Monetary Policy in a DSGE Model for Europe

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Abstract

This paper studies the role of monetary policy in a DSGE model estimated for Europe. The interaction between inflation, output gap and monetary policy rules is analyzed within the framework of a dynamic general equilibrium model derived from optimizing behavior and rational expectations. The model follows closely the work of Smets and Wouters (2003). The main motivation is to see how the economy reacts under backward looking and forward looking Taylor type monetary policy reaction functions in order to make conclusions on which type performs better within the estimated model for the Euro area. Also, using model simulations, the conclusions on the optimality of weights assigned to the reaction function coefficients are drawn. It is illustrated that although the monetary objective can be defined narrowly in terms of inflation targeting, the central bank should take a larger set of economic variables into account in deciding on the course of its policy and commit to the rule with backward looking components satisfying the Taylor principle.

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1 Introduction

Macroeconomic models are valuable and necessary tools for monetary policymakers. Such models can help produce forecasts of future inflation, output, and other variables, which are crucial for a forward-looking central bankers that in their decision making take into account lagging effects of monetary policy on the economic environment. Furthermore, they can help quantify the amount of uncertainty that central bankers face in making their policy choices. Maintaining price stability as a main monetary policy goal is nowadays practiced in most central banks in the world, and inflation forecasts and output forecasts play a crucial rule in achieving this goal.

Today, the macroeconomic model that is commonly used at central banks around the world is the structural model, which has been improved over the last ten years resulting in explicit expectations and better long-run properties. However, there have existed strong intentions in the last decade for DSGE models combined with Bayesian methods of inference to become a useful alternative and to form the standard framework for macroeconomic policy modeling.

In 2003, Frank Smets and Raf Wouters developed and estimated a stochastic dynamic general equilibrium (DSGE) model with sticky prices and wages for Euro area. Besides sticky prices and wages that adjust according to the Calvo mechanism the model incorporates various other features such as habit formation, costs of adjustment in capital accumulation and variable capacity utilization. Also, a full set of structural shocks is introduced. The model is estimated using the data on the seven key macro-economic variables over the period from 1973 till 1999. According to the estimation results there is considerable degree of price stickiness in the euro area that seems to explain the empirical persistence of the euro area inflation and ensures transmission lags between monetary disturbances and its effects on real variables.

In this paper, the same DSGE model of Smets and Wouters with sticky prices and wages will be used as base for analyzing monetary policy presented in the form of the backward looking Taylor type reaction function that closes the model. A deeper analysis of the various trade-offs the monetary authorities face with by committing to this type of the rule is to be done, as well as the effort to decide upon the optimality of the rule affected by assigning the weights to reaction function coefficients. Also, the suggested backward looking rule will in analysis be confronted with its forward-looking version. . The main criteria in drawing conclusions remains that the central bank should fulfill its primary objective of maintaining price stability and at the same time ensure low variability of inflation and output growth.

The paper is organized as follows: section two gives a brief overview of what modern economic literature has to say about the monetary models and monetary policy. Section three presents some facts about monetary policy execution in the practice. Section four thoroughly describes a macroeconomic model, designed by Smets and Wouters (2003) for the Euro area, putting an accent on the features important for the monetary policy analysis. Section five analyses monetary policy in the presented model. The center of the analysis is the backward looking Taylor type policy rule estimated for the Euro area. The aim of the analysis is to outline what effects have different policy rules and objectives on the impulse response of the model and which one is more efficient. The backward-looking rule will also be compared in its performance with the policy rule that responds to the forecasts of future inflation. Some theorists as well as practitioners argue that the forecast-based rules can better control both current and future inflation and provide with a suitable degree of output smoothing by accounting for the lags in transmission mechanism (see for example Clarida, Gali, Gertler 1999). Forecasting seems to ensure that policy is responsive to most available information. The argument goes further suggesting that committing to the rule based on inflation expectations ensures credibility. The performance of different policy rules will be evaluated given the introduced model and according to following evaluation criteria: the best performing policy rule is the one that can stabilize the effects of disturbances by minimizing deviations of inflation from target and of output from potential. Finally section seven provides some concluding remarks on the way towards an optimal monetary policy.

2 Monetary policy and a DSGE model: Links with Theory

After the breakdown of Bretton Woods and the times of high inflation in major world economies in 1970s, the central banks started to doubt the effectiveness of monetarism and there was a surge to find the new solutions also within the theoretical framework.

The proposition that the monetary disturbances affect the real side economy has gained substantial support among macroeconomists. The precise amount remains open to debate but it is no longer an issue to downplay. Examples include Romer and Romer (1988), Bernanke and Blinder (1992), Galí (1992), Bernanke and Mihov (1997a), Christiano, Eichenbaum, and Evans (1996, 1998), Leeper, Sims and Zha (1996) and Bernanke, Gertler, and Watson (1997) presenting the evidence that the monetary policy rule may have important effects on real activity.

Also, there has been considerable improvement in the underlying theoretical frameworks used for policy analysis. There has been a trend in ensuring that the model structure is consistent with the underlying behavior of optimizing agents. To provide theoretical underpinnings, the literature has incorporated the techniques of dynamic general equilibrium theory pioneered in real business cycle analysis to account for expectations based on the information about the future economic developments structural models do not control for. A key point of departure from real business cycle theory is the explicit incorporation of frictions such as nominal price rigidities (Keynesian approach) that are needed to make the framework suitable for evaluation of monetary policy since nominal price rigidities provide the key friction that gives rise to non-neutral effects of monetary policy.

This, so-called “New Keynesian Perspective” in its basic form consists of three components. First, the demand side is presented by a linear approx. to the representative household’s Euler equation for optimal consumption. Second, inflation adjustment is derived under the assumption of monopolistic competition, with the individual firms adjusting prices in staggered, overlapping fashion. Third, monetary policy is presented by a rule for setting the nominal interest rate. This policy rule is specified exogenously or derived from the CB' objection function. Early examples of models with these properties include Yun (1996), Goodfriend and King (1997), Rotemberg and Woodford (1995, 1997), and McCallum and Nelson (1999).

With this kind of model framework, the need to obtain more detailed picture of monetary policy's effects has motivated a large amount of research work in the last two decades aimed at proving the statistical relationship between monetary policy and the economy. Yun (1996), Woodford (1996), Clarida, Gali, Gertler (1999), Woodford (1999a, 2001a), McCallum and Nelson (1999), and Svensson and Woodford (1999, 2000) among others, have popularized this simple model for use in monetary policy analysis. Gali (2002) discusses some of the model's implications for monetary policy. Much of the literature has focused on the effects of monetary policy shocks. The literature has not yet converged on a particular set of assumptions for identifying the effects of an exogenous shock to monetary policy. Nevertheless, there is considerable agreement about the qualitative effects of a monetary policy shock and that inference is robust across different theoretical models.

The use of monetary DSGE models for monetary policy analysis has grown enormously in the last few years and this approach has widespread support in both theoretical and applied work (See, for example, the survey by Goodfriend and King, 1997).

There are, however, important strands of the literature that either reject the idea of nominal price rigidities (e.g., real business cycle theory) or focus on other types of nominal rigidities, such as frictions in money demand. As highlighted by Fuhrer and Moore (1995), Fuhrer (2000) and Chari, Kehoe and McGrattan (2001) amongst others, the popular micro-founded New Keynesian DSGE model with nominal price and wage staggering is not able to match the persistence and cross-correlations of the main macroeconomic time series (and in particular output and inflation) very well.

In order to improve the empirical fit, a number of additional features has been introduced that should assure structural persistence in the basic building blocks of those models. These features typically result in the introduction of lagged endogenous variables in the various Euler equations, price and wage rigidity, habit formation on a consumption path and costly investment decisions.

There has been a great resurgence of interest in the very issue of conducting monetary policy. Over the past several years many leading macroeconomists have either proposed specific policy rules or have at least staked out a position on what the general course of monetary policy should be. The accent has been put on proposing the simple rules of monetary policy that offer a hypothetical path for the policy instrument, short-term interest rate, dependent on deviations of the real economic variables.

John Taylor's recommendation of a simple interest rate rule (Taylor, 1993) is a well-known example. He suggests a simple monetary policy formula for the United States

$$r = p + .5y + .5(p - 2) + 2$$

where r is the federal funds rate in percent per year, p is the rate of inflation over the past four quarters and y is the percent deviation of real GDP from target. Target GDP would be its value at full employment. Potential GDP in this sense has been growing at 2.2 to 2.5 percent per year. Here, the nominal interest rate deviates from the level consistent with equilibrium real rate and target inflation both approximated to be 2%) if output gap and inflation gap are nonzero.

One widely held view is that monetary policy has been broadly consistent with Taylor-type policy rules in which the interest rate target responds to actual or expected inflation and the level of the output gap. A key coefficient in these estimated policy rules is the inflation response coefficient, which measures the long-term response of the interest rate to the inflation rate. The rule uncovers an important issue, the so-called Taylor principle, of changing the nominal interest rate for more than one for one with deviations of inflation from the target. This insures that the economy has unique stationary rational expectations equilibrium. Taylor (1999a) and Clarida, Gali and Gertler (2000) provide evidence that indicates the inflation response coefficient was below unity during the late 1960s and 1970s, whereas it was well above unity during the early 1980s.

Therefore, the results the Taylor rule 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. Also, Clarida, Gali and Gertler (1998) have showed that a Taylor-type monetary policy reaction function is able to describe the behaviour of both the Bundesbank, which acted as de facto anchor of the European exchange rate mechanism, and the French and Italian central banks since the early 1980s.Peersman and Smets (1998) present evidence in favor of a Taylor rule for the Bundesbank's behaviour and for an average of EMU participants in the 1990s. This is in line with the findings of Gerlach and Schnabel (2000) that since the early 1990s average interest rates in the euro area can be characterised quite well by a Taylor rule. As Williams (1999) shows, the additional use of the lagged interest rate in the Taylor rule attributes to the superior performance of this type of rule relative to the standard form.

Given the difficulty of measuring the output gap accurately, the alternative strategies have been proposed ignoring the output gap altogether. One such alternative is for policymakers to concentrate on the difference between the actual and potential growth rates of the economy. In this case, policymakers would react to the rate of inflation and the rate of growth of output instead of its level (Orphanides, 1999). In the absence of measurement problems, such strategies appear to be inferior to strategies that rely on the output gap, but they may be superior once measurement problems are taken into account.

Recently, there is a spreading endorsement of inflation targeting as a monetary policy rule (see Bernanke and Mishkin, 1997). A standard argument in the literature is that to avoid real indeterminacy the central bank must respond aggressively to either expected inflation (see Bernanke and Woodford 1997, and Clarida, Gali, Gertler 1997) or current inflation (Kerr and King, 1996). There may be further theoretical advantages to operating monetary policy according to an inflation forecast. For example, in some models, targeting an inflation forecast is equivalent to the fully optimal rule (Svensson, 1997).

No matter which type of the rule is being protected as optimal the important issue is that much of the recent literature on monetary policy emphasizes desirability of commitment over discretion for monetary policy (see for example Woodford 1999, Taylor 1993). It has been shown that by committing to conduct monetary policy in a systematic way helps stabilize inflation and output more efficiently then in the case of discretion. Also, as stressed in Woodford (1999) every optimal monetary policy should involve a degree of history dependence. Much of the literature has emphasized that an inefficiently high steady state inflation rate may arise in the absence of commitment, if the central bank's target for real output exceeds the market clearing level. The potential of inflationary bias occurring under discretion was originally emphasized by Kydland and Prescott (1977) as well as Barro and Gordon (1983).

On the other hand in Tobin (1983), it is argued that mechanical rule blind to actual economic events and outcomes could not work, and therefore would not be tolerated by central bankers. However, it would be impossible to anticipate all events that might require policy adjustments and to specify in advance the correct direction and size of the response to each of them. He stresses that actual responses would have to depend on the best estimates and judgments of the policy makers at the time and in that sense protects discretion.

Overall, the attention is centered on simple robust rules that produce desirable results in a variety of competing macroeconomic frameworks.

3 Monetary policy in practice

From the 1950s through the 1970s Milton Friedman's monetarism provoked hot debates on the conduct of monetary policy. The monetarists wanted the central bank to stop setting interest rates and instead to target growth in any of the monetary aggregates, from the monetary base to intermediate aggregates as M2 and M3. The use of money stock targets spread throughout the central banks of the world. The main purpose was to overcome the inflationary bias alleged to result from operating by discretionary movements of interest rates. In practice, numerical money stock growth targets were reconsidered every year or even every quarter.

However, around 1979 there was a fundamental shift in the way that central banks conduct their policy moved by the inflationary crisis of the 1970s worldwide. The two decades of swing of monetarism faded away and the modern central banks have greatly downgraded the role of monetary aggregates in the implementation of policy as it came to be understood that central banks did not need the discipline of intermediate money growth targets to achieve more fundamental goals, including the control of inflation. Controlling inflation by systematically adjusting real interest rates became major focus of monetary policy. Observing the behavior of the three major central banks in the world, Federal Reserve, Bundesbank and the Bank of Japan, it can be concluded that prior to 1979 each central bank kept short-term interest rate at or below the rate of inflation. Real short-term interest rates accordingly were around zero or below. However, since 1979 real as well as nominal interest rates started to move up significantly in response to raise in expected inflation relative to target. The interest rate started to co-move with the inflation. It appears that each central bank substantially raised short-term interest rate in that periods of high inflation (just as suggested in theoretical framework of Taylor principle). This worldwide shift in monetary policy provides explanation for the dramatic rise in real interest rates in early 1980s. So, the primary focus of monetary policy appears to be on managing inflation through the interest rate instrument. Because the rule is relatively simple for private sector to understand and follow, it is conductive to building and maintaining credibility. At the same time there is a modest pure stabilization component to each monetary policy rule. Holding constant expected inflation, each central bank adjusts rates in response to the position of output relative to trend, though generally not by a great amount.

