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THE MONETARY TRANSMISSION MECHANISM FOR A SMALL OPEN ECONOMY IN A MONETARY UNION

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The Monetary Transmission Mechanism for a Small Open Economy in a Monetary Union*

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Abstract

This paper develops a model of a small open economy integrated in a monetary union. The model incorporates the standard nominal and real frictions in the literature. The parameters of the model are calibrated to the Portuguese data and the effects of the standard monetary policy shock are studied.

Key words: Small open economy; Monetary union; Monetary transmission mechanism; Local determinacy; Impulse response function;

JEL classification: E21; E22; E32; E42; E61; F41; F42.

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1. Introduction

This paper develops a stylized model of a small open economy integrated in a monetary union. Since the small country trades with countries inside and outside of the monetary union there are three economies in the model. The small open country, the economy represented by all the remaining countries that belong to the monetary union too, and the one that includes all countries that do not belong to the monetary union.

The Taylor principle, which says that the interest rate rule should be such that the response of the interest rate to a unitary change in inflation should be larger than unity, is a necessary condition to have local determinacy in the model. If the inflation in all countries of the union, except in the small country, was taken as exogenous the Taylor principle would be violated. The reason is easy to understand. The interest rate relevant for the small country is the one set by the central bank of the monetary union. The central bank of the monetary union follows an interest rate rule that is a function of the union's inflation and output. If those union aggregate variables were taken as exogenous then the Taylor principle would be violated. A change in the small country's inflation would imply a negligible change in the interest rate, since the small country contributes little to the union's inflation. Thus, to guarantee local determinacy the variables associated with the countries outside the union can be assumed exogenous, but not the variables associated the other countries in the union.

To guarantee that the model possesses the local uniqueness property we adopted a straighforward ad-hoc specification of two blocks of equations, each containing three equations, that specify the behavior of some aggregate variables inside and outside of the union. One block contains three reduced form equations, an IS curve, a Phillips curve and an interest rate rule that describe the behavior of output, of inflation and of the interest rate for the countries outside of the union. These three variables are determined entirely inside this block. The other block of equations contains three other similar reduced form equations, regarding the behavior of inflation, output and interest rate in the union. This block of equations contains three equations and five variables. These variables are: the inflation rate and the output in the small open economy and in the remaining countries of the union, and the interest rate in the monetary union. The arguments in this block of equations associated with the small open economy are scaled down in accordance with the dimension of the small country in the union. These five variables interact with the other variables in the model, and are determined together with them.

This paper can be seen as an extension to the paper by Adolfson et al (2007), as it considers that the small open economy is integrated in a monetary union. Adolfson et al (2007) developed a model of a small open economy taking as exogenously given foreign inflation, foreign output and foreign interest rate. Following their work and the literature, we consider various nominal and real frictions, such as sticky wages, sticky prices, variable capital utilization, capital adjustment costs, habit persistence and volume premium on the foreign interest rate.

Adolfson et al (2007) calibrated and estimated their model using the Euro area data. This paper presents a model designed to assess the transmission of monetary policy shocks in a small country in a monetary union. As Portugal can be thought as a such an economy, we used the Portuguese data to calibrate the parameters of our model. We assume that after the monetary shock, inflation, output and interest rate outside of the union are unchanged and that inflation, output and interest rate inside the union change according to the referred three equation block, containing an IS curve, a Phillips curve and an interest rate rule. More specifically, in the quantitative exercise performed we consider parameters for the IS curve, Phillips curve and interest rate rule that generate responses of these variables to the typical Euro area monetary shock that mimic the paths of the responses of these variables in the general equilibrium model of Adolfson et al (2007) to the same shock.

Some of the model parameters are calibrated to the steady state values of the Portuguese economy variables, for others we do not have information and they correspond to the estimates obtained (or values assumed) by Adolfson et al (2007) for the Euro area. The shape and sign of the impulse responses of the main macro variables to an unanticipated temporary decrease in the nominal interest rate are well in line with the literature. When compared with the Euro area, output, investment and real wage in Portugal increase more and inflation in Portugal adjusts quicker and reacts slightly more on impact. On the other hand, consumption in Portugal has a behavior almost identical to the one of the Euro area. The trade with the two areas responds differently. Trade with countries outside of the Euro area changes substantially more than the trade with countries inside of the Euro area. Both exports and imports to and from the Euro area increase, with exports change less. Imports from outside of the Euro area decrease initially and exports to outside of the Euro area increase.

The paper is organized as follows. In section 2 the model is explained. Section 3 describes how the model is solved. Section 4 shows how the model is calibrated. Section 5 studies the effects of a monetary shock on the Portuguese economy. The last section, section 6, provides some conclusions.

2. Model

The model has 3 economic areas: the small open country, the other countries inside the monetary union and the countries outside of the monetary union. We are concerned with the small open economy and believe the developments in the small open economy have little efffects over the remaining economic areas. As such, in the model the small open economy is described in detail, but the other economic areas are not.

2.1. Households

There is a representative household in the small open economy, whose preferences over stochastic sequences of consumption C_t, real money $\frac{M_t}{P_t}$, and labor L_t are represented by the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\log\left(C_t - bC_{t-1}\right) + \nu \log\left(\frac{M_t}{P_t}\right) - \xi \frac{L_t^{1+\psi}}{1+\psi} \right) \tag{1}$$

where E_0 is the conditional expectation operator, $\beta \in (0,1)$ is the discount factor, and b is a parameter that controls the habit persistence. This utility function is similar to the one used by Christiano et al (2005) and Adolfson et al (2007). The aggregate consumption is a bundle given by a CES index of domestically produced and imported foreign goods:

$$C_t = \left[(1 - \varpi_{o,c} - \varpi_{u,c})^{\frac{1}{\eta_c}} \left(C_t^h\right)^{\frac{\eta_c - 1}{\eta_c}} + (\varpi_{o,c})^{\frac{1}{\eta_c}} \left(C_t^o\right)^{\frac{\eta_c - 1}{\eta_c}} + (\varpi_{u,c})^{\frac{1}{\eta_c}} \left(C_t^u\right)^{\frac{\eta_c - 1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c - 1}}, \tag{2}$$

where C_t^h denotes consumption of the home good, C_t^o denotes consumption of the good produced outside of the union, C_t^u denotes consumption of the good produced inside of the union, $\varpi_{o,c}$ is the share of imported consumption from outside of the union in total consumption, $\varpi_{u,c}$ is the share of imported consumption from inside of the union in total consumption and η_c is the elasticity of substitution between the three consumption goods. Thus, consumers derive utility from the consumption of domestically produced goods as well as from the consumption of goods produced outside and inside of the union. The price of aggregate consumption (defined as the minimum expenditure required to buy one unit of C_t) is given by

$$P_t^c = \left[(1 - \varpi_{o,c} - \varpi_{u,c}) \left(P_t\right)^{1-\eta_c} + \varpi_{o,c} \left(P_t^o\right)^{1-\eta_c} + \varpi_{u,c} \left(P_t^u\right)^{1-\eta_c} \right]^{\frac{1}{1-\eta_c}},$$

where P_t is the price of the domestically produced good, P_t^o is the price of the outside of the union imported good and P_t^u is the price of the inside of the union imported good. All these prices are in units of the domestic currency. Consumers choose quantities of each of these three goods that for a given expenditure maximize aggregate consumption. The individual demands for each good that maximize (2) subject to $P_t C_t^h + P_t^o C_t^o + P_t^u C_t^u = P_t^c C_t$, are

$$C_t^h = (1 - \varpi_{o,c} - \varpi_{u,c}) \left(\frac{P_t}{P_t^c} \right)^{-\eta_c} C_t,$$

$$C_t^o = \varpi_{o,c} \left(\frac{P_t^o}{P_t^c} \right)^{-\eta_c} C_t,$$

and

$$C_t^u = \varpi_{u,c} \left(\frac{P_t^u}{P_t^c} \right)^{-\eta_c} C_t.$$

Also, the aggregate investment is a bundle given by a CES index of domestically produced and imported foreign goods:

$$I_t = \left[(1 - \varpi_{o,i} - \varpi_{u,i})^{\frac{1}{\eta_i}} \left(I_t^h\right)^{\frac{\eta_i - 1}{\eta_i}} + (\varpi_{o,i})^{\frac{1}{\eta_i}} \left(I_t^o\right)^{\frac{\eta_i - 1}{\eta_i}} + (\varpi_{u,i})^{\frac{1}{\eta_i}} \left(I_t^u\right)^{\frac{\eta_i - 1}{\eta_i}} \right]^{\frac{\eta_i}{\eta_i - 1}},$$

where I_t^h denotes the home good investment, I_t^o denotes outside of the union investment good, I_t^u denotes inside of the union investment good, $\varpi_{o,i}$ is the share of outside of the union investment good in total investment, $\varpi_{u,i}$ is the share of inside of the union investment good in total investment and η_i is the elasticity of substitution between the three investment goods. The price of aggregate investment is equal to

$$P_t^i = \left[(1 - \varpi_{o,i} - \varpi_{u,i}) (P_t)^{1-\eta_i} + \varpi_{o,i} (P_t^o)^{1-\eta_i} + \varpi_{u,i} (P_t^u)^{1-\eta_i} \right]^{\frac{1}{1-\eta_i}}.$$

