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Abstract

In this paper we construct a dynamic stochastic general equilibrium model for a small open economy allowing for perfect capital mobility. The model incorporates price rigidities in monopolistically competitive goods and labor markets and real rigidities in the form of capital adjustment costs. The model matches some nominal and real business cycles features observed in European economies and produces a significant output response to monetary policy shocks. The transmission mechanism of these shocks is nonetheless different from that of conventional keynesian models used for policy analysis. It takes a strong price inertia to generate a positive response of real balances after a persistent and positive money shock. What is more striking, the liquidity effect and, hence, the exchange rate overshooting effect depend on the existence of a strong intertemporal substitution and consumption smoothing that is only compatible with a small set parameterizations of preferences.

1. Introduction

In this paper we develop a dynamic stochastic general equilibrium model for monetary policy evaluation. The model sets a clear distinction between the transmission mechanism and the sources of fluctuations in the economy. It is structural since the private sector's behavioral functions are the optimal responses of rational households and firms facing a stochastic environment and intertemporal budget constraints. Since the parameters of these reaction functions can be traced out to the preferences and technology parameters, policy simulations are free from the Lucas critique. Therefore this model is most useful to analyze the response of output and inflation to monetary policies after a change in regime as the one which is currently taking place within the European Monetary Union.

The model is an extended version of some others existing in the literature, and focuses in the monetary transmission mechanism in an open economy with capital accumulation and full capital mobility. Firms and workers operate in monopolistically competitive markets and several nominal and real rigidities are also allowed for to generate real effects of changes in the rate of growth of money. Households are willing to hold money balances because they get some utility out of it. In order to asses the relevance of the model for policy evaluation we look at the way output, real balances, the exchange rate and, above all, the nominal interest rate respond to monetary shocks, i.e. the *output*, *real balances*, *overshooting* and *liquidity* effects that have been empirically identified by the VAR literature. The model is calibrated to match a well defmed steady state and reproduce some well known business cycles features. Also, following the standard practice the money process is included in the model as an exogenous rule whereby the central bank decides upon the rate of growth of the monetary base.

Our results confirm the potential usefulness of this class of models for the purpose at hand. The model is able to match reasonably well the pattern of correlations observed in market economies and generates the expected positive response of output to monetary shocks, given the presence of nominal inertias in less than perfectly competitive markets. A closer look at the transmission of monetary impulses reveals some unconventional features that only a fully specified model like that is able to uncover. It takes a strong inertia to generate a positive response of real balances to positive and persistent money shocks and, what is more striking, the liquidity effect and, hence, the exchange rate overshooting effect depend on the existence of a strong intertemporal substitution and consumption smoothing that is only compatible with a small set parameterizations of preferences. We show that producing liquidity and overshooting effects requires large enough intertemporal substitution in consumption and complementarity between consumption and real balances. Such parameterizations lead to counterintuitive domestic consumption movements in the impact period of a persistent money shock. Finally, increasing price adjustment costs and nominal rigidities leads to more prominent liquidity and overshooting effects but generating implausible large output movements. These results stem from the hybrid nature of the model relative to the monetary transmission mechanism. The output effect is driven by countercyclical changes in the markup in which price rigidities play a crucial role as recently advocated by Goodfriend and King (1997). The liquidity effect is explained in terms of substitution and wealth effects on households asset allocations as described by RBC followers.

The rest of the paper is organized as follows. We describe the model in section 2. In section 3 the model is calibrated to be compatible with a meaningful and well-behaved steady state. We also explore the business cycle implications of the model. In section 4 the features of the monetary transmission mechanism are discussed at length. In section 5 the model is extended for alternative preference specifications generating different properties of money demand. Section 6 concludes with some additional remarks.

2. The Model

In this section we present a dynamic stochastic general equilibrium model for a small open economy[1]. Within a monopolistic competitive economy we incorporate real and nominal rigidities. Real rigidities are introduced via costs of adjustment in the capital stock. Nominal rigidities are introduced in the domestic good markets. We consider that firms are subject to quadratic adjustment costs of changing domestic prices. Labor is immobile across boundaries and, to simplify matters, we assume that only consumption goods are traded. Financial markets are fully integrated so that

(1) Some of the closed economy features of the model are built upon previous work by Hairault and Portier (1993), Rotemberg and Woodford (1995), and specially Kim (1998). The small open economy features are related to previous work by Kollmann (1997).

domestic wealth can be held in physical capital, domestic currency and domestic and foreign bonds (thus, nationals cannot hold foreign currency). The government and the monetary authority conduct the fiscal and monetary policies, respectively. The government derives revenue from issuing money and debt that it uses to transfer money to the households and to pay interests on outstanding debt. Monetary policy is described through an exogenous process for the money growth in the economy.

2.1. The economic environment

The aggregators and the market structure. There are I domestic households indexed by i, and J domestic firms indexed by j. Two aggregators transform heterogeneous labor and goods supplies into two composite baskets, thus generating demand schedules in terms of relative wages and prices; these "agents" allow us to handle monopolistic competition structures[2]. In such an environment these aggregators simply transform heterogeneous inputs (H_n) into a composite input (H). More formally, the problem faced by the (domestic) aggregator can be stated as follows:

$$Max_{\{H_n\}}\ P^H H - \sum_{n=1}^{N} P_n^H H_n,\ s.t.,\ H = N^{1/1-\theta}\left[\sum_{n=1}^{N}\frac{H_n^{\theta-1}}{\theta}\right]^{\theta/\theta-1}$$

where θ is the elasticity of substitution among the different inputs (say, H_n). The first order conditions of this problem with respect to H_n yield the following demand schedules:

$$P_n^H = P^H\left[N\frac{H_n}{H}\right]^{-1/\theta} \quad or \quad H_n = H/N\left[P_n^H/P^H\right]^{-\theta}$$

using this result and the zero profit condition for the aggregator yields:

$$P^H = \left[1/N\sum_{n=1}^{N}\ (P_n^H)^{1-\theta}\right]^{1/1-\theta}$$

thus, in the labor and domestic goods markets those expressions specialize as follows:

[2] See, for details, Blanchard and Kiyotaki (1987), Rotemberg and Woodford (1995) and references therein.

$$W_{it} = W_t \left[\frac{IL_{it}}{L_t}\right]^{-1/\theta_L} \tag{1a}$$

$$W_t = \left[1/I\sum_{i=1}^{I} (W_{it})^{1-\theta_L}\right]^{1/1-\theta_L} \tag{2a}$$

$$P_{jt}^{Y} = P_t^{Y}\left[\frac{JY_{it}}{Y_t}\right]^{-1/\theta_Y} \tag{1b}$$

$$P_t^{Y} = \left[1/J\sum_{j=1}^{J} (P_{jt}^{Y})^{1-\theta_Y}\right]^{1/1-\theta_Y} \tag{2b}$$

where W_{it}, P^{Y}_{jt}, and W_t, P^{Y}_t are the individual and aggregate nominal wage and output prices, respectively. Finally, since the elasticity of substitution between the different labor and goods (say, θ_L, θ_Y) is finite, each household and firm have some monopoly power in its own market. As those elasticities are strictly higher than one, each household (worker) and firm care about its own wage/price relative to the aggregate ones. Thus, in the economy households/workers and firms will play a Nash game on its respective markets choosing prices and quantities through the previously presented inverse demand functions and taking as given aggregate variables.

Households. Households are identical, and they choose a joint plan for domestic and foreign consumption (C^D and C^F), real balances (M/P) and leisure (1-L), in order to maximize the expected lifetime utility U_{i0}, which is defmed as the present discounted value of the momentary utility U_{it} conditional on the information available at $t=0$:

$$U_{io} = E_o \left[\sum_{t=0}^{\infty} \beta^t \, U_{it} \left[C_{it}, \frac{M_{it}}{P_t}, L_{it} \right] \right] \tag{3a}$$

$$U_{it} \; \frac{1}{1-\sigma_1} \left[(C^*_{it})^a (1-L_{it})^{1-a} \right]^{1-\sigma_1} \tag{3b}$$

$$C^*_{it} = \left[C_{it}^{\frac{\sigma_2-1}{\sigma_2}} + b_t \left[\frac{M_{it}}{P_t} \right]^{\frac{\sigma_2-1}{\sigma_2}} \right]^{\frac{\sigma_2}{\sigma_2-1}} \tag{3c}$$

$$C_{it} = (C^D_{it})^{\gamma} (C^F_{it})^{1-\gamma} \tag{3d}$$

notice that the utility of the real balances stems from the transaction services allowed by money, as in the cash in advance models. Notwithstanding, this model allows us to derive a well defined money demand equation in which real balances depend on consumption and nominal interest rates. The parameter σ_2 is the elasticity of substitution between the bundle of consumption (C) and real balances, and it has to satisfy the following restrictions: $(1-\sigma_2)/\sigma_2>-1$ and $(1-\sigma_2)/\sigma_2> \neq 0$. The parameter σ_1 is the curvature parameter, and it is inversely related to the elasticity of intertemporal substitution of both leisure and the consumption bundle. This parameter is restricted to be $\sigma_1>0$ and different from 1. This parameter plays a crucial role in understanding the smoothing of saving after a monetary shock, since it isolates the substitution effects that expected changes in the real interest rates induce on consumption changes. The parameter a $(0<a<1)$ is related to the share of the consumption bundle C^* in the utility. The parameter γ (which is also between zero and one) is the share of domestic good on the consumption bundle C. Notice that, with this preferences we are imposing a <u>unit</u> elasticity of substitution between leisure and the bundle of consumption, and similarly between the consumption of domestic goods (C^D) and the consumption of foreign goods (C^F). Finally, without loss of generality b_t is considered as a constant in the analysis[3].

