

This version: July 31, 2003  
First version: November 29, 2002  
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# **Should Central Banks React to Exchange Rate Movements?**

## **An Analysis of the Robustness of Simple Policy Rules under Exchange Rate Uncertainty**

Paper prepared for the  
2<sup>nd</sup> Workshop on Macroeconomic Policy Research, Budapest, October 2-3, 2003

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### **Abstract**

This paper evaluates the performance of simple policy rules in an open economy model. By introducing a high degree of exchange rate uncertainty we find that policy rules with an important feedback from movements in the real exchange rate are very robust to uncertainty about the true exchange rate model. A closed economy rule performs badly in most exchange rate specifications. This is in sharp contrast to the findings of many other studies according to which reacting to the exchange rate only slightly improves (if at all) the macroeconomic performance. In our view, this result is due to the fact that most of these studies assume a known and reliable relationship between the exchange rate and the interest rate and therefore neglect the poor empirical evidence on models of exchange rate behaviour in the short and medium run.

**Keywords:** Exchange rate uncertainty; Robustness; Simple policy rules

**JEL classification:** E52, E58, F41

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## 1 Introduction

In recent years there has been a considerable progress in the field of monetary policy analysis. A growing academic literature explores simple policy rules expressed in terms of interest rate instruments as guides for monetary policy under a strategy of flexible inflation targeting. Since most inflation targeting countries today are small open economies the role of the exchange rate for the conduct of monetary policy is a central issue. In particular, the question whether the exchange rate (in whatsoever form) should enter the policy rule or not is still a matter of debate in the literature. Thus, the evaluation of so-called open economy policy rules has become an important extension to the closed economy analysis of interest rate rules.

Empirically, the tendency of central banks to indirectly influence the exchange rate by interest rate adjustments is largely confirmed (even for developed countries) by work on monetary policy rules. One strand of evidence results from the estimation of structural VARs in which, among other dynamic relationships such as aggregate demand, an equation for the monetary policy instrument has to be specified. For example, Clarida and Gertler (1997) reported estimates according to which the Bundesbank responded to a depreciation of the real exchange rate with a rise in short-term interest rates. Based on a small-scale model of the Australian economy, Brischetto and Voss (1999) and Dungey and Pagan (2000) found that the Reserve Bank of Australia reacts with the short-term interest rate to movements in the exchange rate. Another strand of empirical evidence results from the direct estimation of monetary policy rules. Clarida et al. (1998) found a small, but significant reaction of the nominal interest rate of the Bundesbank (1979-1993), the Bank of Japan (1979-1994) and the Bank of England (1979-1990) to the real exchange rate. Gerlach and Smets (2000) estimated interest rate policy rules according to which the Reserve Bank of New Zealand and the Bank of Canada respond significantly with the short-term interest rate to changes in the nominal exchange rate, whereas the Reserve Bank of Australia does not. Investigating the inflation targeters Australia, Canada, New Zealand, Sweden, United Kingdom Hüfner (2003) found that the exchange rate term in the policy rule is only significant for the United Kingdom and New Zealand. He explains the differences to the study of Gerlach and Smets (2000) mainly by a somewhat larger sample period. For the emerging market economies Chile, Israel, South Africa, the Czech Republic and Mexico Ades et al. (2002) also found significant (and, in comparison with the developed economies of the aforementioned studies, larger) exchange rate coefficients in the interest rate policy rule.

In contrast to the rather clear-cut results from empirical studies, the results from numerical simulations of calibrated open economy macro models are mixed. By adding an exchange rate term to a simple policy rule, Ball (1999), Svensson (2000), Batini et al. (2001) and Leitemo and Söderström (2001) find a small improvement of the macroeconomic performance of a central bank's interest rate policy. In contrast to this, Côté et al. (2002) come to the result that using an open economy monetary policy rule often increases the value of the loss function. Taylor (1999c) gets somewhat mixed results in his multi-country study, favouring open economy rules for some countries and rejecting their usefulness for other countries. In a recent overview, he finally comes to the conclusion that "research to date indicates that monetary policy rules that react directly to the exchange rate, as well as to inflation and output, do not work much better in stabilizing inflation and real output and sometimes work worse than policy rules that do not react directly to the exchange rate" (Taylor, 2001, p. 267).

