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MODEL-BASED INFLATION FORECASTS AND MONETARY POLICY RULES

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Abstract

In this paper, the interaction between inflation and monetary policy rules is analysed within the framework of a dynamic general equilibrium model derived from optimising behaviour and rational expectations. Using model simulations, it is illustrated that the control of monetary policy over the inflation process is strongly dependent on the role of forward looking expectations in the price and wage setting process and on the credibility of monetary policy in the expectation formation process of the private sector. Furthermore, the central bank should take into account a wide variety of indicators in making monetary policy decisions in order to approach the optimal monetary policy rule as closely as possible.

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1. INTRODUCTION

Inflation forecasts depend on the expected monetary policy behaviour, at least if central bank actions have some effect on inflation over the forecast horizon. Model-based inflation forecasts will therefore depend on the maintained hypothesis about future monetary actions in the simulation exercise. Empirical studies have illustrated that this central bank behaviour can be approximated by relatively simple monetary policy rules that describe systematic relations between the monetary policy instrument, in practice the short-term interest rate, and some measure of inflation and/or output developments in the economy[1].

If the central bank inflation objective is perfectly credible, the forecast of inflation over the horizon over which the central bank has control will equal the central bank's inflation target that is present in the monetary policy rule. But this control is not perfect, for various reasons. For instance, the cost of bringing down inflation quickly can be too high, given that the central bank also cares about the real economy. Furthermore, monetary policy objectives are not always considered as perfectly credible by the public. Such arguments explain why inflation can deviate from the objective even over a relatively longer time horizon.

In this paper a small structural model is proposed which is able to explain the inflation process and its major interactions with other macro-economic aggregates and which makes it possible to illustrate the role of monetary policy rules in making inflation forecasts. A model needs to fulfil certain conditions in order to be able to discuss and compare different monetary policy rules. Ireland (1997) and Rotemberg and Woodford (1998) argue that structural models derived from optimising behaviour based on rational (or model-consistent) expectations are robust to the Lucas critique and therefore make it possible to compare and evaluate alternative monetary policy rules.

The model, calibrated for the euro area, enables us to discuss the impact of monetary policy rules on inflation forecasts. The importance of monetary policy rules for model-based forecasts is illustrated by comparing the outcome of a demand shock on

1 The results for the US federal funds rate, known as the Taylor rule (Taylor 1993), were generalised in subsequent research for different countries. Clarida, Gali and Gertler (1997) present a forward looking version of the Taylor rule for the G3 central banks. Peersman and Smets (1998) present evidence in favour of a Taylor rule for the Bundesbank's behaviour and for an average of EMU participants in the 1990s.

inflation and broader macro-economic aggregates under different monetary policy reactions.

But the model also enables us to discuss other issues related to the interaction between the inflation process and monetary policy behaviour in the context of model simulations. A first topic is the relative importance of lagged inflation versus forward looking inflation expectations in the price and wage dynamics. Optimising models derived from the Calvo model or from quadratic adjustment costs[2] result in inflation equations that are purely forward looking. The traditional Taylor nominal-contract model also results in a purely forward looking inflation equation. This specification has important implications for monetary policy: it makes disinflation costless if the announced inflation targets are regarded as credible by the public. This result conflicts with empirical evidence on the cost of disinflation[3]. This type of inflation equation is also criticised for not explaining observed persistence in inflation[4]. However, the relative importance of lagged versus forward looking terms in the inflation equations remains an empirical debate. Gali and Gertler (1998), for instance, found a dominant weight for the forward looking term using the marginal cost, instead of the traditional output gap, as an explanatory variable in the inflation equation. In the calibration of our model, a general dynamic specification for both price and wage inflation is specified and the implications for model simulations and the sacrifice ratio, in particular, are presented.

A crucial hypothesis in simulations with model-consistent expectations is the credibility of monetary policy rules and inflation targets in the perception of the private sector[5]. This assumption strongly supports the power of monetary policy over inflation expectations and indirectly over actual price and wage setting. The impact of the perfect credibility hypothesis is pointed out by comparing the simulation results of a demand shock under perfect credibility of the monetary policy reaction and inflation target with an alternative scenario in which the public perceives an incorrect inflation target and only gradually learns the actual inflation target of monetary policy. The experiment with our model confirms that the credibility assumption has important effects on the inflation outcome and that credibility is particularly valuable for central banks as it greatly reduces the sacrifice ratio of combating inflationary tendencies.

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2 See Rotemberg (1996), Hairault and Portier (1993).
3 See Ball (1993) for a discussion of the costs of disinflation policies.
4 See Fuhrer and Moore (1995) for evidence on inflation persistence within the framework of contracting models.
5 See Bomfin a.o. (1997) and Blake and Westaway (1996) for a discussion of the credibility issue and the implications for the costs of disinflation policies.

A third issue in the relation between monetary policy rules and the inflation process is the question of whether monetary policy should react to inflation or whether monetary policy should also consider other macro-economic indicators in making policy decisions. Svensson's (1998) argument for "inflation forecast" targeting implies that the central bank should use all relevant information in evaluating and deciding on policy actions. In the literature, this issue of "optimal monetary rules" is often discussed using a loss function containing the variance of inflation and output[6]. Such exercises, based on stochastic simulations, seek to arrive at a complete model estimate and identification of the major shocks that drive the economy. In this paper, the topic of "optimal" or "information-efficient" rules is simply illustrated by pointing to the consequences of different instrument rules for the sacrifice ratio.

[6] Examples are Svensson (1998), Haldane and Batini (1998). King and Wolman (1998) and Rotemberg and Woodford (1997) derive the evaluation criterion in a welfare-maximising context.

2. A DYNAMIC GENERAL EQUILIBRIUM MODEL FOR AN OPEN ECONOMY

The model is an application of the real business cycle methodology for an open economy with sticky prices and wages[7]. Households maximise a utility function over a finite life horizon with the following arguments: consumption of domestic and foreign goods, money and leisure. Consumption appears in the utility function relative to the time-varying external habit variable[8]. Labour is differentiated over households, so that there is some monopoly power over wages which results in an explicit wage equation and allows for the introduction of sticky nominal wages à la Calvo. Households allocate wealth among money, equity, domestic and foreign assets, which are considered as perfect substitutes, so that UIRP applies in the linear approximation. Firms produce differentiated goods and decide on labour, capital (with capital adjustment costs), capacity utilisation[9] and prices, again according to the Calvo model. Prices are therefore set in function of current and expected marginal costs. These marginal costs depend on the marginal unit labour cost (average over the economy) and on the price of imported intermediate inputs, described further in the text as energy inputs, which are used in fixed proportions in the production process. The composite domestic good is an imperfect substitute for the foreign good, so that the real exchange rate is not constant over time.

The model is calibrated on the euro area economy as far as the economic structure is concerned, while other behavioural parameters are set at realistic values found elsewhere in the literature. The linear approximation is solved using the forward simulator available in the Troll software.

Models that are based on dynamic micro-economic foundations for macro-economic relations are now becoming the standard tool for analysing monetary policy questions[10]. The specific model specification, presented in this paper, makes it possible to discuss various topics: the open economy problem (total versus domestic inflation), energy or broader commodity price shocks (either as intermediate input in the production process or as final demand component in consumption), and wage versus price stickiness (against the one-price models, which do not explicitly incorporate the wage

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7 This model is a version of the model considered in Kollman (1997,1998) and features monopolistic competition in both the goods and labour markets.

8 Habit depends on lagged aggregate consumption which is unaffected by any one agent's decisions. Abel calls this the "catching up with the Joneses" effect. See Abel (1990,1996) and Campbell (1998).

9 Following the approach of King and Rebelo (1998).

10 Examples are Svensson (1998), Rotemberg and Woodford (1997), Ireland (1997) and Goodfriend and King (1997).

formation process in the labour market)[11]. In this paper the interaction between inflation and output behaviour under different monetary policy rules is discussed. On the following pages we present a brief description of the main building blocks of the model.

2.1. Technologies and firms

The country produces a single final good and a continuum of intermediate goods indexed by *j* where *j* is distributed over the unit interval ($j \in [0,1]$). The final-good sector is perfectly competitive and uses as inputs domestic and imported intermediate goods. The final good is used for consumption by the representative household and the government and for investment by the firms that rent out capital. There is monopolistic competition in the markets for intermediate goods: each intermediate good is produced by a single firm.

2.1.1. Final-good sector

The final good is produced using domestic and imported intermediate goods in the following CES technology:

$$(1) \qquad Y_t = \left[\left(y_t^H\right)^{1/(1+\gamma)} + \left(y_t^F\right)^{1/(1+\gamma)} \right]^{(1+\gamma)}$$

where γ is a parameter and y_t^H and y_t^F are indices of domestic and imported intermediate goods. y_t^H can be written as:

$$(2) \qquad y_t^H = \left[\int_0^1 \left(y_{t,j}^H\right)^{1/(1+\upsilon)} dj \right]^{1+\upsilon}$$

where υ is a parameter, and $y_{t,j}^H$ denotes the quantity of domestic intermediate good of type *j* that is used in final goods production, at date t.

The cost minimisation conditions in the final goods sector can be written as:

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11 Using a similar specification, Smets and Wouters (1999) analyse the exchange rate behaviour and the monetary transmission mechanism. Aucremanne and Wouters (1999) discuss the optimal definition of core inflation from a monetary policy point of view.

