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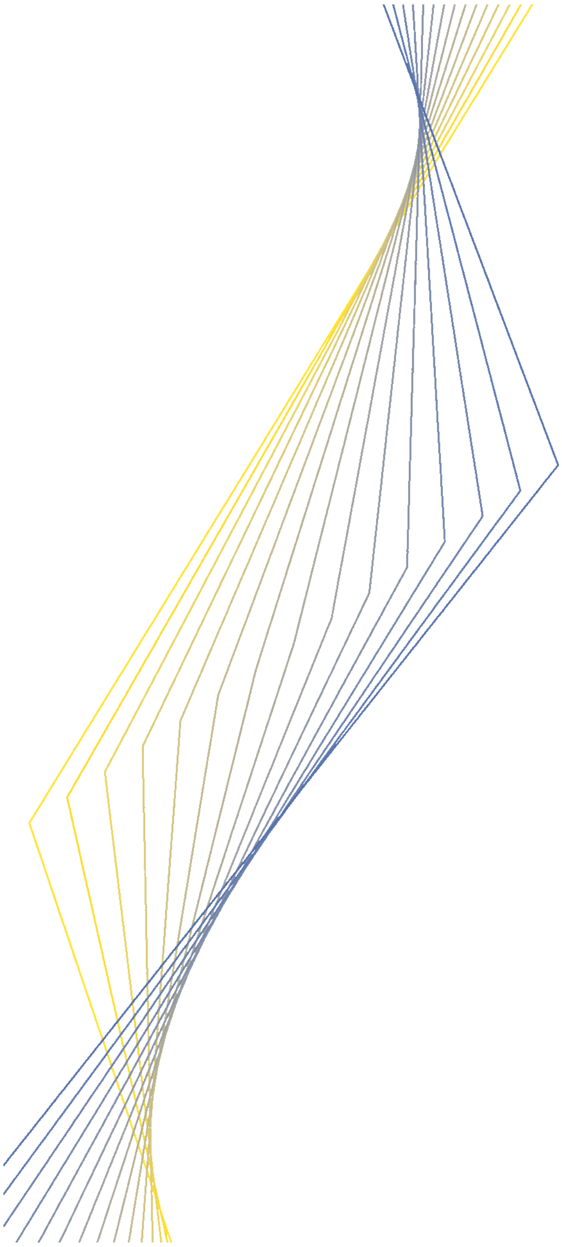

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BY NICOLA GIAMMARIOLI[2]
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Contents

Abstract

In this paper, we discuss the consequences of taking into account the variations of the natural real interest rate (r_t^*) in simple monetary policy rules. We also provide one possible model-based analysis of the level of r_t^* that has prevailed in the euro area since the early 1970s, and present the implied "real rate gap" as a possible additional indicator to assess the stance of monetary policy.

Key words: Natural rate of interest; monetary policy; euro area.
JEL-calssification: E4 - E5

Non-technical summary:

Measures of the monetary policy stance based on the spread between the actual real interest rate and what is thought of being its "natural" (or equilibrium) level are presented in the literature as valuable alternatives to standard indicators based on monetary aggregates or exchange rates. Determining the forces driving the fluctuations of the underlying real interest rate level is therefore a relevant issue for monetary policy.

In this paper, we use a stochastic dynamic general equilibrium (SDGE) model in order to assess three specifications of monetary policy rules: an interest-rate smoothing rule, a simple Taylor rule and a Taylor rule including a time-varying measure of the natural real rate. In particular, this paper adds to the empirical literature by applying the Neiss and Nelson (2001) framework to the natural short term real interest rate that has prevailed in the euro area. The measure of the natural rate we obtain for the euro area has been declining over the period 1994-2000 (between levels of around 3.7% to 3%), after remaining stable and high for about a decade.

Second, the paper relates the real interest rate gap, i.e. the fluctuations of the observed real interest rate around its natural cyclical path, to monetary policy rules. The gap, proposed as a possible measure of the monetary policy stance, is found to be negative between 1996 and mid-2000, although it has been consistently rising since late 1999, reaching positive values at the end of the sample.

Third, the response of macroeconomic variables to technology, preferences and monetary policy shocks seems to depend on central bank preferences, in particular on whether or not it smoothes interest rates. However, accounting for time-variations of the natural real rate in the policy reaction function seems to make little difference. Looking at the performance of a simple Taylor rule that takes into account the time variations in the natural real rate, it is found that accounting for the fluctuations of r^* over time only slightly improves the stability of the economy, mostly through

a better stabilisation of the output gap. At the same time, short-term inflation fluctuations are smoothened, but at the expense of more volatile nominal and therefore real rates.

Finally, we briefly look at the leading indicator properties of the real interest rate gap for inflation. Although a deeper statistical analysis would be warranted, our empirical measure of the real interest rate gap may contain information about future inflation.

1 Introduction

Measures of the monetary policy stance can be based on the spread between the actual real interest rate and what is thought of being its “natural”, “neutral”, or “equilibrium” level. Such measures are presented in the literature as valuable alternatives to standard indicators.

We believe that the “natural real rate” is a relevant issue for monetary policy. Central banks use their policy instrument, the short-term interest rate, to achieve inflation objectives. For this to be done more effectively, it is useful for the central bank to have an idea (i) of the underlying level of real interest rates that corresponds to a neutral monetary stance, and (ii) of the driving forces behind the fluctuations of this underlying level.

There is no such thing as a consensual concept of “natural” real interest rate. Therefore, we had to take a stance and chose a stochastic dynamic general equilibrium (SDGE) model where we assess three specifications of monetary policy rules: interest-rate smoothing, a simple Taylor rule and a Taylor rule including a time-varying measure of the natural real rate. In particular, this paper adds to the empirical literature by applying the model developed by Neiss and Nelson (2001) to the level of the natural short term real interest rate that has prevailed in the euro area. Moreover, the paper relates the real interest rate gap, i.e. the fluctuations of the observed real interest rate around its natural cyclical path, to monetary policy rules. We find that the natural real rate has been declining since the early 1990s, after remaining stable and high for about a decade. The implied real rate gap declined to negative values in 1998-1999, before rising again to positive values, thereby suggesting that the monetary policy stance has gradually tightened until the end of 2000. In addition, the response of macroeconomic variables to technology, preferences and monetary policy shocks seems to depend on central bank preferences, in particular on whether or not it smoothes interest rates. However, accounting for time-variations of the natural real rate in the policy reaction function seems to make little difference. This nothwithstanding, the Taylor rule that includes a time-varying natural rate is better able to stabilise the output gap at no expense for inflation variability, but at the expense of more volatile interest rates. Furthermore, we briefly look at the leading indicator properties of the real interest rate gap for inflation and find that our empirical measure of the real interst reate gap may contain information about future inflation. Finally, natural real rate measures based on alternative parameter estimates are discussed.

The paper is structured as follows. In section 2, natural real rates are discussed in the context of SDGE models. Section 3 introduces the model and the policy rule specifications. In section 4, we discuss the model linearisation and calibration. The paper then presents the dynamic responses of key variables to technology, preferences and monetary shocks, together with welfare considerations in section 5. Model-based historical series for the natural rate and natural rate gap are proposed in sections 6 (where the leading indicator proposerties of the real interest rate gap are also discussed) and 7 under our baseline and alternative calibrations. Section 8 concludes.

2 General equilibrium models and the natural real rate

SDGE models have various advantages for our purposes. First, the structural equations are derived from first optimization principles, hence the Lucas critique does not apply so fiercely as for traditional macroeconomic models. Our aim is to relate the natural real rate to deeper structural parameters and fundamental shocks to technology and preferences, while retaining a readable and tractable format. The SDGE framework allows for a full specification of the structure of shocks and provides theoretical underpinnings to the parameters that are being estimated/calibrated. In particular, the specification of the taste and technology parameters together with the shock processes determine in turn the reduced-form parameters and the shocks to the structural equations. Obviously, assumptions about the economic nature of shocks can lead to very different implications for the natural real rate.