Even though the inflationary crisis has been overcome and the inflation remains relatively stable, there has been the dominant trend in the theory and practice of monetary policy today to target the stability of price level and not the rate of inflation. This implies that any inflation that occurs as a result of supply or demand shocks must be sooner or later expunged. Less drastic monetary strategies accept price level increases resulting from big shocks as permanent and seek to avoid subsequent inflations.

The consequence of dedicating monetary policy to price stability is official indifference to real macro economy, employment, real domestic product and its growth rate. These are likely to be ignored or drastically subordinated in the priorities of most central banks today. The real outcomes become a policy concern only after the central bank, and the government too, is confident that the price stability target is met.

The Federal Reserve monetary policy is a striking exception to the fashion of choosing price stability as the target of monetary policy. Faced with inflation rates above 10 percent in 1979, the Federal Reserve shifted its tactical operating instrument from money-market interest rates to bank reserve aggregates. For three years 1979–82 the ultimate policy target of the FED was to bring down inflation. By mid-1982 inflation had fallen to 5 percent and unemployment had risen from 6 percent to 10.5 percent. At this point the FED (Chairman Paul Volcker) reversed course, returned to its previous interest-rate operating procedure, and initiated and managed a six-year recovery, which reduced unemployment below 6 percent while inflation continued to decline. Alan Greenspan, has continued to lead monetary policy directed to reduction of unemployment rates and output gap, as well as to stabilization of inflation.[1]

[1] Source of information: Clarida, Gali, Gertler (1997), Monetary Policy Rules in Practice: Some international evidence

In contrast to the United States, European central banks have been concentrated on eliminating the slightest chance of any resurgence of inflation. With the signing of Maastricht Treaty central banks of the EMU countries (belonging to the European Monetary Union) gave up their political independence and thereby bounded the new central bank, the European Central Bank (ECB), to respond to Europe-wide and inter-regional shocks, both demand and supply. The two-pillar strategy of the ECB, aims primarily for price stability on the basis of analysis of money-supply growth (first pillar) and other economic and financial indicators (second pillar). As stressed in the Bulletin of the ECB (January, 1999), the main argument for price stability is that it improves the transparency of the relative price mechanism, thereby avoiding distortions and helping to ensure that the market allocates real resources efficiently over time. As a quantitative target Harmonized Index of Consumer Prices (HICP) of the countries belonging to the union is required not to exceed 2%. Eventually, it is permitted to stimulate the growth of different regions but without jeopardizing the goal of price stability.

However, macroeconomic indicators show that countries of the Euro area (belonging to EMU) are at different stages of the business cycle and the ECB policy is faced with a great deal of variety in both inflation levels and GDP growth. Furthermore, in some countries inflation has a significant forward-looking component such as Germany, whereas in others inflation dynamics are mixed by a forward and a backward looking component such as France, Italy and Spain.[2] This kind of behavior brings asymmetry in the transmission mechanism of monetary policy and represents a serious problem in suggesting and following an optimal policy rule.

Monetary policy rules are in practice understood to have two different interpretations. One is they provide a descriptive path for interest rates; they passively mimic the behavior of monetary policy in real. Second is that policy rules are useful prescriptive tool, they can be used actively to diagnose when monetary policy may be deviating from a goal, by comparing actual and hypothetical paths of interest rate. However, the simplest monetary rules seem to undermine one important aspect of monetary policy making in

[2] See Benigno and Lopez-Salido 2002

the real world, its forward-looking perspective. Therefore, there is a trend in practice to base policy decisions on expectations of future inflation and output rather than their actual values. The forward-looking dimension of monetary policy is most clearly seen among inflation targeting countries, such as United Kingdom and Netherlands.

4 DSGE model for Europe

In this section the estimated model for the Euro area economy[3] developed by Smets and Wouters (2003) that is used in the subsequent analysis will be briefly described. As it is common in the recent literature on monetary policy evaluation, the model exploits first the micro-foundations of the environment in order to provide a basis for the Central Bank actions and losses implied by the distortions included in the model.[4]

The model is an extended version of the standard New-Keynesian DSGE two-sector, closed-economy model with sticky prices and wages featuring monopolistic competition in both the goods and labor markets and incorporating rational expectation formation.

4.1 The household sector

A non-separable utility function is maximized by continuum of households (indicated by τ) with two arguments, consumption and leisure, over an infinite life horizon.[5]

$$\max_{C_t^\tau, \ell_t^\tau} E_0 \sum_{t=0}^{\infty} \beta^t \varepsilon_t^B \left(\frac{1}{1-\sigma_c} \left(C_t^\tau - H_t \right)^{1-\sigma_c} - \frac{\varepsilon_t^l}{1+\sigma_l} \left(\ell_t^\tau \right)^{1+\sigma_l} \right) \tag{1}$$

Utility depends positively on consumption C_t^τ relative to external habit H_t and negatively on the labour supply ℓ_t^τ. σ_c represents a relative risk aversion or inverse of the inter-temporal elasticity of substitution, and σ_l is a parameter on disutility of labour. Two structural shocks, preference shock ε_t^B and labour supply shock ε_t^l are introduced. Both

[3] Countries of the EMU.
[4] Rotemberg and Woodford (1997), Woodford (999b) and Erceg, Henderson and Levin (2000)
[5] As is common in the much of the recent literature, the model is introduced without real money balances in the utility function since a number of recent papers have come to the conclusion that real money balances play no statistically significant role in estimated New-Keynesian models and there is therefore no role for money in the transmission mechanism of monetary policy. According to Rudebusch and Svensson (1999) even if there exists stabile money demand, money provides little information about future inflation or output. See for example, the evidence provided by Peter Ireland (2002) for the USA and by Andres et al. (2001) for the Euro area.

are assumed to follow a first order autoregressive process with an IID-Normal error term generally presented as $z_t = \rho_z z_{t-1} + \eta_t^z$.

What is specific for this utility function is that consumption appears dependent on the time-varying external habit formation defined as:

$$H_t = hC_{t-1} \tag{2}$$

showing that habit relies on the lagged aggregate consumption and not affected by other agents decisions.[6] Habit persistence replaces the level of consumption (usually included in the utility maximization problem) with its growth rate in the utility function. Different authors have argued that including habit formation in the model is important for understanding the monetary transmission mechanism (see McCallum and Nelson 1998, Fuhrer 2000, Christiano et al. 2001). The reason is that low interest rate implies high current consumption relative to the future and the model with habit persistence replaces the level of consumption with its growth rate in the utility function so that a low interest rate is associated with high current consumption growth rate relative to the future. Since consumption is the largest component in GDP, habit formation is a plausible candidate to explain the output persistent for Europe and a hump shaped response to monetary policy shocks. The intuition behind it is that habit-forming agents dislike large changes in consumption and thereby the consumption response to shocks is smoother and more persistent

Introduced objective function is maximized subject to the intertemporal budget constraint given by

$$b_t \frac{B_t^\tau}{P_t} = \frac{B_{t-1}^\tau}{P_t} + Y_t^\tau - C_t^\tau - I_t^\tau \tag{3}$$

[6] Abel (1990) calls this the "catching up with the Joneses" effect.

Households are homogeneous with respect to consumption and asset holdings. The wealth is held in the form of riskless bonds B_t with price b_t and current income and financial wealth are used for consumption and investment in capital.

Household's total income is introduced by:

$$Y_t^\tau = w_t^\tau l_t^\tau + A_t^\tau + (r_t^k z_t^\tau K_{t-1}^\tau) - \psi\left(z_t^\tau\right)K_{t-1}^\tau + Div_t^\tau \tag{4}$$

consisting of basically three components: 1)labour income $w_t^\tau l_t^\tau$ plus cash flow from investing in the state securities A_t^τ, 2)return on the real capital stock rented to the firms sector $r_t^k z_t^\tau K_{t-1}^\tau$ minus costs associated to the different degrees of capital utilization $\psi\left(z_t^\tau\right)K_{t-1}^\tau$ and 3)income from dividends Div_t^τ. State securities are introduced to insure the households against variations in household-specific labour income resulting in identical marginal utility of wealth across different types of households (See Christiano et al., 2001). Specific for the model is that it incorporates the issue of the cost of capital utilization defined as $\psi\left(z_t^\tau\right)$[7], where z_t^τ represents capital utilisation rate. So, households decide on how much capital to accumulate given the rental price of capital r_t^k and certain capital adjustment costs.

As households own the capital stock that they rent out to the firms it is important to point out that the supply of the capital can be increased either through investment which need one period to be installed or by changing the utilization rate of the capital already installed. Capital stock, investment and utilization rate are additionally chosen in order to maximize the intertemporal budget constraint and the following capital accumulation equation:

$$K_t = K_{t-1}\left[1-\delta\right] + \left[1 - S\left(\varepsilon_t^I I_t / I_{t-1}\right)\right] I_t \tag{5}$$

[7] In the steady state equilibrium $\psi(1)=0$.

where capital accumulation is set to depend on depreciated capital stock from period t-1, gross investment and negatively depending on the adjustment cost positive function S(.)8.The function S summarizes the technology, which transforms current and past investment into installed capital for use in the following period and introduces thereby a certain degree of stickiness in the model. As is recently suggested for the DSGE models with sticky prices, a shock to the investment adjustment cost function ε_t^I is introduced, which is assumed to follow a first-order autoregressive process with an IID-Normal error term (See Keen, 2001).

The maximization of the objective function (1) subject to the budget constraint (3) with respect to consumption C_t^τ and holdings of bonds B_t^τ yields the following first-order conditions for consumption:

$$\lambda_t = \varepsilon_t^B \left(C_t^\tau - H_t\right)^{-\sigma_c} \qquad (6)$$

$$1 = \beta E_t \left(\frac{\lambda_{t+1} P_t}{\lambda_t P_{t+1} b_t} \right) \qquad (7)$$

Further, the Fisher equation is introduced defining the nominal short-term interest rate as follows:

$$R_t = 1 + i_t = \frac{1}{b_t} \qquad (8)$$

At this point it is also necessary to incorporate a general inflation equation depending on the relation between present and past prices:

$$\pi_t = \frac{P_t}{P_{t-1}} \qquad (9)$$

By aggregating the first order conditions calculated on the basis of the individual household the Euler equation (13) describes the consumption path dependent on the past

[8] In the steady state equilibrium *S (1)=0, S''(1)=0.*

consumption relative to habit as well as future consumption, interest rate and future inflation expectations.

$$1 = E_t\left[\frac{\varepsilon_{t+1}^B (c_t - hc_{t-1})^{\sigma_c}}{\varepsilon_t^B (c_{t+1} - hc_t)^{\sigma_c}} \cdot \frac{R_t}{\pi_{t+1}}\right] \tag{10}$$

Capital stock, investment and utilization rate are chosen to maximize the intertemporal objective function subject to the given budget constraint (2) and the capital accumulation equation (5) described above.

$$Q_t = \beta E_t\left(\frac{\lambda_{t+1}}{\lambda_t}\left(Q_{t+1}(1-\delta) + r_{t+1}^k z_{t+1}\right)\right) \tag{11}$$

$$Q_t\left(1 - S\left(\frac{\varepsilon_t^I I_t}{I_{t-1}}\right) - S'\left(\frac{\varepsilon_t^I I_t}{I_{t-1}}\right)\frac{\varepsilon_t^I I_t}{I_{t-1}}\right) + \beta E_0\left(\frac{\lambda_{t+1}}{\lambda_t} Q_{t+1} S'\left(\frac{\varepsilon_{t+1}^I I_{t+1}}{I_t}\right)\frac{\varepsilon_t^I I_{t+1}}{I_t}\frac{I_{t+1}}{I_t}\right) = 1 \tag{12}$$

$$r_t^k = \psi'(z_t) \tag{13}$$

In equations (11) and (12) the parameter Q_t stands for ratio of the Lagrangian multiplier to the capital accumulation equation and Lagrangian multiplier to the budget constraint and is interpreted as the value of the capital stock. This implies that the value of the extra unit of capital is expressed in terms of value of a unit of consumption.[9]

Equation (11) represents the Euler equation for capital accumulation and states that the value of the installed capital depends on its expected future value taking into account the depreciation rate and the expected future return defined as rental rate on capital times the expected rate of capital utilization.

[9] See Appendix

By equation (13) the cost of higher capital utilization is positively correlated with the rental rate so when the rental rate increases it becomes more profitable to use capital stock more intensively.

4.2 The wage decision

Households differ in the type of the labour they supply (hours worked) allowing them to have monopolistic power over wages and providing the ground for introducing the Calvo stickiness of the nominal wages (see Calvo 1983)[10]. Differential labour services supplied from the household are transformed into an aggregate labour input L_t over the following function:

$$L_t = \left[\int_0^1 \left(\ell_t^\tau \right)^{\frac{1}{1+\lambda_{w,t}}} d\tau \right]^{1+\lambda_{w,t}} \qquad (14)$$

The demand curve for labour is defined by:

$$l_t^\tau = \left(\frac{W_t^\tau}{W_t} \right)^{-\frac{1+\lambda_{w,t}}{\lambda_{w,t}}} \cdot L_t \qquad (15)$$

where W_t is the aggregate wage rate, which is connected to the individual wage rate over the relationship:

$$W_t = \left[\int_0^1 (W_t^\tau)^{-1/\lambda_{w,t}} d\tau \right]^{-\lambda_{w,t}} \qquad (16)$$

Households take L_t and W_t as given.

[10] The Calvo pricing is a highly obedient approach to introducing staggered price-setting in DSGE models constructed for monetary policy analysis (See Yun (1996), Woodford (1996),CEE (2001))

In accordance to the Calvo stickiness, it is assumed that households can re-optimise their wages only after receiving some random wage signal. So, the probability that a particular household will reoptimise its nominal wage in a certain period is equal to *(1-ξ_w)*. That is why only the household receiving such a signal will set new nominal wage $\widetilde{w}_t$ thereby taking into account that it could not be re-optimised in the near future. The uncertainty over whether they can re-optimise the wages is idiosyncratic in nature (one can change it at exogenously and randomly determined times).[11] By this staggering process it is assured that not everyone in the economy sets prices at the same time. The wages that cannot be reoptimised are adjusted according to the following partial indexation procedure:

$$W_t^\tau = \left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_w} W_{t-1} \qquad (17)$$

where γ_w is the degree of the indexation and determines the relative weight of backward and forward looking part in the wage setting. When the parameter equals to zero there is no indexation and the wages that cannot re-optimise in the certain period remain constant. If $\gamma_w=1$ we observe perfect indexation of wages to the past inflation. This indexation of the wages that cannot be freely set augments the stickiness in the model.

