BUSINESS CYCLE AND MONETARY POLICY ANALYSIS IN A STRUCTURAL STICKY-PRICE MODEL OF THE EURO AREA

Miguel Casares[1]
Universidad Pública de Navarra

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Abstract

Structural models are a powerful tool for business cycle and monetary policy analysis because they are assumed to be invariant to either policy changes or external shocks. In this paper, we derive a neoclassical monetary model in which both the demand and supply side are structural in the sense that the behavioral equations obtained are rigorously calculated from optimizing decisions of the individuals. Moreover, we introduce price stickiness on the supply side decisions so as to have relevant short-run real effects of monetary policy through the real interest rate channel. The resulting medium-size model will be calibrated and estimated for the euro area economies. As two examples of the applications of the model for the euro area, some simulations on business cycle and monetary policy analysis will be carried out.

Keywords: optimizing dynamic models, sticky prices, business cycle, Taylor rules.

JEL codes: E20, E32, E52.

1 Introduction

The overall motivation of this paper is twofold: derive and outline a dynamic macroeconomic monetary model with rigorous microfoundations both on the demand and supply side, and illustrate how the model can be used to explore macroeconomic phenomena in the euro area.

Structural monetary models with nominal rigidities (the so-called "sticky prices") are very appropriate for macroeconomic analysis because of two important reasons. First, its behavioral equations are assumed to be independent from the monetary/fiscal policy regime because they are obtained from rational (optimizing) decisions under any implemented policy. Secondly, slow-adjustment nominal prices can help capturing the short-run real effects of these policies observed in actual data. Price stickiness will arise in our model from rigidities in both selling prices setting and nominal wages contracting.

Regarding selling price decisions, we follow the assumption found in Calvo (1983) that producers are bound to maintain the price under some fixed probability. If they have the chance to set a new price they will choose their profit-maximizing price within a monopolistic competition scenario.

With respect to nominal wages, they are predetermined in the model. Contracts are signed one period in advance attempting to maintain purchasing power of households. There will be contracts signed growing at the long-run inflation rate and others that grow taking into account the rate of inflation expected for the period when the contract is in effect. In turn, predetermined nominal wages becomes another supply-side source that can generate nominal rigidities leading to output and inflation changes in the presence of a monetary shock. The rationale of the wage setting pattern chosen here relies on the assumption that neither employers nor employees have sufficient market power to unilaterally decide wages.

The demand-side of the model is entirely obtained from optimizing agents behavior in the context of the discrete-time IS-LM framework recently used in the literature (Kerr and King (1996), McCallum and Nelson (1999), and Rotemberg and Woodford (1997)) following the tradition of the neoclassical monetary models (see Sidrauski (1967), and Brock (1975)) where decisions are made to maximize agent´s utility by discounting expected values in an infinite horizon. There are two contributions in this paper to the standard model utilized in the literature. First, the role of money as a medium of exchange is explicitly incorporated through a transaction costs function entering the household's budget constraint (instead of the more traditional money in the utility function or cash-in-advance approaches). Second, investment in capital goods is calculated endogenously from the first order conditions.

Section 2 is devoted to describe the entire model. There, we will focus special attention on deriving the behavioral equations (consumption, investment, money demand, selling price) and on defining a monetary policy rule, the output gap, and the nominal and real wages.

As the resulting system of equations representing supply and demand behavior have the potential to be policy invariant they can be estimated without being subject to the Lucas critique. Hence, the model will be estimated and calibrated for the euro area in Section 3 based on (if available) quarterly observations during the period 1970.1-2000.4.

In Section 4 of this paper we study the business cycle patterns of the euro area model by means of analyzing impulse response functions. These functions represent predictions of the model for situations where there are unexpected changes in technology, preferences, or monetary policy. The design of Taylor-type monetary policy rules in the euro area is another application of the model. Hence, the performance of Taylor rules under different coefficients will be compared in Section 5 aiming at providing some monetary policy recommendations. Conclusions will be listed in Section 6.

2 The Model

The economy consists of a continuum of alike households that seek to maximize in period t the expected sum of the current and discounted future utility values depending on the state of consumption preferences ζ, and the level of consumption c

$$E_t \sum_{j=0}^{\infty} \beta^j U(\zeta_{t+j}, c_{t+j}) \tag{1}$$

where $\beta = \frac{1}{1+\rho}$ is the discount factor, $E_t[.]$ is the rational expectations operator conditional on all the information available in period t, and the standard utility function assumptions $U_c > 0$, and $U_{cc} < 0$ hold. Households are also producers. Each household produces a different good and consumes a bundle of goods that purchases from the other households. Hence, c_t denotes the number of bundles of goods aggregated using Dixit-Stiglitz indexes as usually employed in the literature (see Dixit and Stiglitz (1977), King and Wolman (1996), Yun (1996), or Erceg *et al.* (2000)).[1]

Households use the available transactions technology to carry out purchases of other-than-produced goods. In doing so, they need to spend some resources, namely, output resources according to the output-cost transactions approach at hand.[2] Our transaction costs function represents the existing transactions technology. In particular, we assume that there is a functional form that gives the amount h_t of output usages (or transaction costs) in period t depending on the number of consumption bundles c_t, and the amount held of real money balances m_t:

$$h_t = h(c_t, m_t) \tag{2}$$

with $m_t = \frac{M_t}{P_t^A}$, M_t denoting nominal money and P_t^A the Dixit-Stiglitz aggregate price level defined in footnote 1. The signs of the first order and cross derivatives are $h_c > 0$, $h_m < 0$, and $h_{cm} < 0$. The transactions-facilitating property of money as a medium of exchange is represented through the signs

[1] Concretely, the consumption bundles are constructed indexing individual consumption goods by $i \in [0,1]$ such as:

$$c_t = \left[\int_0^1 c_t(i)^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}.$$

Each household produces a single good and consumes all of them according to the constant-elasticity demand function:

$$c_t(i) = \left(\frac{P_t(i)}{P_t^A} \right)^{-\theta} c_t \text{ for all } i \in [0,1],$$

where P_t^A is the aggregate price level obtained from $P_t^A = \left[\int_0^1 P_t(i)^{1-\theta} di \right]^{\frac{1}{1-\theta}}$. This single good demand function can be obtained from optimizing criteria (to be proved under request). The condition $P_t^A c_t = \int_0^1 P_t(i) c_t(i) di$ is implied by combining the single-good demand function with the definition of P_t^A.

[2] Alternatively, we could think of transaction costs in terms of time resources and then the transaction cost function (shopping time function) would enter the time constraint instead of the budget constraint (see Casares (2000) for a formal representation of such model).

$h_m < 0$ and $h_{cm} < 0$ which imply that the use of more monetary services reduces the total and marginal transactions costs.

Investment is set as the increase in the stock of capital net of depreciation decided for next period's production plan. Thus, we denote x_t as the amount invested in period t according to the relation

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

Such amount x_t is obtained by transforming part of output into capital goods. We assume that some adjustment costs arise during the installation of capital goods.[3] As Casares and McCallum (2000) show for optimizing models, when investment is endogenous some sluggish mechanism is necessary to smooth investment movements reaching more realistic business cycle patterns. Accordingly, there exists a function $C(x_t)$ that gives the adjustment costs in terms of output due to installing x_t units of new capital goods.

The production function determines the amount of output y_t produced in period t by employing labor n_t, and the stock of capital k_t provided an (exogenous) state of technology measured by z_t

$$y_t = f(z_t, n_t, k_t). \tag{4}$$

It is assumed that $f(.)$ is homogeneous of degree 1 with the standard first and second order conditions $f_n > 0$, $f_k > 0$, $f_{nn} < 0$, $f_{kk} < 0$, and $f_{nk} > 0$. Households sell their product in a monopolistic competition market where the quantity produced is sold in the final goods market according to the Dixit-Stiglitz single good demand function:

$$f(z_t, n_t^d, k_t) = \left(\frac{P_t}{P_t^A}\right)^{-\theta} y_t^A, \qquad \textit{with } \theta > 1, \tag{5}$$

where P_t is the selling price, P_t^A is again the Dixit-Stiglitz price index, y_t^A is the Dixit-Stiglitz output index, $y_t^A = \left[\int_0^1 y_t(i)^{\frac{\theta-1}{\theta}} di\right]^{\frac{\theta}{\theta-1}}$, and θ is the constant elasticity with respect to the relative price.

[3] There can be various sources of adjustment costs: information costs, learning costs, start-up costs, etc. The key point is that investing in real assets is conceptually different from investing in financial assets (bonds).

In real magnitudes, the budget constraint faced by the households is

$$g_t + \left(\frac{P_t}{P_t^A}\right)^{1-\theta} y_t^A - C(x_t) = c_t + x_t + h(c_t, m_t) + w_t(n_t - 1) + \\ m_t - (1+\pi_t)^{-1} m_{t-1} + (1+r_t)^{-1} b_{t+1} - b_t, \quad (6)$$

where π_t is the rate of inflation $\left(\pi_t = \frac{P_t^A - P_{t-1}^A}{P_{t-1}^A}\right)$ and r_t is the real interest rate. There are two sources of real income for the household: lump-sum real transfers from the government (g_t), and their own demand-determined output production after subtracting the adjustments cost of investment. Income is spent on consumption (c_t), on investment (x_t), on paying the transaction costs ($h(.)$), on payments to the labor force hired in the market ($w_t(n_t - 1)$, with w_t denoting the real wage and assuming a one-unit inelastic labor supply), and on increasing the amounts held of real money ($m_t - (1+\pi_t)^{-1} m_{t-1}$) or bonds ($(1+r_t)^{-1} b_{t+1} - b_t$).

As of period t, households make rational choices of c_t, k_{t+1}, n_t, m_t, b_{t+1}, and P_t by maximizing (1) subject to the market demand condition (5), and the budget constraint (6). Regarding P_t's optimal decision, we assume as in Calvo (1983) that each seller can adjust the price with a probability associated equal to $1 - \eta$ whereas they will have to stick to the last period price with a probability equal to η.[4] Assuming the former state of nature, the resulting first order conditions concerning the t-period choice variables include the market and budget constraints (5), (6), and[5]

[4]Price setting *á la* Calvo creates two differences among households: they will have a different selling price depending upon when it was decided and the amount produced will also be different according to their particular price entering their demand constraint. However, as they share preferences, production technology, and transactions technology, demand-side decisions (consumption, investment, and money demand) are identical among households.