In our view the problem of most of these numerical simulation studies is that they disregard the poor knowledge of the economic profession about the determinants of exchange rate movements and the interaction between exchange rates and other fundamental variables.<sup>1</sup> Thus, the main objective of this paper is to find out whether the empirically observable uncertainty about the true determination of the exchange rate in a system of independently floating exchange rates has any influence on the structure of the policy rules that central banks should commit to in a small open economy. Following McCallum (1988) we seek to identify policy rules that possess a high degree of robustness against these uncertainties in the sense that they perform well across a range of alternative models. Our results indicate rather clearly that, due to the introduction of a high degree of exchange rate uncertainty, open economy rules become superior to simple policy rules that only react to inflation and output. By following an open economy policy rule a central bank adopts a strategy that insulates the economy from the uncertainties stemming from the mostly unknown and unreliable relationship between the nominal exchange rate and the nominal interest rate or other macroeconomic variables.

The remainder of this paper proceeds as follows. We begin in Section 2 by presenting a standard Neo-Keynesian open economy macro model typically used by academics and central banks for the evaluation of monetary policy rules. In this model, to which we refer as the baseline model, the path of the nominal exchange rate is determined according to uncovered interest parity. We will reproduce the result usually obtained from numerical simulations by evaluating the performance of

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<sup>1</sup> A notable exception is the paper of Leitemo and Söderström (2001).

six simple policy rules. As the exchange rate mainly determined by the interest rate itself, a separate interest rate reaction to exchange rate movements is redundant.

Section 3 defines the types of uncertainty stemming from the poor knowledge about the determination of exchange rates in the context of small open economy models. In particular, we will focus on deviations from uncovered interest parity that – in spite of its poor empirical support – still constitutes a major building block of traditional open economy models. As alternatives to UIP we propose exchange rate specifications that either show a much better fit in empirical studies, that allow for deviations from the rational expectations hypothesis by introducing backward-looking expectations, or that simply display purely random exchange rate behaviour. Apart from the exchange rate specification all the models are identical with respect to the IS curve and the Phillips curve.

Section 4 evaluates the extent to which the performance of the six policy rules which are derived from the baseline model is affected by the risk that instead of uncovered interest parity another exchange rate model is a better description of actual exchange rate behaviour. We will show that this exchange rate uncertainty impacts on the conduct of monetary policy on two levels. First, the exchange rate appears as an own source of shocks which conveys independent information to the policy maker. And second, the transmission of interest rate impulses on the central bank's final targets via the exchange rate channel is subject to a high degree of uncertainty. We will then identify the characteristics of those policy rules that perform reasonably well over all exchange rate specifications.

Section 5 summarises the main results.

## **2 Monetary policy in a standard open economy macro model**

### **2.1 Presentation of the baseline model**

The baseline model is a modified version of the backward-looking Neo-Keynesian Ball (1999) model for open economies. We have opted for the purely backward-looking specification of the inflation and output equation to get dynamics that match those of available economic data most consistently. Actual data usually shows a high degree of persistence in both, inflation and output (see Estrella and Fuhrer, 2002, and the papers cited there). We thereby deliberately abstained from any optimising foundations and the related forward-looking 'jump' behaviour of inflation and output. According to Ball (1999, p. 128) the advantage of the backward-looking specification is that it "is similar in spirit to the more complicated macroeconomic models of many central banks."

This superiority of the backward-looking specification in practical use is also confirmed by a study of the Bank for International Settlements (1995) in which 11 central bank models were compared to each other, all of which were purely backward-looking. An additional aspect that contributed to this decision was stressed by Rudebusch and Svensson (1999) who also used a purely backward-looking model, albeit for a closed economy. In their view, a backward-looking specification of the behavioural relationships is appropriate in particular if the inflation targeting strategy has only been recently introduced, implying that the public is still learning about the new monetary policy regime. And indeed, many small open emerging market economies to which the present analysis applies foremost switched from monetary targeting or some form of exchange rate targeting to inflation targeting no earlier than the late 1990s.