As the wage setter in the labour market every household that can reoptimise its wage rate at time *t* sets the nominal wage $\widetilde{w}_t$ to maximise the utility function optimisation problem. It is anticipated that all the firms that are allowed to re-optimise choose the same price (see Woodford 1996, Christiano et al. 2001) and that is why $\widetilde{w}_t$ is not allowed to depend on τ. The resulting first order condition associated is:

$$\frac{\widetilde{w}_t}{P_t} = \left(1+\lambda_{w,t+i}\right)\frac{E_t\sum_{i=0}^{\infty}\beta^i\xi_w^i l_{t+i}^\tau MU_{t+i}^\ell}{E_t\sum_{i=0}^{\infty}\beta^i\xi_w^i\left(\frac{P_t/P_{t-1}}{P_{t+i}/P_{t+i-1}}\right)^{\gamma_w} l_{t+i}^\tau MU_{t+i}^c} \qquad (18)$$

[11] Martin Eichenbaum and Jonas D. M. Fisher, 2004

Here it is important to notice that the $\widetilde{w}_t$ influences household's utility only as long as it cannot reoptimise its wage. The probability that this would happen for *i* periods is ξ_w^i. The presence of ξ_w^i has the effect of isolating future idiosyncratic uncertainty where $\widetilde{w}_t$ continues to affect household's utility. So, the nominal wage of the household that can change its wage in period *t* is set to be the present value of the marginal disutility of labour, MU_{t+i}^{ℓ} is a mark-up over the present value of the marginal utility of consumption, MU_{t+i}^{c}. When wages are perfectly flexible ξ_w is equal to zero and the real wage turns to a constant mark-up over the expected marginal rate of substitution between consumption and leisure. The shock introduced to the wage mark-up is a "cost-push" shock denoted by $\lambda_{w,t}$ and is IID-Normal around the constant (generally, $z_t = \lambda_z + \eta_t^z$).

Finally, given equation (14) and (15), the law of motion of the aggregate nominal wage can be defined as:

$$(W_t)^{-1/\lambda_{w,t}} = \xi_w \left(W_{t-1} \left(\frac{P_{t-1}}{P_{t-2}} \right)^{\gamma_w} \right)^{-1/\lambda_{w,t}} + (1-\xi_w)(\widetilde{w}_t)^{-1/\lambda_{w,t}} \tag{19}$$

New Keynesian theories and econometric results suggest that, besides habit formation, presented wage rigidity and variability in adjustment costs to capital play an important role in explaining the monetary policy influence on economic activity. In particular, they prevent a sharp change in marginal costs and output following monetary policy shock and account for the model persistence.

4.3 The firms' sector

In the firms' sector we introduce two kinds of firms, final good firms and intermediate goods firms. There is only a single final good produced used for consumption and investment. The final-good sector is perfectly competitive. On the other hand a continuum of intermediate goods are produced indexed by *j*. As intermediate goods firms produce differentiated goods and each firm produces just one good, this part of the sector faces monopolistic competition and sets the prices in the goods market again according to the Calvo model. All the firms decide on labour and capital inputs.

The final good is produced using the intermediate goods according to the following production function:

$$Y_t = \left[\int_0^1 (y_t^j)^{1/(1+\lambda_{p,t})} dj \right]^{1+\lambda_{p,t}} \tag{20}$$

where y_t^j denotes the quantity of domestic intermediate good of type j that is used in final goods production, at date t. The shock introduced to the production function is a "cost-push" shock denoted by $\lambda_{p,t}$ that determines the time-varying mark-up in the goods market and follows an IID-Normal process around the constant.

The maximization of a profit function $P_t Y_t - \int_0^1 (p_t^j \cdot y_t^j) dj$ results in the following Euler equation:

$$\frac{y_t^j}{Y_t} = \left(\frac{P_t}{p_t^j} \right)^{\frac{1+\lambda_{p,t}}{\lambda_{p,t}}} \tag{21}$$

where p_t^j is the price of the intermediate good j and P_t is the price of the final good. Accordingly, the demand for intermediate goods is a decreasing function of the relative price of that good and an increasing function of aggregate output.

As there is a perfect competition in the final goods market integrating (21) subject to (20) implies that the price of the final good is set as follows:

$$P_t = \left[\int_0^1 (p_t^j)^{-1/\lambda_{p,t}} dj \right]^{-\lambda_{p,t}} \tag{22}$$

In the intermediate goods market the good j is produced by a firm j using the following Cobb- Douglas production function:

$$Y_t^j = \varepsilon_t^a \widetilde{K}_{j,t}^{\alpha} L_{j,t}^{1-\alpha} - \Phi \tag{23}$$

where $\widetilde{K}_{j,t}$ is the effective utilization of the capital stock given by $\widetilde{K}_{j.t} = z_t K_{j,t-1}$, $L_{j.t}$ denotes labour services used to produce an intermediate good and ε_t^a is the total factor productivity shock which follows a AR(1) process. Also, Φ denotes the fixed costs of production and it is set so that profits equal to zero in steady state (see Hall, 1998, and Rottemberg and Woodford, 1995, who argue that economic profits are zero on average).

Capital-labour ratio is constant and equal across intermediate firms, given by:

$$\frac{W_t L_{j,t}}{r_t^k \widetilde{K}_{j,t}} = \frac{1-\alpha}{\alpha} \tag{24}$$

Following the statement that all the firms decide on labour and capital inputs in goods' production, the total costs for intermediate firm develop as follows:

$$TC = w_t L_t + r_t^k \widetilde{K}_t \tag{25}$$

Using the fact that the introduced Cobb-Douglas production function exhibits constant returns to scale and intermediate firms are competing in a monopoly market, firms average and marginal cost are set to be equal and given by:

$$AC_t = MC_t = \frac{1}{\varepsilon_t^a} W_t^{1-\alpha} r_t^{k\,\alpha} (\alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}) \tag{26}$$

This shows that marginal costs are independent of the intermediate good produced and are identical across firm.

Nominal profits of firm j can then be defined as:

$$\pi_t^j = (p_t^j - MC_t)\left(\frac{p_t^j}{P_t}\right)^{-\frac{1+\lambda_{p,t}}{\lambda_{p,t}}}(Y_t) - MC_t\Phi \tag{27}$$

Each firm j has market power in the market for its own good and maximizes expected profits by deciding on price.

The price setting decision follows Calvo (1983) capturing firm's response to costs of changing prices. In the presence of these costs (information gathering, decision making, negotiation, communication) firms fully optimise their prices only periodically and follow simple rule otherwise (see also Christiano eta al., 2001). In each period, the proportion of firms that receive a random price-change signal and are allowed to reoptimise their price in a certain period is constant and equal to *(1-ξ_p)*. Other firms that cannot re-optimise, target their price on last period's inflation rate according to the following partial indexation procedure:

$$p_t^j = \left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_p} p_{t-1}^j \tag{28}$$

It is important to point out that the indexation of prices, denoted by γ_p, decreases the difference between individual prices of the monopolistic competitors and at the same time augments the price stickiness.

It is anticipated that all the firms that are allowed to re-optimise choose the same price (see Woodford, 1996 and Christiano et al., 2001) and that is why $\tilde{p}_t$ is not allowed to depend on j. Profit optimisation of producers that receive a signal to reoptimise their prices at time t results in the following first-order condition:

$$E_t \sum_{i=0}^{\infty} \beta^i \xi_p^i \lambda_{t+i} y_{t+i}^j \left(\frac{\tilde{p}_t}{P_t} \left(\frac{P_{t-1+j} / P_{t-1}}{P_{t+i} / P_t} \right)^{\gamma_p} - (1 + \lambda_{p,t+i}) mc_{t+i} \right) = 0 \tag{29}$$

showing that $\tilde{p}_t$ influences the j's profits only as long as it cannot reoptimise its price. The probability that his happens for i periods is ξ_p^i. When ξ_p^i is greater then zero, firm set price as a mark-up over the weighted average of expected marginal costs over time. If ξ_p^i is set to zero (the case if the prices are flexible) firms set price equal to a mark-up over expected marginal cost conditional on the information set in *t-1*.

Given the pricing decision of an individual intermediate firm, the aggregate price level defined with equation (29) evolves according to:

$$\left(P_t\right)^{-1/\lambda_{p,t}} = \xi_p \left(P_{t-1} \left(\frac{P_{t-1}}{P_{t-2}} \right)^{\gamma_p} \right)^{-1/\lambda_{p,t}} + (1-\xi_p)\left(\tilde{p}_t\right)^{-1/\lambda_{p,t}} \qquad (30)$$

4.4 The equilibrium

For the general equilibrium to be satisfied supply has to equal demand in four different perspectives. The total production of the firms sector should be equal to the demand of households defined through consumption and investment and the government expenditure:

$$Y_t = C_t + G_t + I_t + \psi(z_t)K_{t-1} \qquad (31)$$

The labour market is in equilibrium if firms' demand for labour equals labour supply at the wage level set by households what we already assumed in solving the optimisation problem. The capital rental market is in equilibrium when the demand for capital by the intermediate goods producers equals the supply by the households.

The endogenously determined equations for describing general equilibrium are:

- for the household: (5), (10),(11),(12),(13), (15),(18),(19)
- for the firms: (24),(26),(29),(30),(31)
- for the market equilibrium: (23),(31)

Finally, the interest rate is to be determined by an exogenously set reaction function that describes monetary policy decisions.

4.4 Solving the model

In order to be able to analyse the model empirically the equations necessary for the macroeconomic equilibrium are log-linearised around the non-stochastic steady state using the principle that $x_t = \bar{x}e^{\hat{x}_t} \approx 1 + \hat{x}_t$, where $\hat{x}_t$ denotes the percentage deviation of x_t from its steady states value. Variables dated *t+1* correspond to the expectation of certain variable at time *t+1* given information available at time *t*.[12]

The consumption equation following from (10) is thereby defined as:

$$\hat{C}_t = E_t\left[\frac{h}{1+h}\hat{C}_{t-1} + \frac{1}{1+h}\hat{C}_{t+1} - \frac{1-h}{(1+h)\sigma_c}\left(\hat{R}_t - \hat{\pi}_{t+1}\right) + \frac{1-h}{(1+h)\sigma_c}\left(\hat{\varepsilon}_t^B - \hat{\varepsilon}_{t+1}^B\right)\right] \tag{32}$$

As mentioned in the model introduction specific relation of the consumption to the external habit formation over habit persistence coefficient leads to the fact that today's consumption depends on the weighted average of the past and the future consumption and also on the current and future preference shock. When *h=0* equation (60) reduces to the traditional forward-looking consumption equation.

The investment equation is given by:

$$\hat{I}_t = E_t\left[\frac{1}{1+\beta}\hat{I}_{t-1} + \frac{\beta}{1+\beta}\hat{I}_{t+1} + \frac{\varphi}{(1+\beta)}\hat{Q}_t - \frac{\beta\hat{\varepsilon}_{t+1}^I - \hat{\varepsilon}_t^I}{1+\beta}\right] \tag{33}$$

where φ is the inverse elasticity of the cost function of changing investment.[13] A positive shock to the adjustment cost function, $\hat{\varepsilon}_t^I$, (also denoted as a positive investment shock) temporarily decreases investment. Modeling the capital adjustment costs as a

[12] See Appendix for explanation on some specifics. Also, since the steady state values, except the steady state return on capital $\bar{r}^k$, seem not to be important for the model analysis, they are presented in Appendix for information.

[13] $\varphi = \frac{1}{S''}$

function of the change in investment rather than its level introduces additional dynamics in the investment equation, which is useful in capturing the hump-shaped response of investment to various shocks including monetary policy shocks (see Christiano et al. 2001).

By log-linearizing the equation (11) and (13) we get the Euler equation for capital:

$$\hat{Q}_t = E_t\left[-\left(\hat{R}_t - \hat{\pi}_{t+1}\right) + (1-\delta)\beta\hat{Q}_{t+1} + \bar{r}^k\beta\left((1+\psi)\hat{r}^k_{t+1}\right) + \hat{\varepsilon}^Q_t\right] \tag{34}$$

where $\bar{r}^k$ is the steady-state rental rate on capital[14] and $\psi = \dfrac{\psi'}{\psi''}$ is inverse of the elasticity of the capital utilization cost function. The current value of the capital stock depends negatively on the ex-ante real interest rate, and positively on its expected future value and the expected rental rate. The introduction of a shock to the required rate of return on equity investment, $\hat{\varepsilon}^Q_t$, is meant as a shortcut to capture changes in the cost of capital that may be due to stochastic variations in the external finance premium.[15] It is assumed that this cost-push shock follows an IID-Normal process around the constant.