The individual demands for each investment good are

$$I_t^h = (1 - \varpi_{o,i} - \varpi_{u,i}) \left(\frac{P_t}{P_t^i} \right)^{-\eta_i} I_t,$$

$$I_t^o = \varpi_{o,i} \left(\frac{P_t^o}{P_t^i} \right)^{-\eta_i} I_t,$$

and

$$I_t^u = \varpi_{u,i} \left(\frac{P_t^u}{P_t^i} \right)^{-\eta_i} I_t.$$

Each household is a monopoly supplier of its own labor and can set its wage according to the mechanism described in Calvo (1983). The wage can be adjusted at exogenously random periods. In order to guarantee that this friction does not cause households to become heterogeneous we assume complete domestic financial markets against the outcomes of this friction. As a result all households have the same budget constraint:

$$P_t^c C_t + P_t^i I_t + M_t + D_t + S_t B_t^o + B_t^u = P_t w_t L_t + P_t(r_t u_t - a(u_t))K_{t-1} + M_{t-1} + D_{t-1}R_{t-1}$$
$$+ S_t R_{t-1}^o \Phi_o(\frac{\mathcal{B}_{t-1}}{z_{t-1}})B_{t-1}^o + R_{t-1}^u \Phi_u(\frac{\mathcal{B}_{t-1}}{z_{t-1}})B_{t-1}^u + T_t + \Gamma_t \tag{3}$$

the terms on the left hand side of the equality show how the households use their income and the terms on the right hand side the various sources of that income. Here, M_t are money holdings, D_t are deposits that pay nominal gross interest rate R_t, B_t^o are holdings of foreign bonds denominated in foreign currency that pay a nominal gross interest rate $R_t^o \Phi_o$, S_t is the nominal exchange rate, B_t^u are holdings of foreign bonds denominated in domestic currency that pay a nominal gross interest rate $R_t^u \Phi_u$ and w_t is the real wage. The term $P_t r_t u_t$ represents the household's earnings from supplying capital services. The function $a(u_t)K_{t-1}$ denotes the cost of setting the utilization rate of capital to u_t. We assume $a(u_t)$ is increasing and convex. These assumptions capture the idea that the more intensely the stock of capital is utilized, the higher are maintenance costs. We assume that $u_t = 1$ in steady state and that $a(1) = 0$, $a' > 0$, and $a'' > 0$. The expression $R_{t-1}^o \Phi_o(\frac{\mathcal{B}_{t-1}}{z_{t-1}})$ is the level-adjusted gross interest rate on foreign bonds denominated in foreign currency, $\mathcal{B}_t \equiv \frac{S_t B_t^o + B_t^u}{P_t}$. The term z_t is a unit root technology shock to be described later. The function $\Phi_i(\frac{\mathcal{B}_t}{z_t})$ for $i = o, u$, is assumed to be strictly decreasing in $\mathcal{B}_t$ and to satisfy $\Phi_i(\overline{\mathcal{B}}) = 1$, where $\overline{\mathcal{B}}$ is the steady state value of $\frac{\mathcal{B}_t}{z_t}$. This function depends on the real holdings of the aggregate foreign assets. This means that domestic households take the functions $\Phi_i(.)$ as given when deciding on the individual optimal holdings of the foreign bonds.

Functions Φ_i try to capture imperfect integration in the international financial markets. If the domestic economy as a whole is borrowing above its steady state, domestic households are charged a premium on the foreign interest rates, if borrowing below its steady state, domestic households pay less. The introduction of this premium is needed in order to ensure a well-defined steady-state in the model (see Schmitt-Grohë and Uribe, 2003, for further details). Without this premium, the stock of bonds and consumption would not be stationary. The remaining variables are T_t which is a lump-sum transfer, and $\digamma_t$ that stands for the profits of the firms in the economy.

Investment I_t induces a law of motion for capital

$$K_t = (1-\delta) K_{t-1} + \left(1 - V\left[\frac{I_t}{I_{t-1}}\right]\right) I_t, \tag{4}$$

where δ is the depreciation rate and V is an adjustment cost function such that $V[\Lambda_i] = V'[\Lambda_i] = 0$, and $V'' > 0$, where Λ_i is the growth rate of investment along the balanced growth path. The household chooses $\{C_t, L_t, M_t, D_t, B_t^o, B_t^u, u_t, K_t, I_t\}$ to maximize expected lifetime utility (1) subject to constraints (3), (4) and initial values for M_0, D_0, B_0^o,and B_0^u. The Lagrangian is:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\begin{array}{c} \left(\log(C_t - bC_{t-1}) + \nu \log\left(\frac{M_t}{P_t}\right) - \xi \frac{L_t^{1+\psi}}{1+\psi}\right) \\ -\lambda_t \left\{ \begin{array}{c} \frac{P_t^c}{P_t} C_t + \frac{P_t^i}{P_t} I_t + \frac{M_t + D_t + S_t B_t}{P_t} - (r_t u_t - a(u_t)) K_{t-1} \\ -w_t L_t - \frac{M_{t-1} + R_{t-1} D_{t-1} + S_t R_{t-1}^o \Phi_o\left(\frac{\mathcal{B}_{t-1}}{z_{t-1}}\right) B_{t-1}^o + R_{t-1}^u \Phi_u\left(\frac{\mathcal{B}_{t-1}}{z_{t-1}}\right) B_{t-1}^u}{P_t} - \frac{T_t}{P_t} - \frac{\digamma_t}{P_t} \end{array} \right\} \\ -Q_t \left\{ K_t - (1-\delta) K_{t-1} - \left(1 - V\left[\frac{I_t}{I_{t-1}}\right]\right) I_t \right\} \end{array} \right]$$

where λ_t and Q_t are Lagrange multipliers. Ignoring the choices of M_t and L_t the first order conditions are:

$$(C_t - bC_{t-1})^{-1} - \beta E_t (C_{t+1} - bC_t)^{-1} b = \frac{P_t^c}{P_t} \lambda_t$$

$$-\frac{\lambda_t}{P_t} + \beta E_t \frac{\lambda_{t+1}}{P_{t+1}} R_t = 0$$

$$-\frac{\lambda_t S_t}{P_t} + \beta E_t \frac{\lambda_{t+1} S_{t+1}}{P_{t+1}} \Phi(t) R_t^o = 0$$

$$-\frac{\lambda_t}{P_t} + \beta E_t \frac{\lambda_{t+1}}{P_{t+1}} \Phi(t) R_t^u = 0$$

$$r_t = a'(u_t)$$

$$-Q_t + E_t \beta Q_{t+1} (1-\delta) + E_t \beta \lambda_{t+1} (r_{t+1} u_{t+1} - a(u_{t+1})) = 0$$

$$-\lambda_t \frac{P_t^i}{P_t} + Q_t \left(1 - V\left[\frac{I_t}{I_{t-1}}\right] - V'\left[\frac{I_t}{I_{t-1}}\right] \frac{I_t}{I_{t-1}}\right) + E_t \beta Q_{t+1} V'\left[\frac{I_{t+1}}{I_t}\right] \left(\frac{I_{t+1}}{I_t}\right)^2 = 0$$

The labor used by the intermediate good producers, to be described below, is supplied by a representative competitive firm that hires labor to each family j. This firm aggregates the differentiated labor of households according to the production function,

$$l_t^d = \left(\int_0^1 l_{jt}^{\frac{\nu^w - 1}{\nu^w}} dj\right)^{\frac{\nu^w}{\nu^w - 1}}$$

where ν^w is the elasticity of substitution between the different types of labor and L_t^d is the aggregate labor demand.

This firm maximizes profits taking as given the labor wages w_{jt} and aggregate labor wage w_t. Its maximization problem is:

$$\max_{L_{jt}} w_t L_t^d - \int_0^1 w_{jt} L_{jt} dj.$$

The first order conditions imply:

$$\frac{w_{jt}}{w_{it}} = \left(\frac{L_{jt}}{L_{it}}\right)^{-\frac{1}{\nu^w}}$$

or

$$w_{jt} L_{jt} = w_{it} L_{it}^{\frac{1}{\nu^w}} L_{jt}^{\frac{\nu^w - 1}{\nu^w}}, \forall j, i.$$

Integrating out this condition and using the fact that profits in perfect competition are zero, $w_t L_t^d = \int_0^1 w_{jt} L_{jt} dj$, we get that

$$L_{jt} = \left(\frac{w_{jt}}{w_t}\right)^{-\nu^w} L_t^d, \forall j.$$

We plug in the zero profit condition the input demand functions to find out the aggregate wage,

$$w_t = \left(\int_0^1 (w_{jt})^{1-\nu^w} \, dj \right)^{\frac{1}{1-\nu^w}}.$$

As referred above households set their wages according to a Calvo's setting, Calvo (1983). In each period, a fraction $1 - \theta^w$ of households can change their wages. All the other households can only partially index their wages to past inflation and past productivity growth. Indexation to past inflation is controlled by the parameter χ^w, and indexation to past productivity growth by the parameter χ^p. Both assume values in the interval $[0, 1]$. Thus, a household that could not change her wage for s periods has real wage $\times_{\tau=1}^{s} \frac{\Pi^{1-\chi^w} \Pi_{t+\tau-1}^{\chi^w} \overline{z}^{1-\chi^p} \overline{z}_{t+\tau-1}^{\chi^p}}{\Pi_{t+\tau}} w_{jt}$, where Π_t is gross inflation of the domestic good in period t, Π is the steady state domestic inflation, $\overline{z}_t$ is gross productivity growth in period t and $\overline{z}$ is the steady state productivity growth.