(3) $$y^H_{j,t} = \left(\frac{p^H_{j,t}}{p^H_t}\right)^{-\frac{1+\upsilon}{\upsilon}} y^H_t \text{ and}$$

(4) $$y^H_t = \left(\frac{p^H_t}{P_t}\right)^{-\frac{1+\gamma}{\gamma}} Y_t$$

where $p^H_{j,t}$ is the price of the home intermediate good j, p^H_t is the price of the domestically produced composite intermediate good and P_t is the price of the final good. Perfect competition in the final goods market implies that the latter two can be written as:

(5) $$p^H_t = \left[\int_0^1 \left(p^H_{t,j}\right)^{-1/\upsilon} dj\right]^{-\upsilon}$$

(6) $$P_t = \left[\left(p^H_t\right)^{-1/\gamma} + \left(s_t p^F_t\right)^{-1/\gamma}\right]^{-\gamma}$$

where s_t is the nominal exchange rate and p^F_t is the foreign-currency price of the composite imported good.

2.1.2. Intermediate goods producers

Each intermediate good *j* is produced by a firm *j* using the following technology:

(7) $$y_{j,t} \le (1+i_e) A K^{\alpha}_{j,t} H^{1-\alpha}_{j,t} ,$$

where $y_{j,t}/(1+i_e)$ is the firm's value added, A is a productivity parameter, $K_{j,t}$ is the effective utilisation of the capital stock (the distinction between the utilisation rate and the physical capital stock is discussed in connection with capital rental firms) and $H_{j,t}$ is an index of different types of labour used by the firm. This index is given by:

(8) $$H_{j,t} = \left[\int_0^1 h_{j,\tau,t}^{\frac{1}{1+\phi}} d\tau\right]^{1+\phi} ,$$

where ϕ is a parameter and $h_{j,\tau,t}$ is the quantity of type τ labour used by firm j at time t. Energy is used in a fixed proportion, i_e, of value added.

Cost minimisation implies:

(9) $$h_{j,\tau,t} = \left(\frac{w_{\tau,t}}{W_t}\right)^{-(1+\phi)/\phi} H_{j,t} \text{ and}$$

(10) $$\frac{W_t H_{j,t}}{R_t K_{j,t}} = \frac{1-\alpha}{\alpha}$$

where R_t is the rental rate of capital, $w_{\tau,t}$ is the wage rate for type τ labour and W_t is an aggregate wage index, given by:

(11) $$W_t = \left[\int_0^1 (w_{\tau,t})^{-1/\phi} d\tau\right]^{-\phi}.$$

Equation (10) implies that the capital-labour ratio will be identical across intermediate goods producers and equal to the aggregate capital-labour ratio.

As the production function exhibits constant returns to scale, the firm's average and marginal cost are equal and given by:

(12) $$MC_t = AC_t = \frac{R_t}{(1+i_e)F_t^K} + s_t p_t^e \frac{i_e}{1+i_e} = \frac{W_t}{(1+i_e)F_t^H} + s_t p_t^e \frac{i_e}{1+i_e}$$
$$= \frac{1}{A} W_t^{1-\alpha} R_t^{\alpha} (\alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}) + s_t p_t^e \frac{i_e}{1+i_e}$$

where F_t^K and F_t^H are respectively the marginal value added of capital and labour and p_t^e is the foreign-currency price of energy. This implies that the marginal cost, too, is independent of the intermediate good produced.

Total demand for firm j's good equals the sum of domestic and foreign demand:

(13) $$y_{j,t} = y_{j,t}^H + x_{j,t}^H,$$

where export demand for good j is in turn given by:

$$x^H_{j,t} = \left(\frac{p^H_{j,t}}{p^H_t} \right)^{-\frac{1+\upsilon}{\upsilon}} x^H_t , \tag{14}$$

and x^H_t is aggregate world demand for the country's exports.

Using equations (3), (13) and (14), nominal profits of firm j are then given by:

$$\pi_{j,t} = (p^H_{j,t} - MC_t) \left(\frac{p^H_{j,t}}{p^H_t} \right)^{-\frac{1+\upsilon}{\upsilon}} \left(y^H_t + x^H_t \right) \tag{15}$$

Each firm j has market power in the market for its own good and maximises expected profits using a discount rate ($\beta\rho_t$) which is consistent with the pricing kernel for nominal returns used by the country's shareholders-households: $\rho_{t+k} = \frac{V^C_{t+k}}{V^C_t} \frac{1}{P_{t+k}}$, where V^C_t is the marginal utility of consumption at time t (see section 2.2).

The model of price determination, inspired by Calvo (1983), assumes that firms are not allowed to change their prices unless they receive a random "price-change signal". The probability that a given price can be changed in any particular period is constant ($1-V$) and determines the fraction of all prices that are changed in each period. A producer who is "allowed" to set a new price at time t will maximise the following intertemporal profit function:

$$\sum_{k=0}^{\infty} \varsigma^k \beta^k E_t \rho_{t+k} \pi_{t+k} \tag{16}$$

Profit maximisation implies the following mark-up equation:

$$p^H_{j,t} = (1+\upsilon) \frac{\sum_{i=0}^{\infty} \beta^i \varsigma^i E_t \rho_{t+i} \left(p^H_{t+i} \right)^{\frac{1+\upsilon}{\upsilon}} y_{t+i} MC_{t+i}}{\sum_{i=0}^{\infty} \beta^i \varsigma^i E_t \rho_{t+i} \left(p^H_{t+i} \right)^{\frac{1+\upsilon}{\upsilon}} y_{t+i}} \tag{17}$$

Equation (17) shows that the price set by firm j, at time t, is a function of expected future marginal costs. The price will be a mark-up over these weighted marginal costs. If prices are perfectly flexible ($\varsigma = 0$), the mark-up will be constant and equal to $1+\upsilon$. With sticky prices the mark-up becomes variable over time when the economy is hit by exogenous shocks. A positive demand shock lowers the mark-up and stimulates employment, investment and real output. Through this last channel the model acquires a Keynesian character.

The definition of the price index in equation (5) implies that its law of motion is given by:

(18) $$\left(p_t^H\right)^{-1/\upsilon} = \varsigma\left(p_{t-1}^H\right)^{-1/\upsilon} + (1-\varsigma)\left(p_{j,t}^H\right)^{-1/\upsilon}.$$

Finally, using equations (3), (7), (10), (13) and (14) the aggregate demand for capital is given by:

(19) $$K_t = \int_0^1 K_{j,t}dj = \frac{y_t}{(1+i_e)A}\left(\frac{\alpha W_t}{(1-\alpha)R_t}\right)^{1-\alpha}\left(\frac{\bar{p}_t^H}{p_t^H}\right)^{-\frac{1+\upsilon}{\upsilon}},$$

where $\bar{p}_t^H$ is determined by the following law of motion:

(18') $$\left(\bar{p}_t^H\right)^{-\frac{1+\upsilon}{\upsilon}} = \varsigma\left(\bar{p}_{t-1}^H\right)^{-\frac{1+\upsilon}{\upsilon}} + (1-\varsigma)\left(p_{j,t}^H\right)^{-\frac{1+\upsilon}{\upsilon}}$$

2.1.3. Capital rental firms

Capital is a homogenous factor of production that is owned by firms that rent capital to producers of intermediate goods. These firms can choose between physical capital accumulation (K^p) or a higher utilisation rate (z) with $K=zK^p$. Capital accumulation is given by:

(20) $$K_{t+1}^p + \frac{\psi}{2}\frac{\left(K_{t+1}^p - K_t^p\right)^2}{K_t^p} = K_t^p\left[1-\tau(z_t)\right] + I_{t},$$

where ψ is an adjustment-cost parameter, I_t is gross investment and $\tau(z_t)$ is the depreciation rate, which is an increasing function of the utilisation rate.

Capital rental firms maximise the following profit function:

(21) $$\sum_{k=0}^{\infty} \beta^k E_t \rho_{t+k} (R_{t+k}\ z_{t+K} K^p_{t+k} - P_{t+k} I_{t+k}),$$

giving rise to the following first-order condition for capital:

(22) $$Q_t = E_t \left[\beta \rho_{t+1} p_{t+1} \left(Q_{t+1} - \tau(z_{t+1}) + \frac{z_{t+1} R_{t+1}}{p_{t+1}} \right) \right],$$

where Tobin's Q is given by:

(23) $$Q_t = 1 + \psi \frac{K^p_{t+1} - K^p_t}{K^p_t}$$

The first order condition for the utilisation rate equates the cost of higher utilisation in terms of faster replacement investments with the rental price of capital services.

(24) $$R_t = p_t \tau_z (z_t)$$

2.2. The household sector

There is a continuum of households indicated by index t. Households differ in that they supply a differentiated type of labour. So each household has a monopoly power over the supply of its labour. Each household t maximises a utility function that is separable in its inputs:

(25) $$V^\tau_t = V \left[\frac{C^\tau_t}{CH_t}, \frac{M^\tau_t}{P_t}, \ell_{\tau,t} \right]$$

Utility depends on consumption of goods, C^τ_t, relative to the external habit variable, CH_t, real cash balances, M^τ_t / P_t and labour supply $\ell_{\tau,t}$. Households act as price-setters in the labour market.

Household τ's intertemporal utility function is given by:

(26) $$E_t \sum_{j=0}^{\infty} \beta^j pr^j V^\tau_{t+j},$$

where β is the discount factor and pr the probability of survival.