For the capital accumulation there is no big surprise:

$$\hat{K}_t = (1-\delta)\hat{K}_{t-1} + \delta\hat{I}_t \tag{35}$$

Due to the feature of Calvo pricing and partial indexation, the inflation equation is not purely forward looking and therefore can be represented by the new Keynesian Phillips curve meaning that current inflation depends on the expected future as well as past inflation and current marginal costs being function of the rental rate on capital, real wage

[14] $\bar{r}^k = \dfrac{1}{\beta} - (1-\delta)$

[15] This is the only shock that is not introduced through the structural economy model. For further explanations of this equity premium shock see Dupor (2001).

and productivity parameter. Our inflation dynamics follows from loglinearizing and rearaging equations (29), (30) and (26):

$$\hat{\pi}_t = E_t\left[\frac{\beta}{1+\beta\gamma_p}\hat{\pi}_{t+1} + \frac{\gamma_p}{1+\beta\gamma_p}\hat{\pi}_{t-1} + \frac{(1-\beta\xi_p)(1-\xi_p)}{(1+\beta\gamma_p)\xi_p}\left[\alpha\hat{r}_t^k + (1-\alpha)\hat{w}_t - \varepsilon_t^a + \hat{\lambda}_{p,t}\right]\right] \quad (36)$$

The importance of the backward looking part of the inflation process depends on the degree of the price indexation to past inflation, i.e. the degree of inflation persistence. The degree of inflation persistence is critical since this factor governs the output/inflation trade-off that the monetary policy faces and the optimal policy depends on the degree of persistence in both inflation and output. When γ_p=0 this equation reverts to the standard purely forward-looking Phillips curve. It is also important to note that when prices are perfectly flexible and ξ_p=0 this equation reduces to the condition that marginal costs are equal to one. From here it is obvious that consumer price inflation is affected by expectation. This comes from the forward-looking behavior on the part of wage-bargainers when setting wages and it embodies inertia, stickiness. This ensures that the time-series behavior of inflation mimics that in the real world. Price stickiness ensures that policy shocks have persistent effects on real values, output and employment and that there exist transmission lags between implementing monetary policy change and its impact on output and inflation as will be showed in the subsequent section.

Similarly, due to the stickiness and partial indexation of wages present in the model the real wage is defined out off equations (18), (19) and (15) as follows:

$$\hat{w}_t = E_t\left[\begin{array}{l} \frac{\beta}{1+\beta}\hat{w}_{t+1} + \frac{1}{1+\beta}\hat{w}_{t-1} + \frac{\beta}{1+\beta}\hat{\pi}_{t+1} - \frac{1+\beta\gamma_w}{1+\beta}\hat{\pi}_t + \frac{\gamma_w}{1+\beta}\hat{\pi}_{t-1} \\ -\frac{1}{1+\beta}\frac{(1-\beta\xi_w)(1-\xi_w)}{\left(1+\frac{(1+\lambda_w)\sigma_L}{\lambda_w}\right)\xi_w}\left[\hat{w}_t - \sigma_L\hat{L}_t - \frac{\sigma_c}{1-h}\left(\hat{C}_t - h\hat{C}_{t-1}\right) - \hat{\varepsilon}_t^l - \hat{\lambda}_{w,t}\right] \end{array}\right] \quad (37)$$

so that the real wage depends on the past and expected future wage, current and past inflation where the relative weight depends on the degree of indexation of the not optimized wages, disutility of labour and consumption with the external habit formation. When γ_w=0, real wages do not depend on the lagged inflation rate. There is a negative effect of the deviation of the actual real wage from the wage that would prevail in a flexible labour market. $\hat{\varepsilon}_t^l$ is a persistent labour supply shock, while $\hat{\lambda}_{w,t}$ is a temporary wage mark-up shock..

By setting marginal costs equal for all firms we get following labour demand dependence for a given installed capital stock:

$$\hat{L}_t = -\hat{w}_t + (1+\psi)\hat{r}_t^k + \hat{K}_{t-1} \tag{38}$$

where $\hat{K}_{t-1}$ is last period's capital stock and ψ is the inverse of the elasticity of the capital utilization cost function.

The goods market equilibrium can be expressed as:

$$\hat{Y}_t = (1-\delta\cdot k_y - g_y)\hat{C}_t + \delta\cdot k_y \hat{I}_t + g_y \hat{G}_t \tag{39}$$

$$= \phi\hat{\varepsilon}_t^a + \phi\alpha\hat{K}_{t-1} + \phi\alpha\psi\hat{r}_t^k + \phi(1-\alpha)\hat{L}_t \tag{40}$$

where k_y is the steady state capital-output ratio, g_y the steady state government spending-output ratio and ϕ is one plus the share of the fixed cost in production. $\hat{G}_t$ captures a government spending shock which follows an AR(1) process.

In order to obtain complete equilibrium the model has to be closed with a exogenous monetary policy reaction function describing the path of the interest rate as the monetary policy instrument. As is recently common in practice and literature, the selected rule is the adjusted Taylor type rule (Taylor, 1993) chosen to fit the estimated model[16].

$$\hat{R}_t = \rho\hat{R}_{t-1} + (1-\rho)\left\{\overline{\pi}_t + r_\pi\left(\hat{\pi}_{t-1} - \overline{\pi}_t\right) + r_y\left(Y_{t-1} - Y_{t-1}^P\right) + r_{\Delta\pi}\left(\hat{\pi}_t - \hat{\pi}_{t-1}\right) + r_{\Delta y}\left(\hat{Y}_t - \hat{Y}_t^P - (\hat{Y}_{t-1} - \hat{Y}_{t-1}^P)\right)\right\} + \hat{\varepsilon}_t^R \quad (41)$$

whereby the monetary policy-makers gradually respond to deviation of inflation from a time-varying inflation objective[17] and the theoretically consistent output gap. r_π and r_y represent the corresponding reaction coefficients. As is consistent with the DSGE theory (canonical model of Woodford, 1999), output gap is defined as a difference of actual and potential output where potential output equals to the output level prevailing in the flexible price and wage economy in the absence of the cost-push shocks.[18] Taking into account the difficulty of measuring the output gap accurately, the short-run feedback from the current change in inflation and output gap is included to complement on this issue. In this case, policymakers would react to the rate of growth of output instead on its gap level. The coefficients $r_{\Delta\pi}$ and $r_{\Delta y}$ are set for the short-run feedback from the current inflation and output changes. The rule is also supplemented by addition of lagged nominal interest rate since there exist evidence of a substantial degree of interest rate smoothing. The parameter ρ captures the degree of interest rate smoothing. This can be explained by the fact that central banks prefer adjusting gradually towards desired level (in order to maintain stability in the financial markets) so a partial adjustment model may capture the behaviour of the nominal interest rate.[19] Given the high value of the smoothing parameter we have CB that each period closes only a small friction of the gap between its policy rate and the desired value. It is important to mention that the reaction function coefficients are not derived from optimal behaviour of the economy. The central bank is the only sector in the model that is not optimising. The reaction function

[16] As has been shown by Gerlach and Schnabel (2000) this type of the rule characterizes well the average interest rate of Euro area.

[17] Inflation target is normalised to be zero for simplicity. However, according to the Maastricht Treaty the Euro area inflation target is 2%.

[18] In order to calculate the potential output level, equations (32) to (41) for the case of flexible prices and wages are added to the system without the three cost-push shocks.

[19] Sack and Rudebusch (2000), on the other hand, argue that this smoothing effect comes from uncertainty about the degree of persistence in economic disturbances because of the imperfect information.

introduces two monetary policy shocks. These are persistent shock to the inflation objective $\overline{\pi}_t$ (time varying inflation target) and temporary interest rate shock $\hat{\varepsilon}_t^R$.

To summarise, we defined 10 endogenous variables (their log deviations from the steady state) of our model and that are: $\hat{C}_t$, $\hat{I}_t$, $\hat{r}_t^k$, $\hat{Q}_t$, $\hat{K}_t$, $\hat{\pi}_t$, $\hat{w}_t$, $\hat{L}_t$, $\hat{Y}$ and $\hat{R}_t$ respectively. The model contains also ten identified exogenous driving forces, which are assumed to be orthogonal to each other. Six of them are modeled as first-order autoregressive processes, $\hat{\varepsilon}_t^a, \hat{\varepsilon}_t^B, \hat{\varepsilon}_t^L, \varepsilon_t^R, \hat{\varepsilon}_t^I, \hat{G}_t, \overline{\pi}_t$, in a general form of $\hat{z}_{t+1} = \rho_z \hat{z}_t + \eta_{t+1}^z$ where $E_t[\eta_{t+1}]$ equals to zero. First five shocks are arising from technology and preferences and the last one is a persistent monetary policy shock. Second set of shocks, three cost-push shocks $\hat{\varepsilon}_t^Q, \hat{\lambda}_{p,t}, \hat{\lambda}_{w,t}$ and a temporary monetary policy shock $\hat{\varepsilon}_t^R$, are assumed to be IID independent processes in a general form of $\hat{z}_{t+1} = \eta_{t+1}^z$.

In order to precede with the analysis of the monetary policy the estimate values of the structural parameters presented in Table A of the Appendix are adopted from Smets and Wouters (2003). They are estimated with Bayesian techniques using the euro area data on GDP, consumption, investment, prices, real wages, employment and the nominal interest rate for the period of 1980:2-1999:4. All estimates are in line with the remaining DSGE literature and robust for the model.

Parameters for monetary policy reaction function are plausible and consistent with those proposed in Taylor (1993). Also, the estimation resulted in evidencing a large degree of interest rate smoothing reflected in a substantial literature on estimated interest rate rules.

5 Monetary policy analysis and results

In this section the adjusted Taylor type monetary policy reaction function will be analysed with its basic characteristics and expected implications that are to be tested within the described model. The nature and performance of the DSGE model for Euro area will not be further analysed in details since the simulations do not provide any surprising results that are not consistent with already known literature. Instead, the analysis is focused on the reaction and action of the monetary policy committed to this specific rule.

The analysis is carried out relying on stochastic simulations that trace out the developments of the model economy continually hit by disturbances to goods and labour markets. Through observing reactions to the non-monetary disturbances, conclusion on the effectiveness of the monetary policy can be made. On the other hand, holding fixed the chosen monetary policy strategy, the economy generated by stochastic simulations of the model is used to evaluate the average economic performance delivered by this specific policy rule.

One of the serious policy design problems is to characterize in what extent should the interest rate adjust to the current state of the economy captured by the real variables presented in the rule. Therefore, besides constructing the rule itself it is of great importance to determine the optimal weights of the reaction function coefficients. In order to highlight this controversial issue simulation results subject to the policy rule with different coefficient choices are to be presented. Performance of the changed rule is evaluated through impulse response analysis as well as by comparing the macroeconomic variability under different coefficient values. In particular, when choosing between any two policies the strategy associated with less volatile economy, yielding lower variability of both output and inflation, is accepted as being superior.

However, the presented backward type Taylor rule incorporates only a subset of the information available about the current and likely future path of inflation and output. Thus, one of the limitations of the rule is that it seems to ignore useful information about the prospects for inflation and activity from other forward-looking indicators. Having in mind lags in the transmission mechanism, monetary authorities are reacting too late by responding to the actual inflation. On the other hand, too distant inflation forecasting can also have negative effects of increasing inflation variability. Therefore, it is useful to analyze the results of imposing a forward-looking version of the rule to the estimated Euro area model.

5.1 Backward looking policy rule

As first, the analysis is preformed for the rule suggested in the model by equation (41) with the associated model-suggested estimates for the reaction function coefficients.

$$\hat{R}_t = \rho \hat{R}_{t-1} + (1-\rho)\left\{\overline{\pi}_t + r_\pi\left(\hat{\pi}_{t-1} - \overline{\pi}_t\right) + r_y (Y_{t-1} - Y_{t-1}^P) + r_{\Delta\pi}\left(\hat{\pi}_t - \hat{\pi}_{t-1}\right) + r_{\Delta y}\left(\hat{Y}_t - \hat{Y}_t^P - (\hat{Y}_{t-1} - \hat{Y}_{t-1}^P)\right)\right\} + \hat{\varepsilon}_t^R$$

From the first glance the rule is explicitly backward looking, reacting to the past inflation deviations from the objective and changes in the lagged output gap. However, by incorporating information on the stance of the output gap in its decisions, the central bank does not look only at the past and actual inflation figures, but also at future inflation pressure that is present in the observed output-gap value and its current growth. It is here important to notice the significant difference between the ultimate objectives of monetary policy on the one hand and the reaction function or instrument rule on the other hand. Although the monetary objective can be defined narrowly in terms of inflation targeting, the central bank should take a larger set of economic variables into account in deciding on the course of its policy.

In order to test the common wisdom of monetary policy influencing real variables, chosen monetary policy strategy described by the above equation is set as fixed and stochastic simulations are used to compute the average real variables' reaction delivered by that very strategy. Price and wage stickiness introduced in the model for Euro area should ensure that monetary disturbances, presented by both temporary and persistent shocks, have persistent effects on real values and ensures also that there are transmission lags between implementing monetary policy change and its impact on output and inflation.

Accordingly, a temporary monetary policy shock is associated with an increase in interest rate, describing monetary policy tightening, and has a hump-shaped negative effect on both output and inflation (Figure 1). Despite dominating forward-looking component in inflation due to stickiness in prices and wages the transmission process is slow and lagging. It takes up to four years for inflation to achieve the new equilibrium one side effect of which is a persisting contraction in output. The degree of inflation persistence is here critical since this factor governs the output/inflation trade-off that the monetary policy faces. Although resulting in somewhat larger effects on output then is estimated in some VARs model, this effect is in line with the evidence for the Euro area.[20]

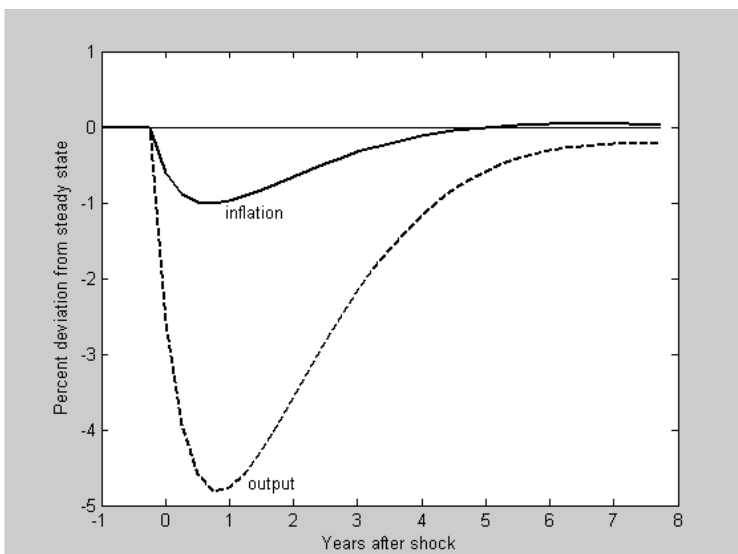

Figure 1: Impulse response to a shock in interest rate, backward looking policy rule

The effects following a persistent monetary policy shock in inflation objective provides interesting results (Figure 2). As inflation expectations increase there is immediate increase in the nominal interest rate, so there is no liquidity effect. This is attributed to

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[20] Smets and Wouters 2003, Peersman and Smets 2000

the persistence of the monetary policy shock. Also, since the change in policy is smooth, expectations have time to adjust and the shock to the real variables is relatively small.