When setting the wage the relevant part of the Lagrangian for the household is,

$$\max_{w_{jt}} E_t \sum_{s=0}^{\infty} (\beta \theta^w)^s \left(-\xi \frac{L_{jt+s}^{1+\psi}}{1+\psi} + \lambda_{jt+s} \times_{\tau=1}^{s} \frac{\Pi^{1-\chi^w} \Pi_{t+\tau-1}^{\chi^w} \overline{z}^{1-\chi^p} \overline{z}_{t+\tau-1}^{\chi^p}}{\Pi_{t+\tau}} w_{jt} L_{jt+s} \right)$$

subject to

$$L_{jt+s} = \left(\frac{\times_{\tau=1}^{s} \frac{\Pi^{1-\chi^w} \Pi_{t+\tau-1}^{\chi^w} \overline{z}^{1-\chi^p} \overline{z}_{t+\tau-1}^{\chi^p}}{\Pi_{t+\tau}} w_{jt}}{w_{t+s}} \right)^{-\nu^w} L_{t+s}^d, \forall j.$$

The first order condition of this problem is

$$E_t \sum_{s=0}^{\infty} (\beta \theta^w)^s \left(\begin{array}{c} \nu^w \frac{\xi}{w_{jt}} \left(\frac{\times_{\tau=1}^{s} \frac{\Pi^{1-\chi^w} \Pi_{t+\tau-1}^{\chi^w} \overline{z}^{1-\chi^p} \overline{z}_{t+\tau-1}^{\chi^p}}{\Pi_{t+\tau}} w_{jt}}{w_{t+s}} \right)^{-\nu^w (1+\psi)} \left(L_{t+s}^d \right)^{1+\psi} \\ + (1-\nu^w) \lambda_{jt+s} \left(\times_{\tau=1}^{s} \frac{\Pi^{1-\chi^w} \Pi_{t+\tau-1}^{\chi^w} \overline{z}^{1-\chi^p} \overline{z}_{t+\tau-1}^{\chi^p}}{\Pi_{t+\tau}} \right)^{1-\nu^w} \left(\frac{w_{jt}}{w_{t+s}} \right)^{-\nu^w} L_{t+s}^d \end{array} \right) = 0$$

All households set the same wage because complete markets allow them to hedge the risk of the timing of the wage change. Thus, we drop the subscript from the wage set by household j

$$\frac{(\nu^w - 1)}{\nu^w} w_t^* E_t \sum_{s=0}^{\infty} (\beta\theta^w)^s \lambda_{jt+s} \left(\times_{\tau=1}^{s} \frac{\Pi^{1-\chi^w} \Pi_{t+\tau-1}^{\chi^w} \overline{z}^{1-\chi^p} \overline{z}_{t+\tau-1}^{\chi^p}}{\Pi_{t+\tau}} \right)^{1-\nu^w} \left(\frac{w_t^*}{w_{t+s}} \right)^{-\nu^w} L_{t+s}^d$$
$$= \quad E_t \sum_{s=0}^{\infty} (\beta\theta^w)^s \xi \left(\times_{\tau=1}^{s} \frac{\Pi^{1-\chi^w} \Pi_{t+\tau-1}^{\chi^w} \overline{z}^{1-\chi^p} \overline{z}_{t+\tau-1}^{\chi^p}}{\Pi_{t+\tau}} \frac{w_t^*}{w_{t+s}} \right)^{-\nu^w(1+\psi)} \left(L_{t+s}^d \right)^{1+\psi}.$$

In each period a fraction $1 - \theta^w$ of the households set w_t^* as their wage while the remaining fraction index their price by past inflation.

$$w_t^{1-\nu^w} = \theta^w \left(\frac{\Pi^{1-\chi^w} \Pi_{t-1}^{\chi^w} \overline{z}^{1-\chi^p} \overline{z}_{t-1}^{\chi^p}}{\Pi_t} w_{t-1} \right)^{1-\nu^w} + (1 - \theta^w) (w_t^*)^{1-\nu^w}$$

2.2. Final Good Producer

There is one domestic final good that is produced with intermediate goods:

$$Y_t = \left(\int_0^1 y_{j,t}^{\frac{\nu^d - 1}{\nu^d}} dj \right)^{\frac{\nu^d}{\nu^d - 1}}$$

where ν^d is the markup in the domestic goods market. The input demand functions of the final producer are

$$y_{j,t} = \left(\frac{p_{j,t}}{P_t} \right)^{-\nu^d} Y_t,$$

and the price of the final home good is

$$P_t = \left(\int_0^1 p_{j,t}^{1-\nu^d} dj \right)^{\frac{1}{1-\nu^d}}.$$

2.3. Intermediate Producers

There is a continuum of intermediate good producers. Each one has the following technology

$$y_{j,t} = A_t k_{j,t-1}^{\alpha} l_{j,t}^{1-\alpha} - \varrho z_t,$$

where A_t is a total productivity technological shock that follows an autoregressive process:

$$A_t = A_{t-1} \exp\left(\Lambda_A + z_{A,t}\right), \text{ where } z_{A,t} = \sigma_A \varepsilon_{A,t}, \varepsilon_{A,t} \sim \mathcal{N}\left(0,1\right)$$

and

$$z_t = A_t^{\frac{1}{1-\alpha}}.$$

The parameter ϱ corresponds to the fixed cost of production to guarantee that economic profits are zero in the steady state. We have

$$z_t = z_{t-1} \exp\left(\Lambda_z + z_{z,t}\right), \text{ where } z_{z,t} = \frac{z_{A,t}}{1-\alpha} \text{ and } \Lambda_z = \frac{\Lambda_A}{1-\alpha}$$

Intermediate producers solve two problems. First, given w_t and r_t,they rent labor and capital in perfect competitive markets in order to minimize real expenditure. Let Υ be the Lagrangian multiplier. Assuming an interior solution, the first order conditions of this problem are

$$w_t = \Upsilon\left(1-\alpha\right) A_t k_{j,t-1}^{\alpha} l_{j,t}^{-\alpha}$$

$$r_t = \Upsilon \alpha A_t k_{j,t-1}^{\alpha-1} l_{j,t}^{1-\alpha}.$$

These two conditions imply that

$$\frac{u_t K_{t-1}}{L_t} = \frac{\alpha}{1-\alpha}\frac{w_t}{r_t}.$$

The real marginal cost, mc_t^d, is given by the expression

$$mc_t^d = \left(\frac{1}{1-\alpha}\right)^{1-\alpha}\left(\frac{1}{\alpha}\right)^{\alpha}\frac{w_t^{1-\alpha}r_t^{\alpha}}{A_t}.$$

The second problem intermediate producers must solve is to choose the price that maximizes expected discounted real profits. Firms set prices according to a Calvo set-up. In each period, a fraction $1-\theta$ of firms can choose optimally their prices. The price chosen in period t is denoted by p_t. We suppressed the firm's indexation because all firms that have the opportunity to choose the price set the same price. The remaining θ firms cannot choose the price they set. In period t these firms update their price to $p_{j,t-1}\Pi^{1-\chi^d}\Pi_{t-1}^{\chi^d}$, where $p_{j,t-1}$ is the price firm j was charging in period $t-1$, Π_{t-1} is past inflation of the domestic good, Π is the steady state domestic inflation and χ^d is an indexation parameter. The indexation parameter, χ^d, assumes values in the interval $[0,1]$. Each firm uses the stochastic discount factor $(\beta\theta)\,\lambda_t$ to compute the value of its profits. The term λ_t is the marginal utility of the households', evaluated in units of the domestic good, in period t, which is exogenous to the firms.

When a firm can choose its price at date t its problem is:

$$\max_{p_t} E_t \sum_{s=0}^{\infty} (\beta\theta)^s \lambda_{t+s}\left\{\left(\frac{\times_{\tau=1}^{s}\Pi^{1-\chi^d}\Pi_{t+\tau-1}^{\chi^d}p_t}{P_{t+s}} - mc_{t+s}^d\right) y_{j,t+s}\right\}$$

subject to

$$y_{j,t+s} = \left(\frac{\times_{\tau=1}^{s}\Pi^{1-\chi^d}\Pi_{t+\tau-1}^{\chi^d}p_t}{P_{t+s}}\right)^{-\nu^d} Y_{t+s}$$

Where P_t is defined as the minimum expenditure in intermediate inputs to produce one unit of final output.

If the demand function is substituted in the objective function we obtain,

$$\max_{p_t} E_t \sum_{s=0}^{\infty} (\beta\theta)^s \lambda_{t+s} \left(\left(\frac{\times_{\tau=1}^{s} \Pi^{1-\chi^d} \Pi_{t+\tau-1}^{\chi^d}}{\times_{\tau=1}^{s} \Pi_{t+\tau}} \frac{p_t}{P_t} \right)^{1-\nu^d} - mc_{t+s}^d \left(\frac{\times_{\tau=1}^{s} \Pi^{1-\chi^d} \Pi_{t+\tau-1}^{\chi^d} p_t}{\times_{\tau=1}^{s} \Pi_{t+\tau} P_t} \right)^{-\nu^d} \right) Y_{t+s}.$$

A first order condition of the problem above is

$$E_t \sum_{s=0}^{\infty} (\beta\theta)^s \lambda_{t+s} \left(\begin{array}{c} \left(1-\nu^d\right) \left(\frac{\times_{\tau=1}^{s} \Pi^{1-\chi^d} \Pi_{t+\tau-1}^{\chi^d}}{\times_{\tau=1}^{s} \Pi_{t+\tau}} \frac{1}{P_t} \right)^{1-\nu^d} p_t^{-\nu^d} + \\ \nu^d mc_{t+s}^d \left(\frac{\times_{\tau=1}^{s} \Pi^{1-\chi^d} \Pi_{t+\tau-1}^{\chi^d}}{\times_{\tau=1}^{s} \Pi_{t+\tau} P_t} \right)^{-\nu^d} p_t^{-\nu^d-1} \end{array} \right) Y_{t+s} = 0.$$

2.4. Central Bank

The central bank sets the nominal interest rates according to the Taylor rule:

$$\frac{R_t}{R} = \left[\frac{R_{t-1}}{R}\right]^{\gamma_R} \left[\left(\left(\frac{\Pi_t^u}{\Pi^u}\right)^{1-\varsigma} \left(\frac{\Pi_t}{\Pi}\right)^{\varsigma} \right)^{\gamma_\Pi} \left(\left(\frac{Y_t^u}{Y^u}\right)^{1-\varsigma} \left(\frac{Y_t}{Y}\right)^{\varsigma} \right)^{\gamma_Y} \right]^{(1-\gamma_R)} \exp(m_t)$$

where m_t is a random shock to the monetary policy that follows $m_t = \sigma_m \varepsilon_{m,t}$, where $\varepsilon_{m,t} \sim \mathcal{N}(0,1)$. Variable Π^u is the target level for the inflation in the union, which is equal to the steady state inflation in the union, Π_t^u is the inflation in period t in the union without including the small open country, Y^u is the steady-state output in the union, Y_t^u is the output in period t in the union without including the small open country. The parameter ς is the weight of the small open country in the union, while γ_R, γ_Π and γ_Π are the usual parameters of the Taylor rule.