Households hold money balances M_t, domestic government bonds B_t, foreign interest-bearing bonds F_t and domestic equity U_t. Bonds are one-period bonds with price b_t for domestic bonds and f_t for foreign bonds. A perfect insurance market inherits consumers' wealth contingent on their death and redistributes wealth in the form of an annuity payment in proportion to household wealth. The budget constraint faced by the household is then given by:

$$\frac{M_t^\tau}{P_t} + b_t \frac{B_t^\tau}{P_t} + s_t f_t \frac{F_t^\tau}{P_t} + d_t \frac{U_t^\tau}{P_t} = \tag{27}$$
$$(\frac{1}{pr}) * \left[\frac{M_{t-1}^\tau}{P_t} + \frac{B_{t-1}^\tau}{P_t} + s_t \frac{F_{t-1}^\tau}{P_t} + d_t \frac{U_{t-1}^\tau}{P_t} + \frac{w_{\tau,t}}{P_t} \ell_{\tau,t} - C_t^\tau - T_t^\tau \right]$$

where d_t represents the capital income return and T_t lump-sum taxes.

Households maximise the objective function (26) subject to the intertemporal budget constraint (27) and the demand for their labour given in equation (9). As in the goods market, we assume that wages can only be changed after some random “wage-change signal” is received. The probability that a particular household can change its nominal wage in period t is constant and equal to $1-\xi$. A household τ which receives such a signal in period t, will thus set a new nominal wage w_τ taking into account the probability that it remains unchanged in the future.

This maximisation yields the following first-order conditions for consumption, wealth allocation and wage-setting, where λ_t is the Lagrange multiplier, i_t is the nominal rate of return on domestic bonds ($1+i_t = 1/b_t$) and i_t^F is the foreign-currency rate of return on foreign bonds ($1+i_t^F = 1/f_t$):

$$V_t^c = \lambda_t / pr \tag{28}$$

$$\beta E_t \left[\frac{\lambda_{t+1}}{P_{t+1}} \right] + \frac{V_t^{M/P}}{P_t} = \frac{\lambda_t}{P_t} \tag{29}$$

(30) $$\beta E_t\left[\frac{\lambda_{t+1}}{p_{t+1}}(1+i_t)\right]=\frac{\lambda_t}{p_t}$$

(31) $$\beta E_t\left[\frac{\lambda_{t+1}}{p_{t+1}}\frac{s_{t+1}}{s_t}(1+i_t^F)\right]=\frac{\lambda_t}{p_t}$$

(32) $$\beta\, E_t\left[\frac{\lambda_{t+1}}{P_{t+1}}\frac{d_{t+1}}{d_t}\right]=\frac{\lambda_t}{P_t}$$

(33) $$w_{\tau,t}=(1+\phi)\frac{E_t\sum_{i=0}^{\infty}\beta^i\xi^i W_{t+i}^{\frac{1+\phi}{\phi}}H_{t+i}(-V_{t+i}^{\ell})}{E_t\sum_{i=0}^{\infty}\beta^i\xi^i W_{t+i}^{\frac{1+\phi}{\phi}}H_{t+i}\frac{V_{t+i}^{C}}{P_{t+i}}}$$

Combining equations (28) and (30) gives the usual first-order condition for consumption growth. Equations (28), (29) and (30) together result in a money demand equation. Real money holdings depend on consumption, with an elasticity that is possibly smaller than one, and the velocity of money depends positively on the interest rate. Equations (30) and (31) give the uncovered interest rate parity condition for nominal exchange rate determination. Equation (32) shows that the expected holding return on equity equals the expected one-period interest rate under certainty equivalence.

Finally, equation (33) shows that the nominal wage at time t of a household t that is allowed to change its wage is set so that the present value of the marginal return to working is a mark-up over the present value of marginal cost (the subjective cost of working)[12]. When wages are perfectly flexible ($\xi=0$), the real wage will be constant mark-up over the ratio of the marginal disutility of labour and the marginal utility of an additional unit of consumption.

12 Standard RBC models typically assume an infinite supply elasticity of labour in order to obtain realistic business cycle properties for the behaviour of real wages and employment. An infinite supply elasticity limits the increase in marginal costs and prices following an expansion of output in a model with sticky prices, which helps to generate real persistence of monetary shocks. The introduction of nominal-wage rigidity in this model makes the simulation outcomes less dependent on this assumption, as wages and the marginal cost become less sensitive to output shocks, at least over the short term.

Given equation (11), the law of motion of the aggregate wage index is given by:

(34) $$(W_t)^{-1/\phi} = \xi(W_{t-1})^{-1/\phi} + (1-\xi)(w_{\tau,t})^{-1/\phi}$$

2.3. The government sector

For the sake of completeness and in order to arrive at a realistic representation of the final demand components, we also introduce a government sector. The government has to satisfy the following budget restriction:

(35) $$\frac{b_t B_t}{P_t} = \frac{B_{t-1}}{P_t} + G_t - T_t\,,$$

which states that the primary deficit, $G-T$, and the debt service has to be financed by the issuing of new public debt B_t at the current price b_t. To rule out explosive debt dynamics, the following endogenous tax behaviour is assumed:

(36) $$T_t = g\left(\frac{B_t}{P_t} - \left(\frac{B}{P}\right)^{\circ}\right),$$

where the reaction coefficient g is greater than the real interest rate ($g > i - \pi$). This ensures a stable public debt at the long-term objective B°.

2.4. The balance of payments and foreign demand

The accumulation of foreign assets F_t is determined by the current account relation:

(37) $$\frac{s_t f_t F_t}{P_t} = \frac{s_t F_{t-1}}{P_t} + \frac{p_t^H}{P_t} x_t^H - s_t \frac{p_t^F}{P_t} y_t^F - s_t \frac{p_t^e}{P_t} IE_t$$

The net foreign asset position depends on the interest payments on existing net foreign assets and the trade balance, which is given by the difference between the real value of exports, X_t^H, and the real value of imports of final goods, Y_t^F, and energy inputs, IE_t. Energy acts only as an input in the production process:

(38) $$IE_t = \frac{i_e}{1+i_e} y_t$$

The demand for exports is a function of the terms of trade $(s_t p_t^F / p_t^H)$ and demand in the rest of the world (ROW_t):

(39) $$x_t^H = \left(\frac{p_t^H}{s_t p_t^F} \right)^{-\vartheta} ROW_t$$

2.5. Market equilibrium

The final goods market is in equilibrium if production equals demand by consumers, the government and the capital accumulation firms:

(40) $$Y_t = C_t + G_t + I_t$$

The capital rental market is in equilibrium when the demand for capital by the intermediate goods producers equals the supply by the capital rental firms. The labour market is in equilibrium if firms' demand for labour equals labour supply at the wage level set by households. Aggregate consumption behaviour deviates from the first-order condition describing optimal decisions at household level by the additional wealth effect resulting from the finite horizon assumption. The external habit variable CH_t is a simple function of the lagged aggregate consumption level:

(41) $$CH_t = C_{t-1}^h$$

The interest rate is determined by a reaction function that describes monetary policy decisions. This rule will be discussed in the following sections of the paper. In order to maintain money market equilibrium, the money supply adjusts endogenously to meet the money demand at those interest rates.

In the capital market, equilibrium means that the government debt is held by domestic investors at the market interest rate i_t (assuming that the country is in a net foreign asset position), and that the net foreign assets are held by investors at the going interest and exchange rates.

2.6. The parameterisation of the model

In the standard simulation of the theoretical model the following values for the coefficients are assumed. The share of capital is set at 0.35 and the parameter for the cost of capital adjustment is 10. The parameter determining the marginal cost of higher capacity utilisation (King and Rebelo (1998)) is set at 0.1. In the utility function, we set the coefficient of relative risk aversion at 1. The habit variable moves with consumption lagged one period with a coefficient equal to 0.8. The macro-economic labour supply elasticity with respect to real wages is 0.5.

The structure of final demand is given by the following steady-state assumptions: final import/gdp = 0.06, energy import/gdp = 0.04, export/gdp = 0.10, consumption/gdp = 0.58, investment/gdp = 0.22, government expenditures/gdp = 0.20, public debt/gdp = 2.4 (60% on annual basis) and net foreign assets/gdp = 0.4 (10% on annual basis). The discount factor β is set at 0.99, the rate of depreciation is 0.02 and capital/gdp ratio is 11.0. The import and export price elasticity is set at 0.75. These parameters reflect the economic structure of a large open economy such as the euro area.

The parameters of the price and wage adjustment equation require further attention. In the theoretical model we assumed a forward looking inflation specification for the whole economy. In the simulation of the model we use a generalisation in which the inflation process is influenced by both forward looking expectations and lagged adjustment effects[13]. Following the approach of Tinsley (1993), we assume some general dynamic

[13] Gali and Gertler (1998) motivate the mix of lead and lagged inflation terms in the inflation specification by the assumption that some of the firms follow the optimal forward looking rule while other firms follow a backward looking or rule-of-thumb behaviour. Svensson (1998) derives a similar specification by adding a simple partial adjustment mechanism to the optimal Calvo-pricing rule. The Fuhrer-Moore relative-contract model, in contrast to the traditional nominal-contract model, also includes both a forward and a backward looking component.

adjustment cost mechanism in estimating the price and wage dynamics. Price and wage setters are assumed to minimise the following cost of adjustment expression:

$$(42) \qquad \sum_{i=0}^{\infty} \beta^i \left[b_0 \left(p_{t+i} - p^*_{t+i} \right)^2 + b_1 \left(p_{t+i} - p_{t+i-1} \right)^2 + \sum_{k=2}^{K} b_k \left(\Delta^k p_{t+1} \right)^2 \right]$$

where p* represents the equilibrium price level. This problem results in a general dynamic expression for inflation:

$$(43) \qquad \Delta p = -A(1) \left(p_{t-1} - p^*_{t-1} \right) + \sum_{j=1}^{k} \gamma_j (b) \Delta p_{t-j} + \sum_{i=0}^{\infty} \varphi_i (\beta, b, k) \Delta p^*_{t+i}$$

where $A(L) = 1 + a_1(b)\, L + a_2(b)\, L^2 + ... + a_{k+1}(b)\, L^{k+1}$. The estimation results using euro-area data for GDP deflator and wages indicate that for inflation the sum of the coefficients for the lagged variables assumes a value of 0.7, while for the wage dynamics the lagged variables have a coefficient equalling 0.55[14]. The impact of the forward looking expectations is therefore greatly reduced compared to the pure Calvo-price mechanism.