[5]For convenience, we use the notation $F_{x_t} = \frac{\partial F(x_t, y_t)}{\partial x_t}$ for the partial derivatives.

$$U_{c_t} - \lambda_t(1 + h_{c_t}) = 0, \qquad (c_t^{foc})$$

$$-\lambda_t(1 + C_{x_t}) + \beta E_t \left[\lambda_{t+1}(1 - \delta + (1 - \delta)C_{x_{t+1}})\right] + \beta E_t \left[\xi_{t+1} f_{k_{t+1}}\right] = 0, \qquad (k_{t+1}^{foc})$$

$$-\lambda_t w_t + \xi_t f_{n_t} = 0, \qquad (n_t^{foc})$$

$$-\lambda_t(1 + h_{m_t}) + \beta E_t \left[\lambda_{t+1}(1 + \pi_{t+1})^{-1}\right] = 0, \qquad (m_t^{foc})$$

$$-\lambda_t(1 + r_t)^{-1} + \beta E_t \lambda_{t+1} = 0, \qquad (b_{t+1}^{foc})$$

$$\sum_{j=0}^{\infty} E_t \left[(1-\theta)\beta^j \eta^j \left(\lambda_{t+j} \left(\frac{P_t}{P_{t+j}^A}\right)^{-\theta} \frac{y_{t+j}^A}{P_{t+j}^A}\right) + \theta \beta^j \eta^j \left(\xi_{t+j} \left(\frac{P_t}{P_{t+j}^A}\right)^{-\theta-1} \frac{y_{t+j}^A}{P_{t+j}^A}\right)\right] = 0, \qquad (P_t^{foc})$$

where λ_t, and ξ_t are respectively the Lagrange multipliers attached to the budget constraint and market demand constraint in period t.

The consumption function.

The first order condition for consumption (c_t^{foc}) implies that the consumption shadow price (i.e., the Lagrange multiplier λ_t) is equal to the marginal utility of consumption divided by one plus the marginal transaction cost[6]

$$\lambda_t = \frac{U_{c_t}}{1 + h_{c_t}}.$$

Combining the previous expression in periods t and $t+1$ with the first order condition for bonds (b_{t+1}^{foc}), it yields:

$$1 + r_t = \beta E_t \left[\frac{U_{c_t} \left(1 + h_{c_t}\right)^{-1}}{U_{c_{t+1}} \left(1 + h_{c_{t+1}}\right)^{-1}} \right]. \qquad (7)$$

Let us assume that households' preferences are well represented by a constant relative risk aversion (CRRA) instantaneous utility function,

[6]Note that when there is no transaction cost we get the standard consumption shadow price equation $\lambda_t = U_{c_t}$.

$$U(\zeta_t, c_t) = \exp(\zeta_t)\frac{c_t^{1-\sigma}}{1-\sigma} \quad (8)$$

$$with\ \sigma > 0,$$

and the transaction technology is given by the following functional form:

$$h(c_t, m_t) = \left\{ \begin{array}{ll} 0 & if\ c_t = 0 \\ b_0 + b_1 \frac{c_t^{b_2}}{m_t^{b_3}} & if\ c_t > 0 \end{array} \right\} \quad (9)$$

$$with\ b_0, b_1, b_2, b_3 > 0,$$

Substituting both functional forms (8) and (9) in the first order condition (7) and then log-linearizing following the techniques described in Uhlig (1999), it yields the consumption function:

$$\widehat{c}_t = E_t\widehat{c}_{t+1} - \vartheta^c (r_t - r^{ss}) + b_3 h_c^{ss} \vartheta^c (\widehat{m}_t - E_t\widehat{m}_{t+1}) + \vartheta^c \left(\zeta_t - E_t\zeta_{t+1}\right), \quad (10)$$

where $\vartheta^c = \frac{1}{\sigma + (b_2 - 1) h_c^{ss}(.)}$ is the semi-elasticity of consumption to changes in the real interest rate and "hat" variables represent percent deviations from steady state (e.g., $\widehat{c}_t = \log(\frac{c_t}{c^{ss}})$). The existence of a (non-separable) transaction costs function in the budget constraint gives rise to the presence of monetary elements in the consumption Euler equation. On this issue and assuming that the shock on preferences is white noise, we can express the consumption function as follows

$$\widehat{c}_t = \vartheta^c \zeta_t + b_3 h_c^{ss} \vartheta^c \widehat{m}_t - \vartheta^c E_t \sum_{j=0}^{\infty} (r_{t+j} - r^{ss}).$$

In this formulation, current consumption depends positively on the current state of preferences ζ_t, and on current real money balances $\widehat{m}_t$; and in a negative fashion on the "long-run" real interest rate $E_t \sum_{j=0}^{\infty} (r_{t+j} - r^{ss})$. There is a real balance effect whose origin is different from the store-of-value function related to the portfolio selection initially described in Tobin (1965). Here, the actual origin for the real balance effect is the medium-of-exchange role of money that makes consumption more attractive when holding greater real money balances due to having less marginal transaction costs associated to purchases of consumption goods. Consequently, more real money balances leads to more consumption.

The investment function.

The decision regarding the quantity to invest is governed by the next period's capital first order condition (k_{t+1}^{foc}). As it can be seen above, that equation depends on the Lagrange multiplier ξ_{t+1}. Recalling the implicit optimality condition for next period's demand of labor (n_{t+1}^{foc}), it is obtained $\xi_{t+1} = \lambda_{t+1}\frac{w_{t+1}}{f_{n_t+1}}$. After substituting that result in (k_{t+1}^{foc}) the investment decision will be optimal when holding

$$\lambda_t(1 + C_{x_t}) = \beta E_t \left[\lambda_{t+1} \left(1 - \delta + (1-\delta)C_{x_{t+1}} + \frac{w_{t+1}}{f_{n_{t+1}}} f_{k_{t+1}} \right) \right]. \tag{11}$$

On the left-hand side we have, in utility units, the marginal costs coming from the last unit of investment taken. On the right-hand side, we have the expected marginal benefits in utility units as well. When we incorporate the relation $\beta E_t \lambda_{t+1} = \lambda_t(1+r_t)^{-1}$ the Lagrange multipliers cancel out resulting in

$$1 + r_t = E_t \left[\frac{1 - \delta + (1-\delta)C_{x_{t+1}} + \frac{w_{t+1}}{f_{n_{t+1}}} f_{k_{t+1}}}{1 + C_{x_t}} \right] \tag{12}$$

The left-hand side of (12) is now the marginal cost (opportunity cost) of one the last unit of physical capital invested and the right hand side is the expected marginal revenue. Now we will assume the existence of a Cobb-Douglas production function,

$$f(z_t, n_t, k_t) = \exp(z_t) n_t^{1-\alpha} k_t^{\alpha}, \tag{13}$$

and an adjustment cost specification used in Abel (1983), and more recently in Casares and McCallum (2000),

$$C(x_t) = \varphi x_t^{\nu} \tag{14}$$
$$with \qquad \varphi > 0 \qquad and \qquad \nu > 1.$$

The functional form (14) implies increasing marginal adjustment cost. Since the production function $f(.)$ is homogeneous of degree 1, we have a production function net of adjustment costs $f(z_t, n_t, k_t) - C(x_t)$ that implies decreasing returns to scale. In other words, the ratio of total adjustment costs to output would increase with the size of the production plant, discouraging the existence of large plants.

Plugging the production function (13) and the adjustment cost function (14) in the investment first order condition (12), log-linearizing, and solving out for $\widehat{x}_t$, it yields the following investment equation

$$\widehat{x}_t = (1-\delta)E_t\widehat{x}_{t+1} + \vartheta^x \psi^{ss} f_k^{ss}(E_t\widehat{\psi}_{t+1} + E_t\widehat{f}_{k_{t+1}}) - \vartheta^x (r_t - r^{ss}), \tag{15}$$

where $\vartheta^x = \frac{1}{C_x^{ss}(\nu-1)}$, and $\widehat{\psi}_{t+1} = \widehat{w}_{t+1} - \widehat{f}_{n_{t+1}}$ is the percent deviations from steady state of the real marginal cost (in terms of labor) faced by the households. Regarding the latter, it enters the investment function with a positive sign. When the real marginal cost is expected to rise ($E_t\widehat{\psi}_{t+1} > 0$), labor becomes more costly and households substitute units of labor for units of capital; investment rises. Likewise, if the capital marginal productivity is expected to be larger in the next period ($E_t\widehat{f}_{k_{t+1}} > 0$) households will decide to invest more in the current period. The third variable affecting investment decisions is the real interest rate which represents the opportunity cost missed. Government bonds yield r_t for the next period and households could be obtaining that return if they switched their physical assets (capital goods) to financial assets (bonds). Hence, the real interest rate enters the investment equation with a negative sign. The value of ϑ^x is the semi-elasticity of current investment with respect to the real interest rate (comparable to ϑ^c therefore). Interestingly, the larger the marginal adjustment costs of investment (C_x^{ss}) are, the smaller the semi-elasticity ϑ^x is, implying a lower variability of investment over the business cycle.

The money demand function.

The amount of real money balances optimally held is determined by the first order condition (m_t^{foc}) derived above. Considering that expression together with the intertemporal relation $\beta E_t \lambda_{t+1} = \lambda_t (1 + r_t)^{-1}$, we reach:

$$E_t \left[(1 + r_t)(1 + \pi_{t+1}) \right] = \frac{1}{1 + h_{m_t}},$$

which, defining the nominal interest through the Fisher equation, is equivalent to write:

$$1 + R_t = \frac{1}{1 + h_{m_t}} \tag{16}$$

Again, the optimality condition collapses to a marginal benefit/marginal cost equality. In this case, the marginal (opportunity) cost is the nominal interest rate missed and the marginal benefit is the reduction in transaction costs due to the use of monetary services. The value of h_{m_t} was obtained from the transaction technology function (9) and then plugged in (16) so that the resulting relation was log-linearized to obtain the money demand function

$$\widehat{m}_t = \tfrac{b_2}{1+b_3} \widehat{c}_t - \tfrac{1}{R^{ss}(1+b_3)} (R_t - R^{ss}). \tag{17}$$

Real money balances depend positively on the amount consumed and negatively on the nominal interest rate. The three equations analyzed so far (consumption, investment, and money demand) describe the demand behavior of the economy. The supply side will be studied now through the derivation of the so-called New Phillips curve.