The baseline model consists of the following equations:

$$y_{t+1} = \beta_y y_t - \beta_i (i_t - \pi_t) + \beta_q q_t + \varepsilon_{t+1}^y \quad (1)$$

$$\pi_{t+1} = \pi_t + \gamma_y y_t + \gamma_q (q_t - q_{t-1}) + \varepsilon_{t+1}^\pi \quad (2)$$

$$i_t = i_t^f + E_t s_{t+1} - s_t + u_t^s \quad (3)$$

$$q_t - q_{t-1} \equiv s_t - s_{t-1} + \pi_t^f - \pi_t \quad (4)$$

The nominal interest rate  $i_t$  serves as the operating target of monetary policy. The real exchange rate  $q_t$  and the nominal exchange rate  $s_t$  are expressed in logarithms. The rate of domestic and foreign inflation ( $\pi_t$  and  $\pi_t^f$ ), the output gap  $y_t$  and the nominal interest rate  $i_t$  are measured in per cent. All parameters are assumed to be positive. The two shocks  $\varepsilon_{t+1}^\pi$  and  $\varepsilon_{t+1}^y$  are i.i.d. white noise shocks with mean zero, whereas  $u_t^s$  represents an autocorrelated disturbance.

The demand side of the Ball (1999) model is given by the open economy IS equation (1) according to which output depends on lags of the real interest rate<sup>2</sup> and the real exchange rate, its own lag and a demand shock. The supply side is given by equation (2). The inflation process is governed by a backward-looking accelerationist Phillips curve in which the rate of inflation is positively related to the lagged value of inflation, the lagged value of the output gap, the lagged rate of real depreciation,

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<sup>2</sup> Note that we defined the real interest rate as the difference between the nominal interest rate  $i_t$  and the *current* rate of inflation  $\pi_t$  (instead of *expected* inflation for the next period  $E_t \pi_{t+1}$  as is for example common in purely forward-looking models). Ellingsen and Söderström (2001) showed that this definition of the real interest rate is consistent with a forward-looking definition of the real interest rate if the Phillips curve is purely backward-looking.

and a supply shock. Both equations are identical to the specifications in the original Ball (1999) model.

In marked contrast to the Ball (1999) model, the nominal exchange rate is modelled as an asset price that is inherently forward-looking and expectations determined. The basic relationship underlying the dynamics of the exchange rate is uncovered interest parity (UIP) given by equation (3). We will come back to Ball's original exchange rate specification below in Section 3 where it will be used as one alternative to UIP. The deviations from UIP which are modelled as an AR(1) process ( $u_t^s = \rho_s u_{t-1}^s + \varepsilon_t^s$ ) are typically referred to as the foreign exchange risk premium that "incorporates any exogenous residual disturbances to the exchange rate, including changes in portfolio preferences, credibility effects, etc." (Svensson, 2000, p. 163). By forward iteration, equation (3) can be solved for the nominal exchange rate:

$$s_t = E_t \sum_{j=0}^{\infty} (i_{t+j}^f - i_{t+j} + u_{t+j}^s) \quad (5)$$

Accordingly, the fundamental determinants of  $s_t$  are current and expected future interest rate differentials as well as current and expected future risk premia. This is the core relationship of an efficient speculative foreign exchange market in which the exchange rate fully reflects information available to market participants and in which every new piece of information should be immediately mapped onto prices.

In the simulations of this Paper we opted for the 'UIP cum persistent risk premium' exchange rate specification as our baseline model for two reasons. First, UIP relies on arbitrage arguments which 'should be true'. Even though we know that arbitrage is often subject to limits (see Shleifer and Summers, 1990, and Shleifer and Vishny, 1997), it is nonetheless one of the basic building blocks of economic decision making. Questioning the validity of UIP without rejecting the underlying arbitrage mechanism then has to rely on mistaken expectations. However, rational expectations are still the predominant paradigm in macroeconomics today. Second, from this follows that in almost all open economy macro models UIP serves as the principal constituent of describing exchange rate behaviour (see for example the models presented in Buitert, 1990, McCallum, 1996, and Svensson, 2000). Moreover, UIP is also a constituent of virtually all contemporary exchange rate models. McCallum (1994, p. 109) summarises the analytical importance of the UIP condition as follows: "[T]he main fact to be kept in mind is that it appears as a key behavioral relationship in virtually all of the prominent current-day models of exchange rate determination. These include not only small models used in theoretical analysis, but also a number of the more ambitious and carefully specified

of today's array of multicountry econometric models – those used by international organizations as well as individual open-economy policy analysts.”