The model specification implies that a monetary shock has persistent effects on output and inflation. These results contrast with the results of other sticky-price general equilibrium models[15]. The difference is explained by some typical characteristics of our model:

- the introduction of both sticky prices and sticky wages slows down the adjustment speed of the price system[16]. Furthermore, the introduction of lagged inflation terms resulting from the assumed adjustment lags in both price and wage relations prevents the domestic inflation process from following the typical jump profile of models with only forward looking expectations[17]. In our specification the inflation process will show a gradual and "hump-shaped" response to nominal and real shocks;

[14] The sum of lagged and lead terms is restricted to one in the estimate.
[15] See Andersen (1998) and Jeanne (1998) for a discussion of this problem.
[16] See Erceg (1997).
[17] Estrella and Fuhrer (1998) discuss the problem of the typical jump-overshooting behaviour for both inflation and real variables in rational expectations models with optimising foundations.

- a second reason for the persistence of the effects results from the assumption underlying aggregate demand behaviour. The introduction of habit formation in the consumption process implies that aggregate demand reacts more smoothly to shocks[18]. A slower reaction of output also moderates the reaction of marginal costs and therefore of prices;

- the introduction of a variable capacity utilisation reduces the short-run impact of output fluctuations on marginal costs. Higher output in the short run is produced with a more intensive use of production capacity, so that marginal productivity of labour declines less strongly and employment moves only slightly more than proportionally to production. The fact that marginal costs behave in a less volatile manner also implies that the effect on domestic inflation is somewhat smoothed over time.

[18] Fuhrer (1998) also presents empirical evidence to motivate the use habit formation models.

3. SIMULATION RESULTS

The role of monetary policy rules in the prediction of inflation based on structural model simulation is illustrated by analysing the consequences of an exogenous demand shock on economic activity and the inflation process. Aggregate demand increases following a shock in government expenditures of one per cent of GDP. The impact of the shock will depend on the reaction function or the monetary policy rule that describes the interest rate decisions of the central bank. After an illustration of the impact of the monetary policy rule on the model simulation outcomes, other aspects of the relationship between the inflation process and the monetary policy rules are discussed. In the first place, it is shown that the control exerted by the monetary policy over the inflation rate will depend on the dynamic properties of the inflation process, the credibility of the monetary policy and the form of the instrument rule of the central bank. To illustrate the role of these arguments in the interaction between monetary policy and inflation, the sacrifice ratio, the output-cost of monetary policy actions necessary to bring inflation down by one per cent, is used to summarise the outcomes[19]. This output cost is essentially a short-term cost related to the gradual adjustment of the inflation expectations following a positive demand shock. The stabilisation of inflation at a low level will increase long term economic welfare through different channels[20]: the reduction in the economy-wide mark-up which will bring the economy closer to a competitive economy, the reduction in the relative price dispersion between individual producers reduces welfare costs from misallocation in aggregate demand, the reduction of the inflation tax on money balances. Inflation may have more negative effects through mechanisms that fall outside the scope of this paper: the interaction with a legal and contractual framework that is not adapted to coping with inflation, uncertainty and volatility of the inflation process disturbing intertemporal and static allocation problems. In both scenarios economic activity will return towards its long-term equilibrium growth path. According to the vertical long-term Phillips-curve theory, this level will be independent of the temporal deviation between actual and steady state output. But the latter may increase if the long-term growth path depends negatively on the average rate of inflation (the positive Phillips-curve relation between inflation and unemployment).

[19] In the literature different monetary policy rules are often compared using the outcome of the loss function, a combination of inflation and output variability, in stochastic simulations. See for instance Haldane and Batini (1998), Svensson (1998), Rotemberg and Woodford (1997).

[20] These gains are difficult to quantify and they are not present in our results as we work with a linearised version of the model around a zero steady state rate of inflation.

3.1. Illustration of the impact of the monetary policy rule on the inflation forecast

Figure 1 summarises the impact of the exogenous demand shock on inflation and economic activity as it is simulated with the model. In this scenario, the central bank is assumed to follow a very simple instrument rule: the interest rate is increased (decreased) every time that inflation increases (decreases) above its target rate:

$$r_t = rr^{\circ} + \Delta p^a + a\left(\Delta p_t - \Delta p^a\right) \quad (44)$$

where rr° represents the equilibrium real interest rate and Δp^a the inflation objective of the central bank. This instrument rule and the inflation objective are announced and are considered by the market participants as a perfectly credible policy, so that the interest rate equation becomes part of the model structure and is used as such by the public when forming model-consistent expectations. In the simulation described in Figure 1, the coefficient "a" is set at 1.5: the real interest rate increases by 50 basis points if inflation increases by 1%.

The outcome in Figure 1 shows that the inflation rate will temporally increase above the target level of the monetary authorities, but the reaction of the central bank will force inflation back to its target level after some time. As economic activity increases, the marginal cost of production will increase through different mechanisms: marginal productivity tends to decrease as the output gap narrows and capacity utilisation increases, whereas wages will come under upward pressure as unemployment decreases and expected inflation rises. Higher production costs and the willingness of firms to restore the mark-up will tend to increase the inflationary pressure in the economy.

Inflation does increase smoothly over time, as the dynamics of price and wage inflation are influenced by both a backward and a forward looking component. The backward looking terms in the inflation equations prevent inflation from jumping immediately to a higher level, thereafter possibly returning gradually to the target rate. This behaviour results from the existence of contracts and other rigidities in the price and wage setting that limit the flexibility of the inflation dynamics. The lead terms in the inflation equations result from the forward looking behaviour: price and wage setters who can change their price at a certain moment will take into account the expected cost increases in the future when deciding on the new price level, as its price is likely to remain fixed afterwards for a certain period of time. The expected price and cost developments will be influenced by the monetary policy rule and the inflation target. The monetary policy actions provide the nominal anchor on which market participants can base their expectations. Depending on the monetary policy rule, expectations regarding future inflation developments will differ and the outcome of the actual price and wage decisions will also differ. If the central bank reacts strongly to inflation movements and keeps clearly to the previously announced inflation target, market expectations regarding future inflation will be very moderate, so that the inflation process does not gain momentum. Firms will be motivated to restrict cost increases and will therefore be reluctant to increase supply or output levels. Higher real interest rates and real appreciation of the exchange rate decrease aggregate demand. Inflation and output will return relatively quickly to the equilibrium growth path.

Figure 2 shows that for a less strong reaction of the central bank to the demand shock (for example when, in the reaction function, the coefficient for inflation "a" is reduced from 1.5 to 1.25), inflation will increase more strongly and more persistently. In this scenario the expansion of output will also be greater. Both inflation and output-gap variance increase in this scenario. In a more extreme case, where the coefficient for inflation is smaller than 1, this means that the real interest rate will decrease following the increase in inflation, the model will not produce a unique solution, and any inflation path becomes possible[21]. The central bank fails to provide a nominal anchor under such a monetary policy rule[22]. Prediction of the future inflation path becomes impossible as any outcome can result from self-fulfilling expectations.

3.2. Difference between accommodating and non-accommodating monetary policies

Figure 3 summarises the results of a simulation in which the central bank reacts accommodatingly to the inflationary pressure resulting from the increase in economic activity. In this scenario the central bank adjusts the inflation objective upwards in order to support economic activity following an expansion in demand. For instance, let us assume that the central bank increases the inflation objective by one per cent following an increase in demand emanating from public expenditures. Here it is assumed that the higher inflation objective is announced and taken into account by market participants when doing their planning and especially when setting their prices and wages.

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21 See Bernanke and Woodford (1997) and Clarida, Gali and Gertler (1998).

22 The absence of such 'fixed end points' for the expectations of market participants is one of the reasons for the observed volatility of exchange rates and stock prices. The problem is that the central bank has only one instrument and therefore can only provide a nominal anchor for one price.

These results should be compared to the results in Figure 1 describing the non-accommodating monetary policy reaction following the demand shock. It is clear that the total area below the output curve is larger under the accommodating monetary policy. This means that the non-accommodating monetary policy has a clear temporal cost in terms of output. This cost is called the sacrifice ratio in the economic literature[23]. The sacrifice ratio is here defined as the cumulative output cost of bringing down inflation by one percentage point in the non-accommodating scenario compared to the accommodating scenario (see Table 1 and Figure 3b).

3.3. Illustration of the importance of rigidity in the inflation process

The long-term price-wage behaviour is determined by fundamental economic determinants (productivity, inflation objective, goods and labour market characteristics, etc.). But the dynamic behaviour is strongly dependent on adjustment lags and expectations about the future. Adjustment lags are largely explained by the existence of contracts and other market rigidities due to market regulation, monopoly situations, or just behaviour by simple rules of thumb.