The selling price equation and the New Phillips curve.

We depart from the first order condition for the selling price (P_t^{foc}) derived above. The resulting equation can be rearranged to be solved out for P_t as follows

$$P_t = \frac{\theta}{\theta - 1} E_t \left[\frac{\sum_{j=0}^{\infty} \eta^j Q_{t,t+j} \psi_{t+j} \left(P_{t+j}^A \right)^{\theta} c_{t+j}^A}{\sum_{j=0}^{\infty} \eta^j Q_{t,t+j} \left(P_{t+j}^A \right)^{\theta - 1} c_{t+j}^A} \right], \tag{18}$$

with $\psi_{t+j} = \dfrac{w_{t+j}}{f_{n_{t+j}}}$ again as the real marginal cost and $Q_{t,t+j}$ being the stochastic discount factor from period t to period $t+j$. The previous expression can be log-linearized to obtain[7]

$$\log P_t = \beta\eta E_t \log P_{t+1} + (1-\eta)\log P_t^A + (1-\eta)\widehat{\psi}_t. \tag{19}$$

The resulting expression implies that the price set by the household depends positively on the expected future evolution of both the aggregate price level and the real marginal costs. The discount rate employed is $(1-\beta\eta)^{-1}$ per period. As for the aggregate price level, if we index prices according to the period when the price was set, the Dixit-Stiglitz scheme yields the expression

$$P_t^A = \left[\sum_{j=0}^{\infty}(1-\eta)\eta^j P_{t-j}^{1-\theta}\right]^{\frac{1}{1-\theta}},$$

in which $(1-\eta)\eta^j$ is the fraction of households that set a new a price j periods ago. This definition of P_t^A is equivalent to

$$P_t^A = \left[(1-\eta)P_t^{1-\theta} + \eta\left(P_{t-1}^A\right)^{1-\theta}\right]^{\frac{1}{1-\theta}}$$

that in log-linear percent deviations from steady state can be expressed as follows

$$\log P_t^A = (1-\eta)\log P_t + \eta \log P_{t-1}^A. \tag{20}$$

[7]In steady state, it can be found:

$$\frac{w^{ss}}{f_n^{ss}} = \psi^{ss} = \frac{\theta-1}{\theta}\frac{1-\beta\eta(1+\pi)^{\theta}}{1-\beta\eta(1+\pi)^{\theta-1}}\left[\frac{1-\frac{\eta}{(1+\pi)^{1-\theta}}}{1-\eta}\right]^{\frac{1}{1-\theta}}.$$

While loglinearizing, we assumed $\psi^{ss} = \frac{\theta-1}{\theta}$ since the two-term factor that post-multiplies $\frac{\theta-1}{\theta}$ is very close to one after calibration. When either $\pi = 0$ (constant prices in steady state) or $\eta = 0$ (fully flexible prices) the assumption exactly holds.

Combining equations (19) and (20), and using the definition of inflation $\pi_t = \log P_t^A - \log P_{t-1}^A$ results in the following formulation for inflation quarter-to-quarter changes (the New Phillips curve)

$$\pi_t = \beta E_t \pi_{t+1} + \frac{(1-\beta\eta)(1-\eta)}{\eta}\widehat{\psi}_t \tag{21}$$

The inflation equation is purely forward looking. Current inflation depends positively on the present and all discounted future percent deviations of the real marginal cost with respect to its steady state value. The impact of an increase in the real marginal cost is larger when a higher fraction of firms are altering their price within the quarter, say, when $(1-\eta)$ is larger. Similar derivations of the New Phillips curve can be found in Yun (1996), King and Wolman (1996), Goodfriend and King (1997), or Galí and Gertler (1999).

Monetary Policy Rule.

The monetary authorities conduct monetary policy in the model by applying a monetary policy rule (MPR) looking for stabilizing the economy over the economic cycle. Assuming that the monetary instrument is the nominal interest rate, an example of a MPR is a generalization of Taylor's rule (Taylor (1993)) with the inclusion of interest rate smoothing[8]

$$R_t - R^{ss} = (1-\mu_3)\left[\mu_1(E_{t-1}\pi_t - \pi^{ss}) + \mu_2 E_{t-1}\widetilde{y}_t\right] + \mu_3(R_{t-1} - R^{ss}) + \epsilon_t. \tag{22}$$

where $\mu_1 \geq 1$, $\mu_2 \geq 0$, $0 \leq \mu_3 < 1$, $\widetilde{y}_t$ is the output gap, and ϵ_t is a nominal interest rate shock.[9] Note that both the output gap $\widetilde{y}_t$, and the rate of

[8]The proposed MPR can be reached by combining a standard Taylor rule:

$$R_t^* - R^{ss} = \mu_1(E_{t-1}\pi_t - \pi^{ss}) + \mu_2 E_{t-1}\widetilde{y}_t$$

with a partial adjustment equation that includes an error term

$$R_t - R^{ss} = (1-\mu_3)(R_t^* - R^{ss}) + \mu_3(R_{t-1} - R^{ss}) + \epsilon_t,$$

and where μ_3 reflects the degree of interest rate smoothing.

[9]The value of the annualized Taylor coefficient of the output gap in (22) is μ_2 multiplied by four. The other two coefficients (μ_2 and μ_3) would remain with the same value in quarterly observations as in annual observations.

inflation enter the rule as expectations of next period's values so as to reflect that the monetary authorities do not know actual values when they set the nominal interest rate. Let us take some lines to describe how the output gap is computed in the model.

The output gap.

The output gap $\widetilde{y}_t$ is defined as the percentage difference between current and market-clearing output

$$\widetilde{y}_t = \widehat{y}_t - \widehat{\overline{y}}_t. \tag{23}$$

Current output $\widehat{y}_t$ is demand determined as the weighted sum of consumption, investment (including adjustment costs of investment), and the transaction costs

$$\widehat{y}_t = \frac{c^{ss}}{y^{ss}}\widehat{c}_t + \frac{x^{ss}+C(x^{ss})}{y^{ss}}\widehat{x}_t + \frac{h^{ss}}{y^{ss}}\widehat{h}_t. \tag{24}$$

This equation can be obtained by plugging the government budget constraint, $g_t = m_t - (1+\pi_t)^{-1}m_{t-1} + (1+r_t)^{-1}b_{t+1} - b_t$, in the household's budget constraint (6) so as to reach the overall resources constraint:[10] $y_t - C(x_t) = c_t + x_t + h(c_t, m_t)$. The overall resources constraint in log-linear terms becomes the demand-determined output equation (24).[11]

Market-clearing (capacity) output is the amount produced when there is equilibrium in both the labor and capital markets. Recalling that labor is inelastically supplied in one unit of time, the Cobb-Douglas technology implies that capacity output evolves depending on the state of technology and the stock of capital:

$$\widehat{\overline{y}}_t = z_t + \alpha\widehat{k}_t, \tag{25}$$

[10] Also assuming that the labor demand dominates in the labor market and becomes the effective amount of labor employed.

[11] Note that equation (24) does not hold in a household-to-household basis because although consumption, investment, and transaction costs are equal among households, each of them produces a different amount of output depending on the timing of their price setting. Therefore, there can be excess demand or supply in particular households but not in aggregate magnitudes. Hence, $\widehat{y}_t$ is meant to represent average (per-household) magnitudes. See Yun (1996) for aggregation technical details.

Nominal and Real Wages

The real wage w_t is defined as the nominal wage W_t divided by the aggregate price level

$$w_t = \frac{W_t}{P_t^A}$$

There are two types of nominal wages signed in the economy. The first type is a "fixed" contract: nominal wage is growing at the steady-state rate of inflation. Accordingly the nominal wage in period t would be predetermined following the rule $W_t = W_{t-i}(1+\pi^{ss})^i$. In the second type, the nominal wage grows at the expected inflation of the quarter of the contract: $W_t = W_{t-1}(1+E_{t-1}\pi_t)$. Note that this type of contract also gives rise to a predetermined nominal wage. The average nominal wage will be a linear combination of both types. In particular, it will be assumed that there is a probability κ that the nominal wage was signed incorporating the inflation revision and a probability $(1-\kappa)$ that the nominal wage was given by the first contract rule. Consequently, the average real wage w_t will be:

$$w_t = \kappa \frac{W_{t-1}(1+E_{t-1}\pi_t)}{P_t^A} + (1-\kappa)\frac{W_{t-1}(1+\pi^{ss})}{P_t^A}$$

Multiplying and dividing by P_{t-1}^A we reach

$$w_t = \kappa w_{t-1}\frac{(1+E_{t-1}\pi_t)}{(1+\pi_t)} + (1-\kappa)w_{t-1}\frac{(1+\pi^{ss})}{(1+\pi_t)},$$

that after log-linearizing results in the linear real wage equation

$$\widehat{w}_t = \widehat{w}_{t-1} - \kappa(\pi_t - E_{t-1}\pi_t) - (1-\kappa)(\pi_t - \pi^{ss}). \quad (26)$$

The real wage falls when either the rate of inflation is above its steady state value (because of the fixed nominal contracts) or when there is a positive inflation "surprise", i.e., current inflation is greater than expected inflation (because of the revised contracts). If all the contracts are revised in every period according to expected inflation ($\kappa = 1$), there would only be an inflation surprise effect. On the contrary, if all the contracts are signed according to the steady-state inflation rule ($\kappa = 0$), the difference between current and steady-state inflation would be the only determinant in the change of the real wage.

Optimizing criteria was not employed to derive nominal wages because we consider that typically they are signed so as to maintain the purchasing power of the workers. Thus, neither employers nor employees have market power to decide over nominal wages. In the related literature, one can find papers where nominal wages are decided optimally in either a wage-rigidity scenario (see Erceg *et al.* (2000)) or in a perfect competition setup (see Yun (1996)).

In the end, the dynamic model described here consists of sixteen rational expectations linear equations and sixteen endogenous variables as shown in the Appendix of this paper. A previous step to solving the model is the calibration/estimation of its parameters.