Due to this popularity within the economic profession the exchange rate specification in our baseline model is similar to that of numerous other studies. In particular, we assumed a known and constant  $\rho_s$ . However, as we will show below, the empirical determination of the degree of persistence often leads to mixed results.

The final relationship of our open economy macro model is the link between the real exchange rate and the nominal exchange rate which is given by identity (4) and which explicitly takes into account that deviations from purchasing power parity occur in the short-run.

On the basis of the four equations of the baseline model we can describe the transmission channels of monetary impulses in a small open economy which can be divided into an *interest rate channel* and an *exchange rate channel*. With the *interest rate channel*, monetary policy affects aggregate demand via its effect on the short-term real interest rate (equation (1)). Subsequently, aggregate demand affects inflation via the supply-side of an economy which is described by the Phillips-curve equation (2). In this respect we follow the current mainstream in monetary macroeconomics according to which the money stock only plays a minor role in describing monetary policy effects (see Romer, 2000, for an illustrative paper). According to the UIP equation (3), the *exchange rate channel* is triggered by changes in the nominal interest rate (see also equation (5)). It can be divided into a direct and an indirect channel. The *direct channel* explains inflation fluctuations via the pass-through of exchange rate fluctuations to import prices, and hence on inflation (equation (2) in conjunction with equation (4)). *Indirectly*, the real exchange rate affects the relative price between domestic and foreign goods, which in turn has an impact on both, domestic and foreign demand for domestic goods, and hence contributes to the aggregate demand channel for the transmission of monetary policy (equation (1) in conjunction with equation (4)).

## 2.2 Optimal simple rules in the baseline model

As is common in the policy-oriented literature, the interest rate policy is implemented by assuming that the central bank follows a simple policy rule for its operating target which prescribes an adjustment of the nominal interest rate in response to only a small set of observable variables (see for example Rudebusch and Svensson, 1999). Depending on this set of variables the policy rules used in our simulations below can be divided into two categories: closed economy Taylor-type rules and open economy policy rules.

A central bank that follows a closed economy policy rule sets short-term interest rates exogenously and independently of any direct exchange rate developments. Policy rule R1 is typical for such a policy since the central bank's operating target only responds to movements in the domestic goal variables inflation and output (see Table 1). By implementing monetary policy through an open economy policy rule the central bank not only reacts to contemporaneous movements in inflation and output, but also to movements in some measure of the exchange rate. There is a multitude of possible formulations of such rules (see e.g. Batini et al., 2001), depending on whether one refers to the real or the nominal exchange rate, to the level or to changes in the exchange rate, or to contemporaneous or to lagged movements of the exchange rate (see policy rules R2 to R7 in Table 1).

Table 1

For the choice of the response coefficients of the simple rules we performed a constrained optimisation. We minimised the policy maker's intertemporal loss function on a restricted state variable set

$$\min_{i_t \langle f_\pi, f_y, f_q, f_{q(-1)} \rangle} E_0 \left[ \sum_{t=0}^{\infty} \delta^t (\lambda_\pi \pi_t^2 + \lambda_y y_t^2) \right] \quad (6)$$

subject to the state and the evolution of the economy represented by equations (1) to (4). The restriction on the response coefficients is shown in brackets below the min operator. Each of the rules shown in Table 1 has been optimised for the baseline specification of the open economy model for identical preferences of the central bank towards inflation and output ( $\lambda_\pi = \lambda_y = 1$ ) and for a discount factor  $\delta$  approaching unity. By scaling the intertemporal loss function in (6) by a factor  $(1 - \delta)$  Svensson (2002) showed that when  $\delta$  approaches unity, the scaled intertemporal loss approaches the weighted sum of the unconditional variances of inflation and the output gap:

$$(7) \quad \lim_{\delta \rightarrow 1} (1 - \delta) E_0 \left[ \sum_{t=0}^{\infty} \delta^t (\lambda_\pi \pi_t^2 + \lambda_y y_t^2) \right] = \lambda_\pi \text{Var}[\pi_t] + \lambda_y \text{Var}[y_t].$$