The relative weight of forward versus backward looking elements in the dynamic price and wage behaviour are crucial for the speed and the cost at which the central bank can influence the inflation process. In the baseline model the dynamic processes for prices and wages were based on estimation results from a general dynamic cost-of-adjustment model for the euro area. In these estimation results the relative weight of forward expectations in the price-setting process was relatively limited (30%) versus (70%) for the lagged price dynamics. For the nominal wage equations the relative importance was estimated at (45%) forward versus (55%) backward.

It is clear that with a 100% forward looking model, monetary policy would have an immediate and costless control over the inflation process if the central bank were fully credible. In such a situation it would be sufficient to announce a lower inflation target to have an immediate impact on the actual inflation rate. If, however, there are adjustment lags or backward looking effects in the inflation process, the adjustment will take more time and it will cause a short-term cost. To illustrate the importance of these relative weights

[23] See Ball (1993) for a discussion of the size and determinants of the sacrifice ratio.

we simulate an alternative model in which the relative weight of the forward looking expectations has been increased by 10% for both prices (40%) and wages (55%).

Repeating the exercise of a demand shock with an accommodating and a non-accommodating monetary policy allows us to calculate again the sacrifice ratio, or in other words the total output costs incurred to obtain a reduction in the inflation rate of 1%. With fewer market rigidities, contracts or other mechanisms causing backward looking elements in the price - wage process, the cost of reducing inflation is substantially lower (see Table 1 and Figure 4). Market expectations have a stronger impact on the actual price and wage setting, so that, under the perfect credibility assumption, the impact of monetary policy announcements will have a stronger impact on actual price movements. This reduces the need for real interest rate increases and the corresponding output effects in the inflation reduction process.

3.4. Illustration of the credibility issue for monetary policy

The price and wage dynamics not only depend on the importance of market rigidities but also on the credibility of monetary policy in the perception of the market participants. In the previous examples, monetary policy was very powerful in influencing the expectations of market participants because of the assumption of perfect credibility. To illustrate the role of the credibility issue, we make an alternative simulation in which the central bank announcement only gradually (over time) affects the expectations of market participants regarding future price and wage developments. The rate at which the market adapts its expectations towards the newly announced target is fixed deterministically at 5% per quarter. Thus the inflation target perceived by the public Δp_t^p gradually moves towards the correct inflation target that determines monetary policy actions Δp^a:

(45) $$\Delta p_t^p = 0.95\,\Delta p_{t-1}^p + 0.05\,\Delta p^a$$

In the previous simulations, full credibility was assumed through the model consistent expectations formation process. As the central bank's monetary policy rule was part of the model structure, the market participants used the announced monetary rule and inflation objective in making their predictions about future variables relevant for actual economic behaviour.

However, market participants may not believe that the central bank will adhere to its monetary policy rule or to the announced inflation objective. To illustrate this problem, we assume that market participants believe that the central bank will react accommodatingly to a demand shock, so that output and inflation can increase strongly. The central bank will actually adhere to the constant inflation target and increase the interest rate according to the previously announced rule and objective. Market participants observe "unexpected" interest rate shocks, and will “learn” only gradually over time that the central bank has kept its original inflation target. In the example we assume a speed of 5% per quarter. In the meantime the central bank has however shocked the economy, by a series of unexpected interest rate increases, so that the output effects will be smaller than in the accommodating case. The output cost of reducing inflation to the original inflation level will in this case be considerably higher than with the perfect credible non-accommodating policy.

Table 1 and figure 5 show that the sacrifice ratio is considerably higher under the "learning" assumption. The cost of reducing inflation by one per cent, calculated as the difference in cumulative output difference under the accommodating and the non-accommodating policy is much higher than in the perfect credibility simulation results. The role of expectations in the disinflation process is limited in this scenario, so that the central bank has to make more use of its interest rate (and exchange rate) instruments to fight the inflation process.

3.5. Illustration of the importance of the information that is included in the monetary policy reaction function

In the previous simulations it was assumed that the central bank used a very simple instrument rule to determine its policy actions. The central bank increases the interest rate each time inflation surpasses the target inflation rate. Such a simple instrument rule will in general not be optimal for the central bank. Even if the objective function of the central bank includes inflation variability as its only objective, the optimal behaviour of the central bank will be more complex than just a simple relation between the interest-rate instrument and the inflation-target variables.

An alternative instrument rule is for instance the Taylor rule, that is considered in empirical research as a good approximation to the actual monetary policy behaviour both of the Federal Reserve in the US (Taylor (1993)) and for European countries, such as the Bundesbank's policy (Clarida a.o. (1998), Peersman and Smets (1998)). Under this strategy the central bank will increase its interest rate if inflation increases above the inflation target (the real interest rate will rise by 0.5 points for a 1% increase in inflation) but also if the output level increases above its equilibrium or potential output level (the real interest rate will rise by 0.5 points for a 1% reduction in the output gap).

(46) $$r_t = rr^{\circ} + \Delta p^a + a\left(\Delta p_t - \Delta p^a\right) + b\left(Y_t - Y_t^0\right)$$

Using the Taylor-reaction function instead of the simple inflation-reaction rule, we can repeat the simulation experiment with an accommodating and a non-accommodating reaction to a demand shock and recalculate the sacrifice ratio. The sacrifice ratio under the more general Taylor rule turns out to be smaller compared to the simpler reaction function (see Table 1 and Figure 6) .

The interpretation of this result is that the central bank uses more information to decide on its monetary policy actions under the Taylor rule. By incorporating information on the stance of the output gap in its decisions, the central bank not only looks at the actual inflation figures, but also at future inflation pressure that is present in the observed output-gap value. The result is that the central bank will react more strongly immediately following the appearance of the demand shock, but that it will reverse its policy more quickly once the output effects of the shock disappear. Using this rule means that monetary policy results in a soft-landing scenario following an expansive demand shock, preventing excessively strong fluctuations in output and inflation.

This result also indicates that there is an important difference between the ultimate objective of monetary policy on the one hand and the reaction function or instrument rule on the other hand. Although the objective can be defined narrowly in terms of inflation targeting, the central bank should take a larger set of economic variables into account in reaching its monetary policy decisions.

This example can be considerd as an illustration of the more general principle that the central bank should use a broad area of indicators for deciding on its monetary policy actions. In these circumstances monetary policy can approach the optimal monetary policy which allows the ultimate target to be approximated at minimum cost. One has therefore to determine the optimal weights in the reaction function with respect to the different indicators. Under such an optimal rule, the impacts of monetary actions are perfectly balanced against the dynamics of the inflation process. In our open economy model this problem is complicated, as the monetary policy has a direct inflation effect via the exchange rate channel and a slower, longer-term effect via the interest rate channel. This profile does not necessarily correspond to the inflationary impact of a demand shock. Thus the central bank has to use all available information for predicting the future course of inflation and the impact of its policy actions before deciding on the optimal policy reaction.

The policy should however remain clear and understandable to the public. Without fulfilment of this condition, a large part of the monetary policy effect, through its impact on market expectations, will be lost. This balancing of arguments summarises the difficult problems facing central banks in their decisions on monetary policy and in communicating the policy to the public. The money aggregate can play a role in this process, as it incorporates information on both the inflation gap (deviation of actual versus optimal target inflation), the output gap and the velocity gap (excess liquidity in the system)[24]. Using a monetary growth rate targeting rule[25], the same simulation experiment shows that the sacrifice ratio can be further decreased, compared to the simple inflation rule or Taylor rule for monetary policy (see Table 1)[26]. Of course such a result disregards the possible problems caused by velocity instability.

24 See Coenen (1998) on the comparison of inflation and monetary targeting in a P-star model.
25 Consumption was replaced by total output, with unit elasticity, in the money-demand equation for this exercise.
26 Comparing different monetary policy rules should ideally be undertaking with optimal coefficients for the different arguments. The result presented here is therefore not necessarily generally valid.

4. CONCLUSION

In this paper, the interaction between inflation and monetary policy rules is analysed within the framework of a structural model derived from optimising behaviour and rational expectations. Using model simulations, it is shown that the control exercised by monetary policy over the inflation process is strongly dependent on the role of forward looking expectations in the price and wage setting process and on the credibility of monetary policy in the expectation formation process of the private sector. Furthermore, the central bank should take into account a wide variety of indicators in making monetary policy decisions, in order to approach the optimal monetary policy rule as closely as possible. However such complications should not conflict with the public's understanding of the monetary policy behaviour. Therefore, clear communication of the monetary strategy and presentation of the arguments supporting it are crucial conditions for efficient central bank behaviour.

The understanding of the transmission mechanism and the price and wage inflation process are important ingredients in the monetary decision process. Further elaboration of dynamic general equilibrium models can help in analysing these mechanisms and show their dependency on the monetary policy behaviour. Especially the theoretical derivation of dynamic price-wage inflation equations and the empirical estimation of these models are necessary steps in this process. The resulting identification of the stochastic shocks makes it possible to carry out stochastic simulation exercises. The optimal monetary policy can then be derived explicitly by using an objective function for central bank behaviour. Such exercises should include the uncertainty in interpreting the latest economic information as well as the credibility issue.