The non-separability hypothesis is rich enough to generate many different degrees of intertemporal substitution between real balances, leisure and consumption

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[3] This term could also be understood as a money demand (preference) shock (see Kim (1998)).

which crucially affect saving decisions and so the response of nominal interest rates to monetary shocks. Moreover, these preferences generate some restrictions on the money demand relationship. Thus, we will explore alternative preferences specifications focusing on the effects that the separability between the arguments of the utility function have in terms of the money demand and the dynamics of the variables in response to a monetary shock.

Real Rigidities: Cost of Adjustment in the Capital. Each household accumulates capital and rents it to firms at the (rental) cost Z. We assume that the capital is not mobile across countries. The accumulation of capital (K) is driven by:

$$K_{it} = I_{it-1} + (1-\delta) K_{it-1} \tag{4}$$

where δ is the rate of depreciation. Adjustment costs of capital are introduced to get a well defined investment rate. These costs are internal to the households and given by:

$$AC^{K}_{it} = \frac{\phi_K}{2} \left[\frac{I_{it}}{K_{it}}\right]^2 I_{it} \tag{5}$$

This function produces a non-zero adjustment costs, thus yielding a well defined investment function at the steady state.

Intertemporal Budget Constraint. The household decides how to allocate savings between money (M), domestic and foreign bonds (B, B^F) or investment (I) in capital. From the income side, it also receives dividends in terms of its share (ω) of profits (π), nominal wage earnings (PW), benefits derived from renting capital, interest from domestic and foreign debt and transfers (T) from the government. They also have to pay the wage adjustment costs and the capital adjustment costs[( )] The budget constraint faced by the household in the economy can be written as follows:

[4] These real costs of adjustment are paid through the purchase of a CES basket of all produced goods of the economy, with the same elasticity of substitution as the consumption basket.

$$P_{jt}^{Y}C_{it}^{D}+P_{jt}^{F}C_{it}^{F}+M_{it}+B_{it}+s_{t}B_{it}^{F}+P_{jt}^{Y}I_{it}\left[1+\frac{\phi_K}{2}\left[\frac{I_{it}}{K_{it}}\right]^2\right]= \tag{6}$$
$$P_tT_{it}+P_tW_{it}L_{it}+P_tZ_tK_{it}+M_{it-1}+r_{t-1}B_{it-1}+s_tr_{t-1}^{*}B_{it-1}^{F}+P_t\sum_{j=1}^{J}\omega_{ij}\pi_{jt}$$

Finally, nominal expenditure in consumption is defined as:

$$P_tC_{it} = P_{jt}^{Y}C_{it}^{D} + P_{jt}^{F}C_{it}^{F} \tag{7}$$

which implicitly defines the Consumer Price Index, P_t.

Firms. The representative domestic firm chooses a plan for production (Y) of domestically consumed goods (C^D) and export goods (X), labor demand (L) and capital (K) as to maximize the expected present value of its profits:

$$\pi_{j0} = E_0\sum_{t=0}^{\infty}\rho_tP_t\pi_{jt} \tag{8}$$

where, since all firms are owned by the households, ρ is a pricing kernel representing the marginal utility value to the representative household of an additional unit of profits accrued in period t: $\rho_t = \beta^t\Lambda_t$. Profits and technology of domestic firms are given by the following expressions:

$$P_t\pi_t = P_{jt}^{Y}Y_{jt}-P_tW_tL_{jt}-P_tZ_tK_{jt}-P_{jt}^{Y}AC_{jt}^{Y} \tag{9}$$

$$Y_{jt} = A_tK_{jt}^{\alpha}L_{jt}^{(1-\alpha)} - \Phi \tag{10}$$

$$A_t = (\bar{A})^{1-\rho_A}(A_{t-1})^{\rho_A}\exp\{\epsilon_{A_t}\} \tag{11}$$

where A_t follows an AR(1) process describing the period t state of technology which is assumed to be identical for all domestic producers; and Φ represents a fixed cost generating increasing returns to scale. Without loss of generality we consider that these costs are constant, so its existence makes it possible for a firm to earn zero profit in the long-run. The term of price adjustment cost, AC^Y, will be discussed later.

In our benchmark economy domestic firms, using the same technology, produce different goods (domestic consumption, exports and investment goods) fixing one relative price and then using the demand functions to decompose total output between domestic and export goods[5]. Firms do not set prices in local currency of sale, so the production price adjust to movements in the exchange rate in order to determine the price of exported goods[6]. For simplicity, we consider that the demand elasticities are the same in both markets. The demand for exports can be derived in the same way as other demand functions, i.e. invoking the aggregator, where X^W_t and P^*_t are the world exports and the world price respectively. This takes the following form:

$$X_t = X^W_t \; [P^Y_t / s_t P^*_t]^{-\theta_Y} \tag{12}$$

Foreign prices, P^*_t, are treated as an exogenous variable following the process:

$$P^*_t / P^*_{t-1} = ((\bar{\pi}_t - 1)^*)^{1-\rho_*} \; (P^*_{t-1}/P^*_{t-2})^{\rho_*} \; exp\;\{\epsilon_{p^*_t}\} \tag{13}$$

Finally, we consider that there are some firms that import foreign consumption goods in order to sell them in the domestic market. They behave as full flexible price takers. Therefore, the law of one price holds in this market: $P^F_{jt} = s_t P^*_t$.

Sticky Prices. The monopolistic competition environment affecting domestic producers of the economy rationalizes the price setting behaviour by those firms. This circumstance makes possible to incorporate sticky prices into the model. In this respect we follow Rotemberg (1982) and specify the following quadratic adjustment cost function:

$$AC^Y_{jt} = \frac{\phi_Y}{2} \left[\frac{P^Y_{jt}}{P^Y_{jt-1}} - \mu \right]^2 Y_t \tag{14}$$

where ϕ_Y is the adjustment costs scale parameter. This expression allows us to develop a dynamic price-setting rule that has essentially the same (aggregate) price implications as the one considered by Calvo (1983). As noted by Woodford (1996) this model leads to a Phillips trade-off in which future inflation expectations play a crucial role in the joint dynamic of inflation and output. Finally, notice that both households and firms pay these adjustment cost if the wage and output price

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(5) Thus, this framework is one with "costless product differentiation".

(6) In other words, the price of exported goods in foreign currency (P^X_t) is given by: $P^X_t = P^Y_t / s_t$.

inflations are higher than the steady-state inflation rate (i.e. steady-state money growth).

The Government. The government budget constraint is given by the following restriction:

$$M_t - M_{t-1} + (B_t - r_{t-1}B_{t-1}) = P_t T_t \tag{15}$$

thus, the government derives revenue from issuing money and debt that it uses to transfer money to the households and pay interests on outstanding debt. Monetary policy is characterized here by the following exogenous process of the money growth:

$$\left[\frac{M_t}{M_{t-1}}\right] = (\mu)\ (\mu_t) \tag{16}$$

where μ represents the steady state money growth. That is, a shift in monetary policy takes the form of an unexpected permanent rise in money.

$$\mu_t = \mu_{t-1}^{\rho_\mu} \exp\{\epsilon_{\mu_t}\} \tag{17}$$

The External Sector: The Current Account. The difference between nominal exports and imports, that is net exports has to be financed using foreign debt. More formally:

$$P_t^Y X_t - P_t^F C_t^F = s_t B_t^F - s_t r_{t-1}^* B_{t-1}^F \tag{18}$$

this expression defines the current account and can be thought as the equation defining the supply of foreign bonds. Finally, consider that the external nominal interest rates follow the exogenous process:

$$r_t^* = (\bar{r}^*)^{1-\rho_r} (r_{t-1}^*)^{\rho_r} \exp\{\epsilon_{r_t}\} \tag{19}$$

2.2. *The (Symmetric) Equilibrium*

We define a *symmetric monopolistic competition equilibrium* as the set of decision rules of household i and firm j such that:

a) The set of quantities: Y_{jt}, X_{jt}, C^D_{it}, C^F_{it}, C_{it}, I_{it}, L_{it}, K_{jt+1}, M_{it}, B_{it}, B^F_{it} maximise the constrained present value stream of utility of the representative household, and the constrained present value of profits earned by the representative firm,

b) The set of prices (P_t, P^Y_{jt}, P^F_{jt},W_{it}, Z_t, s_t, r_t) clear the goods markets (domestic and foreign), the labor market, the money and capital markets and the market for foreign and domestic bonds.