In their reference paper, Rotemberg and Woodford (1997) propose a quantitative evaluation of monetary policy rules within a small structural econometric model based on intertemporal microeconomic optimisation. Their analysis starts with the estimation of a small recursive VAR model of interest rates, inflation and output with state vector $[r_t, \pi_{t+1}, y_{t+1}]$ in order to estimate the actual policy rule of the Federal Reserve and to evaluate the responses of the three variables to stochastic shocks to the monetary policy rule. The overall responsiveness of interest rates to inflation and output fluctuations is derived from long-run multipliers.[1] In the second step of their approach, a stochastic model is specified in order to account for the properties of output, inflation and the rate of interest obtained from the VAR analysis. The model features a staggered price adjustment "à la Calvo" (1983) and Dixit-Stiglitz (1977) household preferences. The parameter values are then set so as to replicate the estimated responses from the VAR. The canonical outcome of the micro-founded model resembles a standard macroeconomic model of aggregate supply and demand characterised by a forward-looking Phillips curve and a "new-Keynesian" IS curve. In a third step, the structural parameters of the model are calibrated/estimated so as to fit the model to the responses obtained in the VAR analysis. The stochastic processes for the three shocks are inferred and three corresponding time-series are constructed. The model parameters and the shock processes are then combined to simulate the path of output, inflation and the rate of interest under alternative assumptions for the policy rule. Finally, the welfare implications of alternative monetary policy rules are compared and the optimal rule that maximizes the utility of the representative agent is computed.

Our chosen measure of the natural real rate of interest in this context can be simply defined as the real interest rate level which would prevail in the economy, were nominal frictions absent from the framework. In other words, the natural real rate can not be empirically observed if we believe that the economy is subject to nominal fricitions in price and possibly wage setting. However, it is possible to infer, from the real interest rate that can be empirically observed, what

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[1] Their estimated values for quarterly US data over the sample period 1980:1 to 1995:2 are given by $r - r^* = 2.13(\pi - \pi^*) + 0.47y$, with values of $\pi^* = 3.26\%$ and $r^* = 6.25\%$, corresponding to a long-run average real rate of 3%.

real interest rates would have been in the absence of those frictions. This possibility can be seen as a first advantage of the framework. In order to do so, we need to explicitely model those nominal fricitions and reconstruct the mechanism by which real rates are affected by the economic shocks hitting the economy.

A second advantage of this framework is related to its ability to account for nominal rigidities that allow monetary policy to affect real variables. In that sense, understanding the structure that those nominal frictions impose on realised real rates is key to enhance our understanding of the transmission mechanism. Third, the frictionless real rate gives a judgment as to how changes in nominal rigidities may affect real rate developments. For example, Erceg, Henderson and Levin (2000) show that when both prices and wages are sticky, the “flexible-prices”, “flexible-wages”, and “fully-flexible” real rates all lead to different policy conclusions, as each indicator responds to shocks differently. Finally, microeconomic foundations provide a welfare criterion to judge the optimality of policy.

3 Baseline model and monetary policy rules

Our investigation of the euro area natural rate of interest is framed within the specification proposed by Neiss and Nelson (2001) where only prices are sticky. Households maximize a separable utility function defined over consumption, leisure and real balances, and they exhibit habit formation in their consumption decisions. Moreover, households may allocate their wealth between cash, riskless bonds or capital, which they may rent to firms. In addition, investment decisions are subject to capital adjustment costs. On the production side, firms produce a differentiated good in a monopolistically competitive environment. Price adjustment is staggered à la Calvo.[2]

The presence of shocks is limited to three in the model: a productivity (or technology) shock, a preference (or demand) shock and a monetary policy shock. A richer shock structure would

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[2] A full recollection of the model is proposed in the appendix.

assuredly allow for a more comprehensive analysis of the fundamental fluctuations of the kind we analyse in this paper. Smets and Wouters (2002), for example, have no less than 10 shock processes in their model. However, constructing an indicator of the natural real rate on the basis of technology and preferences shocks should provide a valid first approximation.

The model is closed with a simple monetary policy rule. Our goal is to state whether, in our theoretical context, accounting for the variations of the natural underlying real rate of interest makes a significant difference for the conduct of monetary policy. To that aim, we choose to compare three alternative specifications of a monetary policy rule of the form:

$$i_{t+1} = \alpha^{r^*} r_t^* + \kappa i_t + (1-\kappa)\left[\sum_{i=0}^{3} 0.25\alpha^{\pi}\pi_{t-i} + \alpha^{y}(y_t - \overline{y})\right] \tag{1}$$

Our baseline policy rule consists of (1) and includes a smoothing interest-rate argument with weight κ, and a reaction to a weighted average of inflation (over the past four quarters) and the output gap (defined as the ratio of real GDP to potential output), with respective coefficients α^{π} and α^{y}. We choose three variants of (1), as shown in Table 1.

	Baseline	Simple Taylor	Time-varying r^*
κ	0.76	0	0
α^{r^*}	0	0	1
α^{π}	1.71	1.5	1.5
α^{y}	0.21	0.5	0.5

Table 1: Parameters of the monetary policy rule

The baseline corresponds to the historical policy rule estimated by Smets and Wouters (2001). Our second specification corresponds to a simple Taylor rule with the most standard coefficient values of 1.5 for inflation and 0.5 for the output gap. Finally, we introduce our "time varying r^* rule". Under this specification, the central bank acknowledges that the natural real rate of interest may vary over time, and it fully reacts to those variations[3] . By reacting to contemporaneous fluctuations of the "natural" real rate, the central bank creates an additional contemporaneous and intertemporal link between the shocks that cause those fluctuations (in our case technology and preferences shocks) and the level of nominal interest rates.

4 Log-linearisation and calibration

The model is linearised around its steady state and solved under its state-space representation. The resulting system consists of 10 equations for 10 endogenous variables: output (y_t), capital (k_t), consumption (c_t), quasi-investment (x_t), the nominal interest rate (R_t), the real interest rate (r_t), the marginal utility of consumption (ψ_t), labour (n_t), the mark-up (μ_t) and inflation (π_t).[4]

The model is calibrated on the basis of euro area estimates obtained by Smets and Wouters (2001), based on quarterly euro area aggregate series provided by Fagan et. al (2001). Table 2 summarises the parameter values we use.[5] The discount factor β is set at 0.99, which corresponds to an annual steady state interest rate of 4%. Further sensitivity analysis shows that our natural rate and interest rate gap series are robust to alternative values of β. The preference parameters (curvature of the utility function, habit formation) have been set in line with the values estimated by Smets and Wouters (2001). While the curvature parameter is in line with Neiss and Nelson, a

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[3] Note that they all correspond to an inflation objective π^* normalised to 0.

[4] The log-linearised system is shown in the Appendix.

[5] Basic statistical properties of the resulting model-based and their comparison with empirical ones are available from the authors upon request.

habit formation coefficient of 0.68 is slightly lower than theirs, still remaining in plausible ranges. The elasticity of money demand has been normalised to one. The steady state fraction of time in employment is set to 1/3, in line with the 8-hours working day. The rate of capital depreciation is equal to 0.025, corresponding to an annual depreciation of 10%. The labour share of total output is set to the value found for the euro area in the estimated production function underlying the AWM dataset. The steady state mark-up has been set to 1.2, as sensitivity analysis shows that results are robust to a wide range of mark-up values. The degree of price rigidity is in line with that of Neiss and Nelson.

Finally, the baseline parameter values related to shocks (persistence and variance of technology, preference and monetary policy shocks) are in line with the initial estimates of Smets and Wouters (2001). Those values imply less persistence of the technology shock and more persistence of the preference shock, and also lower variances than Neiss and Nelson's calibration. It is difficult to say whether this is due to differences in the estimation approaches or to structural differences between the euro area and the UK economies. However, sensitivity analysis shows that those parameters are critical to the resulting historical natural rate series, so calibrations based on alternative sets of estimated parameters for the euro area are reported in section 7.