Table 1 - Indices of sacrifice ratios under different monetary policy and model assumptions
(Annual basis, sacrifice ratio of first reported result is set equal to 1)

	Cumulative output difference between accommodating and non-accommodating monetary policy
Simple inflation rule	
$r_t = rr° + \pi° + 1.5 (\pi_t - \pi°)$	1
Less rigidity - more forward looking behaviour in price and wage equations	0.57
Non-accommodating but with a learning rule for credibility of the inflation target at 5% per quarter	1.96
Taylor-rule	
$r_t = rr° + \pi° + 1.5 (\pi_t - \pi°) + 0.5 (Y_t - Y°)$	0.69
Monetary growth rate target	
$r_t = rr° + \pi° + 1.5 (\Delta m_t - \Delta m°)$	0.63

Figure 1 - Impulse-response of a demand shock (public expenditures) under a non-accommodating monetary policy following a simple inflation instrument rule

$r_t = rr° + \pi° + 1.5\ (\pi_t - \pi°)$

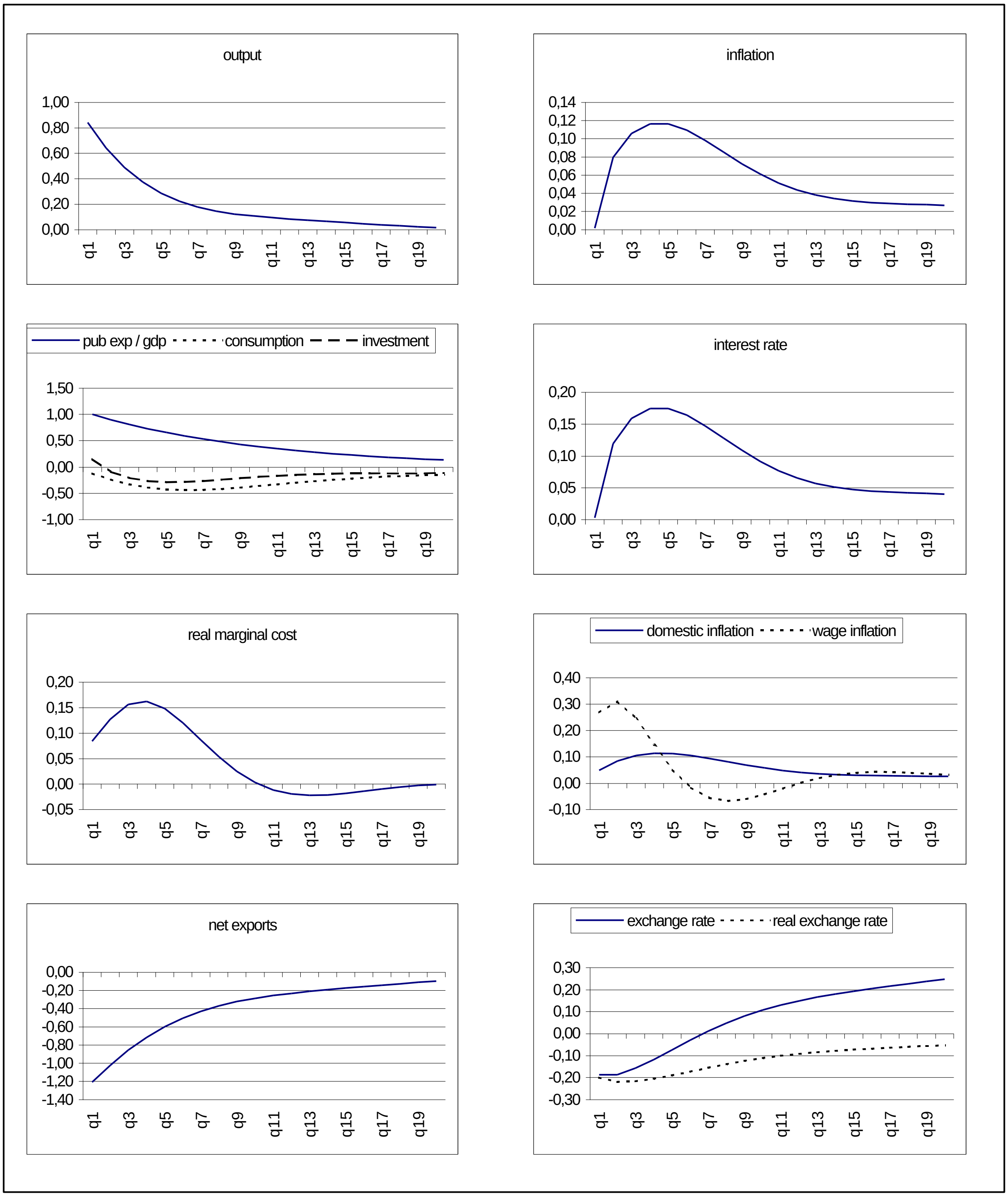


Figure 2 - Impulse-response function of a demand shock (public expenditures) under a non-accommodating monetary policy following a simple inflation instrument rule

$r_t = rr° + \pi° + 1.25\ (\pi_t - \pi°)$

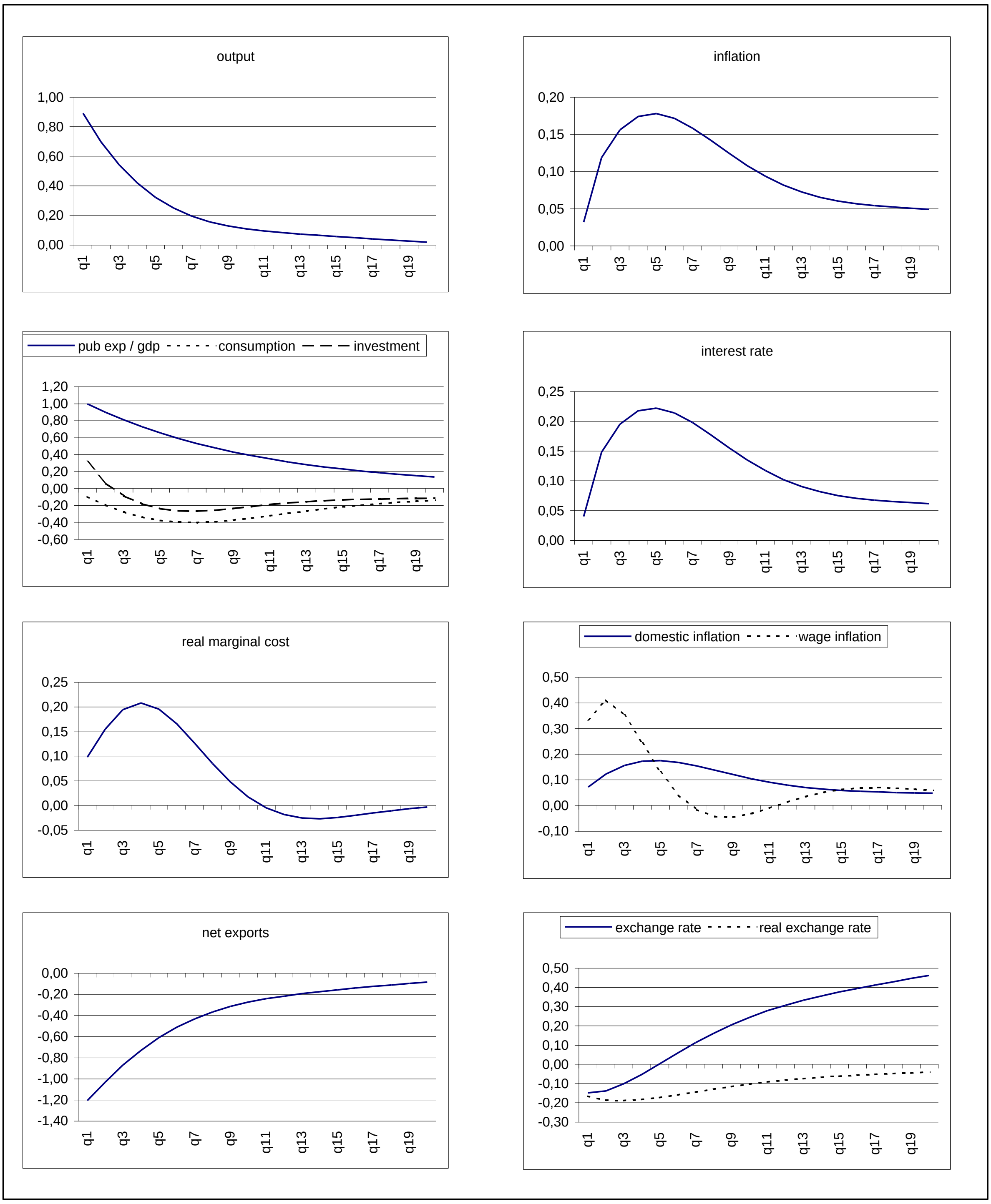


Figure 3 - Impulse-response function of a demand shock (public expenditures) under an accommodating monetary policy following a simple inflation instrument rule