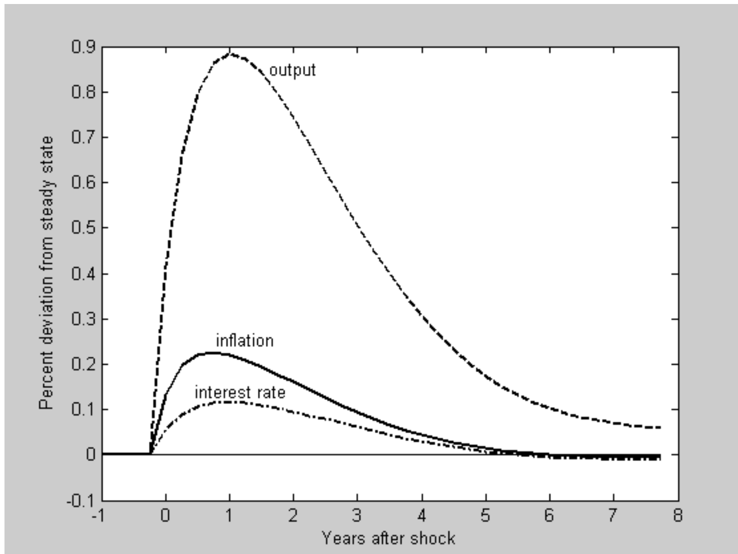

Figure 2: Impulse response to a shock in inflation objective, backward looking policy rule

It is also essential to observe how the monetary policy repairs the effects of non-monetary disturbances. For that purpose the impulse response to one of the ten shocks presented in the model, the demand shock in preferences, is presented (Figure 3).

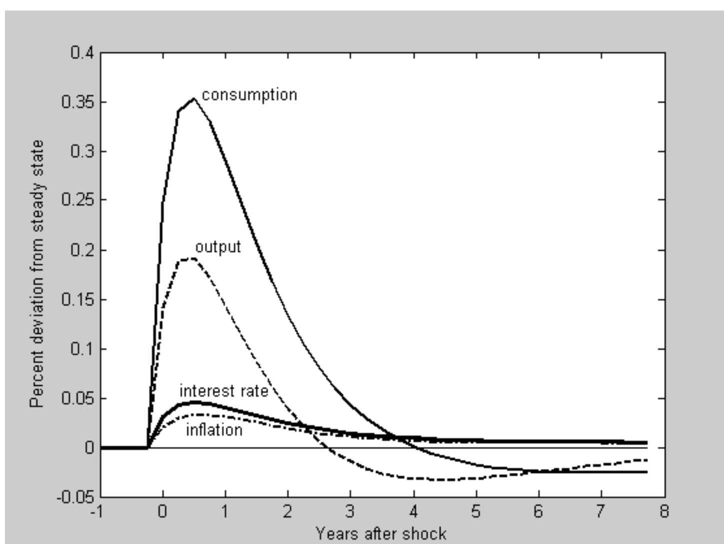

Figure 3: Impulse response to a shock in preferences, backward looking policy rule

The shock in preferences increases overall demand and thereby consumption and output significantly. Also, there is an upward pressure on factor prices, marginal costs and inflation but not to a great extent since there is a substantial degree of price stickiness. Despite forward-looking component of inflation, there is no problem in capturing the empirical fact that output changes lead changes in inflation (Gali and Gertler 2000). As the result of incorporating information on the output gap in its decisions, monetary authority reacts immediately by increasing interest rate, tightening monetary policy. By trying to hinder the inflation swing monetary authorities are facing a tradeoff between output gap stabilization and inflation stabilization and automatically negatively influencing the output development. Since output is less persistent then the inflation before converting to is steady state it contracts even in negative direction reacting to increase in interest rate as inflation approaches steady state firstly after four periods. So, monetary authority committing to this rule reacts to all disturbances and stabilizes the economy.

Even though there was no single monetary policy in the Euro area over the most of the estimation period the estimated coefficients of monetary policy reaction function seem to deliver plausible results. They are in line with the underlying base of the Taylor rule (1993) and satisfy the Taylor principle fully by implying that in the long run the response of interest rates to inflation has to be greater than one.[21] That is, the monetary authorities should adjust the nominal rate sufficiently in the direction that is offsetting to any movement in expected inflation. The response to output is also similar to the one suggested by Taylor.

In order to check whether the chosen coefficients are really the optimal choice and if there exist any other combination of the weights in the reaction function that might deliver better results in terms of macroeconomic stability, the unconditional standard deviations of output and inflation associated with different combination of values for its coefficients as well as associated impulse response are computed within the model

[21] See Appendix for values on coefficients.

simulation. The results for sensitivity of output and inflation variability are summarized in Table 1. Each case is compared to the "Base case".

Table 1: The sensitivity of output and inflation variability to varying relative weights for reaction function coefficients

	Standard deviation (HP-filtered series)		
	Inflation	**Output**	**Interest rate**
Base case[22]	0,2204	0,6315	0,1972
Case 1: Changing r_{π}			
r_{π} = **5**	0,0955	0,5209	0,1467
r_{π} = **0,5**	1,0524	2,9577	0,7088
Case 2: Changing $r_{\Delta\pi}$			
$r_{\Delta\pi}$ = **5**	0,2227	0,6135	0,2016
$r_{\Delta\pi}$ = **0**	0,2192	0,6733	0,1785
Case 3: Changing r_{y}			
r_{y} = **2**	0,3951	0,7886	0,2842
r_{y} = **1**	0,3591	0,6872	0,2779
r_{y} = **0**	0,2408	0,8389	0,1588
Case 4: Changing $r_{\Delta y}$			
$r_{\Delta y}$ = **5**	0,2259	0,5521	0,2378
$r_{\Delta y}$ = **0**	0,2038	0,9282	0,1140

By increasing the coefficient on the inflation gap (Table 1, Case 1) variability of both output and inflation decrease. However, if the response to fluctuations is too large there exist danger of cost and not benefit to responding to fluctuations so aggressively that inflation in the subsequent period has opposite sign from the current one. Putting more weight on the inflation targeting in the reaction function leads to more aggressive

[22] The "Base case" coefficients' values are the ones estimated as optimal for the Euro area model. See Appendix, Table A. For other cases, the value of indicated coefficient is varied whereas others remain at the "Base case" level.

monetary authority reaction to the non-monetary shocks with the goal of inflation stabilization. Also, output-inflation trade off is slightly decreased (Figure 4). The overall reaction to the monetary shocks is stronger with higher deviation of real variables from the steady state but no effect on the speed of the transaction mechanism (Figures 5 to 6).

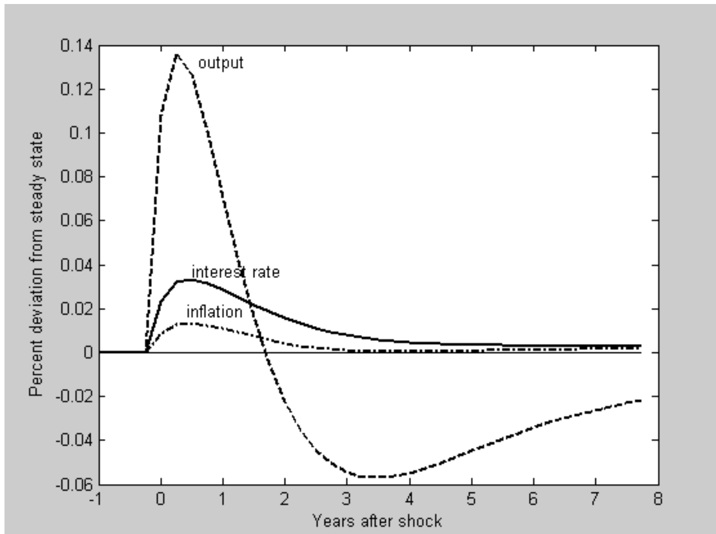

Figure 4: Impulse response to a shock in preferences, backward looking policy rule
Calibration: r_{π}=5

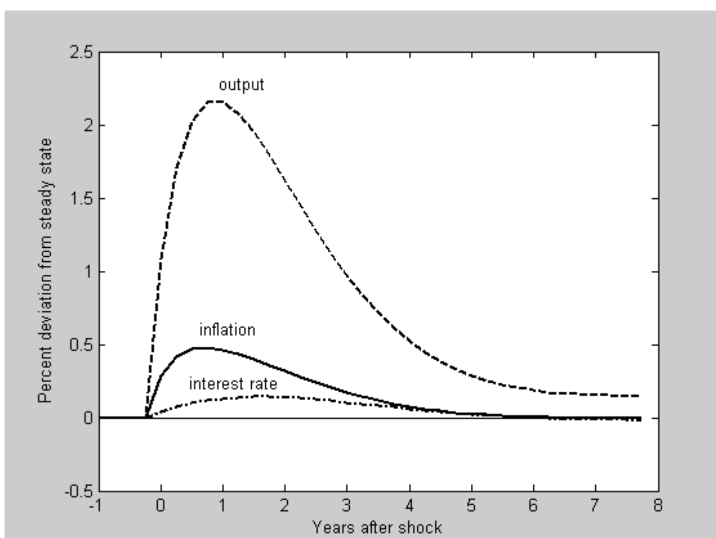

Figure 5: Impulse response to a shock in inflation objective, backward looking policy rule
Calibration: r_{π}=5

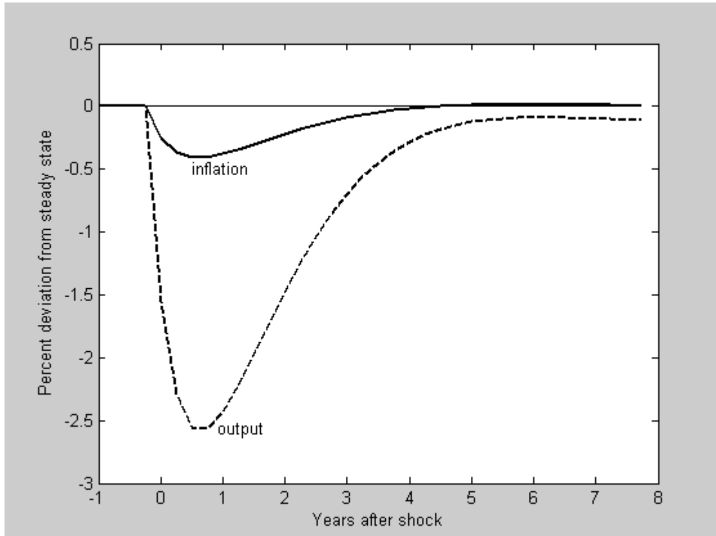

Figure 6: Impulse response to a shock in interest rate, backward looking policy rule
Calibration: $r_{\pi}=5$

On the other hand, concentrating less to the inflation gap then suggested by the Taylor principle, leads to odd results of increasing macroeconomic variability towards a direction of instability ($r_{\pi}=0$). Less aggressive reaction of monetary policy on the inflation gap leads to higher deviation of real variables from steady state before authorities decide to react. Instead of increase in expected inflation and increase in interest rate, low coefficient on inflation targeting leads to unwanted result after the inflation objective shock of decrease in interest rate, inflation and output creating the ground for inflationary spirals (Figures 7 to 9). It is here proven again that if the rule does not satisfy the Taylor principle, saying the nominal interest rate must increase more than one for one with increases in inflation, then increase in inflation would decrease real interest rate, which would lead again in increase in inflation.

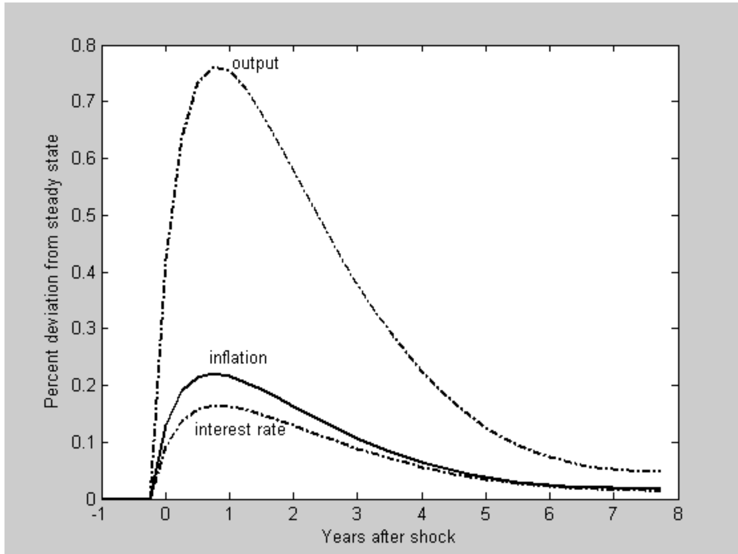

Figure 7: Impulse response to a shock in preferences, backward looking policy rule
Calibration: r_{π}=0,5

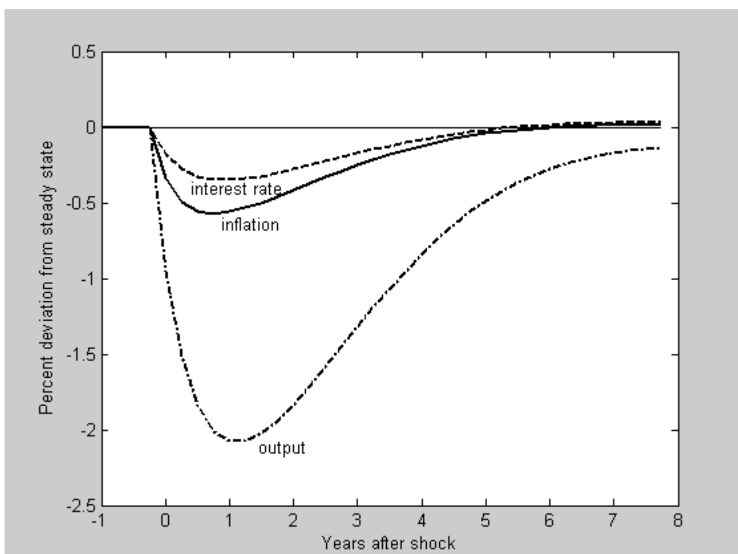

Figure 8: Impulse response to a shock in inflation objective, backward looking policy rule
Calibration: r_{π}=0,5