Variable	**Parameter**	**Quarterly Value (euro area)**
Discount factor	β	0.99
Curvature of the utility function	σ	0.63
Habit formation	h	0.68
Elasticity of money demand (scaled)	$1/\sigma\varepsilon$	1
Labour share	α	0.586105
Steady-state fraction of time in employment	N^{SS}	0.33
Capital depreciation rate	δ	0.025
Capital adjustment cost	ϕ	0.125
	η	2
Steady-state mark-up (gross)	μ, $1/\rho$	1.2
Degree of price rigidity	α_{μ}	0.012
Persistence of technology shock	ρ_a	0.88
Variance of technology shock	$Var\left(e_a\right)$	0.177
Persistence of preferences shock	ρ_{λ}	0.69
Variance of preferences shock	$Var\left(e_{\lambda}\right)$	0.103
Variance of the monetary policy shock	$Var(\varepsilon_R)$	0.023

Table 2: Calibration

The parameter values shown in Table 2 caracterise an economy where price rigidities operate. We compute its flexible price counterpart by setting α_μ at a very high value ($\alpha_\mu = 10000$). The natural real rate is the rate that would prevail in such an economy. Obviously, the monetary policy rule (which corresponds to the linearised equation L.10 in the appendix) becomes redundant when prices are perfectly flexible. In addition, the natural real rate obtained on the basis of the linearised system corresponds to fluctuations around the steady state and will therefore be centered around zero. An empirical estimate of these deviations of the natural rate will be shown in section 6.

5 Theoretical responses to shocks and welfare analysis

The advantage of our standard micro-founded model is its ability to tell how different the implications of distinct sources of shocks can be for macroeconomic variables and therefore monetary policy. The model-based reactions of inflation, output, the nominal interest rate, consumption, the real interest rate and r^* to three alternative shocks are shown in the appendix. Each of those responses are now described in turn.

1% technology shock: Under the interest rate smoothing rule, the response of inflation to a positive technology shock is muted and inflation falls by about half as much as under non-smoothing specifications. However, at the same time, output is more responsive to such shocks when the central bank smoothes interest rates, ans so is consumption, although the asymmetry is less pronounced. As could be expected, the nominal interest rate reacts much more smoothly and gradually under our baseline specification, with an impact of approximately -0.01 percentage points for the smoothing specification against an impact of about -0.04 percentage points under the two Taylor specifications. Finally, by construction, the responses of the natural real rate are the same under all specifications, while that of the realised real rate is tuned-down, smoother and slower to return to steady state under our baseline specification.

1% shock to preferences: Unlike after a technology shock, the response of inflation to a shock to preferences is stronger under the interest-rate smoothing rule. So is the response of output to such a shock. Notice that the signs of the responses of output and inflation to technology and preference shocks are economically intuitive: while a positive technology shock may be seen as a favorable supply shock, a positive shock to preferences corresponds to an (inflationary) adverse demand shock. Note as well that the response of inflation outweights that of nominal rates under the smoothing rule, so that the impact on the realised real interest rate is negative. On the contrary, the non-smoothing rules are better able to control inflation in the short run; in addition, by definition, non-smoothing rules allow for a reaction of the nominal rate that is sufficient to keep real interest rates positive, even in the short run. However, from a longer term point of view, inflation goes back to equilibrium much faster under the smoothing rule.

1% monetary policy shock: Finally, a monetary policy shock has a very similar impact on all variables under all policy rules (the effect on output is only slightly more negative under the smoothing rule). However, all variables are much faster to adjust under non-smoothing rules. Note that by construction, the monetary policy shock has no effect on the natural real interest rate.

Overall, the plots of the responses under the simple Taylor and the "r^*-varying" specifications are very close to each other. However, although the dynamic responses imply relatively little gain from taking time variations in r^* into account in the Taylor rule, the predicted variances under each rule, as reported in Table 3, show that there are stability gains to explicitely reacting to variations in the natural level of real rates.

STANDARD DEVIATIONS
UNDER ALTERNATIVE POLICY RULES

Rule	*Cons.*	*Output*	*Real rate*	*Nom. rate*	*Inf. (Q)*	*Pot. out.*	*r**	*Inf. (A)*	*Out. gap*	*LOSS*
Standard Taylor rule	0.797	2.364	0.698	0.711	0.082	1.463	0.034	0.052	2.63	6.92
Taylor rule with time-varying natural real rate	0.78	2.377	0.706	0.718	0.081	0.447	0.034	0.052	2.284	5.22

Table 3: Volatility under a simple Taylor rule *vs* r^*-varying Taylor rule

While the volatility of output only marginally increases, that of potential output and the output gap decreases substantially. In addition, inflation becomes slightly more stable. However, the nominal and real interest rates become more volatile. This increased volatility of nominal rates in turn feeds through into a higher volatility of the realised real rate against a background of more stable inflation. To give one possible welfare assessment of each policy rule, we provide in the last column of Table 3 a value for the loss incurred if the central bank's objective were to minimize the weighted sum of the variance of the output gap and annual inflation[6] :

$$L = Var(\pi) + Var(y - \overline{y})$$

These comparisons show that the stability and welfare gains from reacting to variations in the natural real rate are minor. However, even marginally, simple monetary policy rules that take into account variations of the "natural" real interest rate are better able to stabilise the quarterly profile of both the output gap and inflation, at the expense of slightly more volatile interest rates.

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[6] An obvious alternative would be to use the household utility function as a measure of welfare.

6 Model-based historical $\mathbf{r}_t^*$ series

In this section, we provide a model-based evaluation of the natural short-term real rate that has prevailed in the euro area since 1973. In the model, the natural rate can be expressed as a function of shocks to technology and preferences. Although we do not have a closed-form expression for this variable, we approximate the corresponding series (that is the real interest rate series which obtains in the absence of nominal rigidities) by a linear combination of technology and preference shocks. This corresponds to estimating the following linear regression:

$$r_t^* = \sum_{i=0}^{n} b_i^{\lambda} \lambda_{t-i} + d_i^{\lambda} a_{t-1} \tag{2}$$

The procedure to compute model-based historical series for the natural rate of interest can be summarised in six steps.

Step 1: Take the series $\{r_t^*\}, \{\lambda_t\}$, and $\{a_t\}$ generated by the calibrated model.

Step 2: Compute OLS estimates of the parameters b_i^{λ} and d_i^{λ} in (2).

Step 3: Store the resulting estimates $\widehat{b_i^{\lambda}}$ and $\widehat{d_i^{\lambda}}$.

Step 4: Replicate steps 1 to 3 (in our case: 200 times).

Step 5: Compute averages of the parameters.

Step 6: Using the averages of step 5, counterfactual series of r^* are computed as linear combinations of technology and preference shocks recovered on the basis of standard quarterly euro area series constructed for the Area-Wide Model of Fagan et al. (2001).[7]

The technology shock is constructed using the Solow residual obtained from the production function:[8]

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[7] Since we do not rely on an "independent" empirical measure of the natural real rate, the statistical properties of our model based natural rate series can not be compared to any empirical ones. However, model-based cross-correlations of r^* with other variables and their lags, obtained from 1000 simulations, are shown in the appendix.

[8] Linearised equation L3 in the appendix.