An extensive representation of the symmetric equilibrium is obtained from the first order conditions of both the *ith* household and the *jth* firm. Aggregating over *i* and *j* yields a set of equations which define the symmetric equilibrium of the economy. The set of equations defining the equilibrium is given in the Appendix, and here we stress three different aspects of the model: the implicit money demand equation, the uncovered interest parity and the optimal price setting of firms.

Combining the equations that characterize the optimal allocation of assets (real balances, domestic bonds and foreign bonds) yields the following two equations:

$$r_t^{-1} = 1 - b_t \left[\frac{P_t C_t}{M_t}\right]^{-1/\sigma_2} \tag{20}$$

$$r_t s_t E_t \Lambda_{t+1} = r_t^* E_t \Lambda_{t+1} s_{t+1} \tag{21}$$

expression (20) is a money demand equation where the interest rate elasticity of real money balances is equal to $-\sigma_2$, and these preferences imply a unit consumption elasticity. Equation (21) represents the uncoverd interest parity (UIP). The UIP arises from the optimality condition relating the allocation of households' wealth between domestic and foreign bonds. Finally, notice that this expression for the UIP involves marginal utilities. This is so because, it is not only the expected depreciation what matters, but instead the expected depreciation in utility terms. This two equations, jointly with the Fisher equation, endogenously determine the behavior of the nominal interest rates in the model.

The first order conditions of the firm with respect to the employment yields the following price setting relationship:

$$P_t W_t = (1-\alpha)\left[\frac{Y_t-\Phi}{L_t}\right] P_t^Y \left[1-(1/e_{Y_t})\right] \tag{22a}$$

The first order condition with respect to capital yields[7]:

$$P_t Z_t = \alpha \left[\frac{Y_t-\Phi}{K_t}\right] P_t^Y \left(1-(1/e_{y_t})\right) \tag{22b}$$

where e_{Y_t} can be thought as the output demand elasticity augmented with price adjustment costs. Finally, note that the time varying price markup, i.e. the ratio of price to marginal cost, is inversely proportional to $(1-(1/e_{Y_t}))$, where e_{Y_t} takes the following expression:

$$e_{Y_t} = \theta_Y \left\{ 1-\phi_Y \left[\frac{P_t^Y}{P_{t-1}^Y}\right]\left[\frac{P_t^Y}{P_{t-1}^Y}-\mu\right] + \phi_Y E_t \left[\frac{\rho_{t+1}}{\rho_t}\left[\frac{P_{t+1}^Y}{P_t^Y}\right]^2 \frac{C_{t+1}^D}{C_t^D}\left[\frac{P_{t+1}^Y}{P_t^Y}-\mu\right]\right]\right\}^{-1}$$

The existence of price rigidities makes the firm problem dynamic, and so they generate stochastic markups. A positive monetary shock moves marginal revenue upwards, as a consequence prices move up, but the presence of adjustment costs implies that they increase less than in the in the flexible case. Therefore output increases and the markup decreases. That is, the ratio of price to marginal cost is countercyclical in response to a money shock. This lower average markup sustains the increase in output and employment. As stressed by Goodfriend and King the role of this markup in the transmission mechanism can be understood as a tax that firms must pay on factor inputs. To see this we can rearrange expression (22a) as follows:

[7] Notice that, in a monopolistic competition setting, prices are function of output and the later depends on employment and capital.

$$\left[\frac{W_t P_t}{P_t^Y}\right] = \frac{1}{M_t^Y}(1-\alpha)\left[\frac{Y_t - \Phi}{L_t}\right] = (1 - \tau_t)(1 - \alpha)\left[\frac{Y_t - \Phi}{L_t}\right]$$

where τ_t is a tax rate at time t and M_t^Y is the markup. Thus the lower the markup, the lower the implicit tax on labor inputs.

2.3. Solution Method

In this model, nominal variables will growth at rate of money growth, μ. So to solve the model we proceed as follows. We first, write the equilibrium equations in terms of stationary variables, that is if the variable x_t grows at μ, the $\bar{x}_t = x_t/\mu$ is stationary. Thus, we get the stationary representation of the equilibrium. Second, an exact expression for the equilibrium can not be found analytically, so we look to an approximate solution log-linearizing the equilibrium around the steady state. Therefore, following Sims (1995), we write the system of equations describing the equilibrium as:

$$\Gamma_0 \Upsilon_t = \Gamma_1 \Upsilon_{t-1} + \Gamma_2 \varepsilon_t + \Gamma_3 \eta_t$$

where Υ_t is the vector of percentage deviations of endogenous variables with respect to their steady state, ϵ_t is the four variable vector of exogenous shocks, and the last term $\eta_t = (\Upsilon_t - E_{t-1}\Upsilon t)$ defmes expectational errors. The parameter matrices Γ_i (i=0,1,2,3) are non-linear transformations of the structural parameters[8].

3. Some Business Cycles Features in a Small Open Economy

3.1. Parameter Values and the Steady State

The parameters characterizing our benchmark economy are presented in Table 1. Table 1a describes the calibrated values of the preferences and technology parameters. For the curvature parameter affecting the intertemporal substitution we choose $\sigma_I = 5$, in line with the one recently used by Chari, Kehoe and McGrattan

[8] The Sims solution method is based on the QZ decomposition. This method is a generalization of the one described by Blanchard and Khan (1980).

(1996). The implicit elasticity of intertemporal substitution of consumption is 0.4, a value close to the one advocated by Hall (1988a)[(9)].

We set a value for the share of consumption in the utility (*a*) equal to 0.4. This parameter is calibrated to produce a steady state labor (*L*) of one third of the time endowment. The parameter σ_2 is calibrated using the estimated values of the elasticity of money demand to nominal interest rates. Following Hairault and Portier (1993) we calibrate this parameter as 1/9. This value is slightly lower that the interest elasticity estimated by Mankiw and Summers (1986). We can anticipate that these differences have no significant effects on the exercises presented in this paper. To obtain *b* we set the average ratio of *M1* to quarterly nominal income in *EU7* (*M/PY*) equals to 0.26, leading a value of 1.610^{-6}. The discount factor, $\beta=0.99$, and the depreciation rate, $\delta=0.02$, are calibrated using conventional values in real business cycle literature. The capital share is $\alpha=0.33$, and the share of domestically produced goods in the consumption bundle, γ, is 0.7, consistent with the observed average of EU countries in the last decades. This value jointly with the previously described implies that the amount of exports to total output (*X/Y*) is 0.2, and that the share of domestic consumption to output (C^D/Y) is 0.58. Finally, when log-linearizing the model we use that the stock of foreing bonds to total output is 4% implying a value of 20% for the ratio of the stock of foreing bonds to exports (see, the second panel of Table 1a).

The third panel of Table 1a describes the degree of monopolistic competition in the product and labour markets considered in our simulations. The degree of monopolistic competition is described through the steady state values of the markup in both markets. In accordance with these steady state values we present the corresponding values for demand elasticities in both markets, say θ_Y and θ_L. The steady state markup in the product market is set at 20%. This value it is consistent with the simulations in Hornstein (1993), Hairault and Portier (1993) and Rotemberg and Woodford (1995), although it is a conservative parameterization of the estimates by Hall (1988b) and Domowitz *et al.* (1987). Notice that to preserve long-run zero benefits, in a non-competitive setting we need non-zero fixed costs in steady state. In fact, a simple trade-off arises. *Caeteris paribus*, the higher the markup, the higher the necessary fixed costs to guarantee a zero profit condition. In our benchmark

[(9)] Notice that, the whithin period non-separability of the preferences imply that these elasticities also depend upon parameters *a*, σ_1 and σ_2 together with the steady state values of *C*, C^* and *L*.

economy, a 20% markup implies a 20% of fixed costs (Φ) relative to the (steady state) output[10]. We do not know of any estimation of the degree of monopolistic competition in the labor markets. Since we are interested in the European economy we impose twice the degree of monopolistic competition of the one considered for the product markets. Changes in this parameter do not significantly affect our results.