3 Estimation and Calibration

This section is devoted to estimate and calibrate the model with euro area data so that the parameters of the structural equations derived in the previous section take certain values. Five macroeconomic series were utilized in the estimation/calibration procedures conducted below: consumption, investment, inflation, short-run nominal interest rate, and the narrow definition for the monetary aggregate, M1. Our source is the euro area-wide model data base developed by Fagan, Henry, and Mestre (2001). All these variables are given in quarterly observations, seasonally adjusted, and were aggregated using fixed weights based on real GDP at PPP rates. Deflated series were computed at 1990 prices. Consumption is defined as real Private Final Consumption Expenditures whereas investment is real Gross Fixed Capital Formation. The inflation rate is the quarter-to-quarter change in the log of the GDP deflator and the nominal interest rate is an average of national three-month interbank (annual) rates divided by four to be expressed in quarterly units. The monetary aggregate M1 comprises currency in circulation and overnight deposits. This narrow definition of the monetary aggregate was selected so as to represent the medium of exchange role of money, with perfect liquidity and zero nominal return. The sample period analyzed is

1970.1-2000.4 except for estimation/calibration involving M1 where we start by the first available observation in 1980.1.

In a Sidrauski-type model such as the one at hand, the steady state real interest rate r^{ss} is equal to the rate of intertemporal preference ρ. As we considered the length of a period here to be equal to one quarter we set arbitrarily $\rho = r^{ss} = 0.005$ in order to imply a 2% real interest rate per year. The baseline steady-state rate of inflation is $\pi^{ss} = 0.005$, i.e. 2% per year. Hence, the steady-state nominal interest rate is $R^{ss} = r^{ss} + \pi^{ss} = 0.01$ per quarter, or 4% per year.

The money demand and consumption equations were estimated to determine the figures assigned to the parameters σ, b_2, and b_3. We start with money demand estimation. The coefficients b_2 and b_3 from the transaction costs function (9) fully determine the elasticities of consumption and the nominal interest rate in the money demand equation (17). In order to estimate b_2 and b_3, then, we ran the following OLS regression by taking the real M1, real consumption, and the short-run nominal interest rate series[12]

$$\begin{aligned} \log m_t &= -2.29 + 0.87 \log c_t - 5.0 R_t \\ &\quad\;\, (0.6) \quad (0.04) \qquad\quad (0.75) \\ R^2 &= 0.90 \quad DW = 0.05 \end{aligned}$$

From the structural money demand equation derived above (17), the estimated interest rate semi-elasticity implies $\frac{1}{R^{ss}(1+b_3)} = 5.0$, and then using $R^{ss} = 0.01$, we set $b_3 = 19.0$. Similarly, the consumption elasticity implies $\frac{b_2}{1+b_3} = 0.87$, and consequently $b_2 = 17.4$. The numbers in parenthesis under the estimates are their standard deviations.

The Durbin-Watson statistic is close to zero indicating high serial correlation in the residuals. The very likely existence of a unit root in the error term brings about poor properties of the estimates. Thus, it would be desirable to compare our results with other empirical works. Clausen (1998) finds a stable money demand equation for the euro area when including a partial adjustment hypothesis. Furthermore, it is claimed there that stability is greater with M1 than with M3 data. With respect to the size of the

[12] The existence of heavy serial correlation in the residuals led us not to choose GMM estimators because we could not use lagged real money balances as instrumental variables. In any event, the GMM estimates, with lagged consumption and nominal interest rates as instruments, are quite similar to the OLS estimates reported here.

elasticities, it is reported a very similar figure for the consumption elasticity and a somewhat smaller figure for the nominal interest rate semi-elasticity is reported. In another recent work Stracca (2001) claims that there is a stable log-log M1 demand function for the euro area with a consumption elasticity equal to 0.75 and with a time-varying interest rate elasticity increasing in the last years of the observed period (from 1995 onwards). In any case, the incidence of money in the model at hand –where monetary policy is instrumented by the nominal interest rate– is very little. Indeed, if there were no real money balance effect in the consumption function the money demand equation could be separated from the rest of the model.

The value assigned to b_1 in (9) implies a steady-state real money over consumption ratio in the model equal to 1.6.[13] The constant transaction costs b_0 was calibrated so as to imply that total transaction costs take 1% of output in steady state ($\frac{h^{ss}}{y^{ss}} = 0.01$).

The next step is estimate the structural consumption equation (10). We used GMM estimation to obtain:

$$\begin{aligned} \log c_t &= E_t \log c_{t+1} - \underset{(0.04)}{0.60} r_t + \underset{(0.027)}{0.12}(\log m_t - E_t \log m_{t+1}) \\ R^2 &= 0.99 \qquad DW = 1.41 \end{aligned}$$

where the list of instruments contains four lags of $\log c_t$, $\log m_t$, R_t, and π_t. The real interest rate was obtained from the data as $r_t = R_t - E_t\pi_{t+1}$. Expectational variables such as $E_t \log c_{t+1}$ and $E_t\pi_{t+1}$ were replaced by actual observations. The signs of the coefficients are correct with high significance, especially the coefficient collecting the real interest rate influence. In accordance with these results, we set $\sigma = 1.43$ in the utility function to yield an interest rate semielasticity equal to -0.60.[14] Regarding the coefficient attached to the real money balances, its theoretical value in the consumption function is given by $\frac{b_3 h_c^{ss}(.)}{\sigma+(b_2-1)h_c^{ss}(.)}$. Once calibrated the values for the parameters in the transaction costs function and the utility function, we can find the steady

[13] On quarterly euro area data, the ratio of M1 real money over consumption at constant prices has a sample mean equal to 1.6 during the period 1970.1-2000.4.

[14] The interest rate semielasticity is equal to $\vartheta^c = \frac{1}{\sigma+(b_2-1)h_c^{ss}(.)}$ which is quite close to the inverse of the coefficient of relative risk aversion σ^{-1} because the marginal consumption transaction cost $h_c^{ss}(.)$ is small in steady state. If no marginal transaction costs were considered ($h_c^{ss} = 0$) we would have $\vartheta^c = \sigma^{-1}$.

state solution of the model and then fully determine $\frac{b_3 h_c^{ss}(.)}{\sigma+(b_2-1)h_c^{ss}(.)} = 0.16$. We will maintain this steady-state figure in the model despite the slightly smaller number estimated from the data. There was no conclusive evidence of serial correlation in the residuals which reported a standard deviation equal to 0.0058.

In the Cobb-Douglas production function (13) we set $\alpha = 0.36$ as the capital share coefficient. It yields a steady-state ratio of consumption over investment near 3, as consistent with euro area observations that report a c_t/x_t sample mean equal to 2.99 for the period 1970.1-2000.4.

The structural investment equation (15) is calibrated so as to match the degree of variability of investment observed in the data. Hence, we assign a semielasticity of investment with respect to the real interest rate ϑ^x such that the variability of investment relative to the variability of consumption is equal to figures observed in actual data. Series of consumption and investment from 1970.1 to 2000.4 were logged and filtered using the Hodrick-Prescott technique as standard in the literature in order to extract the cyclical (stationary) component of the original series. Then, we calculated the standard deviation of the transformed series and found that the standard deviation of investment is around three times the standard deviation of consumption. Thus, we intended to match this ratio of standard deviations by setting an adequate value for ϑ^x. It turned out that the required semi-elasticity should be 5.0. In addition, the size of the total adjustment cost is considered to be 1% of output in steady state. Thus, these two features (semi-elasticity and size of the adjustment costs) were utilized to calibrate the adjustment cost function (14). As a result, it was calibrated $\varphi = 0.081$ and $\nu = 2.62$. The depreciation rate is 2.5% per quarter ($\delta = 0.025$).

In the New Phillips curve derived above (21) the only parameter to calibrate is the probability for the household to maintain her price fixed η. It will be assumed here that households change their price once a year on average which is equivalent to say that the probability to maintain their price is $\eta = 0.75$ and the probability to set a new price is $1 - \eta = 0.25$. Consequently, the number of quarters without changing the price is on average $(1 - \eta)^{-1} = 4$, i.e., one year.

As for nominal wage contracting, they are signed with probability $\kappa = 0.25$ growing at the expected inflation for next period. In other words, one fourth of the contracts are revised every quarter to incorporate expected deviations of inflation over target. The rest of the contracts imply a nominal increase equal to the steady-state rate of inflation.

With respect to the proposed MPR, it does not seem to be appropriated any calibration for the current euro area when for the sample period observed (1970.1-2000.4) there were different central banks operating, with different targets, instruments, and observed figures of those targets and instruments. As we got closer to the era of the European Monetary Union, monetary policies were more coordinated and nominal interest rates converged following quite similar paths. However, the shortness of the adequate sub-period (starting in the middle of the 1990's or so) does not allow an accurate estimation of the rule. Our task here will be then some experimenting with a Taylor-type rule. In Section 5 we will check how the model responds to varying the coefficients of the rule so that we can extract some recommendations for applying such rule. As the baseline calibration we set $\mu_1 = 1.50$, $\mu_2 = 0.20$, and $\mu_3 = 0.75$.

Regarding the stochastic processes hitting the system we had a technology shock to the production function z_t, a consumption preferences shock to the utility function ζ_t, and a monetary policy rule shock ϵ_t. It is assumed that the technology shock remains mostly in the process following an AR(1) with a coefficient of autocorrelation equal to 0.95. The other two shocks are considered to be white noise.

In the following table we present all the parameters calibrated in the model:

Calibration of baseline parameters.

$\rho = 0.005$	$\alpha = 0.36$	$\mu_1 = 1.50$	$b_0 = 0.0313$	$\eta = 0.75$	$\pi^{ss} = 0.005$
$\beta = 0.995$	$\delta = 0.025$	$\mu_2 = 0.20$	$b_1 = 72.71$	$\kappa = 0.25$	$r^{ss} = 0.005$
$\sigma = 1.43$	$\varphi = 0.081$	$\mu_3 = 0.75$	$b_2 = 17.4$		$R^{ss} = 0.01$
	$\nu = 2.62$		$b_3 = 19.0$		

4 Business Cycle Analysis

The sixteen-equation model was solved as a linear rational expectations system of equations. We ran Paul Klein's algorithm "solvek.m" in MatLab in order to find the minimal state variable solution of the system (see Klein (1997) and McCallum (1999b) for the technical particularities). The solution is expressed as decision rule functions of the endogenous variables responding to the state variables. There are two types of state variables: predetermined and exogenous (shocks).