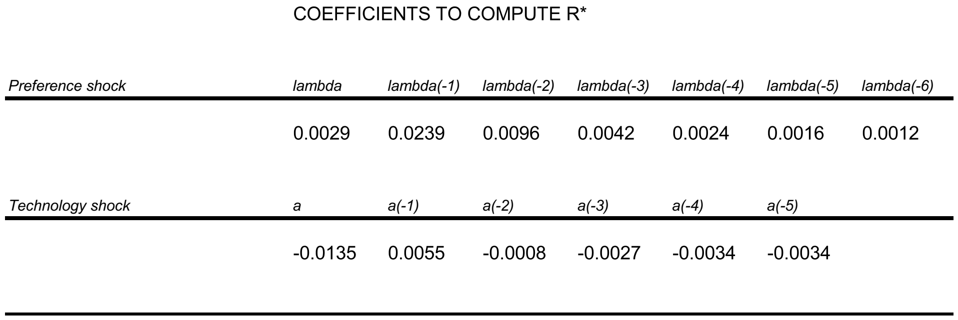
$$a_t = y_t - (1-\alpha) - k_t - \alpha n_t \tag{3}$$

where the labour share of total output (α) is set to be 0.586 for the euro area. The series involved in (3) are euro area output, capital and employment (all in logarithms). The empirical demand shock is derived combining the law of motion for consumption and the Fischer equation (respectively L8 and L9 in the appendix). We obtain:

$$\lambda_t = \frac{\begin{pmatrix} -\beta\left(h-\sigma h\right) E_t \Delta c_{t+2} + \left(1+\beta h^2 - \sigma\beta h^2 - \sigma\beta h\right) E_t \Delta c_{t+1} \\ +\sigma\left(1-\beta h\right) E_t \Delta p_{t+1} - \left(h-\sigma h\right)\Delta c_t - \sigma\left(1-\beta h\right) R_t \end{pmatrix}}{\sigma\left(1-\rho_\lambda+\beta h\rho_\lambda^2-\beta h\rho_\lambda\right)} \tag{4}$$

All parameters in (4) are calibrated according to the values shown in Table 2. Inflation is computed as the first difference in the logarithm of quarterly CPI. The short-term interest rate is the quarterly 3-month money market rate, annualised. Δc_t is defined as the first difference of log-quarterly consumption. As a simplification, expected future consumption is proxied by realised consumption.

From this procedure, we see that the series is *model based* to the extent that the parameter estimates $\widehat{b_i^\lambda}$ and $\widehat{d_i^\lambda}$ are obtained from the properties of the series generated by the model, while counterfactual series of r_t^* are *historical* to the extent that they are obtained by applying those model-based estimates to shock series obtained from actual euro area data.



COEFFICIENTS TO COMPUTE R*

Preference shock	*lambda*	*lambda(-1)*	*lambda(-2)*	*lambda(-3)*	*lambda(-4)*	*lambda(-5)*	*lambda(-6)*
	0.0029	0.0239	0.0096	0.0042	0.0024	0.0016	0.0012
Technology shock	*a*	*a(-1)*	*a(-2)*	*a(-3)*	*a(-4)*	*a(-5)*	
	-0.0135	0.0055	-0.0008	-0.0027	-0.0034	-0.0034	

Table 4: Coefficients for the construction of r^*

The coefficients of the linear approximation (2) are shown in Table 4.[9] We use those coefficients to construct the empirical counterpart to r_t^* obtained in the model. The resulting natural real rate series (2) corresponds to absolute deviations of r_t^* around the steady state. Those deviations are shown in Figure 1 below.

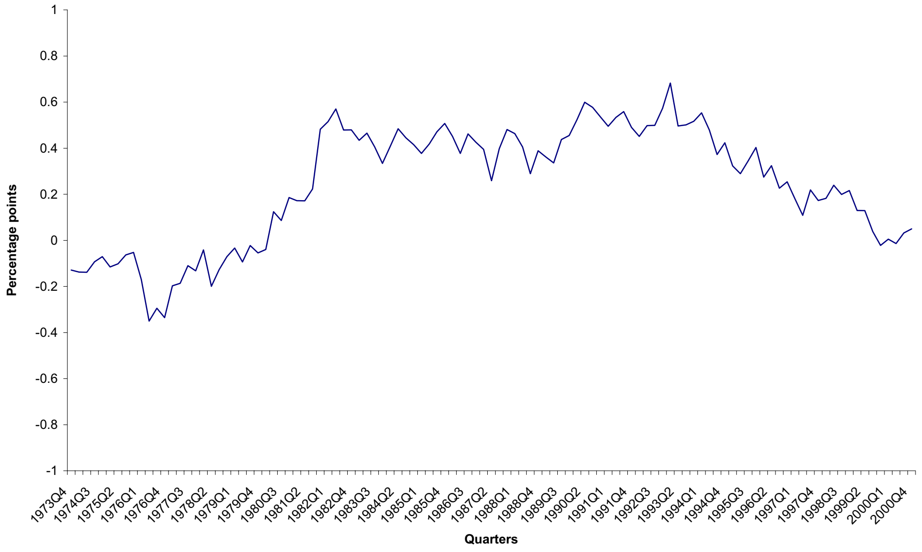


Figure 1: Fluctuations of the natural real rate around the steady state until 2000

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[9] Coefficients on further lags are negligible.

Overall, the series shows that the natural real rate has consistently declined since the mid-1990s, after a decade at relatively high levels. An indicator of the real interest rate gap can easily be generated as the difference between the realised short-term real interest rate, as measured by the three-month money market rate minus the annualised quartery HICP inflation, and the fluctuations shown in Figure 1 rescaled around the empirical average of the realised real interest rate over the period considered, 2.52%. This measure is shown in Figure 2 below, starting in 1973 and ending in 2000.

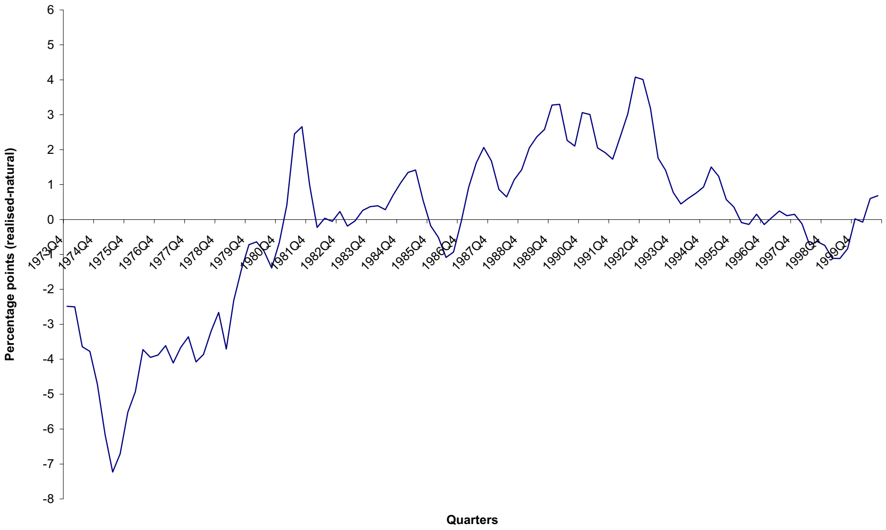

Figure 2: Real interest rate gap until 2000

According to this measure, the real interest rate gap has been generally declining between 1993 and mid-1999, turning negative in 1996. Quite remarkably, the gap has remained reasonably narrow in the later period of the sample. One possible interpretation is that EU central banks may have decided, in the second half of the 1990s, to steer real rates down because inflation was approaching price stability. In turn, lower realised real rates turned out to be closer to the natural level as defined in our model. In addition, inflation has become lower and less volatile over the past decade, thereby contributing to mute the observed swings in short-term real rates. In the years preceding 1998, the gap has remained fairly small, and negative values suggest that real rates may have remained below their natural level. In 1999-2000, the trend has been reversed and the interest rate gap has become positive, which may suggest a tightening in the monetary policy stance, although this needs to be interpreted with due caution.

Following Neiss and Nelson, we may ask whether the real interest rate gap shown in Figure 2 is a valuable leading indicator for inflation in the euro area. Simple partial correlation between inflation and real interest rate gaps up to 8 lags suggests that the lagged interest rate gap is negatively correlated with actual inflation, as shown in Table 5 below.

