.	See Appendix 4
X*	Exports	96-USD mill.	See Appendix 4
M*	Imports	96-USD mill.	See Appendix 4
YEN*	Gross domestic product	USD mill.	Bureau of Economic Analysis
PCN*	Private consumption	USD mill.	Bureau of Economic Analysis
GCN*	Public consumption	USD mill.	Bureau of Economic Analysis
ITN*	Gross private investment	USD mill.	Bureau of Economic Analysis
GIN*	Gross public investment	USD mill.	Bureau of Economic Analysis
XN*	Exports	USD mill.	See Appendix 4
MN*	Imports	USD mill.	See Appendix 4
P*	Private consumption prices	1996=1	Bureau of Economic Analysis
PC*	Private consumption prices	1996=1	Bureau of Economic Analysis
PG*	Private consumption prices	1996=1	Bureau of Economic Analysis
PI*	Gross private investment prices	1996=1	Bureau of Economic Analysis
PX*	Export prices	1996=1	See Appendix 4
PM*	Import prices	1996=1	See Appendix 4
ITOT*	Total gross investment	96-USD mill.	See Appendix 4
CA*	Current account	USD mill.	Bureau of Economic Analysis
NFN*	Net factor income	USD mill.	See Appendix 4
NFA*	Net foreign assets	USD mill.	See Appendix 4
WIN*	Compensation of employees	USD mill.	Bureau of Economic Analysis
π^*	Quarterly inflation rate	%	See Appendix 4
$\bar{\pi}^*$	Quarterly inflation rate target	%	Calibrated
R^*	3 month Interbank rate	%	Reuters
LR*	10 years government bond yield rate	%	Reuters
R*	2 month real interest rate	%	See Appendix 4

GDN*	General government gross debt	USD mill.	OECD Economic Outlook
GLN*	General government: deficit (-)/ surplus (+)	USD mill.	Bureau of Economic Analysis
TAX*	Personal and profit tax	USD mill.	Bureau of Economic Analysis
TIN*	Indirect business tax and non-tax accruals	USD mill.	Bureau of Economic Analysis
GOY*	Contributions for social insurance	USD mill.	Bureau of Economic Analysis
INN*	General government net interest paid	USD mill.	Bureau of Economic Analysis
TRN*	General government: transfer	USD mill.	Bureau of Economic Analysis
GYN*	General government disposable income	USD mill.	See Appendix 4
TAR*	Direct tax rate	%	See Appendix 4
TIR*	Indirect tax rate	%	See Appendix 4
L*	Total employment	1000 pers.	Bureau of Economic Analysis
F*	Labour force	1000 pers.	See Appendix 4
N*	Working age population	1000 pers.	OECD Economic Outlook
U*	Unemployment rate	%	Bureau of Economic Analysis
$\overline{U}^*$	NAIRU	%	Calibrated
A*	Value of private asset wealth	USD mill.	See Appendix 4
ASTR*	Real private asset wealth	96-USD mill.	See Appendix 4
K*	Fixed capital stock	96-USD mill.	See Appendix 4
KI*	Inventories	96-USD mill.	See Appendix 4
TFP*	Total factor productivity	Index	See Appendix 4
WFG*	Windfall gain	%	See Appendix 4
YDN*	Private disposable assets	USD mill.	See Appendix 4
YFN*	GDP at the factor cost	USD mill.	See Appendix 4
YFD*	GDP deflator at factor price	Index	See Appendix 4

BANK OF FINLAND RESEARCH
DISCUSSION PAPERS

ISSN 0785-3572, print; ISSN 1456-6184, online

1/2005 Patrick M. Crowley **An intuitive guide to wavelets for economists.** 2005. 68 p. ISBN 952-462-188-6, print; ISBN 952-462-189-4, online.

2/2005 Tuomas Saarenheimo **Ageing, interest rates, and financial flows.** 2005. 30 p. ISBN 952-462-190-8, print; ISBN 952-462-191-6, online.

3/2005 Timo Vesala **Relationship lending and competition: Higher switching cost does not necessarily imply greater relationship benefits.** 2005. 27 p. ISBN 952-462-192-4, print; ISBN 952-462-193-2, online.

4/2005 Johanna Sinkkonen **Labour productivity growth and industry structure. The impact of industry structure on productivity growth, export prices and labour compensation.** 2005. 88 p. ISBN 952-462-196-7, print; ISBN 952-462-197-5, online.

5/2005 Matti Virén **Why do capital intensive companies pay higher wages?** 2005. 23 p. ISBN 952-462-198-3, print; ISBN 952-462-199-1, online.

6/2005 Maritta Paloviita – Matti Virén **The role of expectations in the inflation process in the euro area.** 2005. 33 p. ISBN 952-462-200-9, print; ISBN 952-462-201-7, online.

7/2005 Marketta Henriksson **Productivity differentials and external balance in ERM II.** 2005. 32 p. ISBN 952-462-202-5, print; ISBN 952-462-203-3, online.

8/2005 Matti Virén **Government size and output volatility: is there a relationship?** 2005. 24 p. ISBN 952-462-204-1, print; ISBN 952-462-205-X, online.

9/2005 Karlo Kauko **Bank interest rates in a small European economy: Some exploratory macro level analyses using Finnish data.** 2005. 44 p. ISBN 952-462-206-8, print; ISBN 952-462-207-6, online.

10/2005 Essi Eerola – Niku Määttänen **The optimal tax treatment of housing capital in the neoclassical growth model.** 2005. 30 p. ISBN 952-462-210-6, print; ISBN 952-462-211-4, online.

11/2005 Karlo Kauko **The mixed oligopoly of cross-border payment systems.** 2005. 31 p. ISBN 952-462-212-2, print; ISBN 952-462-213-0, online.

12/2005 Patrick M. Crowley – Jim Lee **Decomposing the co-movement of the business cycle: a time-frequency analysis of growth cycles in the euro area.** 2005. 67 p. ISBN 952-462-214-9, print; ISBN 952-462-215-7, online.

13/2005 Jarmo Pesola **Banking fragility and distress: An econometric study of macroeconomic determinants.** 2005. 95 p. ISBN 952-462-216-5, print; ISBN 952-462-217-3, online.

14/2005 Karlo Kauko **The demand for money market mutual funds.** 2005. 29 s. ISBN 952-462-218-1, print; ISBN 952-462-219-X, online.

15/2005 Matti Virén **Fiscal policy in the 1920s and 1930s. How much different it is from the post war period's policies?** 2005. 27 p. ISBN 952-462-220-3, print; ISBN 952-462-221-1, online.

16/2005 Alistair Milne **What's in it for us? Network effects and bank payment innovation.** 2005. 27 p. ISBN 952-462-223-8, print; ISBN 952-462-224-6, online.

17/2005 Hilde C Bjørnland – Kai Leitemo **Identifying the interdependence between US monetary policy and the stock market.** 2005. 43 p. ISBN 952-462-225-4, print; ISBN 952-462-226-2, online.

18/2005 Juha Tarkka – Mika Kortelainen **International economic spillovers and the liquidity trap.** 2005. 86 p. ISBN 952-462-227-0, print; ISBN 952-462-228-9, online.

Suomen Pankki
Bank of Finland
P.O.Box 160
FI-00101 HELSINKI
Finland