Impulse response functions were calculated to see how endogenous variables respond to the three shocks hitting the system. Figures 1-3 plot the results. The response functions shown in order of appearance from left to right and top to bottom correspond to: current output (y), market-clearing output (ybar), consumption (c), investment (x), marginal product of labor (fn), marginal product of capital (fk), the real wage (w), inflation, the real interest rate (r), and the nominal interest rate (R). The first seven variables represent percent deviations from steady state (for example,output j quarters after the shock is $\log(\frac{y_{t+j}}{y^{ss}})$) whereas the rate of inflation, and the nominal and real interest rates are given as simple departures from steady state (for example, inflation j quarters after the shock is $\pi_{t+j} - \pi^{ss}$). The monetary policy rule (22) was applied with the baseline coefficients $\mu_1 = 1.50$, $\mu_2 = 0.20$, and $\mu_3 = 0.75$ for this business cycle exercise.

A technology shock to the production function gives rise to increases in both market-clearing and current output as we can see in Figure 1. Indeed, changes in production technology are the major factor to explain market-clearing (capacity) output variability (in the other two shocks the responses are very little as mentioned below). The responses of consumption, investment and output are very persistent and still noticeable many quarters after the shock, because of the high serial correlation in the shock. Investment moves up by around three times the response of consumption. The rate of inflation and the nominal interest rate are driven down whereas the real interest rate, and the marginal products of capital and labor rise. As labor productivity rises inflation falls because of lower real marginal costs. The real wage shows an increasing pattern as a consequence of the drop in actual inflation from its long-run value. Finally, the nominal interest rate decreases because of applying the Taylor-type monetary policy rule to this scenario of decreasing inflation.

Figure 2 shows the effects of an unexpected increase in the nominal interest rate or, in other words, a monetary policy rule shock. With sticky prices the real interest rate increases in a similar size to the rise of the nominal interest rate. As a result, both consumption and investment fall, the latter being almost five times the fall of the former. In turn, current output has a significant drop of more than four times the size of the shock. Meanwhile, capacity output slightly falls due to the reduction of the stock of capital via less investment. In addition, inflation moves down right after the shock because the real marginal cost falls due to greater productivity of labor. This increase in the marginal product of labor is caused by less labor hired in the markets where actual output is falling substantially. As for the real wage, it shows some positive response as inflation falls. All the peaks are observed immediately after the shock and little persistence is shown in responses.[15]

In Figure 3 the effects of a positive shock to consumption preferences are described. When consumption is more satisfying, this variable goes up and so current output does. Neither there is significant change in investment nor in capacity output. Labor productivity moves down as more labor force is hired to satisfy demand pressure. On the contrary, the marginal product of capital increases because output moves up while no more capital is in use.[16] Inflation slightly increases as marginal cost rises due to lower marginal product of labor. The presence of a positive output gap does not lead to changes in the nominal interest rate because it was not foreseen by the central bank (recall that we have $E_{t-1}\widetilde{y}_t$ and not $\widetilde{y}_t$ in the MPR). No persistence is shown in any response due to the lack of serial correlation in the shock.

In summary, variability of current output can be affected by any of the three shocks whereas variability of market-clearing (capacity) output is almost exclusively determined by the technology shock with very little influence due to monetary the other shocks, and variability of the inflation and the nominal interest rate stem mostly from both the technology shock and the MPR shocks.

5 Monetary Policy Analysis

As shown in the recent literature, there are two major ways to bring about a MPR. One way is to proceed by presenting a central bank's loss function whose arguments are the monetary policy targets. The loss function is then minimized subject to aggregate demand and aggregate supply equa-

[15]Indeed, more realistic responses should include some lag in the effects on inflation and on actual output. This delay is not achieved with the model at hand. However, the inclusion of a backward-looking element in price-setting decision could result in later peaks in inflation responses (see Galí and Gertler (1999) for an example). Likewise, some habit formation term in the utility function (see Fuhrer (1998)), or a partial adjustment equation between "actual" and "optimal" consumption (or output) would lead to later peaks in output responses.

[16]Note that although the actual marginal product of capital increases, the expected next period´s marginal product of capital remains the same and therefore investment does not change.

tions that constitute the model of the economy (for examples see Svensson (1999), Clarida, Galí, and Gertler (1999), Woodford (1999)). An implicit reaction function, a MPR, might be written as the optimal response of the monetary policy instrument (typically the nominal interest rate) to current or/and expected values of state variables.

Other authors prefer to propose simple rules that are robust to model settings (e.g., Taylor (1993, 1999), and McCallum (1988, 1999a)). They argue that optimal control can be misleading due to its strict dependence on the definition and calibration of the model. In addition, the instrument reaction function implicitly derived from optimal control rules becomes convenient for policy making only within small-size models. In large models the number of explanatory variables is very high making the applicability of the MPR costly and subject to many possible computational mistakes.

The type of medium-size model at hand led us to use a simple rule approach because the resulting MPR coming from the optimal control analysis would be quite complex, i.e., with a lot of explanatory variables. Nevertheless, we loose the efficiency property found in optimal control models. As we focus the analysis on the design of easy-to-apply rules the issue of efficiency is not our main concern here.

In Section 2, we already presented the central bank behavior through a simple interest rate rule, a generalization of a Taylor-type rule that incorporates nominal interest rate smoothing:

$$R_t - R^{ss} = (1-\mu_3)\left[\mu_1(E_{t-1}\pi_t - \pi^{ss}) + \mu_2 E_{t-1}\widetilde{y}_t\right] + \mu_3(R_{t-1} - R^{ss}) + \epsilon_t. \tag{22}$$

At the beginning of period t, the central bank announces the interest rate that will be in effect during that period depending on the expected departure of inflation over its steady state value, on the expected output gap and on the previous nominal interest rate.

A monetary policy performance exercise for the euro area can be carried out by computing standard deviations of the target variables of the estimated model under the proposed Taylor-type rule for various figures assigned to μ_1, μ_2, and μ_3.[17] In our analysis, we study how changes in the coefficients of the

[17] As needed, we set standard deviations for the shocks of the model: the technology innovation entering the production function has a standard deviation equal to 0.007 (as usual in the Real Business Cycle literature), the consumption preferences shock has a

rule affect variability of the rate of inflation, the output gap, and the nominal interest rate to evaluate the stabilizing properties of the rule and define an appropriate range of coefficients. Thus, it can be seen in Figures 4, 5, and 6 how standard deviations of the rate of inflation, the output gap, and the nominal interest rate are altered when increasing μ_1 from 1.0 to 5.0, μ_2 from 0.0 to 1.0, and μ_3 from 0.0 to 1.0.

After examining the figures, one may reach the following conclusions for the intervals of coefficients at hand:

• An increase in the inflation coefficient μ_1 (see Figure 4):
  - decreases variability of inflation.
  - increases variability of the output gap.
  - increases variability of the nominal interest rate.

• An increase in the output gap coefficient μ_2 (see Figure 5):
  - increases variability of inflation (except when μ_2 is close to 0.0).
  - decreases variability of the output gap.
  - decreases variability of the nominal interest rate.

• An increase in the nominal interest rate smoothing coefficient μ_3 (see Figure 6):
  - does not significantly change variability of inflation (except when μ_3 is close to 1.0).
  - does not significantly change variability of the output gap (except when μ_3 is close to 1.0).
  - decreases variability of the nominal interest rate (except when μ_3 is close to 1.0).

In more concrete term, three monetary policy recommendations stem from the results of these simulations:

1) A large responsiveness to inflation deviations, a μ_1 coefficient greater than 2.0, would lead to too high output gap volatility without gaining a significant reduction observed in the standard deviation of inflation.

2) A medium-size responsiveness to the output gap is desirable. If it were the case that μ_2 is close to 0.0, the three standard deviations could be moved down by rising μ_2. By contrast, a large value of μ_2 –from 0.5 onwards– does not produce a visible reduction in the output gap standard deviation.

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standard deviation of 0.0058 (as estimated via the consumption structural equation in Section 3), and the MPR shock is (arbitrarily) set with a standard deviation equal to 0.001 in order to imply a high degree of nominal interest rate control with little unsystematic variability.

3) A moderate degree of interest rate smoothing is beneficial for the economy because it does not substantially affect either the output gap or the inflation variability whereas it reduces the nominal interest rate variability. A low volatility of the nominal interest rate has been both pursued by central bankers in recent years and recommended in the literature. Apart from the arguments related to precaution at policy implementation and model miss-specification described in Clarida, Galí, and Gertler (1999), McCallum (2000) has also pointed out that a small standard deviation of the nominal interest rate would also be desirable to make less likely to fall on the zero lower bound (i.e., on the liquidity trap). Thus, we recommend certain degree of interest rate smoothing. On the contrary, an interest rate smoothing with a coefficient on the vicinity of 1.0 would be harmful because the three standard deviations show a sharp increasing pattern. Therefore a number around 0.7 or 0.8 would satisfy our goals of nominal interest rate stability.

Summarizing, the baseline triplet of numbers (1.50,0.20,0.75) initially proposed seem to perform quite well in the simulations of the calibrated model. Perhaps, both the inflation and the output gap coefficients, μ_1 and μ_2, could be raised a little bit so that the inflation and output gap volatility respectively fall. However, when μ_1 is greater than 2.0 the standard deviation of the output gap begins to rise rapidly as mentioned above. In addition, when μ_2 reaches 0.5 the reduction of the output gap variability vanishes. Accordingly, the triplet of coefficients with reasonably good performance are values of μ_1 between 1.0 and 2.0, values of μ_2 between 0.2 and 0.5, and values of interest rate smoothing around $\mu_3 = 0.75$.

Accompanying the birth of the European Monetary Union, there has been much research work recently published on the issue of monetary policy in the euro area. In this regard, it is remarkable the paper by John Taylor (see Taylor (1999)) where he carries out a robustness exercise with Taylor rules in nine different models that collect the variety of models appearing in the literature. He concludes that the originally proposed coefficients of his rule ($\mu_1 = 1.5, \mu_2 = \frac{0.5}{4}, \mu_3 = 0.0$) perform sufficiently well in all the models and thus he recommends them as a guideline for interest rate setting by the ECB. Our results can be included in his line of argument. When we plug the triplet of Taylor's originally proposed coefficients in the monetary policy rule (22), the percent annual standard deviations that we obtain in the simulations are low and similar to one for the rate of inflation (1.06), the output gap (1.10), and the nominal interest rate (1.05).