	$k=0$	$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=6$	$k=7$	$k=8$
$Corr(\pi_t, r_{t-k} - r^*_{t-k})$	-0.50	-0.50	-0.49	-0.49	-0.50	-0.52	-0.54	-0.56	-0.58

Table 5: Correlation between model-based real interest rate gaps at lag k and inflation

The negative partial correlation is of the same order as that found by Neiss and Nelson, consistently negative and increasing at longer lags. The leading indicator properties of the interest rate gap could be investigated further by regressing the inflation rate on past inflation and the lagged interest rate gap. Estimating an equation of the form:

$$\pi_t = a_1 + a_2 \pi_{t-1} + a_3 \left(r_{t-1} - r^*_{t-1} \right) + \varepsilon_t$$

on our 1974:1-2000:4 sample suggest that a_3 is positive but statistically not significant.[10]

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[10] $a_1 = 2.31E-05$ (0.001); $a_2 = 0.99$ (0.017); $a_3 = 0.014$ (0.024) and $Adj.R^2 = 0.98$ (standard errors in brackets)

However, omitting lagged inflation in the set of regressors yields significant estimates with values (standard errors in brackets):

$$\begin{aligned} \pi_t &= \underset{(0.003)}{0.051} - \underset{(0.118)}{0.71} \left(r_{t-1} - r^*_{t-1}\right) + \varepsilon_t & \qquad Adj.R^2 = 0.25 \end{aligned}$$

suggesting that the real interest rate gap may contain valuable information about future inflation. However, poor performance of this regression in terms of residual misspecification tests, in particular autocorrelation and to a lesser extent heteroschedasticity, suggests that a deeper analysis should be carried out. As a result, we would not conclude from such an equation and on the basis of quarterly aggregated series that the real interest rate should be taken as a leading indicator for inflation.[11]

7 Model-based historical series under alternative calibrations

As mentioned in section 4, the underlying processes governing the shocks critically matter for the properties of the natural rate of interest. In particular, Smets and Wouters (2002) propose a much richer measure of the natural real rate, which is rather different from the one obtained in our benchmark calibration. There are two possible reasons why our series may differ. The first and most obvious one is that since it is determined by a full set of structural shocks, the natural real rate in Smets and Wouters (2002) is also much more volatile. Second, the differences may come from the parameter values that we use. To put those differences in perspective, we confront our baseline model with two alternative calibrations. The first is defined as the relevant subset of

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[11] Further investigation of the issue on the basis of monthly series could be of interest and is left for further research.

parameter values estimated by Smets and Wouters (2002). The second is based on the euro area estimates obtained by Andrés, López-Salido and Vallés (2002).

Compared to our baseline, the estimates provided by Smets and Wouters (2002) exhibit a lower habit formation, larger labour share, slightly higher capital adjustment costs and a slightly lower degree of price rigidity. More pronounced differences come from the persistence and volatility of technology, preferences and monetary policy shocks. In Smets and Wouters (2002), preference shocks are a lot more persistent (0.905 versus 0.69) and less volatile; technology shocks are less persistent but significantly more volatile (0.347 versus 0.103); monetary policy shocks remain i.i.d. with less volatility. The estimates provided by Andrés, López-Salido and Vallés (2002), when compared to our baseline, imply a slightly lower discount factor, a higher curvature of the utility function, and stronger habit formation. Both preference and technology shocks are significantly more persistent, and all shocks have a significantly lower variance. The natural rate and real rate gap series obtained under each calibration are shown in Figures 3 and 4 below.

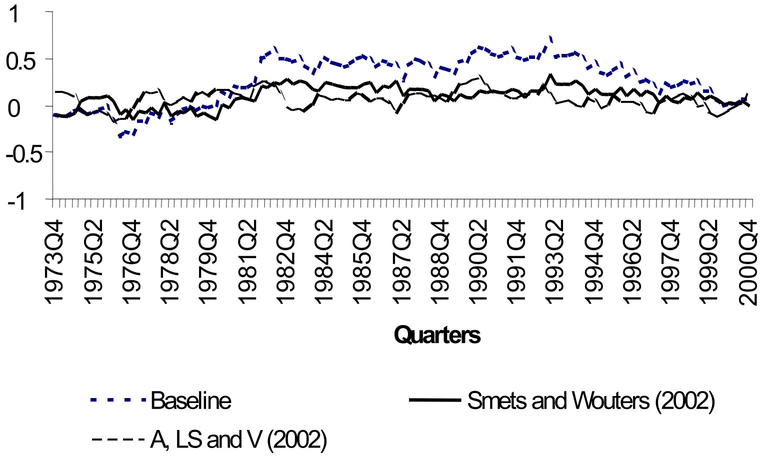

Figure 3: Natural real interest rate under alternative calibrations

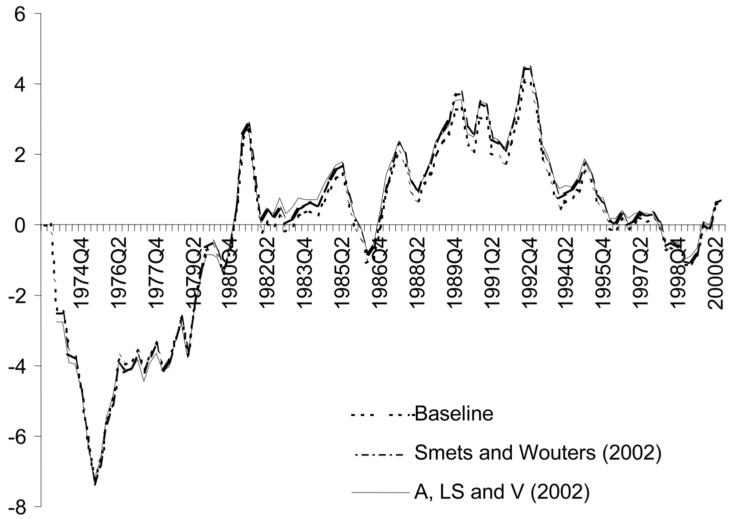

Figure 4: Real interest rate gap under alternative calibrations

Overall, the characteristics of shocks seem to be the key driving forces behind the different natural real rate estimates, as can be seen in Figure 3. The series obtained with the estimates of Smets and Wouters (2002) and Andrés, López-Salido and Vallés (2002) are significantly less volatile than our baseline. This suggests that the higher persistence of shocks (in particular those to preferences) has a smoothing effect on the natural rate, even when, as in the calibration based on Smets and Wouters (2002), technology shocks are more volatile. Finally, the comparison of the resulting gap measures as shown in Figure 4 suggests that if anything, alternative calibrations yield an only marginally wider real rate gap than in our benchmark.

8 Conclusion

In this paper, we have investigated the empirical properties of the natural real short-term interest rate in the euro area using a standard SDGE with price stickiness developed by Neiss and Nelson (2001). The measure of the natural rate we obtain for the euro area has been declining over the period 1994-2000 (between levels of around 3.7% to 3%). The resulting real interest rate gap, proposed as a possible measure of the monetary policy stance, is found to be negative between 1996 and mid-2000, although it has been consistently rising since late 1999, reaching positive values at the end of the sample.

We have also investigated the performance of a simple Taylor rule that takes into account the time variations in the natural real rate. It is found that accounting for those fluctuations of r^* over time only slightly imporves the stability of the economy, mostly through a better stabilisation of the output gap. At the same time, short-term inflation fluctuations are smoothened, but at the expense of more volatile nominal and therefore real rates.

Finally, we test whether the real interest rate gap might be a leading indicator for inflation in the euro area for the period under review. Even if a negative correlation between inflation rate and lagged values of interest rate gaps have been found, a clear role for the interest rate gap as a leading indicator for inflation must be investigated further.

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Appendix 1: Model specification

In this appendix, we present the model developed by Neiss and Nelson (2001) that underlies our analysis of the natural real rate of interest in the euro area.

A.1.1 The Household sector

The economy is populated by an infinite number of households who maximise an intertemporal utility function defined on a composite good (C_t), leisure (L_t) and real money balances $\left(\frac{M_t}{P_t}\right)$

$$E_t\sum_{j=0}^{\infty}\beta^j\left[\lambda_t\frac{\sigma}{\sigma-1}\left(\frac{C_{t+j}}{C^h_{t+j+1}}\right)^{\frac{\sigma-1}{\sigma}}+bL_{t+j}+\frac{\gamma}{1-\varepsilon}\left(\frac{M_{t+j}}{P_{t+j}}\right)^{1-\varepsilon}\right] \tag{5}$$

Consumers are subject to habit formation, represented in the model by the parameter h being non time separable over consumption. σ is the coefficient of relative risk aversion (also the inverse of the intertemporal elasticity of substitution), ε is the inverse of the elastcity of money holdings with respect to the interest rate and γ determines the steady-state consumption/money ratio. λ_t is a shock to household preferences and can be considered a demand shock. We asssume that λ_t follows an AR(1) process.