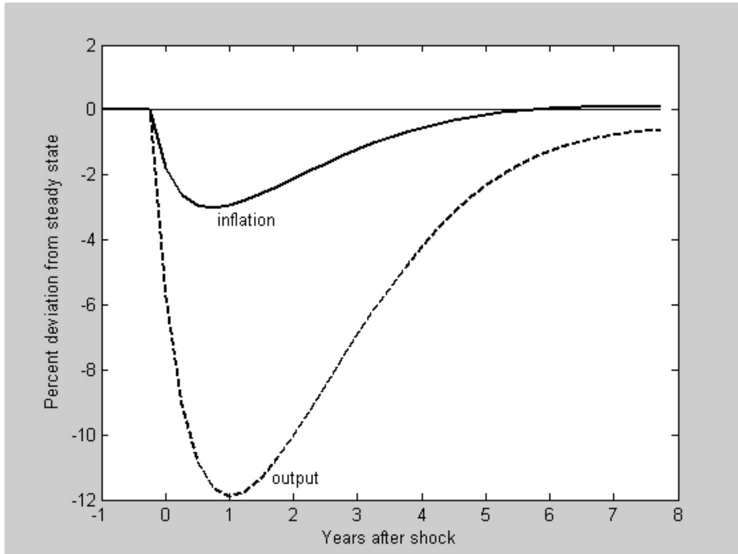

Figure 9: Impulse response to a shock in interest rate, backward looking policy rule
Calibration: r_{π}=0,5

Further results from Table 1 show that reacting to the current inflation change (Table 1, Case 2) less or more aggressive does not influence the stabilization conditions by much. It is therefore proven here that adding the term of current inflation change in the reaction function serves only as a short-run policy feedback.[23]

Observing the variability of output and inflation under changing the value of coefficient on output gap (Table 1, Case 3) provides ground for sound conclusion on this parameter. By increasing the weight put on the output gap in the reaction function above the weight of the inflation coefficient results in increase of output as well as inflation variability. So, in case of prevailing output gap targeting the economy presented by this system runs into higher volatility. It is also interesting that even lowering the output gap coefficient below the weight put on the inflation targeting, still does not provide satisfying results. Compared to the base case the variability is higher. However, totally ignoring the output gap in striving to stabilize inflation, monetary authorities face with a higher macroeconomic volatility than in the base case. It is therefore to conclude that, in line with the Taylor principle, in order to stabilize inflation in the economy, monetary policy

[23] See Appendix for figures on impulse responses.

rule should not loose the output gap stabilization out of sight and the weight of the output gap coefficient should not exceed 0,5 in value. According to the base case calibration, it seems like it uses the information on output gap exclusively as a forecast of future inflation since the coefficient suggested for the policy rule is very small but not equal to zero. Because of the eternal output-inflation trade off monetary policy is faced with, it is also interesting to observe changes in the impulse response governed by changes in output gap coefficient.

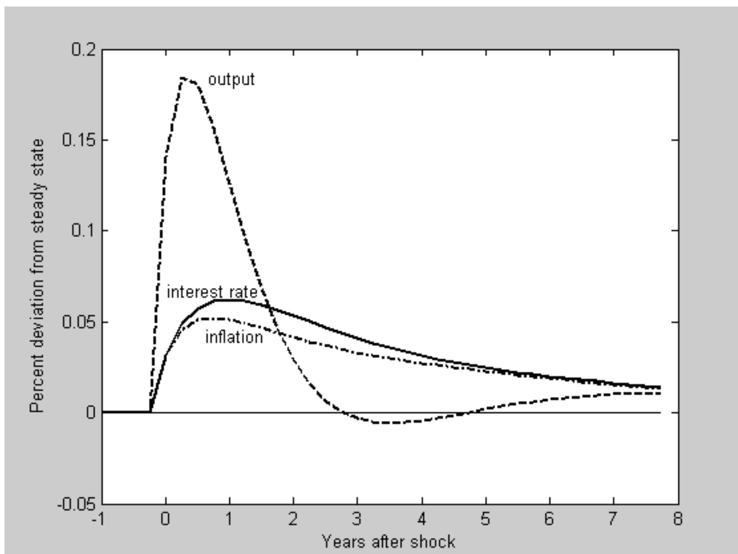

Figure 10: Impulse response to a shock in preferences, backward looking policy rule
Calibration: r_y=1

By increasing the weight of the output gap in the reaction function, output reacts less in response to demand shock and the inflation-output trade off is reduced. However, the duration of the transmission mechanism is longer and inflation looks as stabilized at the higher level then before the shock. Monetary shocks seem to have less effect on the real variables and interest rate is relatively smooth. Also, it is important to notice that deviation in output is sharper and of inflation even smoother than in the base case (Figures 10 to 12).

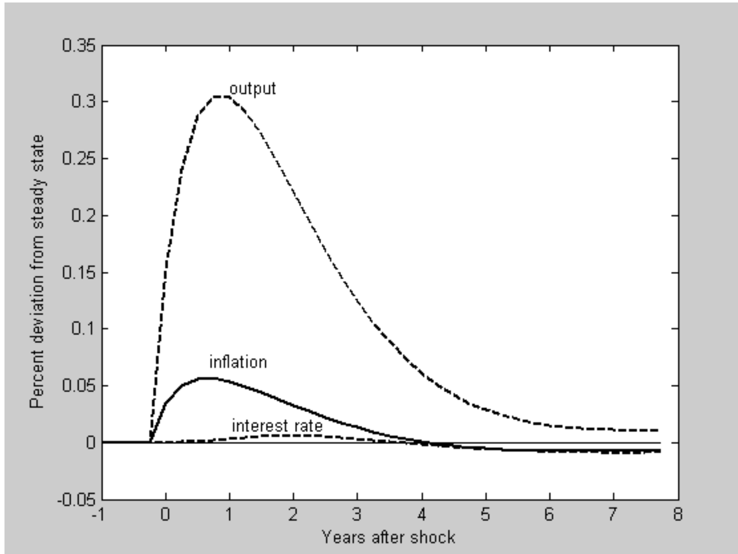

Figure 11: Impulse response to a shock in inflation objective, backward looking policy rule
Calibration: r_y=1

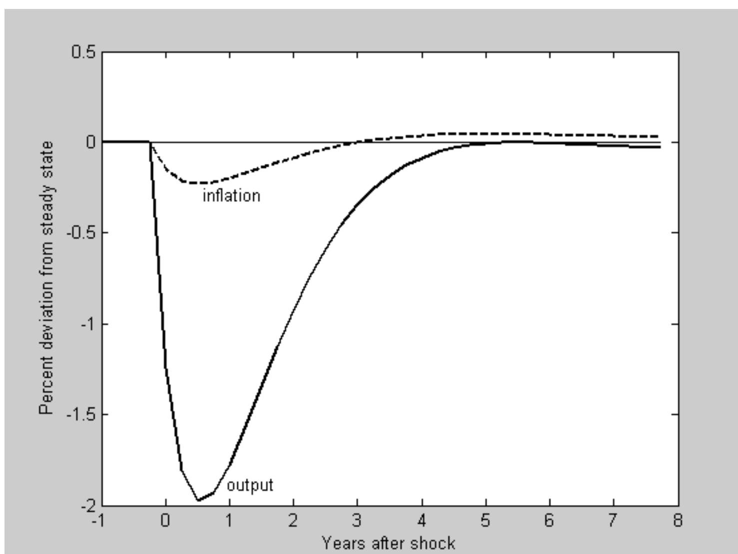

Figure 12: Impulse response to a shock in interest rate, backward looking policy rule
Calibration: r_y=1

When output gap is totally neglected as a reference in conducting monetary policy, real variables deviate largely from the steady state (Figures 13-15).

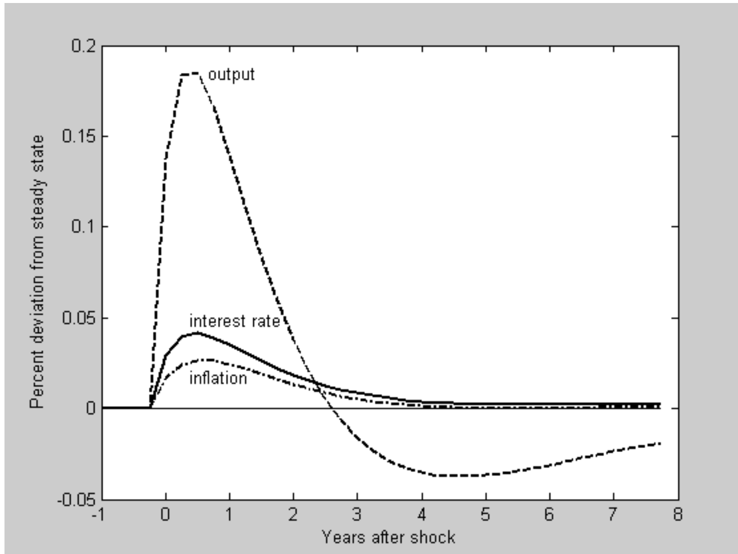

Figure 13: Impulse response to a shock in inflation objective, backward looking policy rule
Calibration: r_y=0

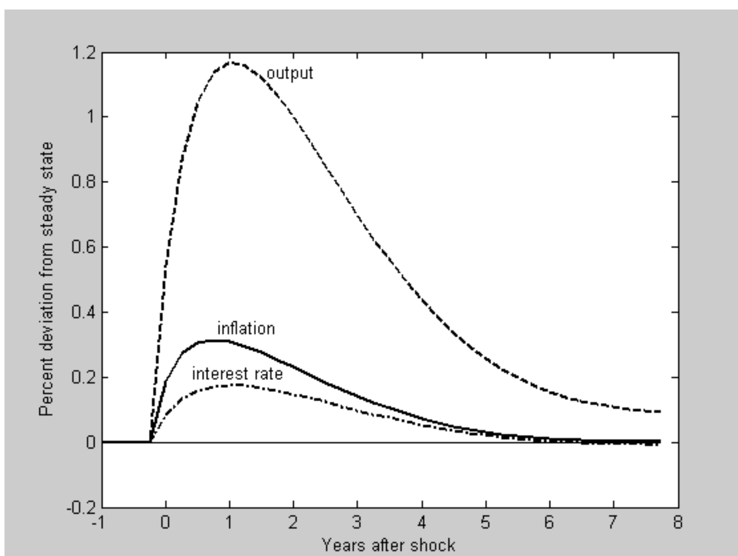

Figure 14: Impulse response to a shock in inflation objective, backward looking policy rule
Calibration: r_y=0

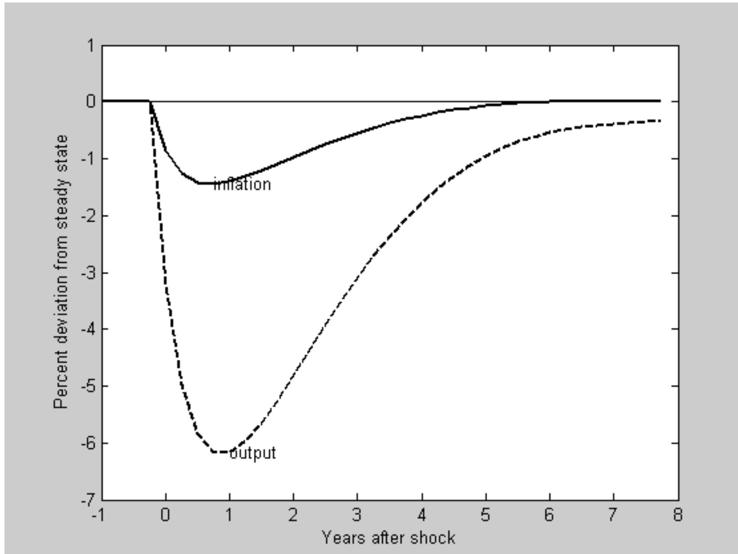

Figure 15: Impulse response to a shock in interest rate, backward looking policy rule
Calibration: r_y=0

Finally, the case of varying coefficient on the current change in output in the reaction function (Table 1, Case 4) shows that neglecting movements in output changes induces somewhat higher output variability. On the other hand, reacting more aggressively on the current change in output does not result in huge improvement of the overall stability. That is because this item serves only as a short-run feedback of the policy committing to a backward looking rule, but it is not to be neglected.[24]

Cases 3 and 4 summarize that if central bank cares about inflation it should respond to movements in both output and inflation to keep inflation under control.

According to the presented analysis and results it is possible to form plausible boundaries for each of the coefficients. Accordingly, for r_π it is proved that the values around 1,5 provide the best choice, $r_{\Delta\pi}$ and $r_{\Delta y}$ have to certainly be above zero, whereas r_y should be chosen to lie between 0 and 0,5 (not allowed to be equal to zero).

[24] See Appendix for Figures on impulse responses.

Overall, the results show that the estimated coefficients in the policy rule presented by equation (41) are in line with Taylor principle, efficient and show optimal combination of weights within created ranges.