In an empirical work, Gerlach and Schnabel (2000) show that actual behavior of European central bankers regarding interest setting in the 90's are well captured by a Taylor rule with its initially proposed coefficients. In another empirical work, however, Clarida, Galí, and Gertler (1998) find that monetary policies conducted in Germany, Italy, and the UK during the period 1979-1993 were less compelling than Taylor's numbers, as they found estimates for μ_1 close to 1.0. Thus, it seems to be the case that as the new era of the European Monetary Union was approaching monetary policy showed a greater degree of responsiveness, as suggested here, for a Taylor rule in the euro area.

6 Conclusions

A neoclassical monetary model with monopolistic competition and sticky prices was presented here as a predictive tool for business cycle and monetary policy analysis. Three extensions were incorporated here: the medium-of-exchange role of money is explicitly collected as one argument of the transaction cost function, capital movements are determined endogenously, and there are predetermined nominal wages signed as an attempt to guarantee the level of purchasing power of the workers. Overall, the model consisted of an optimizing IS-LM sector with transactions-facilitating money and endogenous investment, an optimizing purely forward-looking inflation equation reflecting sticky prices (New Phillips curve), a real wage equation obtained from staggered and revised nominal contracts, and a Taylor-type MPR with a smoothing component.

The consumption equation obtained is forward looking and depends negatively on the real interest rate and positively on a real money balances element. The transactions-facilitating role of money gives rise to the existence of a positive real-balance effect in consumption choices. The investment equation is also forward looking and contains three explanatory variables: the real interest rate with a negative sign and both the expected marginal product of capital and the expected real marginal cost (i.e., real wage over marginal product of labor) with a negative sign. The money demand equation is affected positively by current consumption and negatively by the nominal interest rate.

On the supply side, the selling price set by the producers is also forward looking and depends on two variables: the aggregate price level and the real marginal cost, both of them entering the price equation with a positive sign.

The model was estimated and calibrated for the euro area. A business cycle analysis was conducted by means of impulse response functions that show how the variables of the model react when there is a technology shock, consumption preferences shock, or a monetary policy rule shock. It turned out that output, consumption, and investment fluctuate significantly with changes in technology, consumer´s preferences, and monetary policy. As for the inflation and the nominal interest rates, they both move considerably when technology or monetary policy are shocked. Conversely, market-clearing (capacity) output only changes significantly with technology shocks.

The design of a Taylor-type monetary policy rule with nominal interest smoothing for the euro area calibrated model was studied in the last part of the paper. We first saw how changing the coefficients may affect the standard deviations of the variables of the model such as the rate of inflation, the output gap or the nominal interest rate. An increase in responsiveness of the nominal interest rate to inflation leads to less inflation volatility but more output gap volatility. When there is a larger response of nominal interest rates to changes in the output gap this variable becomes less volatile whereas it only increases inflation volatility for large coefficients of output gap responsiveness. As for the degree of interest rate smoothing, it was observed that more smoothing results in less interest rate volatility (except when the smoothing coefficient is close to 1.0) with no other substantial change.

By looking at the performance of the rule under different coefficients in the euro area estimated model we obtained the following conclusions: the coefficient of responsiveness to inflation deviations perform well in the range between 1.0 and 2.0, the output gap coefficient between 0.2 and 0.5, and the coefficient of nominal interest rate smoothing close to 0.75.

APPENDIX. An structural sticky-price model for business cycle and monetary policy analysis.

- Five-equation IS-LM sector:

$$\widehat{c}_t = E_t\widehat{c}_{t+1} - \vartheta^c\left(r_t - r^{ss}\right) + b_3 h_c^{ss}\vartheta^c(\widehat{m}_t - E_t\widehat{m}_{t+1}) + \vartheta^c\zeta_t, \tag{A1}$$

$$\widehat{x}_t = (1-\delta)E_t\widehat{x}_{t+1} + \vartheta^x\psi^{ss}f_k^{ss}(E_t\widehat{\psi}_{t+1} + E_t\widehat{f}_{k_{t+1}}) - \vartheta^x\left(r_t - r^{ss}\right), \tag{A2}$$

$$\widehat{m}_t = \tfrac{b_2}{1+b_3}\widehat{c}_t - \tfrac{1}{R^{ss}(1+b_3)}(R_t - R^{ss}), \tag{A3}$$

$$\widehat{h}_t = b_2\left(1 - \tfrac{b_0}{h^{ss}}\right)\widehat{c}_t - b_3\left(1 - \tfrac{b_0}{h^{ss}}\right)\widehat{m}_t, \tag{A4}$$

$$\widehat{y}_t = \tfrac{c^{ss}}{y^{ss}}\widehat{c}_t + \tfrac{x^{ss}+C(x^{ss})}{y^{ss}}\widehat{x}_t + \tfrac{h^{ss}}{y^{ss}}\widehat{h}_t. \tag{A5}$$

- New Phillips curve:

$$\pi_t = \beta E_t\pi_{t+1} + \tfrac{(1-\beta\eta)(1-\eta)}{\eta}\widehat{\psi}_t. \tag{A6}$$

- Production function. Current output and market-clearing output:

$$\widehat{y}_t = z_t + \alpha\widehat{k}_t + (1-\alpha)\widehat{n}_t, \tag{A.7}$$

$$\widehat{\overline{y}}_t = z_t + \alpha\widehat{k}_t, \tag{A.8}$$

- Monetary Policy Rule:

$$R_t - R^{ss} = (1-\mu_3)\left[\mu_1(E_{t-1}\pi_t - \pi^{ss}) + \mu_2 E_{t-1}\widetilde{y}_t\right] + \mu_3(R_{t-1} - R^{ss}) + \epsilon_t. \tag{A.9}$$

- Real wages:

$$\widehat{w}_t = \widehat{w}_{t-1} - \kappa(\pi_t - E_{t-1}\pi_t) - (1-\kappa)(\pi_t - \pi^{ss}). \tag{A.10}$$

- Definitions:

$$\widetilde{y}_t = \widehat{y}_t - \widehat{\overline{y}}_t, \tag{A.11}$$
$$r_t = R_t - E_t\pi_{t+1}, \tag{A.12}$$
$$\widehat{\psi}_t = \widehat{w}_t - \widehat{f}_{n_t}, \tag{A.13}$$
$$\widehat{f}_{n_t} = \widehat{y}_t - \widehat{n}_t, \tag{A.14}$$
$$\widehat{f}_{k_t} = \widehat{y}_t - \widehat{k}_t, \tag{A.15}$$
$$\widehat{k}_{t+1} = \delta\widehat{x}_t + (1-\delta)\widehat{k}_t. \tag{A.16}$$

This is a rational expectations linear system consisting of sixteen equations (A1)-(A16) and sixteen endogenous variables $\widehat{y}_t$, $\widehat{\overline{y}}_t$, $\widetilde{y}_t$, $\widehat{c}_t$, $\widehat{x}_t$, $\widehat{m}_t$, $\widehat{h}_t$, $\widehat{k}_{t+1}$, $\widehat{n}_t$, $\widehat{w}_t$, $\widehat{f}_{n_t}$, $\widehat{\psi}_t$, $\widehat{f}_{k_t}$, R_t, π_t, and r_t.

There also are three predetermined variables: $\widehat{k}_t$, $\widehat{w}_{t-1}$, and R_{t-1}, and three exogenous processes (shocks): ζ_t, z_t, and ϵ_t.

REFERENCES

Abel, A., 1983, Optimal investment under uncertainty, American Economic Review 73 (March), 228-233.

Brock, W.A., 1975, A simple perfect foresight monetary model, Journal of Monetary Economics 1, 133-150.

Calvo, G. A., 1983, Staggered pricing in a utility-maximizing framework, Journal of Monetary Economics 12 (Sept.), 383-396.

Casares, M., 2000, Dynamic analysis in an optimizing monetary model with transaction costs and endogenous investment, Doctoral Thesis, 61-103.

——, and B. T. McCallum, 2000, An optimizing IS-LM framework with endogenous investment, NBER Working Paper Series, 7908.

Clarida, R., J. Galí, and M. Gertler, 1998, Monetary policy rules in practice. Some international evidence, European Economic Review 42, 1033-1067.

——, ——, and ——, 1999, The science of monetary policy: a new Keynesian perspective, Journal of Economic Literature 37, 1661-1707.

Clausen, V., 1998, Money demand and monetary policy in Europe, Weltwirtschaftliches Archiv, 134(4), 712-740.

Dixit, A. K., and J. E. Stiglitz, 1977, Monopolistic competition and optimum product diversity, American Economic Review 67, 297-308.

Fagan, G., J. Henry, and R. Mestre, 2001, An area-wide model for the euro area, Econometric Modelling Division, European Central Bank, ECB Working Paper Series No. 42.

Fuhrer, J. C., 1998, An optimizing model for monetary policy analysis: can habit formation help?, mimeo, Federal Reserve Bank of Boston.

Galí, J., and M. Gertler, 1999, Inflation dynamics: a structural econometric analysis, Journal of Monetary Economics 44, 195-222.

Gerlach, S., and G. Schnabel, 2000, The Taylor rule and interest rates in the EMU area, Economics Letters 67, 165-171.

Goodfriend, M., and R. G. King, 1997, The new neoclassical synthesis and the role of monetary policy," NBER Macroeconomics Annual, MIT Press.

Kerr, W., and R. G. King, 1996, Limits on interest rate rules in the IS model, Federal Reserve Bank of Richmond Economic Quarterly 82 (Spring), 47-75.

King, R. G., and A. Wolman, 1996, Inflation targeting in a St. Louis model of the 21st century, NBER Working Paper Series, 5507.

Klein, P., 1997, Using the generalized Schur form to solve a system of linear expectational difference equations, Working paper, University of Stockholm.

McCallum, B. T., 1988, Robustness properties of a rule for monetary policy, Carnegie-Rochester Conference Series on Public Policy, 29, 173-204.