The representative household maximises (5) by choosing the optimal paths for consumption (C), leisure (L), nominal money (M) , the quantity of riskless bonds B and capital K, subject to the following budget constraint

$$\begin{aligned} C_{t+j}+\frac{M_{t+j}}{P_{t+j}}+\frac{B_{t+j+1}}{P_{t+j}}+X_{t+j} &= w_{t+j}N_{t+j}+z_{t+j}K_{t+j}+R^G_{t+j-1}\frac{B_{t+j}}{P_{t+j}}+ \\ &\quad +\frac{M_{t+j-1}}{P_{t+j}}+\frac{\tau_{t+1}}{P_{t+j}}-\phi X^{\eta}_{t+j} \end{aligned} \tag{6}$$

where w_t and z_t represent the respective "prices" of labour and capital, τ_t government transfers and X_t the fraction of wealth devoted to capital investments, i.e.

$$X_{t+j} = K_{t+j+1} - (1-\delta)K_{t+j} \tag{7}$$

The last term of the budget constraint (ϕX_{t+j}^{η}) measures the size of the capital adjustment costs, determined by the two parameters ϕ and η.

We assume that the endowment of time, normalised to one, is divided between labour and leisure.

$$N_t + L_t = 1 \tag{8}$$

The composite consumption good C_t and its price P_t are determined on the basis of the aggregation of differentiated goods

$$C_t = \left[\int_0^1 C_t(i)^{\rho} di \right]^{\frac{1}{\rho}} \tag{9}$$

$$P_t = \left[\int p_t(i)^{\frac{\rho}{1-\rho}} di \right]^{\frac{1-\rho}{\rho}} \tag{10}$$

where ρ determines the degree of substitutability among the different consumption goods (when $\rho \to 1$, the goods are perfect substitutes). $\frac{1}{\rho}$ represents the gross steady state mark-up.

The households' first order conditions are:

$$\begin{cases} C_t: & \lambda_t \left(\frac{C_t}{C_{t-1}^h}\right)^{\frac{\sigma-1}{\sigma}} \frac{1}{C_t} - \beta h E_t \lambda_{t+1} \left(\frac{C_{t+1}}{C_t^h}\right)^{\frac{\sigma-1}{\sigma}} \frac{1}{C_t} = \psi_t \\ L_t: & b = w_t \psi_t \\ M_t: & \gamma \left(\frac{M_t}{P_t}\right)^{-\varepsilon} = \psi_t - \beta E_t \frac{\psi_{r+1}}{P_{t+1}/P_t} \\ B_{t+1}: & 0 = \psi_t - R^G E_t \frac{\beta \psi_{t+1}}{P_{t+1}/P_t} \\ K_{t+1}: & 0 = \psi_t \left(1 + \phi \eta X_t^{\eta+1}\right) - \beta E_t \psi_{t+1} \left[(1-\delta)\left(1 + \phi \eta X_{t+1}^{\eta+1}\right) + z_{t+1}\right] \\ \psi_t: & C_t + \frac{M_t}{P_t} + \frac{B_{t+1}}{P_t} + X_t = w_t N_t + z_t K_t + R_{t-1}^G \frac{B_t}{P_t} + \frac{M_{t-1}}{P_t} - \frac{\tau_t}{P_t} - \phi X_t^{\eta} \end{cases}$$

where ψ_t is the Lagrange multiplier on the budget constraint.

A.1.2 The production sector

The production sector is characterised by a continuum of firms which compete monopolistically. Each firm j maximises its profit function

$$p_{jt}\frac{Y_{jt}}{P_t} - w_t N_{jt} - z_t K_{jt} \tag{11}$$

under demand and technology constraints. The demand function for the firm j product is given by

$$\frac{p_{jt}}{P_t} = \left(\frac{Y_{jt}}{Y_t}\right)^{-(1-\rho)} \tag{12}$$

The production function is Cobb-Douglas with constant returns to scale:

$$Y_{jt} = A_t N_{jt}^{\alpha} K_{jt}^{1-\alpha} \tag{13}$$

A_t represents an AR(1) technology shock. The firm's first-order condition is

$$K_t: \qquad (1-\alpha)\frac{Y_t}{K_t} = \mu_t^G z_t$$

A.1.3 Price Setting

Following Calvo (1983), all firms cannot reoptimize their prices every period, and only a fraction of them can change prices at each t. In aggregate this condition implies that prices are sticky. As a result, inflation evolves according to the so-called New-Keynesian Phillips curve:

$$\beta E_t \pi_{t+1} = \pi_t + \alpha_\mu \mu_t \tag{14}$$

where π_t is the inflation rate, μ_t is the gross-mark-up (equal to $\frac{1}{\rho}$ at steady-state), and α_μ the index of price rigidity (i.e. prices are fully flexible for $\alpha_\mu \rightarrow 1$).

A.1.4 Market Equilibrium

The final goods market equilibrium condition is given by

$$Y_t = C_t + X_t + \phi X_t^\eta \tag{15}$$

A.1.5. Log-linearisation

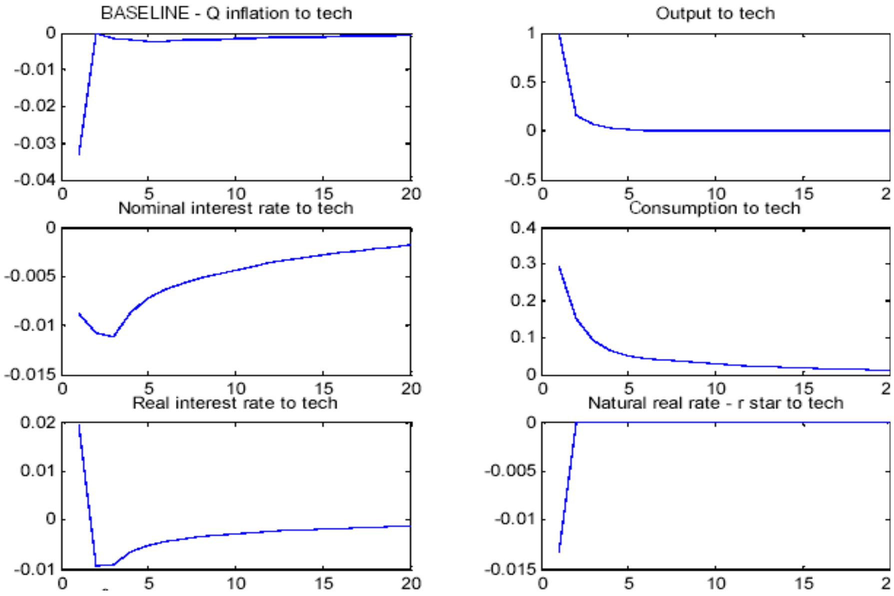
The system is log-linearised around its teady state as follows:

	Log-linearised equations	
L.1.	$0=-X^{SS}+\phi\eta\left(X^{SS}\right)^{\eta}x_t-C^{SS}c_t+Y^{SS}y_t$	Resource constraint
L.2.	$\frac{1}{\delta}k_{t+1}=x_t+\frac{1-\delta}{\delta}k_t$	Capital law of motion
L.3.	$0=y_t-\alpha n_t-(1-\alpha)k_t-a_t$	Production function
L.4.	$0=y_t-n_t+\psi_t-\mu_t$	Labour market equilibrium
L.5.	$\beta E_t\pi_{t+1}=\pi_t+\alpha_\mu\mu_t$	Price-setting
L.6.	$(1-\delta)(\eta-1)\phi\eta\left(X^{SS}\right)^{\eta-1}E_tx_{t+1}$ $+(1-\alpha)\rho\frac{Y^{SS}}{K^{SS}}E_ty_{t+1}-(1-\alpha)\rho\frac{Y^{SS}}{K^{SS}}E_tk_{t+1}$ $-(1-\alpha)\rho\frac{Y^{SS}}{K^{SS}}E_t\mu_{t+1}=(\eta-1)\phi\eta\left(X^{SS}\right)^{\eta-1}x_t+r_t$	Quasi-investment law of motion
L.7.	$E_t\psi_{t+1}=\psi_t-r_t$	Euler equation
L.8.	$\frac{\beta h(\sigma-1)}{\sigma(1-\beta h)}E_tc_{t+1}=\frac{\beta h^2\sigma-\beta h^2+h\sigma-1}{\sigma(1-\beta h)}c_t$ $-\psi_t-\frac{h(\sigma-1)}{\sigma(1-\beta h)}c_{t+1}+\frac{1-\beta h\rho_\lambda}{1-\beta h}\lambda_t$	Consumption law of motion
L.9.	$E_t\pi_{t+1}=-r_t+R_t$	Fisher equation
L.10.	$0=-R_t+\rho_RR_{t+1}+(1-\rho_R)\rho_yy_t$ $+\sum 0.25(1-\rho_R)\rho_\pi\pi_{t-i}+e_{R_t}$	Monetary Policy Rule