Since we have imposed that price adjustment costs are zero at the steady state, it is not possible to calibrate ϕ_Y based on such an information. In our benchmark simulation we set a value of $\phi_Y=5$. To give a hint about the magnitude of those (menu) costs, the real value of adjustment cost (as a percentage of output) of a one point price inflation above steady state inflation is 0.03%[11]. Increasing ϕ_Y to 35 will increase that cost in terms of output to a value of 0.24%. The parameter of capital adjustment, say ϕ_k, is set equal to 10. This value implies that in steady state the installation of 100 unit of capital is accompanied by 0.28% cost in terms of output or a 1.3% cost in terms of investment and imply an investment to output ratio of 0.22. Increasing ϕ_k to 100 will increase those costs to 2.8% with respect to output and 13.2% with respect to investment but both figures of the capital adjustment costs are consistent with the findings with microdata obtained for example by Whited (1992) for the US economy.

3.2. Sources of Fluctuations and Business Cycles

Business cycles models have tried to reproduce some stylized facts from the data mainly analysing the role of real disturbances. Cooley and Hansen (1995) introduce money in a closed economy and see how nominal contracts affect the dynamics of real and nominal variables. Nevertheless until very recently there were no monetary models in open economies looking at business cycles properties. An exception is Kollmann (1997) that matches some of the nominal and real features of the data in a small open economy model with nominal rigidities. Here we show some of these statistics for a model that considers capital accumulation and incorporates real

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(10) Including increasing returns in the aggregate production function makes possible to reduce these fixed costs values with even higher degree of monopolistic competition. Nevertheless, the accuracy of the estimates of the increasing returns parameter is not very reliable (see Hall (1990)).

(11) This value is in the range of the one considered by Hairault and Portier (1993).

rigidities as a new friction. As we will see latter both things are crucial to shape the propagation mechanism of monetary shocks.

The model is simulated for the calibrated parameter values under four sources of exogenous fluctuations. Each shock is assumed to follow an AR(1) process. Two shocks, foreign inflation and nominal interest rates, cover the two most important sources of external fluctuations and they are estimated with the change in the U.S. GDP deflator and the 3-month treasure bill rate between 1984:1 and 1997:4. The period chosen represents a stable period on the evolution of prices as well as in the monetary policy followed by the U.S. (the post-Volcker period). The other two shocks, money and technology, represent the domestic source of fluctuations from an average European country. The technology process measures deviations of total factor productivity from average and it is taken from the estimation of Hairault and Portier (1993) for France. Money is measured as the deviations of the money growth rate and its standard error has been calibrated to get the observed average price volatility in Europe (between 1 and 2%) whereas its persistence parameter takes the same value than the estimated for US (Cooley and Hansen) or France (Hairault and Portier). The processes' parameters for these shocks are described in Table 1b.

Table 2 reports the simulated moments for some of the endogenous variables in the model under different values for two key parameters, the price rigidity, ϕ_Y, and the capital adjustment cost, ϕ_k. The cyclical components of the simulated data have been calculated with the Hodrick-Prescott filter. The first column, our benchmark economy with ϕ_Y=5 and ϕ_k=10, reproduces many of the business cycles facts reported in the literature for the largest European economies[12]. Output volatility is 1.2%, consumption and labor are less volatile than output, whereas investment and real exchange rates fluctuate more than output. The correlation of total consumption with output is around 0.8 whereas the labor correlation is lower than that figure. Prices are slightly countercyclical whereas nominal and real exchange rates are highly correlated. In the second column we see that higher price rigidities generate more fluctuations in labor and output whereas prices are not procyclical. In the model firms hire workers to equate labor's marginal product to a markup over the cost. This markup is a function of the demand elasticity affected by past and expected prices. More price rigidities induce more movements in the labor demand curve and therefore more volatility in employment and less volatility in prices.

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(12) See for example Backus and Kehoe (1992), Fiorito and Kollintzas (1994) or Kollmann (1997).

There are two features in those simulated moments clearly rejected by the data: investment is too volatility relative to output and net exports are not countercyclical[13]. In the last two columns of Table 2 we change the value of the capital adjustment cost parameter. Real adjustment cost of capital is modeled as an extra cost for the households that want to rent capital to the firms. A larger adjustment cost generates a lower investment volatility and thus through the aggregate constraint of the economy a more countercyclical net exports. Nevertheless this implies a much lower volatility in the real exchange rates. We conclude by saying that the calibrated model reproduces many of the business cycles facts observed in open economies and that the nominal and real rigidities play a relevant role for that account.

4. The Liquidity Effect

In this section we discuss the main features of the monetary transmision mechanism built in the model, i.e. the way in which monetary policy shocks affect real and nominal variables. The literature of VAR models and the conventional wisdom among central bankers coincide in characterizing monetary policy shocks as those which exert a positive influence on output (*output effect*) and on real money balances (*real balance effect*); also, a monetary stimulus is expected to reduce the nominal interest rate on impact (*liquidity effect*) and, in an open economy setting, to depreciate the currency probably overshooting its long-run response (*overshooting effect*). Indeed, the transmission mechanism in conventional keynesian models used for policy evaluation purposes in most central banks relies heaviliy on the ability of monetary policies to affect two crucial relative prices, namely those of current versus future consumption and of domestic versus foreign demand. In this class of models, faster monetary growth which is not matched by similar increases in prices (due to price sluggishness) leads to an increase in real money balances and hence to a fall in the nominal rate. The rise on inflation expectations contributes to reduce the real interest rate further, so that investment and consumption rise. At the same time, the arbitrage condition among domestic and foreign assets requires the nominal exchange rate to depreciate strongly on impact, so that net exports rise, as in the standard Mundel-Fleming-Dornbusch model. The additional demand is matched by an increase

[13] A related issue, not examinated here, is that net exports are also too volatile.

in aggregate supply due to a fall in real wages (if nominal wages are sticky) or in the markup (in monopolistically competitive models, if prices are sticky).

Although these components of the transmision mechanism can be thought as pertaining to a particular set of models, they are deeply rooted in many economists' minds and have played a dominant role to identify properly structural or exogenous monetary policy shocks. For that purpose, the empirical VAR literature has considered these effects as informal overidentifying restrictions to characterize monetary policy shocks.[14] Furthermore, among these effects, the ***real balances*** and the ***liquidity effect***, in particular the later, empirically are of particular relevance[15]. This is so because the response of output does not help to discriminate among supply and demand monetary shocks and because the response of the nominal exchange rate in a model with perfect capital mobility is heaviliy dependent on the initial reaction of the interest rate. Thus, in what follows we focus in the role of nominal and real rigidities along with that of preferences and other features of the model as to generate a fall in the interest rate following an unexpected increase in the rate of growth of the money supply.

To organize the discussion is useful to think of the nominal rate as the sum of the real rate plus expected inflation (π^e), the real rate being closely related to the marginal product of capital (*MPK*). These two components are endogenous and their response depend on all the parameters of the model. Nevertheless, the evolution of marginal product of capital relies mainly on the specification of preferences and of real inertia, whereas that of expected inflation depends on the persistence of the monetary shock and on the degree of nominal inertia. So we focus on one of each of them at one time.

The marginal product of capital

In partial equilibrium, adjustment costs of capital drive a wedge between the marginal product of capital and the real interest rate. This generates a well defined investment function and following an open market operation, the *LM* moves along a downward sloping *IS* curve. The monetary shock reduces the real rate, but since inflation

(14) See, for instance, the evidence presented by Kim and Roubini (1996) for G-7 countries.

(15) See Christiano, Eichenbaum y Evans (1998).

expectations go up (i.e. the IS curve itself shifts upwards) the overall response of output is higher but the response of the nominal rate may have any sign. In this case, the liquidity effect is more likely the less elastic is the IS curve. The message thus is clear, adjustment costs of capital are a necessary, though not sufficient, condition for the liquidity effect.