2.5. Government

The budget constraint of the government in the small open economy is:

$$P_t G_t + T_t = M_t - M_{t-1},$$

where G_t is government consumption, which includes only domestic produced goods and we take as exogenous.

2.6. Evolution of Net Foreign Assets

The evolution of net foreign assets at the aggregate level satisfies:

$$S_t B_t^o + B_t^u = S_t R_{t-1}^o \Phi_o(\frac{\mathcal{B}_{t-1}}{z_{t-1}}) B_{t-1}^o + R_{t-1}^u \Phi_u(\frac{\mathcal{B}_{t-1}}{z_{t-1}}) B_{t-1}^u + TB_t.$$

The trade balance is

$$TB_t = P_t X_t^u + P_t X_t^o - P_t^u M_t^u - P_t^o M_t^o.$$

The total imports from the union are $M_t^u = \varpi_{u,c} \left(\frac{P_t^u}{P_t^c}\right)^{-\eta_c} C_t + \varpi_{u,i} \left(\frac{P_t^u}{P_t^i}\right)^{-\eta_i} I_t$ and the total imports from outside of the union are $M_t^o = \varpi_{o,c} \left(\frac{P_t^o}{P_t^c}\right)^{-\eta_c} C_t + \varpi_{o,i} \left(\frac{P_t^o}{P_t^i}\right)^{-\eta_i} I_t$. The total exports to the union are $X_t^u = \varpi_{u,u} \left(\frac{P_t}{P_t^u}\right)^{-\eta^{u,x}} Y_t^u$ and the total exports to outside of the union are $X_t^o = \varpi_{o,o} \left(\frac{P_t}{P_t^o}\right)^{-\eta^{o,x}} Y_t^o$, where $\varpi_{u,u}$ and $\varpi_{o,o}$ are shares, and $\eta^{u,x}$ and $\eta^{o,x}$ are elasticity parameters. The variables Y_t^u and Y_t^o denote the output of the other countries in the union and the output of the countries outside of the union, respectively. The variables Y_t^u and Y_t^o have growth rates z_t^u and z_t^o, respectively.

2.7. Relative Prices

When deciding their consumption and investment baskets agents in the small open economy use the following relative prices: $\xi_t^{c,d} \equiv \frac{P_t^c}{P_t}$ and $\xi_t^{i,d} \equiv \frac{P_t^i}{P_t}$. To decide imports consumers use two relative prices: the relative price between imports from the union and the domestically produced good $\xi_t^{u,d} \equiv \frac{P_t^u}{P_t}$ and the relative price between imports from outside of the union and the domestically produced good $\xi_t^{o,d} \equiv \frac{P_t^o}{P_t}$.

From the definitions of prices we have,

$$\left(\xi_t^{c,d}\right)^{1-\eta_c} = (1-\varpi_{o,c}-\varpi_{u,c}) + \varpi_{o,c}\left(\xi_t^{o,d}\right)^{1-\eta_c} + \varpi_{u,c}\left(\xi_t^{u,d}\right)^{1-\eta_c},$$

$$\left(\xi_t^{i,d}\right)^{1-\eta_i} = (1-\varpi_{o,i}-\varpi_{u,i}) + \varpi_{o,i}\left(\xi_t^{o,d}\right)^{1-\eta_i} + \varpi_{u,i}\left(\xi_t^{u,d}\right)^{1-\eta_i},$$

2.8. Aggregation

The aggregate demand in the small open economy is

$$Y_t = C_t^h + I_t^h + a(u_t)K_{t-1} + G_t + X_t,$$

where C_t^h and I_t^h denotes consumption and investment of the home good. Thus, the demand for each intermediate good producer is:

$$y_{i,t} = \left(C_t^h + I_t^h + a(u_t)K_{t-1} + G_t + X_t\right)\left(\frac{p_{i,t}}{P_t}\right)^{-\nu^d}, \forall i$$

and using the production function is:

$$A_t k_{i,t-1}^{\alpha} l_{i,t}^{1-\alpha} - \varrho z_t = \left(C_t^h + I_t^h + a(u_t)K_{t-1} + G_t + X_t\right)\left(\frac{p_{i,t}}{P_t}\right)^{-\nu^d}.$$

Since all firms have the same optimal capital-labor ratio, $\frac{k_{i,t-1}}{l_{i,t}} = \frac{\alpha}{1-\alpha}\frac{w_t}{r_t}$, and since market clearing implies $\int_0^1 l_{i,t} = L_t$, $\int_0^1 k_{i,t-1} = u_t K_{t-1}$, then $\frac{k_{i,t-1}}{l_{i,t}} = \frac{u_t K_{t-1}}{L_t}$. Also, $A_t k_{i,t-1}^{\alpha} l_{i,t}^{1-\alpha} = A_t\left(\frac{u_t K_{t-1}}{L_t}\right)^{\alpha} l_{i,t}$. Integrating out,

$\int_0^1 A_t \left(\frac{u_t K_{t-1}}{L_t}\right)^\alpha l_{i,t} di = \ A_t \left(\frac{u_t K_{t-1}}{L_t}\right)^\alpha \int_0^1 l_{i,t} di = \ A_t \left(u_t K_{t-1}\right)^\alpha L_t^{1-\alpha}$. Thus,

$$A_t \left(u_t K_{t-1}\right)^\alpha L_t^{1-\alpha} - \varrho z_t = \left(C_t^h + I_t^h + a(u_t) K_{t-1} + G_t + X_t\right) \vartheta_t.$$

where $\vartheta_t = \int_0^1 \left(\frac{p_{i,t}}{P_t}\right)^{-\nu^d} di$.

2.9. Rest of the World

As already referred, the rest of the world is composed by two regions: the remaining countries in the union and the countries outside of the union. We assume that the demands from the other countries for the product produced domestically have the same functional form as the demands by the domestic consumers:

$$X_t^i = \left(\xi_t^{i,d}\right)^{\eta^{i,x}} Y_t^i, \text{ for } i = u, o.$$

The output, inflation and the interest rate in the union and outside of the union are given by two blocks one for each region i, each containing three equations: an IS equation, a Phillips equation and an interest rate equation,

$$Y_t^i = f_Y^i \left(Y_{t-1}^i, Y_{t+1}^i, \Pi_{t+1}^i\right),$$

$$\Pi_t^i = f_\Pi^i \left(\Pi_{t-1}^i, \Pi_{t+1}^i, Y_{t+1}^i\right),$$

and

$$R_t^i = f_R^i (R_{t-1}^i, \Pi_t^i, Y_t^i),$$

for $Y_t^i = Y_t^o$ or $Y_t^i = (1 - \varsigma) Y_t^u + \varsigma Y_t$, $\Pi_t^i = \Pi_t^o$ or $\Pi_t^i = (1 - \varsigma) \Pi_t^u + \varsigma \Pi_t$, and $R_t^i = R_t^o$ or $R_t^i = R_t$. The parameter ς is the size of the domestic country in the union.

2.10. Equilibrium

The definition of equilibrium for this economy is standard. It is a vector of prices, policy variables and quantities that satisfies certain conditions. These conditions are the following:

- The first order conditions of the households;
- The first order conditions of the firms;
- The government's budget constraint;
- The budget constraint with the foreign sector,
- The IS, Phillips and interest rate equations for each region,
- The markets clearing conditions.

3. Solving the model

3.1. Stationary Equilibrium

We want to solve the system of equilibrium equations. However, there are two main difficulties in determining the solution. First, since there is growth in the model, there are variables that are growing and others that are stationary. Thus, to solve the model we need to make the variables stationary. Second, the equilibrium equations are non-linear difference equations and typically their solution is not trivial. The usual procedure involves simplifying each equation of the system. Each equation of the system is approximated by a linear equation. More specifically each equation is replaced by its first order Taylor approximation. That approximation is taken around the equilibrium steady state.

We start by redefining the variables to obtain a system in stationary variables. Let the stationary variables have a upper bar. Thus, $\overline{C}_t = \frac{C_t}{z_t}$, $\overline{\lambda}_t = \lambda_t z_t$, $\overline{r}_t = r_t$, $\overline{q}_t = q_t \equiv \frac{Q_t}{\lambda_t}$, $\overline{I}_t = \frac{I_t}{z_t}$, $\overline{w}_t = \frac{w_t}{z_t}$, $\overline{K}_t = \frac{K_t}{z_t}$, $\overline{Y}_t = \frac{Y_t}{z_t}$,

$\frac{S_{t+1}}{S_t} = \Omega_{t+1}, \overline{\mathcal{B}}_t^o = \frac{S_t B_t^o}{z_t P_t}$, and $\overline{\mathcal{B}}_t^u = \frac{B_t^u}{z_t P_t}$. The transformation of the original system of equations into a system of equations with stationary variables is trivial, but involved, and it will not be described here.

Next, we compute the steady equilibrium. More notation needs to be introduced, we adopt the convention that the value of a variable at its steady state does not have subscript. For instance $\overline{C}$ is the steady state value of $\overline{C}_t$. Let $\overline{z} = \exp(\Lambda_z)$, and $\overline{A} = \exp(\Lambda_A)$. In order to find the steady state we need to give functional forms to $a\,(.)$, $V\,(.)$ and $\Phi(.)$. Let $a\,(u) = \gamma_1\,(u-1) + \frac{\gamma_2}{2}\,(u-1)^2$. Since in the steady state we have $u = 1$, then $a\,(1) = 0$ and $a'\,(1) = \gamma_1$. The investment adjustment cost function is given by $V\left[\frac{I_t}{I_{t-1}}\right] = \frac{\kappa}{2}\left[\frac{I_t}{I_{t-1}} - \Lambda_I\right]^2$. Thus, in the steady state, $V\,[\Lambda_I] = V'\,[\Lambda_I] = 0$. Finally the volume premium factor is given by $\Phi_i(\overline{\mathcal{B}}_t) = \exp(-\phi_i\left(\overline{\mathcal{B}}_t - \overline{\mathcal{B}}\right))$, at the steady state $\Phi_i(\overline{\mathcal{B}}) = 1$ for $i = u, o$. Additionally, there are stationary processes $\frac{z_t^u}{z_t} = \overline{z}_t^u$ and $\frac{z_t^o}{z_t} = \overline{z}_t^o$. The process $\overline{z}_t^u$ measures the degree of asymmetry between the domestic shock and the rest of the union shock, and $\overline{z}_t^o$ measures the degree of asymmetry between the domestic shock and the outside of the union shock. In the steady state $\frac{z^u}{z} = \frac{z^o}{z} = 1$.