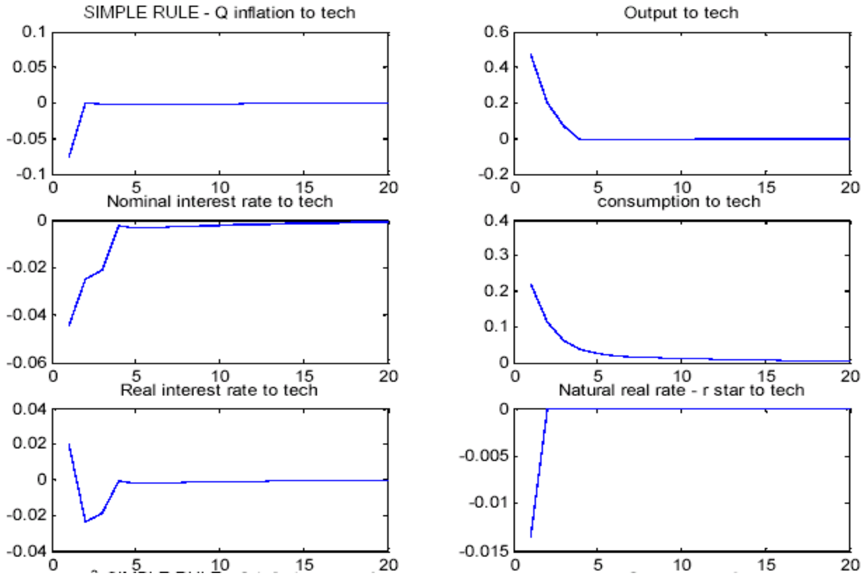
Appendix 2: Impulse response functions of inflation, output, the nominal interest rate, consumption, the real interest rate and r^* to shocks

In each figure, panel (a) corresponds to the baseline policy rule while panel (b) and (c) display responses under the simple Taylor rule and the time-varying r^* rule.

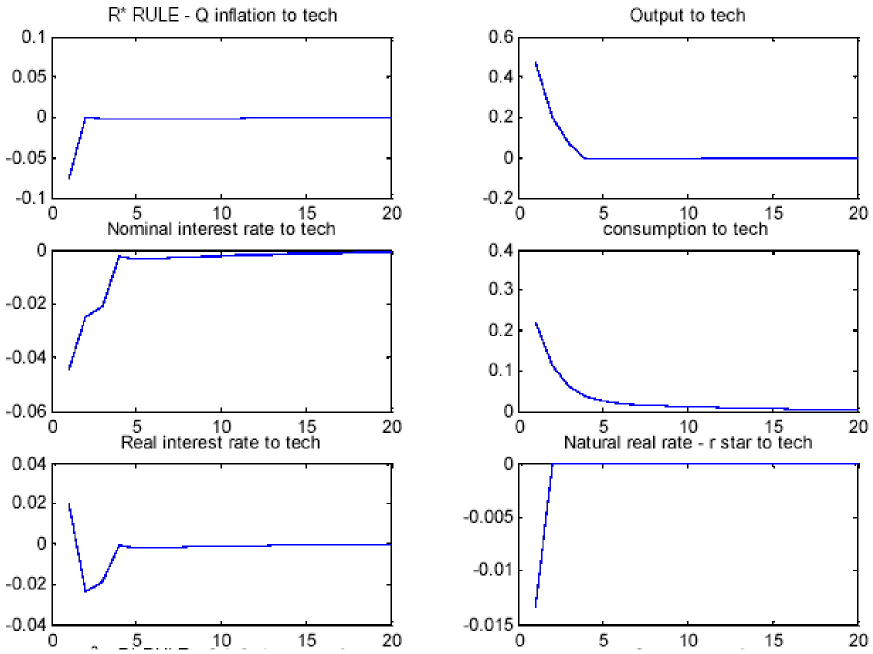
Figure A.1: Responses to technology shock