For a given response of expected inflation, a strong fall in the marginal product of capital is needed to bring about a fall in the nominal rate. But, this in turn depends on the relative response of the supply and demand of capital. The later rises in response to the increased output whereas, in a general equlibrium setting, the response of the supply of capital goods depends on the reaction of savings after a monetary shock and the proportion of these savings that are allocated into different assets (see, for instance, Kimball (1995)). Two parameters turn out to be of crucial importance for that effet to take place, σ_l and ϕ_k. Figure 1 represents the impulse-responses of the variables to a shock in the money growth rule for two alternative curvature parameter values (σ_l). In an economy with moderate costs of adjusting capital ($\phi_k=10$) in which agents have a high intertemporal elasticity of substitution in consumption ($\sigma_l=0.02$) the nominal interest rate falls on impact, unlike what happens for our benchmark elasticity of substitution ($\sigma_l=5.0$)[16]. In this model the *liquidity effect* requires a strong downwards reaction of the real interest rate, and that is likely the larger the increase in savings and the more attractive is for households to keep their wealth in productive capital.

Figure 2 confirms this surmise comparing the impact response of the nominal interest rate under different real adjustment costs parameters and elasticities of substitution. For a given value of ϕ_k the liquidity effect will be more likely the higher the intertemporal elasticity of substitution in consumption (i.e. a low σ_l). This impact effect on nominal interest rates can be described through the demand and supply of capital. For a given supply of capital the demand of capital by firms increases as a result of the expansionary shock, also increasing expected inflation. These two effects tend to push the nominal rate upwards. A low σ_l implies a strong consumption smoothing so that the additional income is mostly devoted to accumulate new savings. If this effect is strong enough the nominal interest will also fall. Notice that, it is not only the amount of savings what matters but also the way these are allocated among the existing assets. In particular, for a given σ_l, the liquidity effect requires low

(16) The case of σ_l=0.02 implies an elasticity of intertemporal substitution in consumption of 1.4 and an intertemporal substitution of labor of 5.8.

adjustment costs. Since the cost of adjusting capital is entirely borne by the households, the lower these costs the higher the proportion of new savings devoted to buy new capital goods.

The discussion so far has left aside open economy considerations. When our economy trades goods and assets with the rest of the world, the liquidity effect is affected in several ways. First, since the price basket has a share of imported goods and we assume that exchange rate movements pass-through immediately to the imported prices, the consumer price index reacts far more quickly after a monetary stimulus. If the currency depreciates on impact, the supply of real balances schedule shifts leftwards by more than in a closed economy. Money demand is also affected since domestic investors have an additional asset to keep their savings: foreign bonds. The incidence of openness in the response of the nominal interest rate depends on the relative strength of these two effects, This strong depreciation produces a boom of exports and an imports fall. Finally, the dynamic response of the nominal exchange rate depends crucially on the degree of nominal rigidities, the higher price inertia the stronger the overreaction of the currency with respect to its long run level so that a substantial appreciation is expected for the following periods.

Inflation expectations

Our utility function imposes a unit consumption elasticity of money demand. Thus whenever consumption increases after the monetary shock, so does the demand for real balances, pushing the nominal interest rate upwards. With nominal inertia but prices reacting on impact, the supply of real balances actually falls so the only way in which the liquidity effect take place is if consumption falls thus shifting the demand for money strongly to the left. For that result to hold we need to assume a strong complementarity between consumption and real balances, i.e. we need low values of σ_l. One salient feature of the impulse-responses depicted in Figure 1 is that in both cases, i.e. regardless of whether there is a liquidity effect or not, prices react on impact faster than the money supply. Hence it might be argued that the difficulties to generate a proper liquidity effect in this model have to do with the fact that real balances actually fall as a consequence of a monetary expansion.

The response of real balances is simply the result of a combination of too little price inertia (to low ϕ_Y) and too much inertia in the money growth process (high ρ_μ). Since there is high inertia in money growth, current increases anticipate further rises of the monetary base in the future, thus leading to expected inflation. Then, current prices react since rational forward-looking consumers and firms try to anticipate the purchase of durables. Since the costs of adjusting prices are low, real balances fall and then the nominal rate must go up so that households reduce their demand for money. Thus it could be argued that the model is in a way far *'too classical'*, thus failing to produce a proper liquidity effect.

To investigate this issue more thoroughly Figure 3 depicts the sign of some nominal and real variables effects, for a broad range of values of ϕ_Y and for two extreme cases of low (ρ_μ=*0.01*) and high (ρ_μ=*0.5*) money growth persistence. The top left figure shows that, as expected, the response of the nominal rate to a monetary shock is more strongly negative the higher the costs of adjusting prices. However this keynesian pattern only holds for high values of the intertemporal elasticity of substitution (low σ_I). When we move towards higher values of σ_I the reaction of the nominal interest rate is virtually unaffected by the degree of price inertia and is positive even if we assume that the change in money growth dies away inmediately (ρ_μ=*0.01*). The real balances rise along with the money supply whenever there is strong inertia and the money process has a low persistence, this is more likely for high σ_I.

The response of output is always positive and is stronger the more persistent is the monetary expansion and the higher the cost of adjusting prices. The transmission mechanism in this model relies heavily on the counterciclycal response of the markup. Since prices are sticky, a positive nominal shock increases nominal demand and lowers the markup (see Figure 1). The economy gets closer to the perfectly competitive equilibrium, thus increasing labor demand and output. Labor supply also increases, following the rise in real wages, thus resulting in a higher equilibrium. Eventually, the price level adjusts to its new level, increasing the markup and getting the economy back to its unchanged steady-state.

Similarly the response of the nominal exchange rate is almost the mirror image of that of the interest rate. Due to the monetary expansion, the domestic currency always depreciates over the long-run, overshooting that level on impact whenever interest rate fall. This is well consistent with the assumptions behind the demand for assets in the model. When the nominal interest rate rises on impact, it is expected to get down to its initial (pre-shock) level and the positive interest rate differential implies that the exchange rate must reach its new steady state value while depreciating all the way; thus, the initial jump must fall short of (undershoot) its long-run one.

The bottom line of the arguments discussed in this section is that the liquidity effect is far from warranted in this kind of general equilibrium models. Since the liquidity effect has been considered the trade mark of the transmission mechanism of monetary policy, it is striking that the output and inflation effects of monetary shocks in our model are robust across specifications, regardless of the response of the nominal rate. The transmission mechanism in the model displays two key keynesian features: monopolistic competition and price rigidities. The financial structure of the model displays a more *'monetarist'* flavour, and is of lesser importance to obtain real effects out of nominal shocks. As discussed above, shifts in the allocation of assets may lead to any sign in the impact response of the nominal interest rate, so that a rise in the nominal rate is not incompatible with a significant output effect.

5. Robustness

We analyze the implications for our results of two alternative preference specifications which crucially affect the money demand specification and the intertemporal substitution of consumption. Under the benchmark preferences of our model the money demand has a unit elasticity with respect to consumption, and $-\sigma_2$ is the elasticity of real balances with respect to nominal interest rates.

The unit elasticity of the money demand to consumption is usually considered a long-run elasticity. Nevertheless, as stressed among others by McCallum (1989), this income elasticity is smaller than one in the short run and that should be the one considered by business cycle models. The same could be applied to the elasticity of money demand with respect to the nominal interest rates (see, for instance, Mankiw and Summers (1986)). To deal with such a possibility we consider the following preferences studied by Chari et al.(1996):

$$U_{it} = (1/1-\sigma_1)\left[(C^*_{it})^a(1-L_{it})^\Psi\right]^{1-\sigma_1},$$

$$C^*_{it} = \left[C^\sigma_{it} + b\left[\frac{M_{it}}{P_t}\right]^\xi\right]^{1/\sigma}$$

Under these preferences the money demand elasticity to consumption is equal to *(σ-1)/(ξ-1)* and the interest rate elasticity is *-1/(ξ-1)*[17]. We fix the interest rate elasticity to the previous value with $\xi=10$ and focus on the effects of changing the elasticity of money demand to consumption (σ). Of the remaining preference parameters only ψ affects the intertemporal labor supply and it is fixed to 3 whereas a affects the intertemporal elasticity of consumption and it is set to 1, the values considered in Chari et al. (1996). We leave free the parameter that measures the curvature of the consumption bundle, C^* (σ_1).

Figure 4 plots how the impact response of interest rates to a money shock is affected by different preference values but with previously used nominal and real rigidities (ϕ_Y=5 and ϕ_K=10). The grid of parameter values considered covers a wide range for the curvature of the consumption bundle and an income elasticity between 0 and 1 that guarantees stable solutions. We find that only for the cases with an income elasticity close to unity and a large consumption smoothing we obtain a negative response of the interest rate. Therefore we see these results as reinforcing the ones obtained in the previous section and showing that they do not depend on the assumption about the income elasticity of money demand.