——, 1999a, Issues in the design of monetary policy rules, in J.B. Taylor and M. Woodford, eds., Handbook of Macroeconomics, (North-Holland, Amsterdam).

——, 1999b, Roles of the minimal state variable criterion in rational expectations models, NBER, Working paper 7087.

——, 2000, Theoretical analysis regarding a zero lower bound on nominal interest rates, Journal of Money, Credit and Banking 32(4) pt. 2, 870-904.

——, and E. Nelson, 1999, Performance of operational policy rules in an estimated semiclassical structural model, Monetary Policy Rules, John B. Taylor (ed.), University of Chicago Press for NBER, 15-45.

Rotemberg, J. J., and M. Woodford, 1997, An optimizing-based econometric framework for the evaluation of monetary policy, NBER Macroeconomics Annual 1997, B.M. Bernanke and J.J. Rotemberg, eds. MIT Press, (Cambridge, MA).

Sidrauski, M., 1967, Rational choice and patterns of growth in a monetary economy, American Economic Review Papers and Proceedings, 47, 534-544.

Stracca, L., 2001, The functional form of the demand for euro area M1, European Central Bank, ECB Working Paper Series No. 51.

Svensson. L. E.O.,1999, Inflation targeting as a monetary policy rule, Journal of Monetary Economics 43(3), Special Issue on Monetary Policy Rules, 607-654.

Taylor, J. B., 1993, Discretion versus policy rules in practice, Carnegie-Rochester Conference Series on Public Policy, 39, 195-214.

——, 1999, The robustness and efficiency of monetary policy rules as guidelines for interest rate setting by the European Central Bank, Journal of Monetary Economics 43(3), Special Issue on Monetary Policy Rules, 655-680.

Tobin, J., 1965, Money and economic growth, Econometrica, 33, 4, part 2, 671-684.

Uhlig, H., 1999, A toolkit for analyzing nonlinear dynamic stochastic models easily, in Computational Methods for the Study of Dynamic Economics, Ramón Marimón and Andrew Scott, (eds.), Oxford University Press.

Woodford, M., 1999, Optimal Monetary Policy Inertia, NBER, Working Paper 7261.

Yun, T., 1996, Nominal price rigidity, money supply endogeneity, and business cycles, Journal of Monetary Economics 37, 345-370.

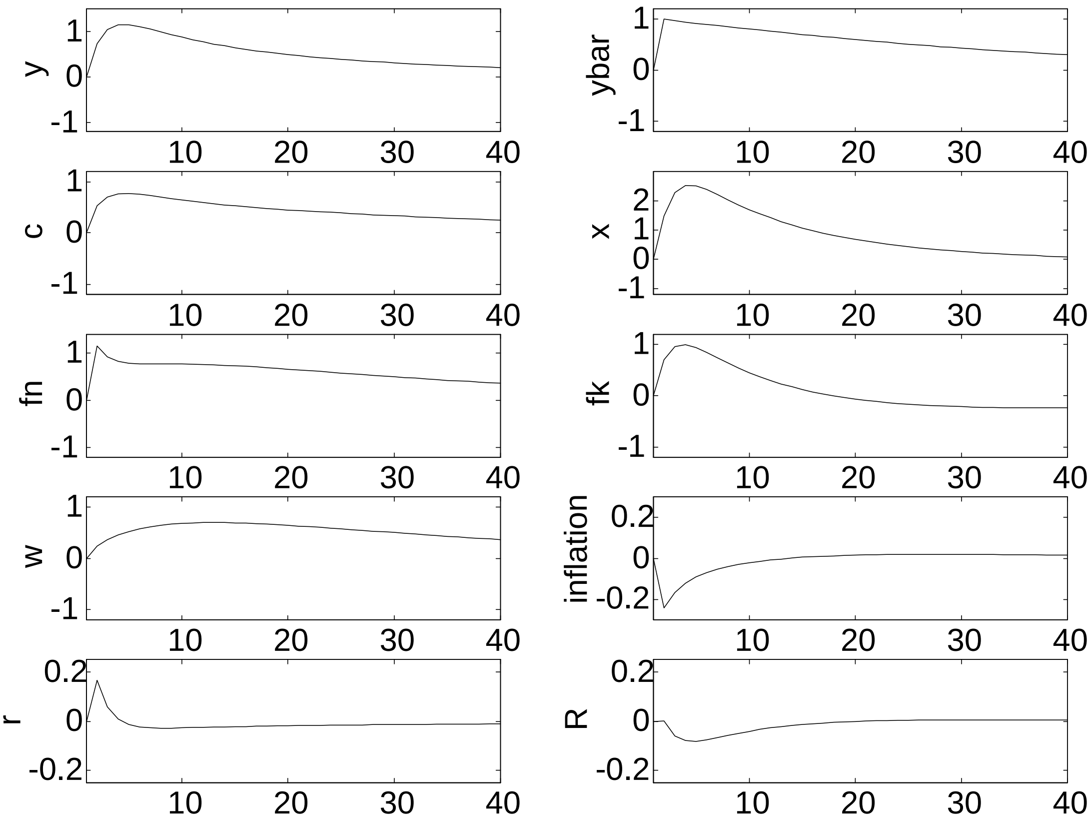

Figure 1: Impulse response functions to one unit technology shock to the production function.

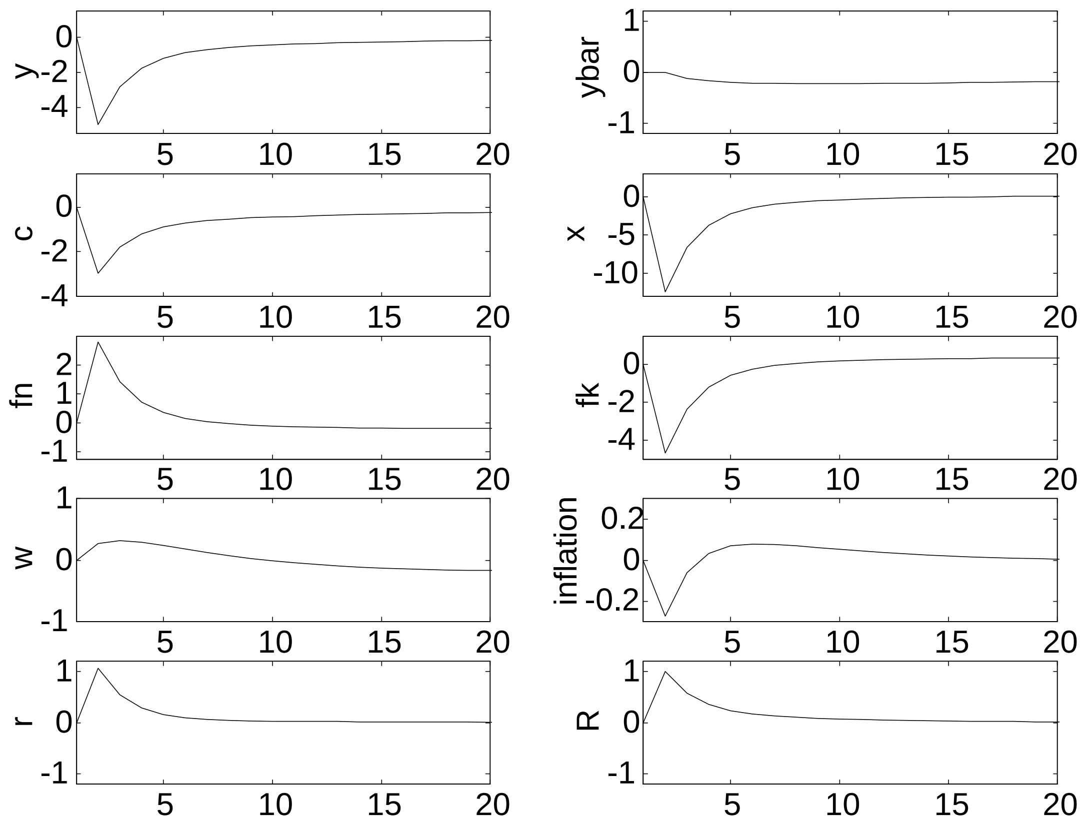

Figure 2: Impulse response functions to one unit Taylor-type monetary policy rule shock.

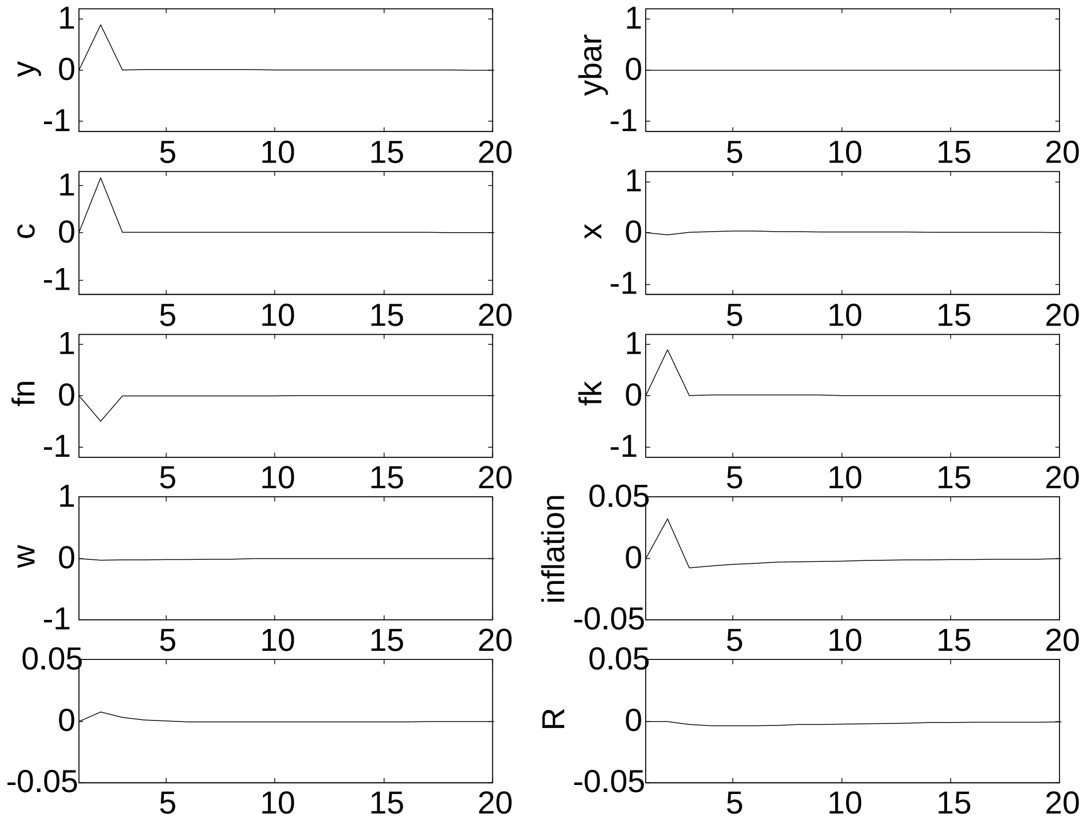

Figure 3: Impulse response functions to one unit consumption preferences shock in the utility function.