5.2 Forward looking vs. backward looking policy rule

In the next simulations it is assumed that the central bank uses a forward-looking rule to determine its policy actions with the coefficients estimates equivalent to those in the base case scenario of the backward looking rule. Proposed forward-looking form still captures smoothing phenomenon even though it presents backward looking component but this is something observed in the data that cannot be neglected. The rule can be described by following reaction function:

$$\hat{R}_t = \rho \hat{R}_{t-1} + (1-\rho)\left\{\overline{\pi}_t + r_\pi\left(\hat{\pi}_{t+1} - \overline{\pi}_t\right) + r_y(Y_t - Y_t^P) + r_{\Delta\pi}\left(\hat{\pi}_{t+1} - \hat{\pi}_t\right) + r_{\Delta y}\left(\hat{Y}_t - \hat{Y}_t^P - (\hat{Y}_{t-1} - \hat{Y}_{t-1}^P)\right)\right\} + \hat{\varepsilon}_t^R$$

The rational explanation to suggesting this kind of rule lies in the fact that existing lags in transmission mechanism complicate the inflation control. So, if policy-makers respond to deviations of lagged inflation from target (as suggested by equation (41)), they might be acting too late to offset the inflationary pressure. Accordingly, there exists need to form and respond to expectations of future inflationary pressures allowing time for monetary policy to take its full effect.

This implies advantageous performance for forward looking rules since they allow aligning the horizon of the inflation forecast and the control lag for monetary policy. The aim is therefore to evaluate if this criticisms of the backward looking is reflected in the evidence that forward-looking policy can offer better results within the model for Euro area.

The impulse response under the expectations oriented Taylor type rule does not seem to provide spectacularly different evidence on relation between monetary policy and the real economy. Under the temporary policy shock the economy reacts by negative hump-shaped movement in output and inflation. Compared to the impulse response under the backward looking policy rule, here inflation deviates slightly more and output slightly less but in the same manner. Change in the inflation objective implies tightening monetary policy since it increases future inflation expectations and has somewhat stronger influence on the real variables. Positive demand shock urges increase in the interest rate to offset inflationary pressures. (Figures 16 to 18).

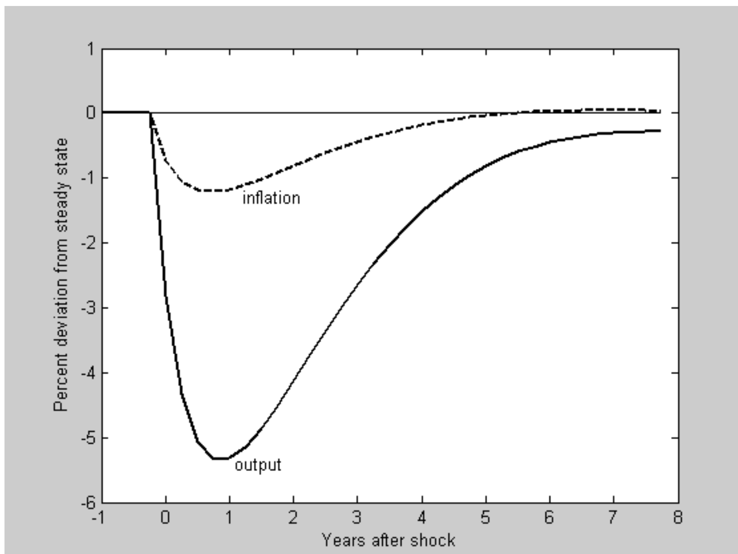

Figure 16: Impulse response to a shock in interest rate, forward-looking policy rule

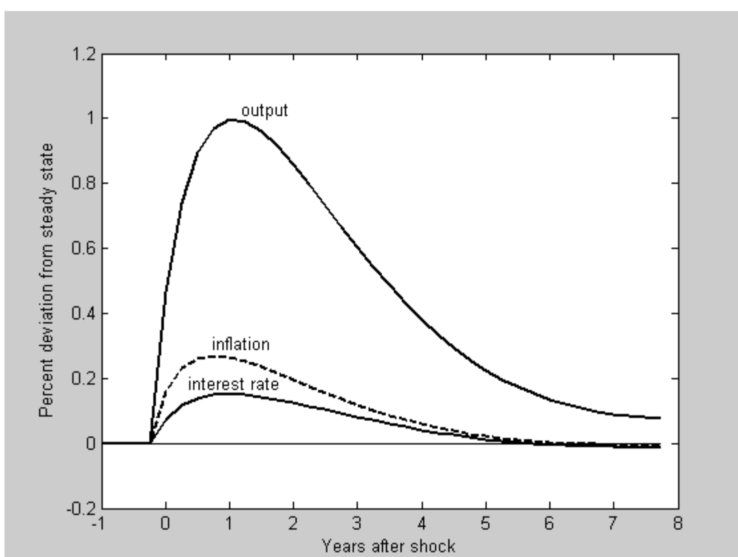

Figure 17: Impulse response to a shock in interest rate, forward-looking policy rule

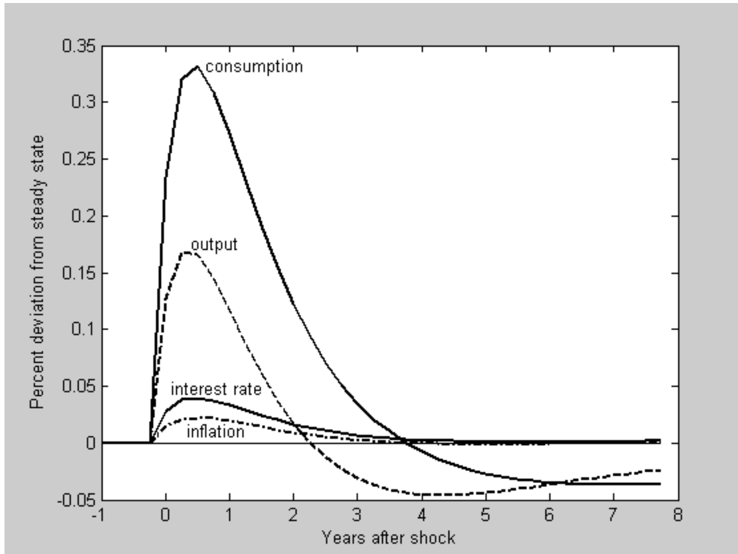

Figure 18: Impulse response to a shock in interest rate, forward-looking policy rule

However, it seems like monetary authorities are able to influence inflation somewhat more and also to improve results in the sense of the inflation-output tradeoff by committing to a forward-looking rule.[25] Still, this evidence does not provide reasonable foundation to make a conclusion on which of the two Taylor type rules might performer better for the Euro area economy.

The aim of monetary policy is primarily the stabilization of the economy. Therefore, comparing the macroeconomic variability that arises under each policy rule might elicit some credible results.

Table 2: Variability of inflation and output

	Standard deviation (HP-filtered series)		
	Inflation	**Output**	**Interest rate**
Backward-looking rule	0,2204	0,6315	0,1972
Forward-looking rule	0,1785	0,7631	0,1541

[25] On this argument see also Clarida, Gali, Gertler (1999).

Using the variability of output and inflation relative to trend under backward-looking rule as a benchmark it can be concluded that under the expected inflation targeting monetary authorities succeed in lowering the inflation variability and interest rate variability whereas the output variability is significantly increased (Table 2). The intuition behind it is that, even though by forecasting inflation and targeting expected inflation the forward looking rule seems to stabilize inflation as well as interest rate more it seems to have problems in taking into account right output developments. This might happen since output gap is hardly observable in current as well as past periods, and the output gap attributable to the slowdown in productivity growth that might began in earlier periods is not perceived by authorities that are committing to a forward-looking rule.

By assuming that both reaction functions are efficient rules and lie on their policy frontier found by minimizing a loss function[26] , it is possible to calculate the values of the loss they engage for monetary authorities, in facing a tradeoff between output and inflation stabilization. Because different types of rules yield different frontiers, they provide a convenient way of comparing each type's overall performance. The loss function is of the form:

$$L = \varphi\sigma_y^2 + (1-\varphi)\sigma_\pi^2$$

where σ_y^2 denotes the variance of output, σ_π^2 the variance of inflation and φ parameter showing the relative weight the central bank puts on inflation.[27]

As can be seen from Table 3 the backward looking rule results in better minimizing of the loss function for all combinations of inflation-output stabilization trade-off in the estimated model for Euro area. The results could lead to a conclusion that a central bank should place more weight on inflation stabilization. However, one should keep in mind that it induces departures of output from its natural rate to bring inflation back to its

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[26] The loss function is minimized for values of φ between one and zero.

[27] This approach was suggested in Orphanides, Porter, Reifschneider, Tetlow, Finan (1999).

optimal value. Therefore, even if the central bank caries only about inflation, it wants to keep output close to its natural rate to prevent large movements in inflation.

Table 3: Loss function values under different rules

	Loss value	
	Backward-looking rule	Forward-looking rule
φ= 0,1	0,364	0,527
φ= 0,2	0,329	0,472
φ= 0,3	0,294	0,417
φ= 0,4	0,259	0,362
φ= 0,5	0,224	0,307
φ= 0,6	0,189	0,252
φ= 0,7	0,154	0,197
φ= 0,8	0,119	0,142
φ= 0,9	0,084	0,087

6 Concluding remarks

Recent research on monetary policy rules indicates that in order to avoid undesirable inflation and output outcomes and be able to speed up the adjustment process of the economy to shocks, a feedback monetary policy rule, like the one analyzed here, has to satisfy the Taylor principle. This requirement is easily met if the inflation response coefficient in the policy rule is well above unity and there exist corresponding weight on observed output gap. Although the monetary objective described by the Taylor type policy rule can be simply explained as inflation targeting, when deciding on the course of its policy the central bank should not underestimate other economic variables that track changes in inflation or may present sources for inflationary pressures if it is to succeed in improving overall economic stability.

In practice, however, a binding commitment to a rule may not be feasible simply because not enough is known about the structure of the economy or the disturbances. So, no major central bank makes any type of binding commitment over the future course of its monetary policy.

Accordingly, policy reaction function is proposed not so much in the sense of mechanical rule that has to be blindly followed, but more as a guidepost to monetary authorities. Deviations from the rule are permitted and opposed to the pure discretion they obligate policy makers to provide arguments on their decisions. There will always be factors in the economy that will force monetary policy to deviate from the rule, but choosing this type of commitment requires that reactions towards inflation and output stabilization are consistent and systematic.

As expected, optimal policy rule should respond to all useful information on the target variables of monetary policy. Forecast based rule should be able to reduced this restriction that backward looking rules are bind with, since for forecasting inflation one has to take into account all useful available information. However, the evidence provided by the model simulation under the forward looking policy rule shows that compared to the backward looking policy it delivers a greater degree of variability in output and even though the inflation is more stabile the loss perceived by the monetary authorities is much higher.

To conclude, given all the specifics of the Euro area macro economy, the central bank does the right thing by committing to a backward looking policy rule that satisfies the Taylor principle and by taking a larger set of economic variables into account in deciding on the course of its policy.

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8 Appendix

Table A: Parameter Estimates

β	0.990	r_{π}	1.668	$\rho_{(\varepsilon^a)}$	0.811
δ	0.025	$r_{\Delta\pi}$	3.432	$\rho_{(\varepsilon^B)}$	0.838
α	0.300	r_y	0.098	ρ_g	0.943
ψ	0.201	$r_{\Delta y}$	3.591	$\rho_{(\varepsilon^L)}$	0.881
γ_w	0.728	ρ	0.956	$\rho_{\bar{\pi}}$	0.855
λ_w	0.500			$\rho_{(\varepsilon^I)}$	0.910
ξ_p	0.905			$\sigma^2_{(\varepsilon^a)}$	0.639
ξ_w	0.742			$\sigma^2_{(\varepsilon^B)}$	0.407
γ_p	0.477			σ^2_g	0.335
σ_c	1.391			$\sigma^2_{(\varepsilon^L)}$	3.818
h	0.57			$\sigma^2_{(\lambda_{p,t})}$	0.165
φ	0.144			$\sigma^2_{(\varepsilon^R)}$	0.090
σ_L	2.503			$\sigma^2_{\bar{\pi}}$	0.033
ϕ	1.417			$\sigma^2_{(\varepsilon^Q)}$	0.613
$\bar{r}^k$	0.035			$\sigma^2_{(\varepsilon^I)}$	0.113
k_y	8.800			$\sigma^2_{(\lambda_{w,t})}$	0.297
g_y	0.183				

1 The model

What is Q_t?