Many papers in the literature have advocated separability in the arguments of the household's utility. For example in the context of two country open economy models Sutherland (1996) has specified the domestic consumer utility as follows:

$$U_{it} = \frac{C_{it}^{1-\sigma}}{1-\sigma} + \psi_0\frac{(1-L_{it})^{1+\psi}}{1+\psi} + \chi\frac{\left[\frac{M_{it}}{P_t}\right]^{1-\epsilon}}{1-\epsilon}$$

where σ and ψ are the inverse of the elasticity of intertemporal substitution of consumption and leisure respectively. We set ϵ to match the usual interest rate elasticity and consider different values of σ and ψ. None of those parameter

[17] The values $\Psi=1-a$, $\sigma=\xi$ and $\xi=10$ correspond to our benchmark specification.

combinations are able to generate a negative effect of interest rates after a money shock.[18]

6. Conclusions

We have analyzed the monetary transmission mechanism in an open economy with full capital mobility, capital accumulation and in presence of nominal and real rigidities when firms and workers operate in monopolistically competitive markets. The model is capable of reproducing many of the business cycle properties observed in the European economies, for a reasonable set of parameter values chosen to generate a meaningful steady state. The most important results are that the positive (temporary) real effect of a monetary expansion appear clearly in the model, regardless of the parameter values, as long as there is some nominal inertia and some goods markets are less than perfectly competitive. Nevertheless, the transmission mechanism from monetary impulses to output and employment bears very little ressemblance with the standard keynesian one which relies on a significant *real balances*, *liquidity* and, to a lesser extent, *overshooting* effects. More specifically, to produce a significant fall in the nominal interest rate and a strong currency depreciation on impact, a large consumption smoothing parameter is needed. Only under that circumstance the intertemporal substitution effect operates in the usual way, leading to a sharp reduction of the real cost of capital although it generates also a drop of real balances and consumption on impact. Higher price inertia and a less persistent money process are needed to generate a positive correlation among nominal and real balances, but this is insufficient to obtain a proper liquidity effect unless the elasticity of substitution is large enough.

The model in this paper has been designed to share some keynesian, classical and monetarist features. Its keynesian flavour is portrayed in the presence of costs of adjusting nominal prices, which in turn requires price setters to have some monopoly power due to product differentiation in the goods markets. The model is classical since agents are rational optimizers aware of their true intertemporal ressource constraints. Finally, the monetarist side is the presence of fully specified supply and demand schedules for all traded assets. The keynesian bit is responsible for a substantial response of output to monetary policy actions; without price inertia and

[18] This result is in line with the one stressed by Christiano, Eichenbaum and Evans (1997) in limited participation model of a closed economy.

monopolistic competition, the impulse response of output is simply flat from the outset, if not negative. But unlike more conventional keynesian models, the positive response of aggregate demand is explained on the basis of a strong intertemporal substitution. Consumption reacts to changes in the permanent income and investment does so in response to a rise of the shadow price of capital; all this despite the fact that, more often than not, both the nominal and the real interest rates rise. All along this process, the substitution among assets in households portfolios play a crucial role.

The dynamic structure of this class of models is far too simple to expect a good forecasting performance vis-a-vis VAR or other, more loosely, specified macroeconomic models. Nevertheless, to the extent that all the behavioural relations are derived from a relative small set of technological and preference parameters, the model is a suitable framework to analyze the response of output and inflation to monetary policies in a changing environment, as the one we are currently witnessing within the European Monetary Union, and can be considered as a natural step forward in relation with more conventional models of policy evaluation.

Appendix: Symmetrical Monopolistic Competition Equilibrium

A symmetrical monopolistic competition equilibrium is given by a set of decision rules for

household i, $C^D_{it}(\mathcal{F}_{it})$, $C^F_{it}(\mathcal{F}_{it})$, $K_{it}(\mathcal{F}_{it})$, $M_{it}(\mathcal{F}_{it})$, $B_{it}(\mathcal{F}_{it})$, $B^F_{it}(\mathcal{F}_{it})$ and $L_{it}(\mathcal{F}_{it})$; where $\mathcal{F}_{it}$ is the household state variable including: $\{K_{it-1}, M_{it-1}, B_{it-1}, B^F_{it-1}, \{P^Y_{jt}\}^J_{j=1}, S_t, W_t, Z_t, r_t, \mu_t, A_t, P^*_t, r^*_t\}$.

firm j, $K_{jt}(\mathcal{F}_{jt})$, $L_{jt}(\mathcal{F}_{jt})$ and $P^Y_{jt}(\mathcal{F}_{jt})$, where $\mathcal{F}_{jt}$ is the firm state variable including: $\{\{P^Y_{jt-1}\}^J_{j=1}, M_t, A_t, r^*_t, P^*_t, W_t, Z_t, S_t, r_t\}$

such that

the households maximise expressions (3a)-(3d) with respect to C^D_{it}, C^F_{it}, K_{it}, M_{it}, B_{it}, B^F_{it} and L_{it} subject to constraints (4)-(7), and

the firms maximise expresssions (8) and (9) with respect to K_{jt}, L_{jt} and P^Y_{jt} subject to the constraint (10)

the aggregate prices of the economy are given by the following expressions and $\{P^Y_{jt}(\mathcal{F}_{jt})\}^J_{j=1}$, $W_t(\mathcal{F}_t)$, $Z_t(\mathcal{F}_t)$, $r_t(\mathcal{F}_t)$, $s_t(\mathcal{F}_t)$ clear the goods markets, the capital markets, the labor market and the money market, that are respectively

$$Y_{jt}(\mathcal{F}_t) = Y_{jt}(S_{jt})\,\forall j \in \{1, J\},\; \sum_{i=1}^{I} K_{it}(\mathcal{F}_{it}) = \sum_{j=1}^{J} K_{jt}(\mathcal{F}_{jt})$$

$$\textstyle\sum_{i=1}^{I} L_{it} = \sum_{j=1}^{J} L_{jt}(\mathcal{F}_{jt}),\; \sum_{i=1}^{I} M_{it}(\mathcal{F}_{it}) = \mu_t M_t,$$

$$\textstyle\sum_{i=1}^{I} B_{it} = B_t,\; \sum_{i=1}^{I} B^F_{it} = B^F_t,$$ where B_t and B^F_t satisfy (15) and (18) respectively

Finally, the symmetry of the equilibrium comes from: $\mathcal{F}_{it} = \mathcal{F}^I_t \;\; \forall\, i \in \{1, I\} \;\; \forall\, t$ and $\mathcal{F}_{jt} = \mathcal{F}^J_t \;\; \forall\, j \in \{1, J\} \;\; \forall\, t$. Where we will use the normalization I = J = 1.

The choice of households between domestic goods and foreign goods is given by equations (A1) and (A2):

$$\frac{\partial U}{\partial C_t^D} = P_t^Y \Lambda_t \qquad \textbf{(A1)}$$

$$\frac{\partial U}{\partial C_t^F} = P_t^F \Lambda_t \qquad \textbf{(A2)}$$

where Λ_t is the Lagrange multiplier of the intertemporal household budget constraint. The consumer price index (P_t) and aggregate consumption (C_t) are defined as:

$$P_t C_t = P_t^Y C_t^D + P_t^F C_t^F \qquad \textbf{(A3)}$$

$$C_t = (C_t^D)^{\gamma} \; (C_t^F)^{1-\gamma} \qquad \textbf{(A4)}$$

notice that from equations (A1), (A2) and (A3) it follows that the Lagrange multiplier is equal to the marginal utility of consumption (i.e. $P_t \Lambda_t = \partial U / \partial C_t$).

The labor supply can be thought as a wage setting:

$$\frac{\partial U}{\partial L_t} = - \Lambda_t P_t W_t \left[1 - 1/\theta_L\right] \qquad \textbf{(A5)}$$

notice that when θ_L tends to infinite we are in the competitive (frictionless) case.

Real balances and bonds demand functions are implicit in equations (A6) and (A7):

$$\frac{\partial U}{\partial M_t} = \Lambda_t - \beta E_t \Lambda_{t+1} \qquad \textbf{(A6)}$$

$$\Lambda_t = \beta \; E_t \; r_t \; \Lambda_{t+1} \qquad \textbf{(A7)}$$

combining these two equations, using the definition of Λ_t, yields to a well specified money demand equation. Combining the Euler equation for foreign bonds,

$$s_t \Lambda_t = \beta E_t r_t^* s_{t+1} \Lambda_{t+1}$$

with equation (A7) yields the uncovered interest parity condition:

$$r_t s_t E_t \Lambda_{t+1} = r_t^* E_t \Lambda_{t+1} s_{t+1} \tag{A8}$$

Optimal capital accumulation is derived from the first order conditions of households with respect to investment and capital:

$$\Lambda_t \left[P_t Z_t + P_t^Y \phi_K \left[\frac{I_t}{K_t} \right]^3 \right] - q_t + \beta (1-\delta) E_t q_{t+1} = 0 \tag{A9}$$

$$\Lambda_t P_t^Y \left[1 + \frac{3\phi_K}{2} \left[\frac{I_t}{K_t} \right]^2 \right] = \beta E_t q_{t+1} \tag{A10}$$

equation (A9) defines the marginal utility of capital (q_t) as the sum of two components: first, the expected marginal utility of capital (discounted and correctly depreciated); second, the marginal utility of the rental rate corrected by the existence of adjustment costs. Equation (A10) is an arbitrage condition between investment and consumption. Thus, the relative price of capital is equal to the expected marginal utility of capital divided by the marginal utility of consumption.