Using these functional forms the system of equations that determines the steady state can be written as:

equation 1:

$$R = \frac{\Pi \overline{z}}{\beta}$$

equation 2:

$$\overline{r} = \gamma_1$$

equation 3:

$$\overline{q} = \frac{\overline{r}}{\left[\frac{\overline{z}}{\beta} - (1-\delta)\right]}$$

equation 4:

$$\xi^{i,d} = \overline{q}$$

equation 5:

$$mc = \frac{\nu^d - 1}{\nu^d},$$

equation 6:

$$\xi^{i,d} = \left[(1 - \varpi_{o,i} - \varpi_{u,i}) + \varpi_{o,i}\left(\xi^{o,d}\right)^{1-\eta_i} + \varpi_{u,i}\left(\xi^{u,d}\right)^{1-\eta_i}\right]^{\frac{1}{1-\eta_i}}.$$

equation 7:

$$\xi^{c,d} = \left[(1 - \varpi_{o,c} - \varpi_{u,c}) + \varpi_{o,c}\left(\xi^{o,d}\right)^{1-\eta_c} + \varpi_{u,c}\left(\xi^{u,d}\right)^{1-\eta_c}\right]^{\frac{1}{1-\eta_c}},$$

equation 8:

$$\begin{aligned} \overline{w} &= \left[\frac{mc}{\left(\frac{1}{1-\alpha}\right)^{1-\alpha}\left(\frac{1}{\alpha}\right)^{\alpha}(\overline{r})^{\alpha}}\right]^{\frac{1}{1-\alpha}} \\ &= (1-\alpha)\left[mc\left(\frac{\alpha}{\overline{r}}\right)^{\alpha}\right]^{\frac{1}{1-\alpha}} \end{aligned}$$

equation 9:

$$\overline{C} = \frac{\left(\frac{\frac{\nu^w - 1}{\nu^w}\overline{w}}{1 - \frac{b}{\overline{z}}}\right)\left(1 - \frac{\beta b}{\overline{z}}\right)}{\xi^{c,d}\xi L^{\psi}}$$

equation 10:

$$\overline{K} = \left(\frac{\alpha}{1-\alpha}\frac{\overline{w}}{\overline{r}}\overline{z}\right)L$$

equation 11:

$$\overline{I} = \overline{K}\frac{\overline{z} - (1-\delta)}{\overline{z}}$$

equation 12:

$$\overline{X^u} = \left(\xi^{u,d}\right)^{\eta^{u,x}} \frac{z^u}{z}\overline{Y}^u$$

equation 13:

$$\overline{X^o} = \left(\xi^{o,d}\right)^{\eta^{o,x}} \frac{z^o}{z}\overline{Y}^o$$

equation 14:

$$\overline{\mathcal{B}} \equiv \overline{\mathcal{B}}^o + \overline{\mathcal{B}}^u = \frac{\beta}{\beta-1}\left\{\overline{X^u} + \overline{X^o} - \xi^{u,d}\overline{M^u} - \xi^{o,d}\overline{M^o}\right\}$$

equation 15:

$$\overline{M^u} = \varpi_{u,c}\left(\frac{\xi^{u,d}}{\xi^{c,d}}\right)^{-\eta_c}\overline{C} + \varpi_{u,i}\left(\frac{\xi^{u,d}}{\xi^{i,d}}\right)^{-\eta_i}\overline{I}$$

equation 16:

$$\overline{M^o} = \varpi_{o,c}\left(\frac{\xi_t^{o,d}}{\xi_t^{c,d}}\right)^{-\eta_c}\overline{C} + \varpi_{o,i}\left(\frac{\xi^{o,d}}{\xi^{i,d}}\right)^{-\eta_i}\overline{I}$$

equation 17:

$$\overline{Y} \; = (1-\varpi_{o,c}-\varpi_{u,c})\left(\xi^{c,d}\right)^{\eta_c}\overline{C} + (1-\varpi_{o,i}-\varpi_{u,i})\left(\xi^{i,d}\right)^{\eta_i}\overline{I} + \overline{G} + \overline{X}^u + \overline{X}^o$$

equation 18:

$$\frac{\frac{\overline{A}}{\overline{\overline{z}}}\left(\overline{K}\right)^{\alpha} L^{1-\alpha} - \varrho}{\vartheta} \; = \overline{Y}$$

with

$$\vartheta = 1$$

3.2. Loglinear Approximations

Now we loglinearize the system of equilibrium conditions for the stationarized variables around the deterministic steady state. The variables with an hat denote logdeviations from the deterministic steady state. All variables are written in logdeviations except the net foreign assets which are written in deviations instead, since it can be assumed that its steady state is zero. Thus, the system of linear stochastic difference equations that needs to be solved is the following:

Equation 1:

$$-\widehat{\overline{r}}_t + \phi_u \widehat{u}_t \ = 0.$$

where $\phi_u = \frac{\gamma_2}{\gamma_1}$.

Equation 2:

$$\frac{(1-\delta)}{\overline{z}}\widehat{\overline{K}}_{t-1} + \left(1 - \frac{(1-\delta)}{\overline{z}}\right)\widehat{\overline{I}}_t - \frac{(1-\delta)}{\overline{z}}\widehat{\overline{z}}_t - \widehat{\overline{K}}_t = 0$$

Equation 3:

$$(1-\alpha)\,\widehat{\overline{w}}_t + \alpha\widehat{\overline{r}}_t - \widehat{mc}_t^d = 0$$

Equation 4:

$$\widehat{u}_t + \widehat{\overline{r}}_t + \widehat{\overline{K}}_{t-1} - \widehat{L}_t - \widehat{\overline{w}}_t - \widehat{\overline{z}}_t - \widehat{\overline{\mu}}_t = 0.$$

Equation 5:

$$\overline{Y}\widehat{\overline{Y}}_t - \ddot{Y}\widehat{\overline{A}}_t + \ddot{Y}\widehat{\overline{z}}_t - \alpha\ddot{Y}\widehat{u}_t - \alpha\ddot{Y}\widehat{\overline{K}}_{t-1} - (1-\alpha)\,\ddot{Y}\widehat{L}_t = 0$$

where $\ddot{Y} = \frac{\overline{A}}{\overline{z}}\left(u\overline{K}\right)^{\alpha} L^{1-\alpha}$.

Equation 6:

$$
\begin{aligned}
&(1-\varpi_{o,c}-\varpi_{u,c})\left(\xi^{c,d}\right)^{\eta_c}\overline{C}\left[\eta_c\widehat{\xi^{c,d}_t}+\widehat{\overline{C}}_t\right]+(1-\varpi_{o,i}-\varpi_{u,i})\left(\xi^{i,d}\right)^{\eta_i}\overline{I}\left[\eta_i\widehat{\xi^{i,d}_t}+\widehat{\overline{I}}_t\right]\\
&+\frac{\gamma_1\overline{K}}{\overline{z}}\widehat{u}_t+\overline{G}\widehat{G}_t+\overline{X}^u\widehat{X}^u_t+\overline{X}^o\widehat{X}^o_t-\overline{Y}\widehat{Y}_t\ =0
\end{aligned}
$$

Equation 7:

$$
\begin{aligned}
\widehat{\overline{\mathcal{B}}}_t=\frac{\Omega R^o}{\Pi\overline{z}}\widehat{\overline{\mathcal{B}}}_{t-1}+\overline{X^u}\left(\widehat{\overline{X^u_t}}\right)+\overline{X^o}\left(\widehat{\overline{X^o_t}}\right)-\xi^{u,d}\overline{M^u}\left(\widehat{\xi^{u,d}_t}+\widehat{\overline{M^u_t}}\right)-\xi^{o,d}\overline{M^o}\left(\widehat{\xi^{o,d}_t}+\widehat{\overline{M^o_t}}\right)+\\
\frac{R^u\overline{\mathcal{B}}^u}{\Pi\overline{z}}\left(\widehat{R^u_{t-1}}-\phi^u_b\widehat{\overline{\mathcal{B}}}_{t-1}-\widehat{\Pi}_t-\widehat{\overline{z}}_t\right)+\frac{\Omega R^o\overline{\mathcal{B}}^o}{\Pi\overline{z}}\left(\widehat{R^o_{t-1}}-\phi^o_b\widehat{\overline{\mathcal{B}}}_{t-1}+\widehat{\Omega}_t-\widehat{\Pi}_t-\widehat{\overline{z}}_t\right)
\end{aligned}
$$

If in steady state both of the foreign debts, $\overline{\mathcal{B}}^o$ and $\overline{\mathcal{B}}^u$, are zero then we have

$$
\widehat{\overline{\mathcal{B}}}_t=\frac{\Omega R^o}{\Pi\overline{z}}\widehat{\overline{\mathcal{B}}}_{t-1}+\overline{X^u}\left(\widehat{\overline{X^u_t}}\right)+\overline{X^o}\left(\widehat{\overline{X^o_t}}\right)-\xi^{u,d}\overline{M^u}\left(\widehat{\xi^{u,d}_t}+\widehat{\overline{M^u_t}}\right)-\xi^{o,d}\overline{M^o}\left(\widehat{\xi^{o,d}_t}+\widehat{\overline{M^o_t}}\right)
$$