Maximizing utility function subject to budget contraint and capital accumulation equation where λ_t and θ_t are the respective Lagrangian multipliers:

$$\frac{\partial L}{\partial K_t} \equiv 0 \Rightarrow \theta_t = \beta E_t \left(\lambda_{t+1} \left(r_{t+1}^k z_{t+1} - \psi(z_{t+1}) \right) + \theta_{t+1}(1-\tau) \right)$$

divide both side by λ_t

$$\Rightarrow \frac{\theta_t}{\lambda_t} = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \left(r_{t+1}^k z_{t+1} - \psi(z_{t+1}) + \frac{\theta_{t+1}}{\lambda_{t+1}}(1-\delta) \right) \right)$$

Let $Q_t = \frac{\theta_t}{\lambda_t}$, $\Rightarrow Q_t = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \left(Q_{t+1}(1-\delta) + r_{t+1}^k z_{t+1} - \psi(z_{t+1}) \right) \right)$

2 Steady State

The steady state i.e. the state in which the economy reaches equilibrium and stays constant for the each equilibrium equation respectively:

From the household conditions and derived Euler equation (35) results:

$$\frac{1}{\beta} = \frac{\overline{R}}{\overline{\pi}}$$

Assuming that $\bar{z} = 1$, $\overline{S} = 0$ and $\overline{S}'' = 0$, investment (12) and capital accumulation (11), (13) conditions in steady state yield:

$$\overline{K} = \frac{\overline{I}}{\delta}$$

$$\overline{r}^k = \psi'(1)$$

$$\overline{r}^k = \frac{1}{\beta}(1-\delta)$$

According to the equations (15), (18), (19) and assuming $\overline{W}^{\tau} = 0$, the wages reach following steady state:

$$\overline{\widetilde{w}} = \overline{W}$$

$$\overline{L} = \overline{\ell}^{\tau} = \overline{l}^{\tau}$$

$$\frac{\overline{\widetilde{w}}}{\overline{P}} = 2\frac{\left(\overline{\ell}^{\tau}\right)^{\sigma_c}}{\left(\overline{C}(1-h)\right)^{-\sigma_c}}$$

From the necessary equations for determining the price level (26), (29), (30) the steady state equals to:

$$\overline{MC} = (\overline{W})^{1-\alpha}(\overline{r}^k)^{\alpha}(\alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)})$$

$$\left(\overline{P}\right) = \left(\overline{\widetilde{p}}\;\right)$$

$$\overline{\widetilde{p}} = \overline{MC}$$

Assuming equalization of marginal costs from (24) for all intermediate goods firms the steady state is equal to:

$$\overline{w}\overline{L} = (1+\psi)\overline{r}^k\overline{K}$$

From the aggregate supply function of the intermediate sector follows:

$$\overline{Y} = \left(\psi \overline{r}^{k}\right)^{\alpha} \left(\overline{K}\right)^{\alpha} \left(\overline{L}\right)^{1-\alpha}$$

Goods market equilibrium steady state is:

$$\overline{Y} = \overline{C} + \overline{G} + \overline{I}$$

3 Loglinearisation procedure

For calculating loglinearised equation (12) and (13) it is necessary to use the trick with the first order Taylor expansion:

Since

$$\overline{z} = 1$$
$$\psi(1) = 0$$

we can express the deviation of function ψ around the steady state $\overline{z}$ as:

$$\psi(z_t) \cong \psi(1) + \psi'(1)(z_t - 1)$$
$$\psi'(z_t) \cong \psi'(1) + \psi''(1)(z_t - 1)$$

and

$$\psi(\overline{z} \cdot e^{\hat{z}_t}) \cong \psi(1) + \psi(1)(\hat{z}_t)$$
$$\psi'(\overline{z} \cdot e^{\hat{z}_t}) \cong \psi'(1) + \psi''(1)(\hat{z}_t)$$

The loglinearising result for equation (13) is as follows:

$$\overline{r} \cdot e^{\hat{r}_t^k} = \psi'(1) + \psi''(1)(\hat{z}_t)$$
$$\psi'(1)(1 + \hat{r}_t^k) = \psi'(1) + \psi''(1)(\hat{z}_t)$$
$$\hat{r}_t^k = \frac{\psi''}{\psi'}$$

The same principle works for the investment equation where the first order Taylor approximation for the *S(.)* function is to be used.

4 Impulse responses (Table 1, Case 2 and 4)

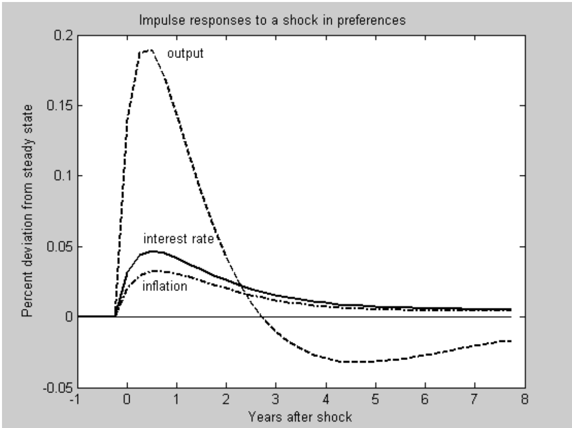

Figure 1: Impulse response to a shock in preferences, backward looking policy rule
Calibration: $r_{\Delta\pi}$=5

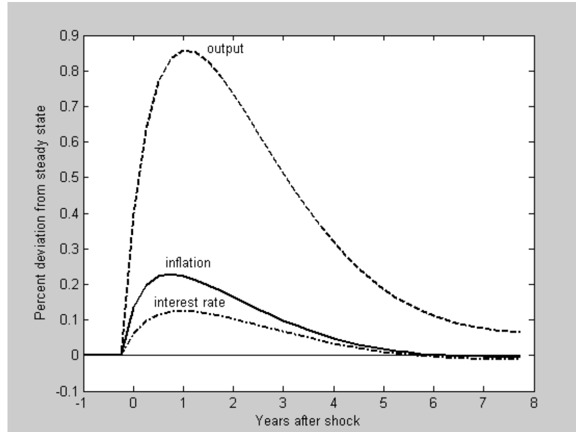

Figure 2: Impulse response to a shock in inflation objective, backward looking policy rule
Calibration: $r_{\Delta\pi}$=5

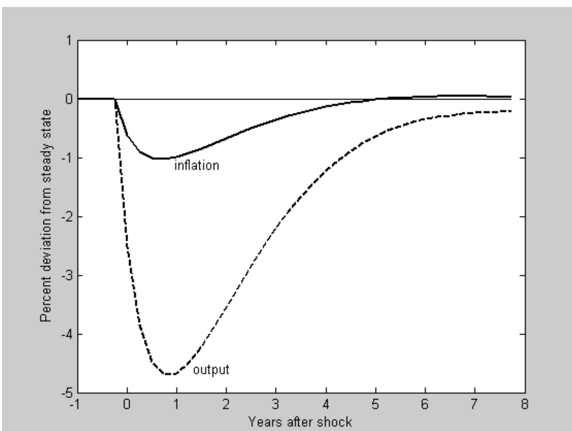

Figure 3: Impulse response to a shock in interest rate, backward looking policy rule
Calibration: $r_{\Delta\pi}$=5

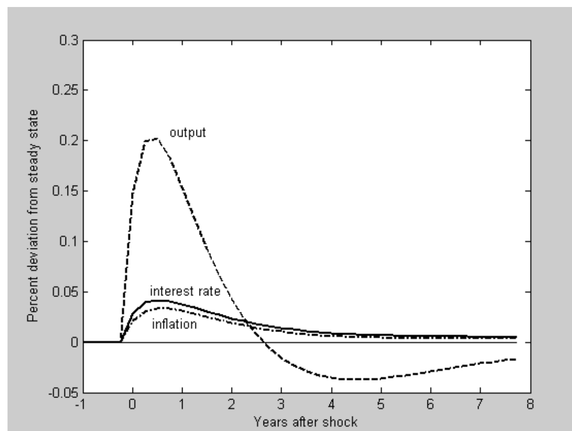

Figure 4: Impulse response to a shock in preferences, backward looking policy rule
Calibration: $r_{\Delta\pi}$=0

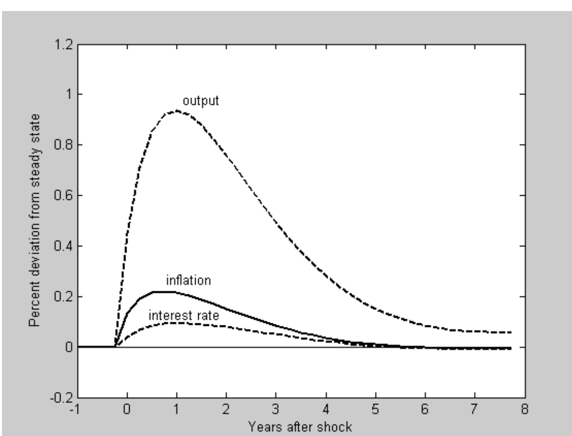

Figure 5: Impulse response to a shock in inflation objective, backward looking policy rule
Calibration: $r_{\Delta\pi}$=0

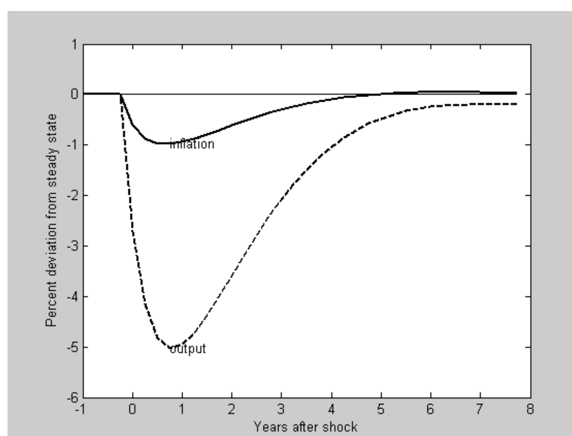

Figure 6: Impulse response to a shock in interest rate, backward looking policy rule
Calibration: $r_{\Delta\pi}$=0

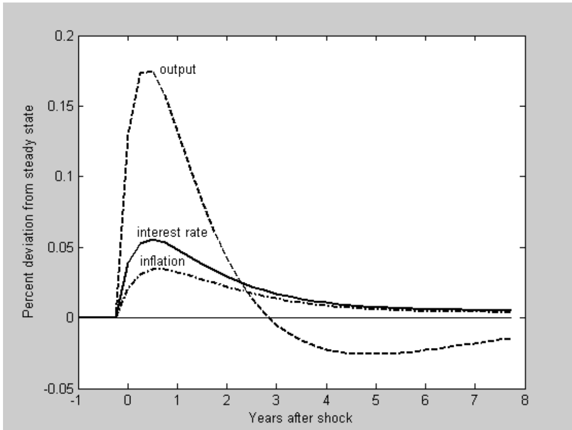

Figure 1: Impulse response to a shock in preferences, backward looking policy rule
Calibration: $r_{\Delta\pi}$=5

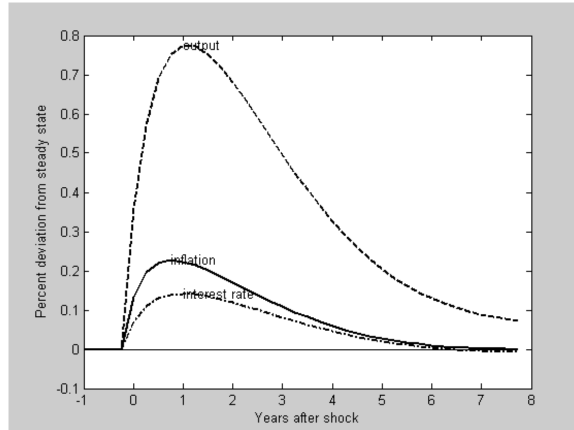

Figure 2: Impulse response to a shock in inflation objective, backward looking policy rule
Calibration: $r_{\Delta\pi}$=5

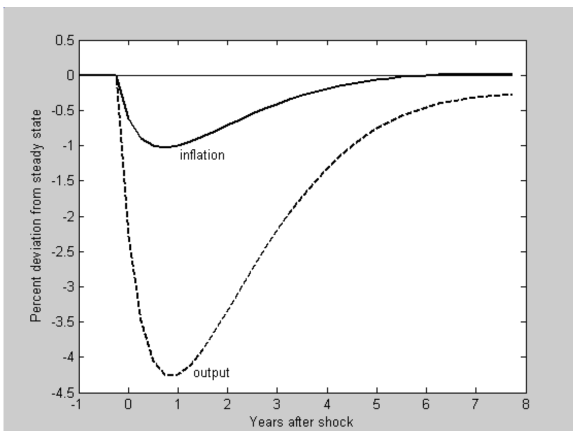

Figure 3: Impulse response to a shock in interest rate, backward looking policy rule
Calibration: $r_{\Delta\pi}$=5

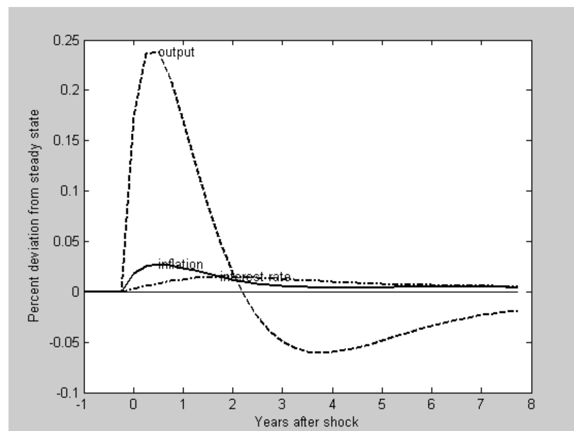

Figure 4: Impulse response to a shock in preferences, backward looking policy rule
Calibration: $r_{\Delta\pi}$=0

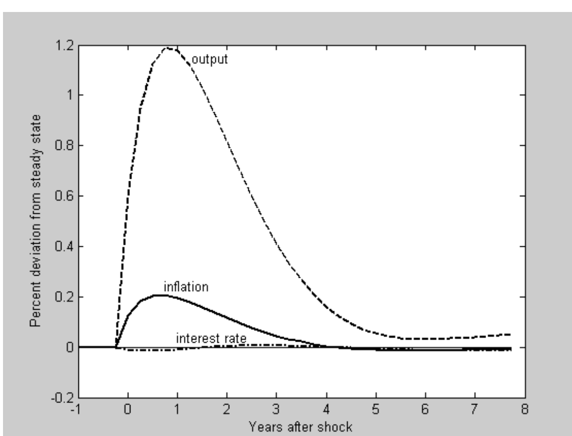

Figure 5: Impulse response to a shock in inflation objective, backward looking policy rule
Calibration: $r_{\Delta\pi}$=0

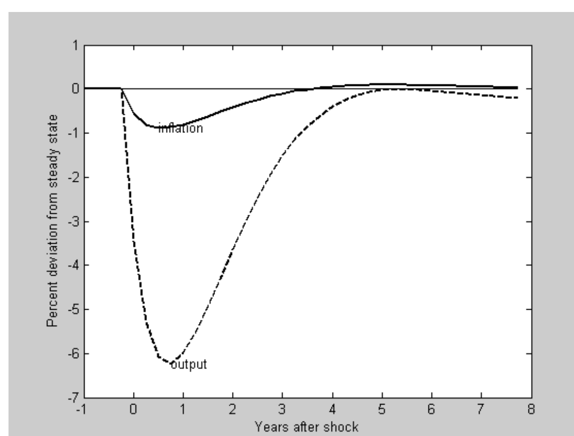

Figure 6: Impulse response to a shock in interest rate, backward looking policy rule
Calibration: $r_{\Delta\pi}$=0

Declaration of Authorship

I hereby state that I have written this paper on my own and with full acknowledgement of the used sources.

Katarina Primorac

Berlin, 5th August 2004