$r_t = rr° + \pi° + 1.5\ (\pi_t - \pi°)$ and $\pi°$ increases by 1%

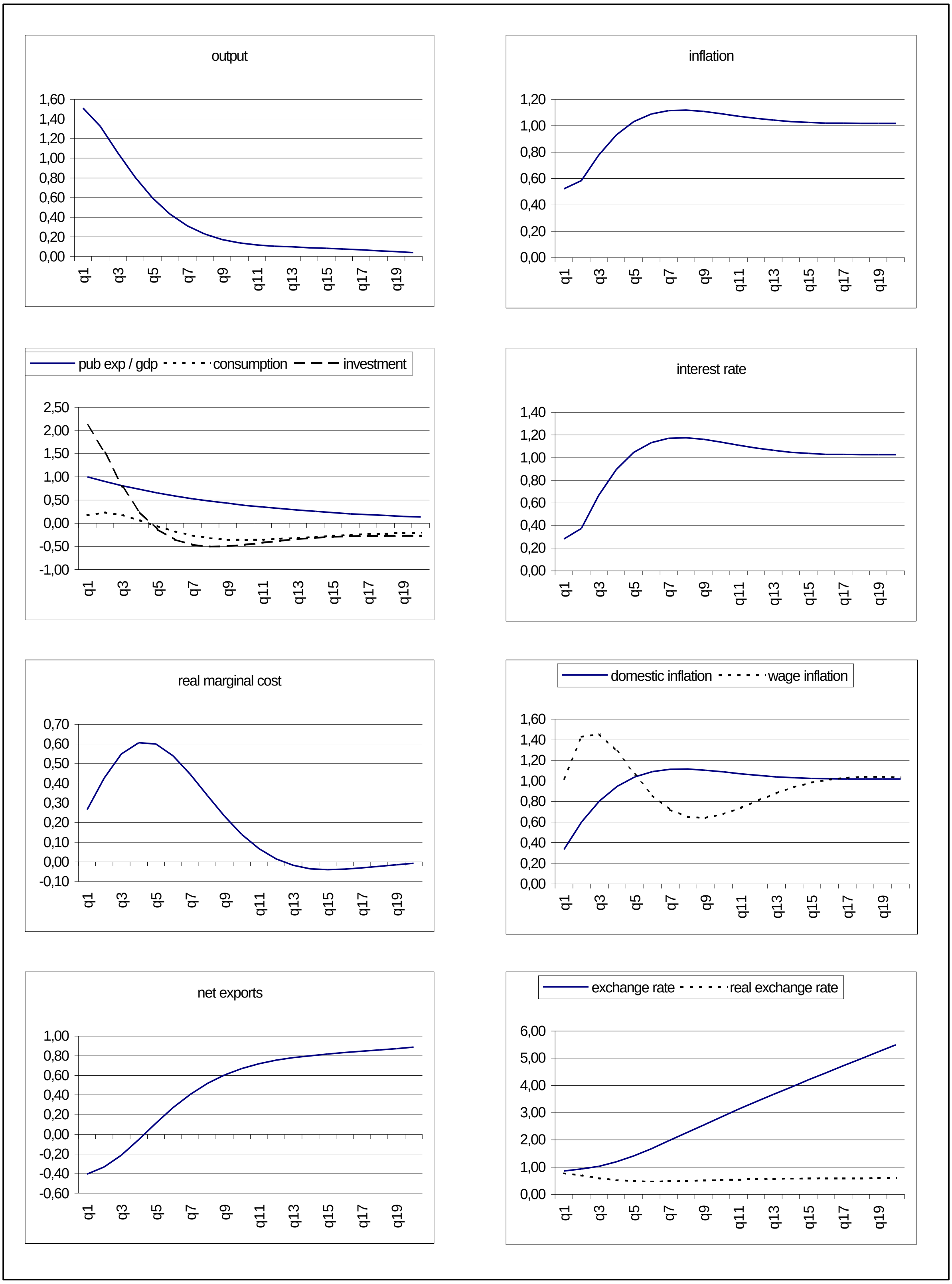
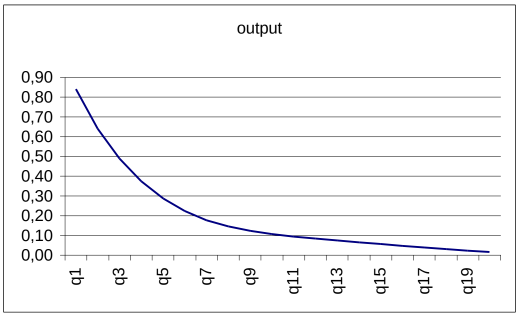
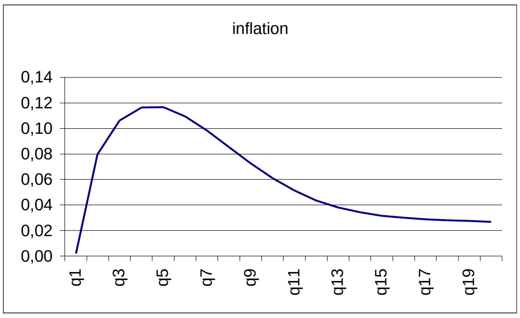


Figure 3b - Impulse-response function of a demand shock (public expenditures) under an accommodating monetary policy following a simple inflation instrument rule

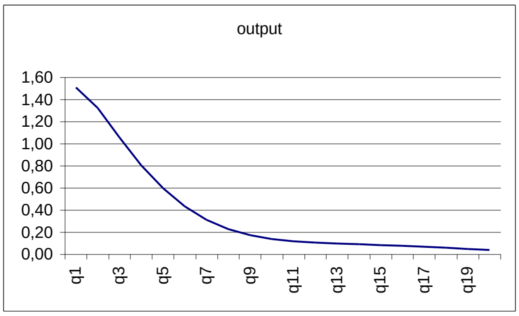
$r_t = rr° + \pi° + 1.5\ (\pi_t - \pi°)$ and $\pi°$ increases by 1%

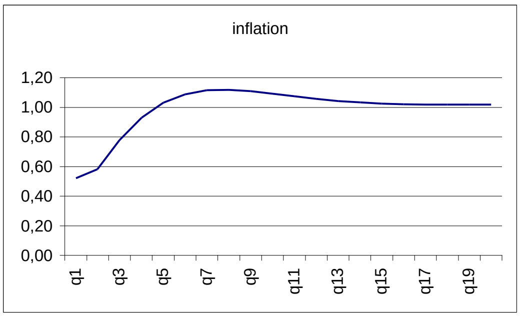
Non-accommodating monetary policy reaction



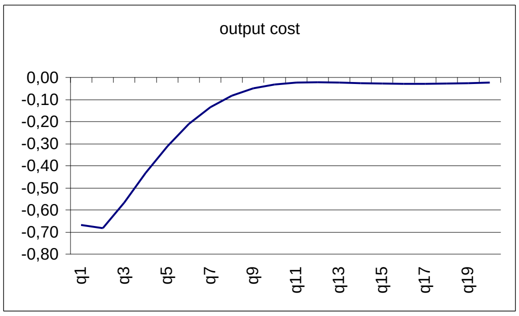


Accommodating monetary policy reaction





Output cost for obtaining inflation reduction



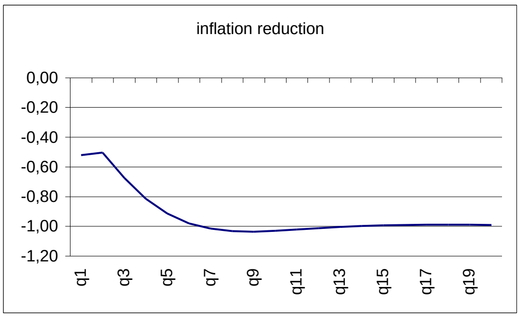


Figure 4 - Impulse-response function of a demand shock (public expenditures) under a simple inflation instrument rule in a model with less rigidity in the price and wage equation