Equation 8:

$$
\begin{aligned}
\overline{M^u}\widehat{\overline{M^u_t}} \quad &= \quad \varpi_{u,c}\left(\frac{\xi^{u,d}}{\xi^{c,d}}\right)^{-\eta_c}\overline{C}\left(-\eta_c\left(\widehat{\xi^{u,d}_t}-\widehat{\xi^{c,d}_t}\right)+\widehat{\overline{C_t}}\right)+\\
&\quad\ \varpi_{u,i}\left(\frac{\xi^{u,d}}{\xi^{i,d}}\right)^{-\eta_i}\overline{I}\left(-\eta_i\left(\widehat{\xi^{u,d}_t}-\widehat{\xi^{i,d}_t}\right)+\widehat{\overline{I}_t}\right)
\end{aligned}
$$

Equation 9:

$$\begin{aligned}\overline{M^o}\widehat{M_t^o} &= \varpi_{o,c}\left(\frac{\xi^{o,d}}{\xi^{c,d}}\right)^{-\eta_c}\overline{C}\left(-\eta_c\left(\widehat{\xi_t^{o,d}}-\widehat{\xi_t^{c,d}}\right)+\widehat{\overline{C}_t}\right)+\\ &\quad \varpi_{o,i}\left(\frac{\xi^{o,d}}{\xi^{i,d}}\right)^{-\eta_i}\overline{I}\left(-\eta_i\left(\widehat{\xi_t^{o,d}}-\widehat{\xi_t^{i,d}}\right)+\widehat{\overline{I}_t}\right)\end{aligned}$$

Equation 10:

$$\widehat{\overline{X_t^u}} = \eta^{u,x}\widehat{\xi_t^{u,d}} + \widehat{\overline{Y}^u_t} + \widehat{\overline{z_t^u}}$$

Equation 11:

$$\widehat{\overline{X_t^o}} = \eta^{o,x}\widehat{\xi_t^{o,d}} + \widehat{\overline{Y}^o_t} + \widehat{\overline{z_t^o}}$$

Equation 12:

$$\left(\xi^{c,d}\right)^{1-\eta_c}\widehat{\left(\xi_t^{c,d}\right)} = \varpi_{o,c}\left(\xi^{o,d}\right)^{1-\eta_c}\widehat{\left(\xi_t^{o,d}\right)} + \varpi_{u,c}\left(\xi^{u,d}\right)^{1-\eta_c}\widehat{\left(\xi_t^{u,d}\right)},$$

Equation 13:

$$\left(\xi^{i,d}\right)^{1-\eta_i}\widehat{\left(\xi_t^{i,d}\right)} = \varpi_{o,i}\left(\xi^{o,d}\right)^{1-\eta_i}\widehat{\left(\xi_t^{o,d}\right)} + \varpi_{u,i}\left(\xi^{u,d}\right)^{1-\eta_i}\widehat{\left(\xi_t^{u,d}\right)},$$

Equation 14: is the loglinearization of

$$\xi_t^{u,d} = \xi_{t-1}^{u,d}\frac{\Pi_t^u}{\Pi_t}$$

or

$$\widehat{\xi_t^{u,d}} = \widehat{\xi_{t-1}^{u,d}} + \widehat{\Pi}_t^u - \widehat{\Pi}_t$$

Equation 15:

$$\widehat{\xi_t^{o,d}} = \widehat{\xi_{t-1}^{o,d}} + \widehat{\Pi}_t^o - \widehat{\Pi}_t + \widehat{\Omega}_t$$

Equation 16: is the central bank interest rate rule,

$$\widehat{R}_t = \gamma_R \widehat{R}_{t-1} + (1-\gamma_R)\,\gamma_\Pi \left[(1-\varsigma)\,\widehat{\Pi}^u_t + \varsigma \widehat{\Pi}_t\right] + (1-\gamma_R)\,\gamma_Y \left[(1-\varsigma)\,\widehat{\overline{Y}}^u_t + \varsigma \widehat{\overline{Y}}_t\right] + \widehat{m}_t$$

Equation 17:

$$E_t \left[\tfrac{b}{\overline{z}\left(1-\frac{b}{\overline{z}}\right)} \widehat{\overline{C}}_{t-1} - \left(\tfrac{1+\frac{\beta b^2}{\overline{z}^2}}{1-\frac{b}{\overline{z}}}\right) \widehat{\overline{C}}_t + \tfrac{\beta b/\overline{z}}{1-\frac{b}{\overline{z}}} \widehat{\overline{C}}_{t+1} - \tfrac{b/\overline{z}}{1-\frac{b}{\overline{z}}} \widehat{\overline{z}}_t - \left(\widehat{\xi^{c,d}_t} + \widehat{\overline{\lambda}}_t\right) \left\{1 - \tfrac{\beta b}{\overline{z}}\right\}\right] = 0$$

Equation 18:

$$0 = \tfrac{(1-\beta\theta^w)(1-\theta^w)}{(1+\nu^w\psi)} \left[-\widehat{\lambda}_t + \nu^w \psi \widehat{w}_t + \psi \widehat{L}^d_t\right] + \beta\theta^w E_t \left(\Pi_{t+1} - \chi^w \widehat{\Pi}_t + \widehat{\overline{z}}_{t+1} - \chi^p \widehat{\overline{z}}_t\right)$$

$$-\theta^w \left(\Pi_t - \chi^w \widehat{\Pi}_{t-1} + \widehat{\overline{z}}_t - \chi^p \widehat{\overline{z}}_{t-1}\right) + \theta^w \widehat{w}_{t-1} + \beta\theta^w E_t \widehat{w}_{t+1} - \left(1 + \beta\,(\theta^w)^2\right) \widehat{w}_t]$$

Equation 19:

$$E_t \left\{\widehat{\overline{\lambda}}_{t+1} + \widehat{R}_t - \widehat{\Pi}_{t+1} - \widehat{\overline{z}}_{t+1} - \widehat{\overline{\lambda}}_t\right\} = 0$$

Equation 20:

$$E_t \left\{\widehat{\overline{\lambda}}_{t+1} - \widehat{\overline{z}}_{t+1} + \widehat{R^u_t} - \phi_u \widehat{\overline{\mathcal{B}}_t} - \widehat{\Pi}_{t+1} - \widehat{\overline{\lambda}}_t\right\} = 0.$$

Equation 21:

$$E_t \left\{\widehat{\overline{\lambda}}_{t+1} - \widehat{\overline{z}}_{t+1} + \widehat{\Omega}_{t+1} + \widehat{R^o_t} - \phi_o \widehat{\overline{\mathcal{B}}_t} - \widehat{\Pi}_{t+1} - \widehat{\overline{\lambda}}_t\right\} = 0.$$

Equation 22:

$$E_t \left(\widehat{\overline{\lambda}}_{t+1} - \widehat{\overline{\lambda}}_t + \frac{\beta\,(1-\delta)}{\overline{z}} E_t \widehat{\overline{q}}_{t+1} + \left(1 - \frac{\beta\,(1-\delta)}{\overline{z}}\right) E_t \widehat{\overline{r}}_{t+1} - \widehat{\overline{q}}_t\right) = 0$$

Equation 23:

$$E_t\left(\widehat{q}_t+\beta\kappa\overline{z}^2E_t\widehat{\overline{I}}_{t+1}-\kappa\overline{z}^2\left(1+\beta\right)\widehat{\overline{I}}_t+\kappa\overline{z}^2\widehat{\overline{I}}_{t-1}-\kappa\overline{z}^2\widehat{\overline{z}}_t-\widehat{\xi_t^{i,d}}\right)=0.$$

Equation 24:

$$\widehat{\Pi}_t-\chi^d\widehat{\Pi}_{t-1}=\beta\left(E_t\widehat{\Pi}_{t+1}-\chi^d\widehat{\Pi}_t\right)+\frac{\left(1-\beta\theta\right)\left(1-\theta\right)}{\theta}\left[\widehat{mc}_t^d-\frac{1}{\nu^d-1}\widehat{\nu}_t^d\right].$$

Equation 25:

$$\begin{aligned}\left(1-\varsigma\right)\widehat{\overline{Y}_t^u}+\varsigma\widehat{\overline{Y}}_t &= \alpha_1\left(\left(1-\varsigma\right)\widehat{\overline{Y}_{t-1}^u}+\varsigma\widehat{\overline{Y}}_{t-1}\right)+(1-\alpha_1)E_t\left(\left(1-\varsigma\right)\widehat{\overline{Y}_{t+1}^u}+\varsigma\widehat{\overline{Y}}_{t+1}\right)+\\ &\quad \alpha_2E_t\left(\left(1-\varsigma\right)\widehat{\Pi_{t+1}^u}+\varsigma\widehat{\Pi}_{t+1}\right)+\widehat{\varepsilon_{Y}}_t\end{aligned}$$

Equation 26:

$$\begin{aligned}\left(1-\varsigma\right)\widehat{\Pi_t^u}+\varsigma\widehat{\Pi}_t &= \alpha_3\left(\left(1-\varsigma\right)\widehat{\Pi_{t-1}^u}+\varsigma\widehat{\Pi}_{t-1}\right)+\alpha_4E_t\left(\left(1-\varsigma\right)\widehat{\Pi_{t+1}^u}+\varsigma\widehat{\Pi}_{t+1}\right)+\\ &\quad \alpha_5E_t\left(\left(1-\varsigma\right)\widehat{\overline{Y}_{t+1}^u}+\varsigma\widehat{\overline{Y}}_{t+1}\right)+\widehat{\varepsilon_{\Pi}}_t\end{aligned}$$

The exogenous processes are $\left\{\widehat{\overline{z}}_t,\widehat{\overline{z_t^u}},\widehat{\overline{z_t^o}},\widehat{m}_t,\widehat{\overline{Y}^o}_t,\widehat{R}_t^o,\widehat{\Pi}_t^o,\widehat{\varepsilon_{Y}}_t,\widehat{\varepsilon_{\Pi}}_t\right\}$.