The first order conditions of the firm with respect to the employment and capital yields the following relationships:

$$P_t W_t = (1-\alpha) \left[\frac{Y_t - \Phi}{L_t} \right] P_t^Y \left[1 - (1/e_{Y_t}) \right] \tag{A11}$$

$$P_t Z_t = \alpha \left[\frac{Y_t - \Phi}{K_t} \right] P_t^Y \left(1 - (1/e_{Y_t}) \right) \tag{A12}$$

where e_{Y_t} takes the following expression:

Given the production price, exports are determined by the following demand equation:

$$X_t = X_t^W \left[P_t^Y / s_t P_t^* \right]^{-\theta_Y} \tag{A14}$$

$$e_{Y_t} = \theta_Y \left\{ 1 - \phi_Y \left[\frac{P_t^Y}{P_{t-1}^Y} \right] \left[\frac{P_t^Y}{P_{t-1}^Y} - \mu \right] + \phi_Y E_t \left[\frac{\rho_{t+1}}{\rho_t} \left[\frac{P_{t+1}^Y}{P_t^Y} \right]^2 \frac{C_{t+1}^D}{C_t^D} \left[\frac{P_{t+1}^Y}{P_t^Y} - \mu \right] \right] \right\}^{-1} \tag{A13}$$

where, for simplicity, $X^{W}{}_t$ will be considered constant.

The model also assumes that every agent has access to a complete and competitive market for contingent claims. This is equivalent to say that firms maximize their market value. In such a situation, there is a unique real discount factor satisfying:

$$\left\{ \frac{\rho_{t+1}}{\rho_t} \right\} = \beta \left\{ \frac{\Lambda_{t+1}}{\Lambda_t} \right\} \tag{A15}$$

In our model import goods are consumed by the households. Thus we impose the law of one price for import goods. This condition is equivalent to a zero profit condition of the import firms:

$$P_{it}^F = s_t \, P_t^* \tag{A16}$$

Finally, five constraints guarantee that markets clear. These are given by the production function, capital accumulation, the current account, the government budget constraint and the economy wide constraint.

$$Y_t = A_t L_t^{1-\alpha} K_t^{\alpha} - \Phi \tag{A17}$$

$$K_t = I_{t-1} + (1-\delta) K_{t-1} \tag{A18}$$

$$P_t^Y X_t - P_t^F C_t^F = s_t B_t^F - s_t r_{t-1}^* B_{t-1}^F \tag{A19}$$

$$M_t - M_{t-1} + (B_t - r_{t-1} B_{t-1}) = P_t T_t$$

to obtain the economy wide constraint we proceed as follows. Using the definition of profits

$$P_t \pi_t = P_t^Y Y_t - P_t W_t L_t - P_t z_t K_t - P_t^Y AC_t^Y$$

and imposing the current account and the government budget constraint in the household budget constraint yields:

$$X_t + C_t^D + AC_t^W + I_t\left[1 + \frac{\phi_K}{2}\left(\frac{I_t}{K_t}\right)^2\right] = Y_t - AC_t^Y \qquad \text{(A21)}$$

As previously stated the price adjustment costs take the following quadratic expression:

$$AC_t^Y = \frac{\phi_Y}{2}\left[\frac{P_t^Y}{P_{t-1}^Y} - \mu\right]^2 Y_t \qquad \text{(A22)}$$

We specify the following fiscal policy in terms of the transfers:

$$P_t T_t = -\kappa B_{t-1} \qquad \text{(A23)}$$

where κ is a positive constant. Thus, transfers are determined to maintain dynamic stability of the model.

In this paper money supply is given by the following process for the money growth

$$\left[\frac{M_t}{M_{t-1}}\right] = (\mu) \quad (\mu_t) \qquad \text{(A24)}$$

where μ_t follows an exogenous first order autoregressive process.

There are four sources of fluctuations in this economy: technology, money growth, external prices and external interest rates. This makes a total of 24 equations with 24 variables: 10 prices (P_t, P^Y_t, P^F_t, W_t, Z_t, ρ_t, λ_t, q_t, s_t, r_t), 8 quantities (Y_t, X_t, C^D_t, C^F_t, C_t, I_t, L_t, T_t), 4 stocks (M_t, B_t, B^F_t, K_t), the markup ($(1-(1/e_{Y_t}))^{-1}$) and the price adjustment costs (AC^Y_t).

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TABLE 1a
BASELINE VALUES FOR CALIBRATION PARAMETERS

PREFERENCES AND TECHNOLOGY	VALUE
σ_1	5.00
a	0.40
σ_2	1/9
Б	1.6 e-6
γ	0.70
β	0.99
α	0.33
STEADY STATE	**VALUE**
μ	1.028
r^*	1.01
M/B	1/3
$P^F C^F / P^Y X$	1.2
$B^F / P^Y X$	0.20
M/PY	0.26
MARKUPS	**ELASTICITIES**
(GOODS) 20	$\theta_Y = 6$
(LABOR) 40	$\theta_L = 3.5$
ADJUSTMENT COSTS	**VALUES**
ϕ_Y	5
ϕ_K	10

TABLE 1b
SOURCES OF FLUCTUATIONS

STOCHASTIC PROCESSES	AUTOCORRELATIONS	VOLATILITY (10^{-2})
$\log\left[\frac{M_t}{M_{t-1}}\right] = \rho^M \log\left[\frac{M_{t-1}}{M_{t-2}}\right] + \epsilon_t^M$	$\rho^M = 0.50$	$\sigma^M = 0.45$
$\log A_t = \rho^A \log A_{t-1} + \epsilon_t^A$	$\rho^A = 0.95$	$\sigma^A = 0.70$
$\log\left[P_t^*/P_{t-1}^*\right] = \rho^* \log\left[P_{t-1}^*/P_{t-2}^*\right] + \epsilon_t^{P^*}$	$\rho^* = 0.50$	$\sigma^* = 0.20$
$\log r_t^* = \rho^r \log r_{t-1}^* + \epsilon_t^{r*}$	$\rho^r = 0.80$	$\sigma^r = 0.50$

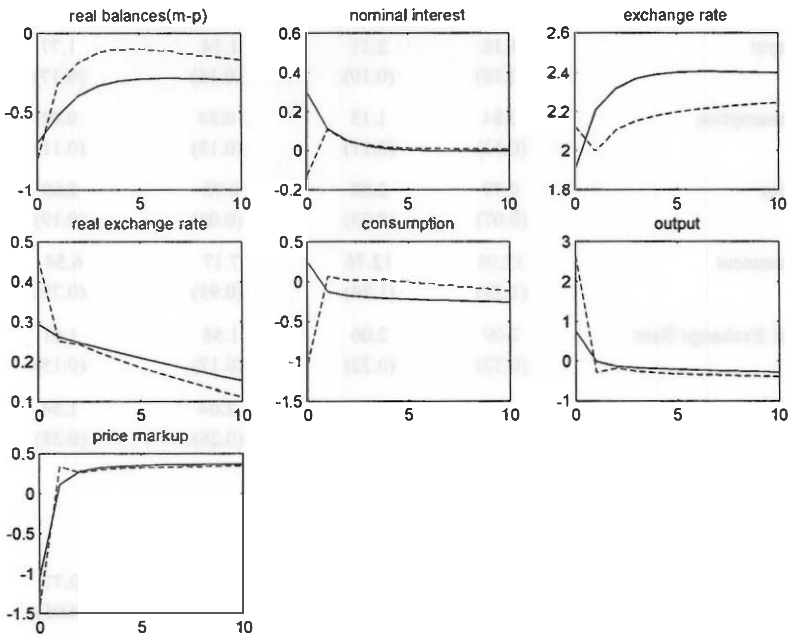
TABLE 2
Population moments implied by the model