(a) Baseline

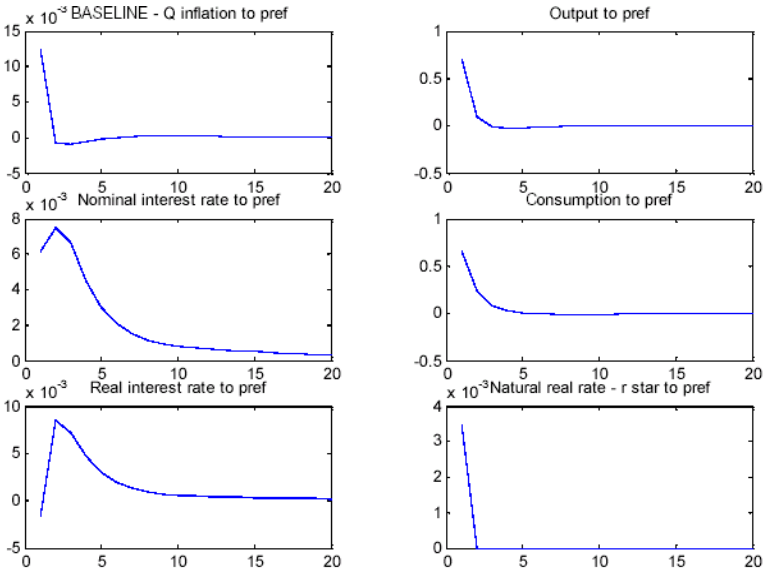


(b) Simple rule

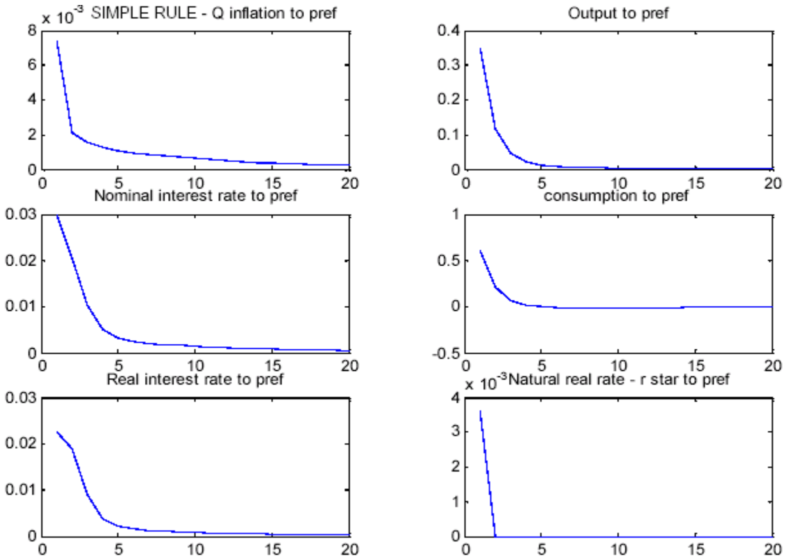


(c) Taylor rule with time varying r^*

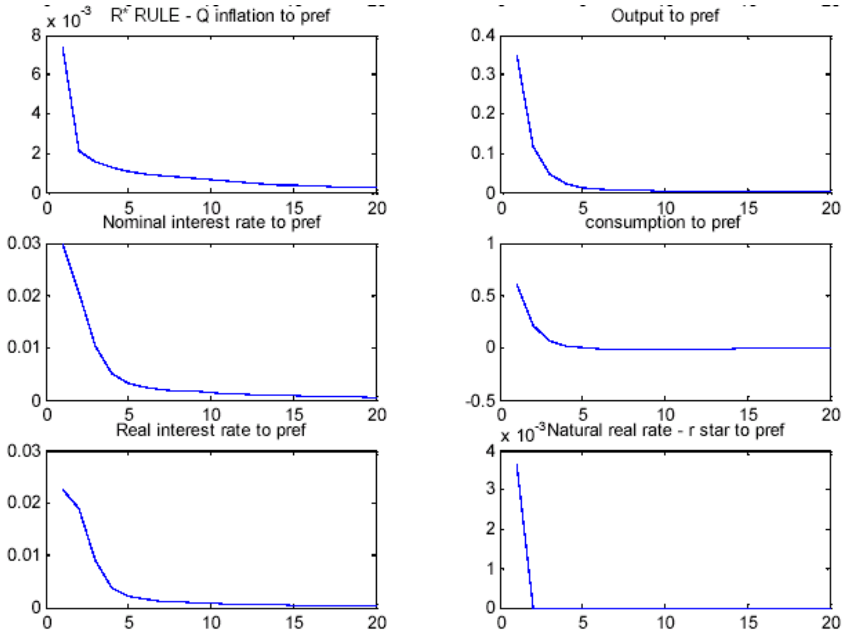
Figure A.2: Responses to preferences shock



(a) Baseline

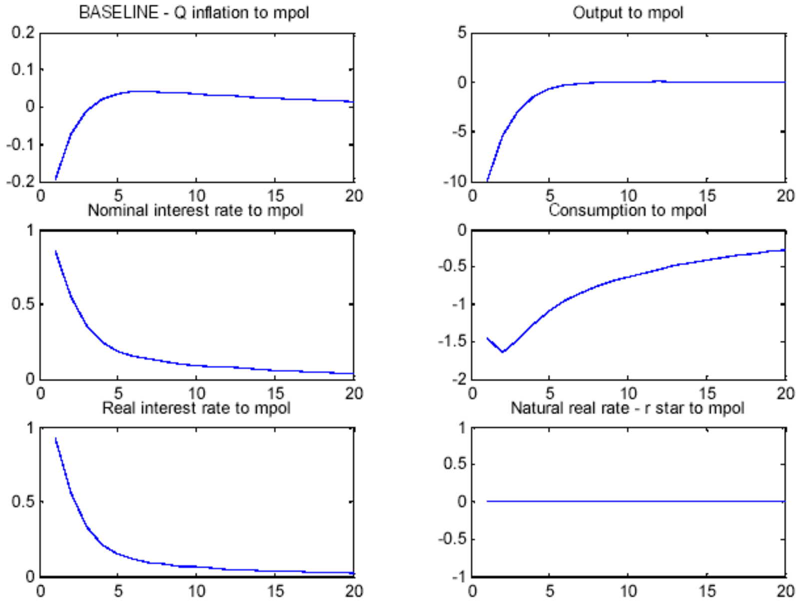


(b) Simple rule

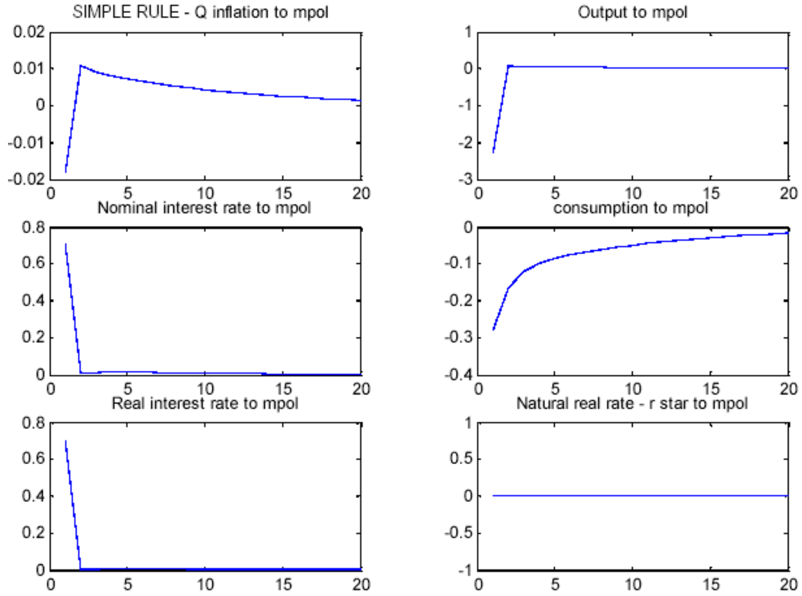


(c) Taylor rule with time varying r^*

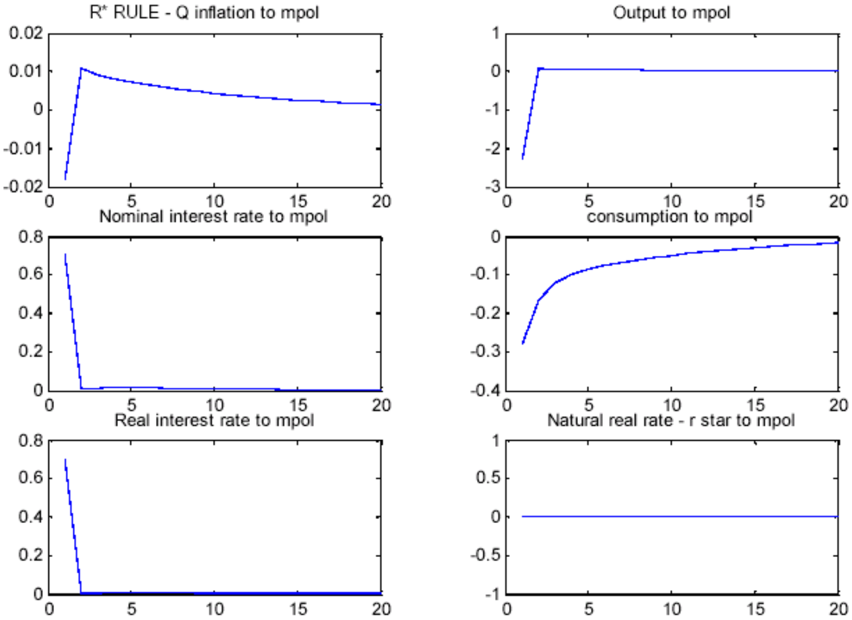
Figure A.3: Responses to monetary policy shock



(a) Baseline



(b) Simple rule



(c) Taylor rule with time varying r^*

Appendix 3: Model-based cross correlations of the main variables

CROSS-CORRELATIONS
MODEL-BASED (EMPIRICAL IN ITALICS WHEN AVAILABLE)

	Cons.	*Output*	*Real rate*	*Nominal rate*	*Inf. (Q)*	*Potential out.*	*r**	*Inf. (A)*
Cons.	1	0.681	-0.789	-0.845	0.176	0.168	-0.038	0.246
Output	0.681	1 *1*	-0.961 *0.177*	-0.927 *0.228*	0.830 *0.142*	0.205	-0.072	0.557
Real rate	-0.789	-0.961 *0.177*	1 *1.000*	0.993 *0.260*	-0.691 *-0.520*	-0.020	0.008	-0.481
Nominal rate	-0.845	-0.927 *0.228*	0.993 *0.260*	1 *1.000*	-0.602 *0.637*	-0.003	0.002	-0.434
Inf. (Q)	0.176	0.830 *0.142*	-0.691 *-0.520*	-0.602 *0.637*	1 *1.000*	0.132	-0.044	0.614
Potential out.	0.168	0.205	-0.020	-0.003	0.132	1	-0.352	0.048
*r**	-0.038	-0.072	0.008	0.002	-0.044	-0.352	1	-0.016
Inf. (A)	0.246	0.557	-0.481	-0.434	0.614	0.048	-0.016	1

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