3.3. Solution

There are a few available algorithms designed to solve the type of difference equations system described in the previous subsection. We used the one developed by Uhlig (1995). Let $state_t$ denote the vector of endogenous state variables and $nstate_t$ denote the vector of endogenous non-state variables. Uhlig's algorithm enables us to write all variables as linear functions of the vector $state_{t-1}$, and a vector of exogenous variables exo_t which are given at date t. More formally, it gives us matrices P, Q , R and S so that the equilibrium described by the recursive equilibrium law of motion

$$state_t = P * state_{t-1} + Q * exo_t$$

and

$$nstate_t = R * state_t + S * exo_t$$

is stable.

4. Calibration

Most of the parameters can be related to the steady state values of the variables in the model and therefore, can be calibrated so as to match the sample mean of these. Others were taken from the literature. Whenever there were various alternatives for the parameters we took the one used by Adolfson et al (2007). Proceeding in that way we minimized the dimensions in which Portugal is different from the Euro area. That makes it easier to identify the causes for the differences between the results obtained for Portugal and the ones for the Euro area obtained by Adolfson et al (2007).

Many of the parameters were calibrated using the "Quarterly Series for the Portuguese Economy" data set, which refers to the period 77:Q1-07:Q4. This data set is included in the Economic Bulletin of the Bank of Portugal, Summer 2008, and is available online. For the period that starts in 1999, the year in which Portugal entered the European Monetary Union, and ends in 2007, per capita Private Consumption grew at 0.29 percent quarterly, per capita Public Consumption grew at 0.32 percent quarterly, per capita Investment grew at -0.11 percent quarterly, per capita GDP grew at 0.25 percent quarterly, per capita Exports grew at 1.05 percent quarterly and per capita Imports grew at 0.79 percent quarterly. We considered the average growth rate of z_t to be 0.25 percent quarterly, which is the growth rate of real GDP per capita in the period 99:Q1-07:Q4.

The stock of capital was computed using data on the different types of investment, a set of depreciation rates, one for each type of capital and equations for the law of motion of the different types of capital, $K_{j,t}$, given by

$$K_{j,t} = (1 - \delta_{j,t}) K_{j,t-1} + I_{j,t}.$$

The per capita aggregate stock of capital, obtained according to this method, grew in the period 78:Q1-07:Q4 at the rate of 0.77 percent quarterly. The quarterly depreciation rate, δ, obtained was 0.011.

For many reasons it is difficult to determine the steady state real interest rate relevant for the representative Portuguese consumer. The average real interest rate measured by the difference between the 3 month money market interest rate and the realized inflation rate was 0.041 percent quarterly in the period 99:Q1-07:Q4.[1] The usefulness of this real interest rate is problematic as it implies a discount factor, β, larger than one. As such we discarded it and considered alternatives. The other available nominal interest rate series are implicit interest rates. They are obtained either by dividing interest received on bank deposits by bank deposits or by dividing interest received on bank loans by the bank loans. The interest rates on deposits we discard as they also imply a discount factor larger than one too. Among the interest rates on credit, the mortgage interest rate is our preferred, as it is the lowest and the most relevant for the representative consumer. The average real interest rate measured by the difference between the implicit mortgage interest rate and the realized inflation rate was 0.46 percent quarterly in the period 99:Q1-07:Q4. These values together with the values assumed for the growth rate of z_t imply a value of β equal to 0.998. This value of β is high, but Adolfson et al (2007) consider an even higher value of β for the euro area, 0.999.

Following Adolfson et al (2007), we set the labor supply elasticity, ψ, to 1 and the habit parameter to 0.65. Christiano et al (2005) consider similar values for these parameters. The constant in the labor desutility function, ξ, is chosen so that in the steady state agents work 30 percent of their time. Adolfson et al (2007) assume agents work 30 percent of their time while Chari et al (2002) assume agents work 25 percent of their total time in steady

[1] This money market interest rate series is the 3-month EURIBOR, and the inflation used was the GDP deflator growth.

state.

We considered labor income to be the sum of "Remunerações do Trabalho" plus "Contribuições para a Segurança Social" and capital income to be all the remaining domestic income.[2] We took as the value of α, the sample mean of the ratio between non-labor income and domestic income, which for the period 99:07 is 0.27. The value that Adolfson et al. (2007) consider to be the share of capital for EMU is 0.29.

The share of imports in the main components of the domestic expenditure were obtained from the national input-output matrices of INE. That calculation, which is involved, was only done for the period 1996-1999. During that period the average share of private consumption that was imported was 27 percent and for the same period the average percentage of investment that was imported was 33 percent. The sample mean, for the period 99:1-07:4, of the share of imports from the euro area was 66 percent and the share of imports from countries outside of the euro area was 34 percent. The percentage of imported consumption from the union was assumed to be proportional to the ratio between total imports from the Euro area and aggregate imports. Thus, the share, $\varpi_{u,c}$, was calibrated to match the sample mean, 0.18. Under this assumption, the other parameters, $\varpi_{u,i}$, $\varpi_{o,c}$, and $\varpi_{o,i}$, were set to 0.22, 0.09 and 0.11. For the period, 99:1-07:4, the ratio between the price of investment and the GDP deflator and the ratio between the price of consumption and the GDP deflator, which we denoted by $\xi^{i,d}$ and $\xi^{c,d}$, averaged 0.98 and 0.99. For the other relative prices $\xi^{o,d}$ and $\xi^{u,d}$ we do not have information. Thus, we cannot use equations 6 and 7 to determine the values of η_c and η_i. Studies seem to indicate that for the United States the elasticity between home goods and foreign goods is between 1 and 2, and values in this range are generally used in empirical trade models. (See, for example, the survey by Stern et al (1976).) For Europe, that seems to be the case also. (See, for example, the discussions of Collard and Dellas (2002), Whalley (1985, Ch. 5) and Deardorff and Stern (1990, Ch. 3).) For the United States Chari et al. (2002) and Backus et al (1994) set the substitution elasticity between foreign and domestic investment goods equal to 1.5. For Europe Christoffel

[2] As the national accounting data of GDP includes net indirect taxes, these need to be subtracted to the GDP to obtain the domestic income.

et al (2008) estimate $\eta_c = 1.9$ and $\eta_i = 1.6$. In view of the above we set $\eta_c = 1.5$ and η_i equal to 1.6, which are the estimates obtained by Adolfson et al (2007) for the euro area. We set both $\eta^{u,x}$ and $\eta^{o,x}$ equal to 1.5. The results are robust to changes of the η's within the interval $[1, 2]$.

The evidence from survey data, as described in Fernando Martins (2006), indicates that the frequency of price changes by Portuguese firms is 1.9 times per year. And of those firms that change prices only about 42 percent use current and future information to set their price. This implies that in each quarter about 20 percent of the firms change their prices optimally. This value is higher than the one estimated by Smets and Wouters (2003) and Adolfson et al (2007) which is around 10 percent, but lower than the one estimated by Christiano et al (2005), 40 percent. Following Adolfson et al (2007) we set the mark-up equal to 16 percent.[3] We set the indexation parameter, χ^d, equal to 0.22, which is the value estimated by Adolfson et al (2007) for the euro area. Following Adolfson et al (2007) and Christiano et al (2005), the markup power in wage setting is set to 1.05. Following Adolfson et al (2007), the indexation of wages, parameter, χ^w, is set to 0.50, and the probability of not being able to change the wage, θ^w, is set equal to 0.69.

Under our assumptions, the steady state of the model is independent of the adjustment cost functions, but the dynamics depend on them. The estimates in the literature concerning the adjustment costs of investment, capital utilization and foreign debt differ substantially. Christiano et al (2005) find estimates of 2.48 and 0.01 for V'' and $\frac{\gamma_2}{\gamma_1}$, respectively. Altig et al (2003) find a value of 0.049 for $\frac{\gamma_2}{\gamma_1}$. Adolfson et al (2007) estimate a value of a 8.67 for V'' and estimate a value of 0.252 for ϕ_b.[4] We took the values reported in Adolfson et al (2007).

It is common in the literature, including Adolfson et al (2007), to assume that in the steady state exports are equal to imports, and the net foreign debt is zero. For Portugal the net value of exports has been consistently negative. The average net value of exports was 10 percent of the GDP value for the period 1954-2007, and for the

[3] Chari et al (2005) have a mark-up of 11%.

[4] These divergent results in the literature are due to the fact that the data sets are divergent and to the different estimation techniques used. Adolfson et al (2007) use Bayesian estimation techniques while Christiano et al (2005) match the impulse response functions of the identified shocks.

more recent period, 1977-2007, they were negative and on average about 9 percent of the GDP value. According to this evidence, it would seem that the steady state net foreign assets for Portugal would be a substantial positive amount. However, this is contradicted by the fact that Portuguese net foreigns assets have been been negative and decreasing. In 2007 the net foreigns responsabilities were 90 per cent of GDP, being 83 per cent denominated in euros. Without excuses we consider a calibration in which the net foreign assets are in steady state -90 per cent of GDP and that 83 per cent are denominated in euros.

During the period 99:01-07:04 the share of the exports to countries outside of the euro area was 0.37, while as referred before, the share of imports from countries outside the euro area was 0.34. The parameters chosen replicate approximately these ratios as well as the average sample shares in the GDP of private consumption, public consumption, investment, total exports and total imports.

The behavior of the nominal interest rate, output and inflation in the union is determined by equations (16), (24) and (25). The parameters of these equations were chosen so that the impulse response function of these variables to a monetary shock could mimic the impulse response function of these variables to a monetary shock in the model estimated by Adolfson et al (2007) for the Euro area. The parameters of the interest rate rule are similar to the ones estimated for the Euro area by Adolfson et al (2007) and Smets and Wouters (2003). The parameter ς reflects the size of Portugal and is set to 0.05. The parameters in the equations that determine the nominal interest rate, output and inflation outside the union do not need to be specified as we assumed these variables are not affected by a monetary policy shock in the union.