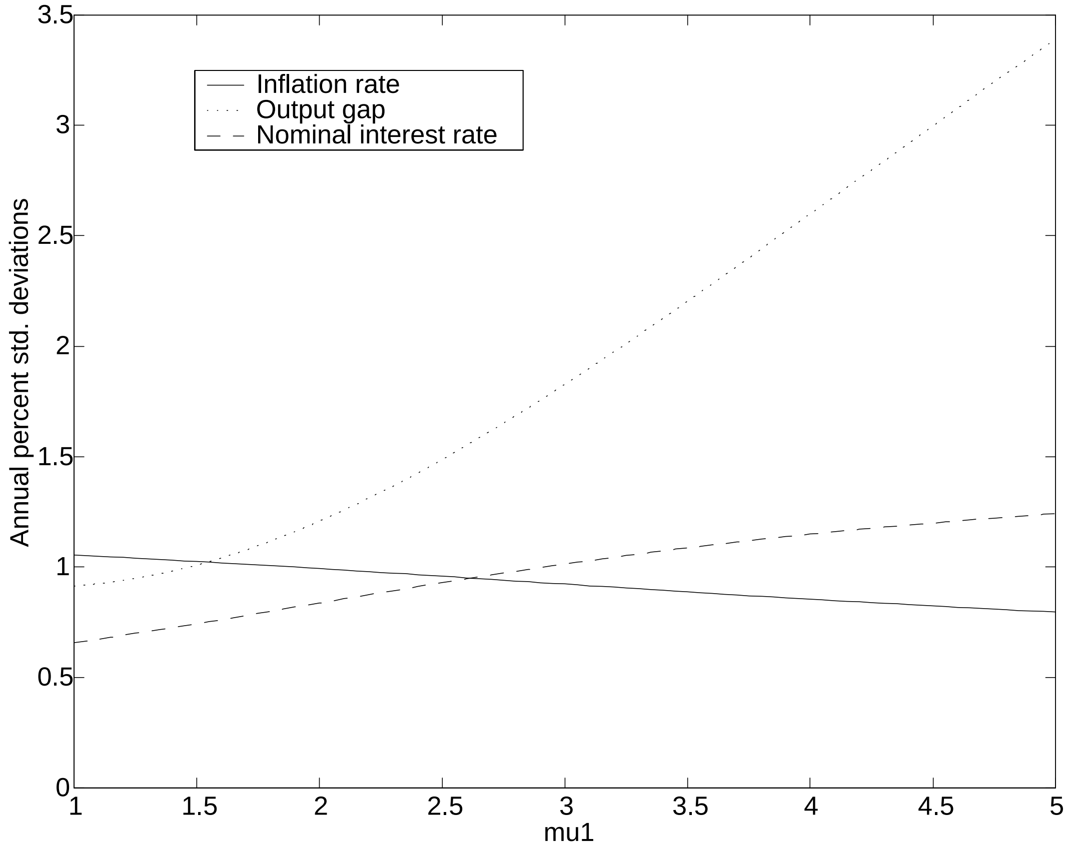

Figure 4: Taylor rule performance varying μ_1 from 1.0 to 5.0. μ_2 and μ_3 are fixed at their baseline figures.

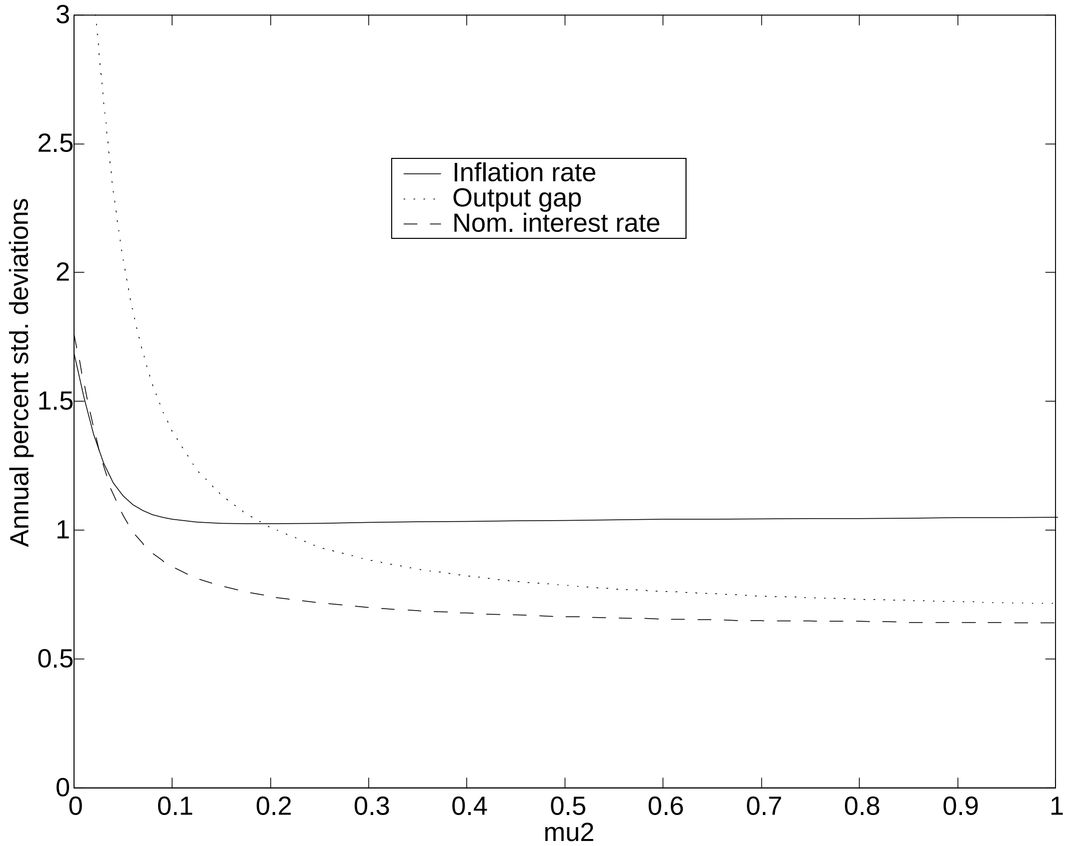

Figure 5: Taylor rule performance varying μ_2 from 0.0 to 1.0. μ_1 and μ_3 are fixed at their baseline figures.

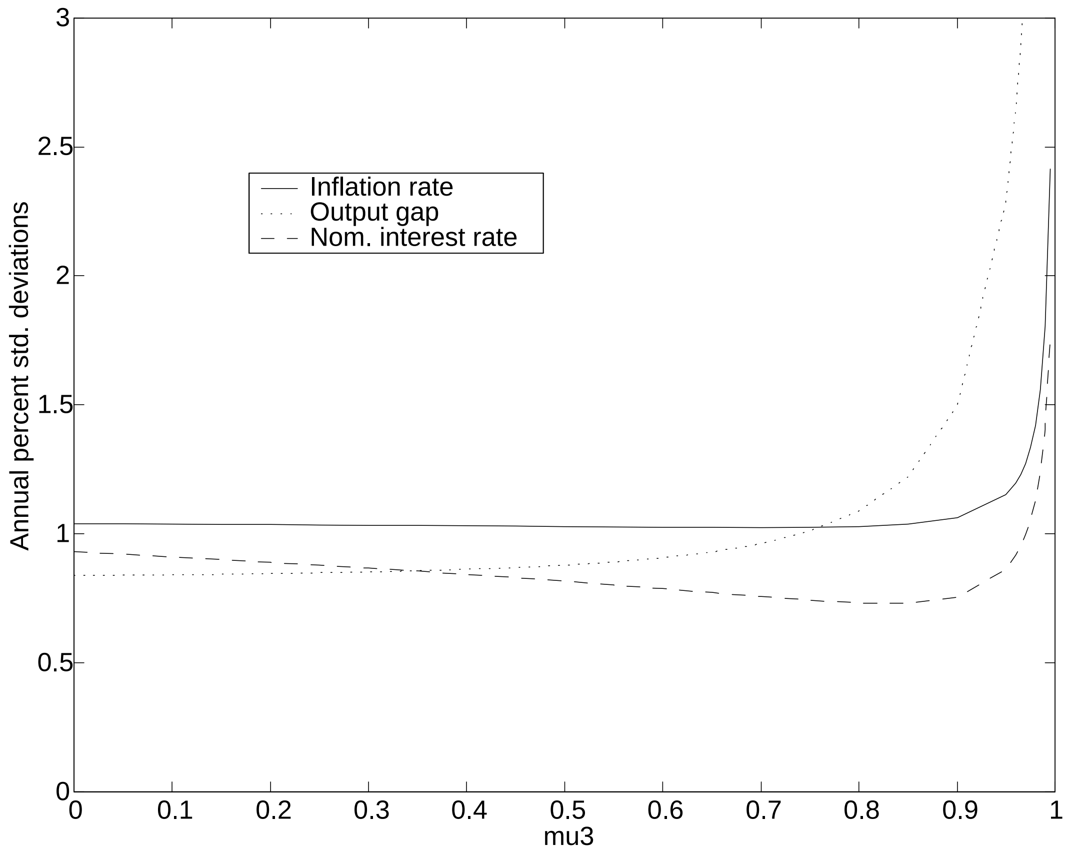

Figure 6: Taylor rule performance varying μ_3 from 0.0 to 0.995. μ_1 and μ_2 are fixed at their baseline figures.