Statistics	Capital Adjustment Costs (ϕ_k= 10)		Capital Adjustment Costs (ϕ_k= 100)	
	ϕ_Y=5	ϕ_Y=35	ϕ_Y=5	ϕ_Y=35
Standard Deviation (%)				
Output	1.18	2.11	1.14	1.77
	(0.18)	(0.19)	(0.16)	(0.17)
Consumption	0.84	1.15	0.84	0.92
	(0.12)	(0.11)	(0.13)	(0.11)
Labor	0.79	2.58	0.75	2.09
	(0.07)	(0.23)	(0.06)	(0.19)
Investment	12.06	12.76	7.17	6.54
	(1.29)	(1.24)	(0.93)	(0.73)
Real Exchange Rate	2.09	2.06	1.58	1.61
	(0.22)	(0.22)	(0.17)	(0.15)
Prices	1.98	1.55	2.04	1.54
	(0.30)	(0.27)	(0.28)	(0.28)
Contemporaneous correlation between Output and				
Consumption	0.77	0.90	0.61	0.77
	(0.08)	(0.02)	(0.09)	(0.05)
Labor	0.67	0.90	0.63	0.87
	(0.05)	(0.02)	(0.06)	(0.03)
Net Exports	0.05	0.02	-0.24	-0.45
	(0.17)	(0.14)	(0.15)	(0.11)
Prices	-0.22	0.18	-0.10	0.31
	(0.20)	(0.11)	(0.11)	(0.11)
Contemporaneous correlation between Nominal and Real exchange rates	0.81	0.83	0.77	0.80
	(0.06)	(0.06)	(0.07)	(0.07)

Note: The simulated data has been detrended with the Hodrick-Prescott filter (λ=1600). For each statistics the average and the standard deviation (in parentheses) of 100 simulations with 100 observations in each simulation are reported. Consumption is total consumption. Net exports is the value of exports minus imports over total incomes. The price is the CPI index.

FIGURE 1

Responses to a Monetary Shock:
Two alternative values for the intertemporal elasticity of consumption



Note: The dotted line corresponds to $\sigma_1 = 0.02$ and the continuous line to $\sigma_1 = 5$.

FIGURE 2

Responses to a Monetary shock:
The liquidity effect under alternative values for the real rigidity (ϕ_K) and the intertemporal elasticity of consumption (σ_1)

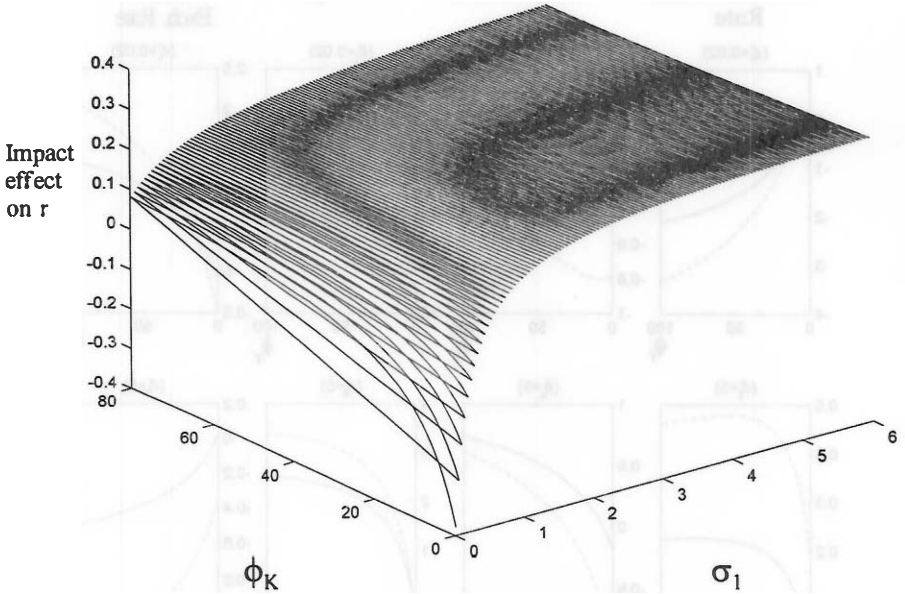
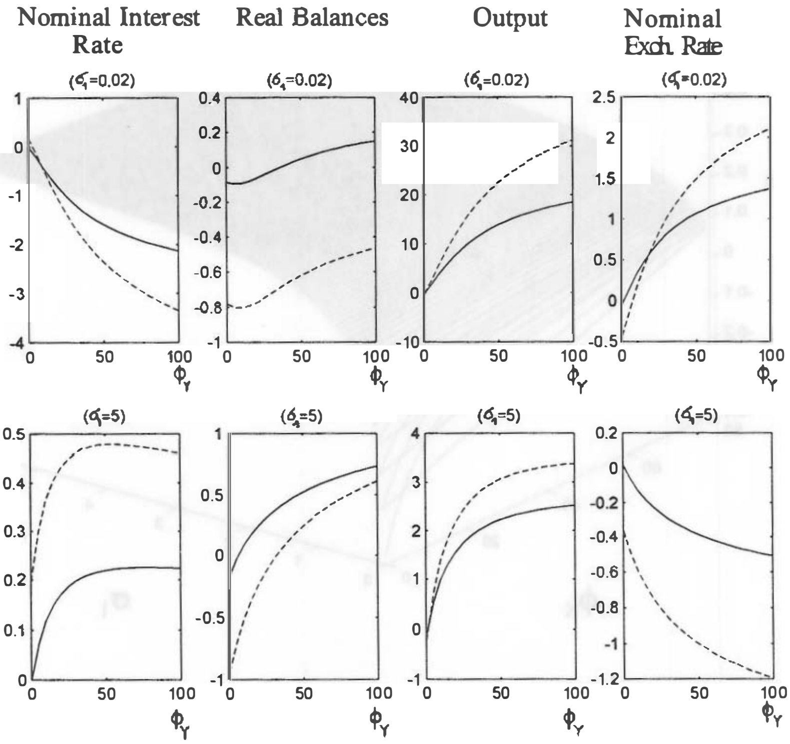


FIGURE 3
Impact effects of money shocks under alternative Price Adjustment Costs (ϕ_Y), Inflation Expectations (ρ_μ) and Intertemporal Substitution (σ_1) Effects

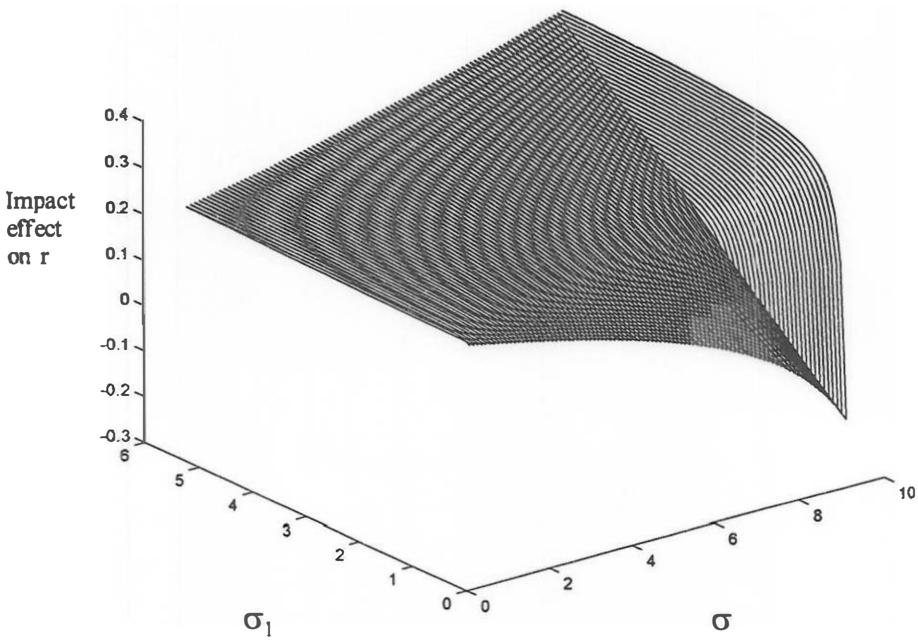


Note: The dotted line corresponds to ρ_μ=0.5 (high inflation expectations) and the continuous line to ρ_μ=0.01 (low inflation expectations). A positive impact effect on nominal exchange rate measures an overshooting effect since it was calculated as the difference between the impact effect and the long-run effect.

FIGURE 4

Responses to a Monetary shock:

The liquidity effect under alternative values for the intertemporal elasticity of consumption (σ_l) and for the income elasticity of the money demand (σ)



Note: Non-separable preferences (see expression (27)) with ξ= 10, a= 1, ψ= 3, ϕ_Y= 5, ϕ_K= 10.

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