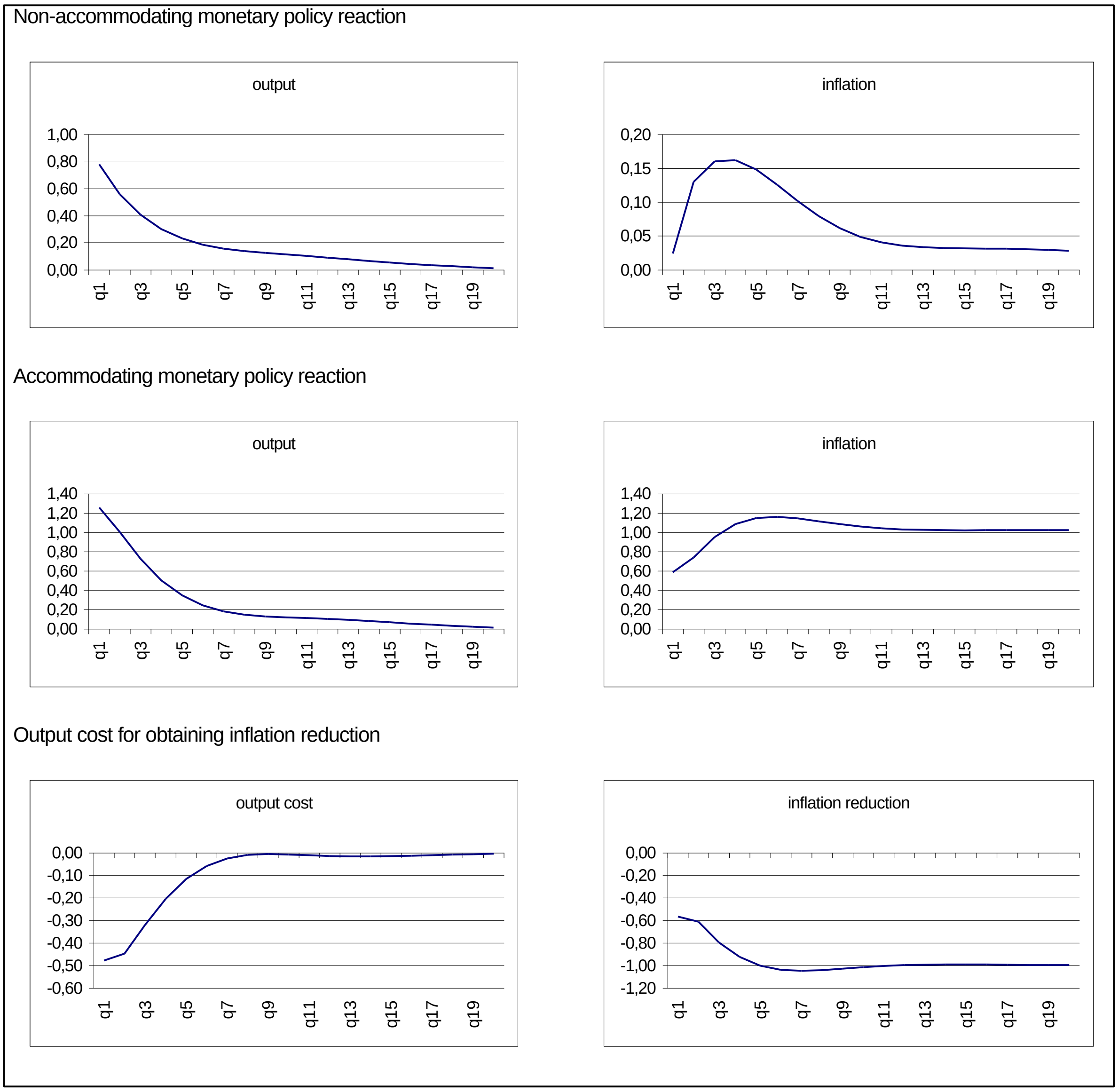


Figure 5 - Impulse-response function of a demand shock (public expenditures) under a non accommodating monetary policy following a simple inflation instrument rule where the announced objectives is only gradually perceived as credible by the public (5% learning rule)

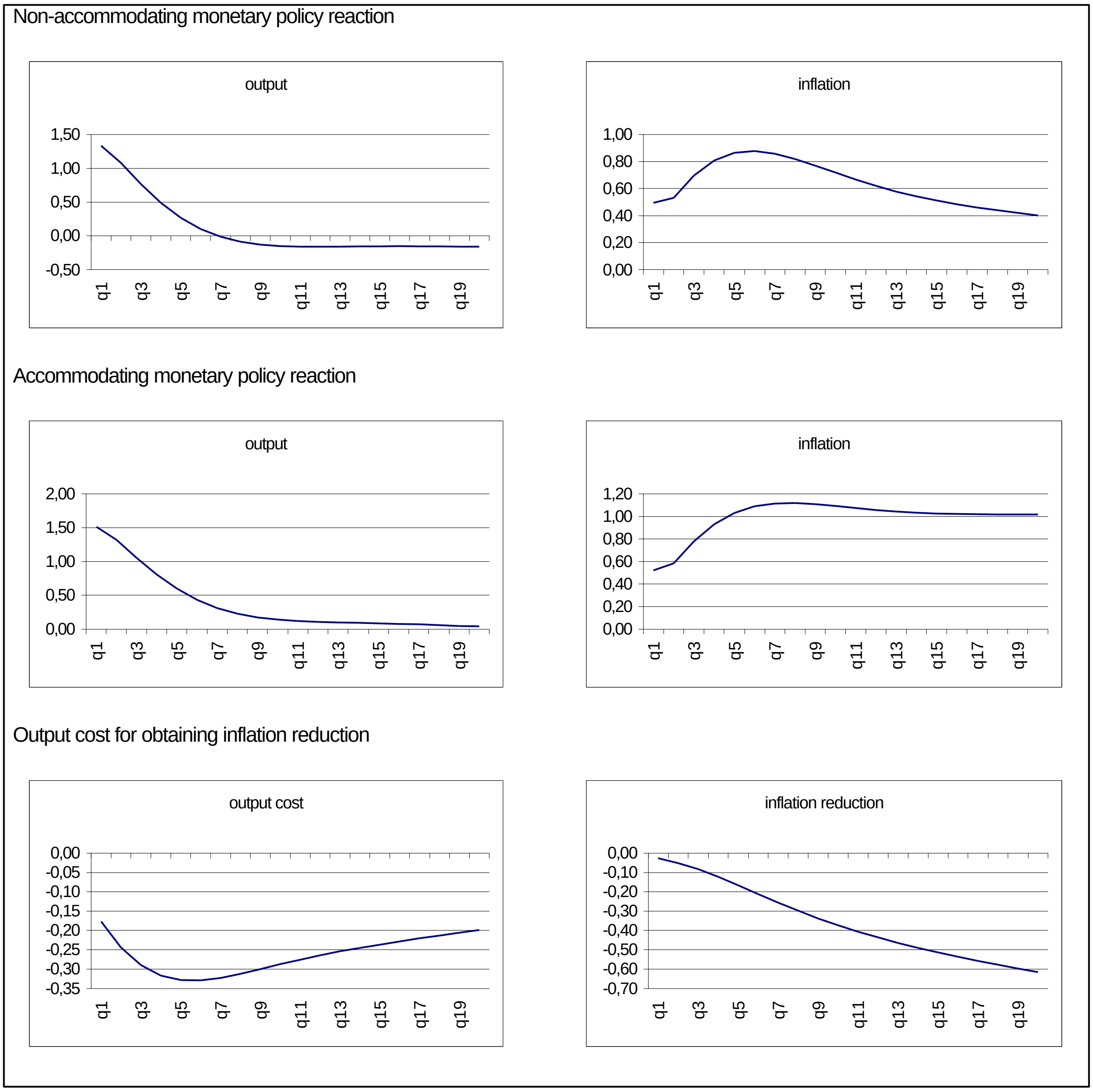
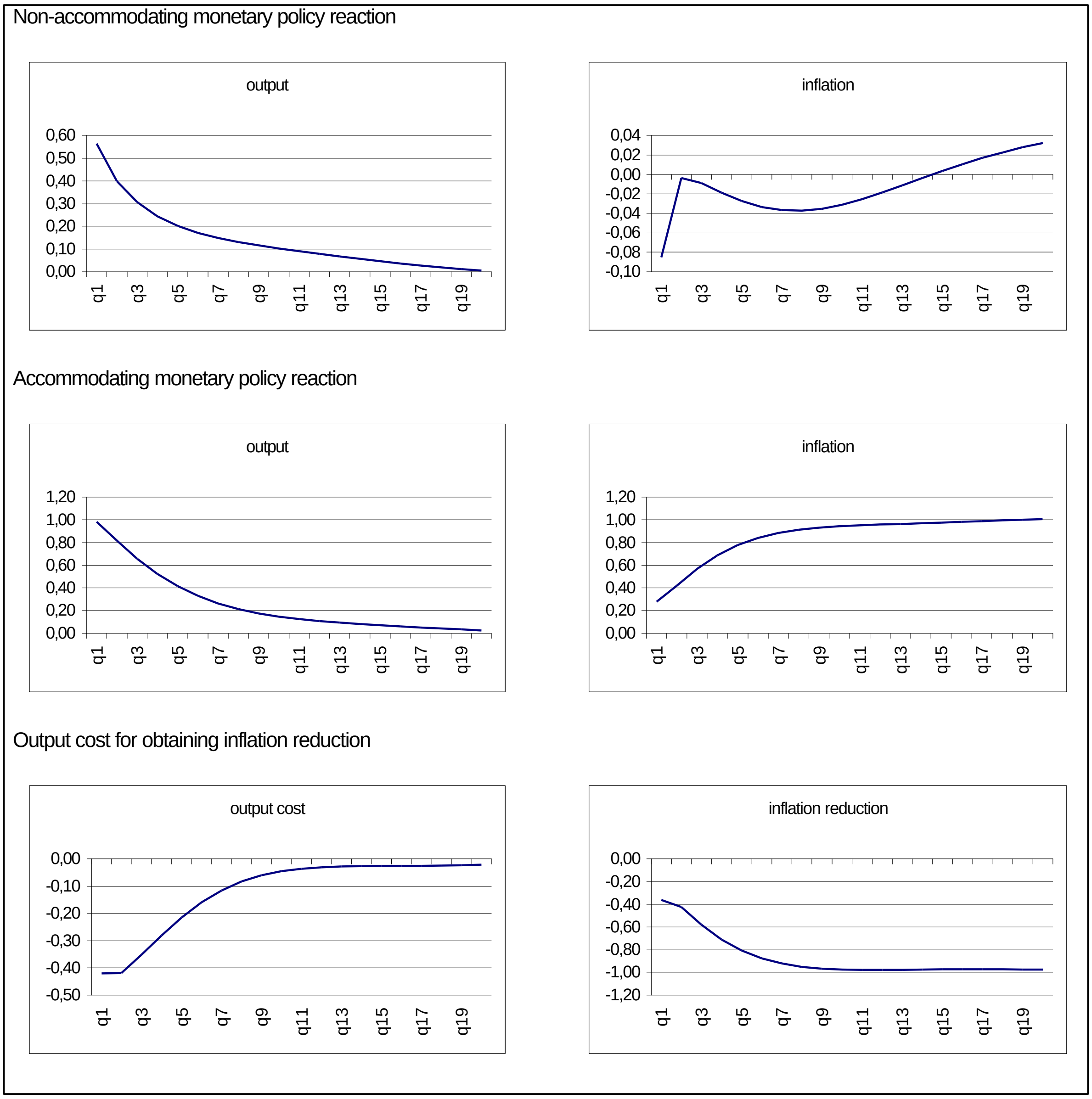


Figure 6 - Impulse-response function of a demand shock (public expenditures) under Taylor-rule for monetary policy

$r_t = rr° + \pi° + 1.5\,(\pi_t - \pi°) + 0.5\,(Y_t - Y°)$



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