5. Impulse Response Functions

Except for the inflations, nominal interest rate and interest rate premium, which are reported as annualized quarterly rates, the graphs associated with the impulse response functions have on the y-axis the percentage deviations of the variables from their steady state values. The shock considered is a white noise shock to the nominal interest rate.

There is a feature on the impulse response functions worth noting. As can be seen from Figure 1, with the exception of the variables associated with trade, most of the variables respond in a hump-shaped form, peaking after 3 or 4 quarters and returning to the preshock levels after about three years. The exceptions are the nominal exchange rate, some relative prices and the different imports and exports.

The euro area variables: nominal interest rate, inflation and output replicate closely the path of the impulse responses of these variables to a monetary shock in the Adolfson et al (2007) model. On impact the nominal interest rate drops by 40 basis points and returns to the steady state four years later. Both output and inflation have hump-shaped responses and achieve their peaks after about one year, around 0.3 percent of the steady state for the output and around 10 basis points (annualized) for inflation.

The small open economy responses to the monetary shock are roughly similar to the ones obtained in a closed economy, even though the model possesses an additional channel of monetary policy transmission. We summarize these responses now. Because prices are sticky, the unexpected decrease in the nominal interest rate implies a decrease in the real interest rate. A lower real interest rate makes bonds less attractive than investment, which leads to an increase in investment. As the stock of capital increases the marginal productivity of labor increases also and firms increase their labor demand.

The temporary lower real interest rate has intertemporal substitution effects over consumption and labor supply. It makes present consumption and present leisure (since nominal wages are sticky) relatively less expensive, which lead households to increase consumption and decrease labor supply. The changes in the labor supply and labor demand lead to an increase in the real wage. Output increases, since consumption and investment increase, and capital utilization increases because there are costs in adjusting capital. As consumption and investment increase the demand for imports increases.

The additional channel for the monetary policy transmission associated with an open economy compels firms to increase production too. In a closed economy households can only smooth out the path of consumption and leisure by varying the path of investment. But in an open economy households have another alternative to accomplish that, the possibility of changing the path of net exports. The monetary shock considered leads to an increase in the domestic income. In order to smooth their path of consumption and leisure households increase their net foreign assets. This behavior of foreign assets implies an increase in net exports and a further increase in the output. After the shock, the stock of net foreign assets is above its steady state value for about four years.

There is an additional income effect in Portugal that is absent in the Adolfson et al (2007) calibrated EMU. They assumed that the net foreign assets of the EMU in the steady state were zero, but we assumed that for Portugal the steady state net foreign assets were negative, -90 per cent of GDP, and that 83 per cent were denominated in euros. Thus, due to the high stock level of the net foreign assets denominated in euro, the impact of a drop in the euro interest rate is favourable for Portugal, but irrelevant for the EMU. For this reason, it should be expected that investment and output in Portugal would vary more than investment and output in the EMU.

In fact the output increases in percentage deviations from the steady state a little more in Portugal than in the Euro area. The impulse response function for the output in Portugal is almost all the time above the one for the EMU. For Portugal the maximum response is just over 0.3 and in the EMU it is just below 0.3. The investment, employment and real wage in Portugal and in the EMU, as computed by Adolfson et al (2007), have similar shapes but in Portugal those variables move considerably more. The impulse response functions for investment, employment and real wage in Portugal are almost all the time above the ones for the EMU. For Portugal the maximum response for investment is just about 0.6, for employment is about 0.25, and for the real wage about 0.1, while for the EMU the maximum response for investment is about 0.5, for employment is about 0.2 and for the real wage is about 0.07. Consumption in Portugal and in the Euro area have almost identical paths.

Inflation in Portugal responds quicker to the shock than the inflation in the Euro area, on impact it increases by more and returns faster to the steady state. The maximum increase of inflation in Portugal is 16 basis points while that maximum in the EMU is around 10 basis points. This should be associated with the fact that we assumed that in Portugal each quarter 20 percent of the firms change their prices optimally, while Adolfson et al (2007) took that only 10 percent of the firms in the EMU change their prices optimally.

The relative price of the Euro area's good is persistently below the steady state in response to the shock due to the referred differentiated behavior of inflation in Portugal and in the euro area. This fact, together with the shock having an impact in the output relatively higher in Portugal than in the Euro area, implies that imports from the Euro area increase more than exports to the Euro area, in response to the shock.

Consumption in Portugal and in the Euro area have almost identical paths. This result is very interesting. It indicates that the households in Portugal use the saving instruments available to them to too smooth out consumption, and are able to replicate the impulse response path of their euro area counterparts, even though, as we saw above, the effects of the shock are stronger in Portugal than in the euro area.

Now we interpret the behavior of the exchange rate. From equations 19 and 21 we obtain the UIP condition $E_t\widehat{\Omega}_{t+1} = \widehat{R_t} - \widehat{R_t^o} + \phi_o\widehat{\mathcal{B}_t}$. The UIP does not restrict the depreciation rate of the euro in the impact period. Apart from the impact period, the nominal exchange rate behavior is the one implied by the UIP. The foreign interest rate is unchanged and the volume premium changes little, as the adjustment costs of the asset stocks were assumed to be relatively small. In the initial periods, just after the impact period, the euro appreciates as the decrease in the interest rate is larger in absolute value than the decrease in the volume premium on the foreign debt, and in the last periods it depreciates as the opposite happens.

In the impact period the currency depreciates because, as we observed before, net exports must increase. Net exports to the Euro area did not increase due to the evolution, described above, of the main aggregate variables in Portugal and in the Euro area. Thus, in order for net exports to increase, net exports to outside of the union must increase. That is possible only if the relative price of the good produced outside of the union increases, given that we assumed that the main aggregate economic variables outside of the union were constant. Equation

15 says that for the relative price of the good produced outside of the union to be persistently above its steady state it is necessary that on impact the euro depreciates sufficiently to compensate its subsequent appreciation and the persistent domestic inflation. Summing up, in the short run, lower real interest rates in the Euro area tend to reduce the foreign exchange value of the euro, which lowers the relative prices of the goods produced in Portugal and in the Euro area. This leads to higher outside of the union aggregate spending on goods and services produced in Portugal and in the Euro area.

The behavior of the net foreign assets impulse response function, which reflects the evolution of the net exports, is a result of the households choice to smooth out consumption through time. It has an hump-shaped pattern, achieves its peak after four quarters at about 0.18 of the steady state, and returns to the steady state after 4 years.

With respect to the impulse response functions of the exports and imports there is a striking difference between those to and from inside the Euro area and those to and from outside of the Euro area. Exports and imports to and from the Euro area increase but imports increase more. This behavior is explained by two facts. First, because the output in Portugal increases more than in the Euro area. Secondly, because the relative price of the good produced in Portugal increased due to the fact that inflation in Portugal is slightly above the Euro area's inflation. The trade with the countries outside of the Euro area evolves in a very different way and is in part explained by the path of the relative price of the good produced outside of the Euro area, which jumps up on impact and returns with some persistence to its steady state four years after the shock. Both exports and imports to and from countries outside of the Euro area change substantially. Exports on impact are about 0.54 percent above the steady state and imports on impact are about 0.32 percent below the steady state. Imports from outside of the union achieve its maximum when investment achieves its maximum, 5 quarters after the shock.

Here the effects over the exchange rate are smaller than in Adolfson et al (2007). In our model on impact the euro depreciates by about 0.4 from the steady state, while in Adolfson et al (2007) it depreciates by about 0.5 from the steady state. Most likely, if we were to change some of the parameters in our model in order to get that higher value for the depreciation of the euro, the effects over many of the real variables like output, investment and real wages, which are already bigger in Portugal than in the union, would be further augmented.

6. Conclusions

In this paper we introduce modifications in the benchmark open economy monetary business cycle model of Adolfson et al (2007) in order to incorporate a small country that trades with countries inside and outside of the monetary union to which it belongs. To guarantee local determinacy the variables associated with the countries outside the union can be assumed exogenous, but not the variables associated the other countries in the union. As the interest rate rule for the union depends on the inflation and output of the union, if we were to take these variables as exogenous the interest rate would be exogenous also and there would not be a unique local equilibrium. We proceeded by assuming that inflation, output and interest rate inside the union change according to a three equation block, containing an IS curve, a Phillips curve and an interest rate rule, which parameters were chosen so that these equations together with the remaining conditions of the model could deliver the impulse response functions to a monetary shock of the European Union's inflation, output and interest rate obtained by Adolfson et al (2007).

We use the model to study the monetary transmission mechanism in Portugal. The shape and sign of the responses of the variables are similar to the ones obtained in the literature for the Euro area. There are two main findings. It seems that some variables in Portugal adjust more or faster. When compared with the Euro area, the output in Portugal expands more on impact and inflation and real wage in Portugal adjust quicker and react further on impact. The trade with the two areas responds differently to the monetary shock. Trade with countries inside of the Euro area increases, as both exports and imports increase. Imports from countries outside of the Euro area change little and exports to countries outside of the Euro area increase.

It could be worthwhile to conduct more empirical work in the context of this model. Different behaviors for the aggregate variables of the countries inside and outside of the Euro area can be considered. For instance, to assume that the equations that determine the evolution of these variables are the ones given by an estimated VAR. Another dimension that can be explored is the estimation of some of the parameters of the model using Bayesian methods, as Adolfson et al (2007) do.[5]

The model has many frictions, but is simplistic in various dimensions. As such it could be interestingly extended in various directions. It could incorporate government debt and non-Ricardian households so that fiscal policy could interact with the monetary policy. It could incorporate a financial sector to study the so called financial accelerator channel of the monetary policy. It could consider the labor market as a more complex market allowing for unemployment. More sectors of production could be considered, in particular the nontradable good sector.

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