For the numerical determination of the optimum response coefficients we have to calibrate the model. Given the time lags in equations (1) to (4) a period can at best be interpreted as a year. The parameter values of the aggregate demand equation (1) and the Phillips curve (2) which are summarised in Table 2 were chosen in accordance with Ball (1999). The variance of the i.i.d. shocks  $\varepsilon_{t+1}^s$ ,  $\varepsilon_{t+1}^\pi$  and  $\varepsilon_{t+1}^y$  is normalised to unity. As the original Ball (1999) specification of the exchange rate equation (see Section 3 below) neglects any influence of the foreign real interest rate



on the exchange rate, we set the variance of  $\varepsilon_{t+1}^f$  as well as the persistence parameter  $\rho_f$  to zero. Additionally,  $\pi_t^f$  is assumed to be constant and zero. This simplification equally applies to all other exchange rate specifications discussed in Section 3 so that each type of model is hit by the same number of shocks (exchange rate shock, supply shock, demand shock). In accordance with many other studies (see Table 6 in Section 3.1) the autocorrelation coefficient of the shock is chosen so as to persist over several periods. Thus, in the baseline model, we somewhat arbitrarily set the degree of persistence of the UIP shock to 0.3.<sup>3</sup> However, as we will show below, the quantitative results are quite robust against variations of the UIP persistence as long as the degree of persistence remains low (i.e. smaller than 0.5).

Table 2

Table 3 provides the results for the optimised coefficients and the related loss in absolute and relative terms. The latter expresses the loss in per cent of the loss from the optimal unrestricted policy under commitment which corresponds to the unrestricted optimum policy and which amounts to 4.92. It shows that the closed economy policy rule R1 performs on average 2.68 per cent worse than the optimal unrestricted rule. With regard to the equally weighted goal variables inflation and output this result means that the variance of both variables is on average 2.68 per cent higher. The coefficients on  $\pi_t$  and  $y_t$  are somewhat larger than 1.5 and 0.5 which are the coefficients of the original Taylor (1993a) rule but this result is in line with many other simulation studies (see e.g. Rudebusch and Svensson, 1999, and other papers in Taylor, 1999b). In particular, with  $f_\pi > 1$  the so-called Taylor principle holds which states that in response to a rise in inflation nominal interest rates should rise sufficiently to increase real rates (Taylor, 1999a).

Adding the current movement of the real exchange rate to the interest rate rule (R2) reduces the loss by one percentage point. The central bank reacts more aggressively on deviations of the inflation rate and the output gap from their target levels, and it raises nominal interest rates when the real exchange rate depreciates. If the lagged real exchange rate is added (R3) instead of the current exchange rate, the central bank lowers the nominal interest rate in response to a real depreciation in the previous period. While the value of the loss function is relatively close to that resulting from R2, the composition of the loss has changed in favour of inflation. In R4 and R5 the interest rate reacts to the change in the exchange rate. On first sight, R5 seems to be quite different from R4 since the

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<sup>3</sup> A persistence parameter of 0.3 signifies a decay for UIP deviations caused by a risk premium shock of 70 per cent per period, implying a half-life for UIP shocks of 0.6 periods.

nominal exchange rate enters the rule. However, with equation (4) it is possible to replace  $\Delta q_t$  with  $\Delta s_t - \pi_t$  and to reformulate R5 as

$$i_t = (f_{\pi}^{R4} - f_{\Delta q}^{R4})\pi_t + f_y^{R4}y_t + f_{\Delta s}^{R4}\Delta s_t \quad (8)$$

Thus, with  $f_{\pi}^{R5} = f_{\pi}^{R4} - f_{\Delta q}^{R4}$ ,  $f_y^{R5} = f_y^{R4}$ , and  $f_{\Delta s}^{R5} = f_{\Delta q}^{R4}$ , R4 and R5 lead to equivalent results in terms of the dynamics of the system, and hence in terms of the loss function. For this reason, we only calculated the optimal parameters for R4. We then derived the parameters for R5 on the basis of (8). Compared to the policy rules that only react to the level of the real exchange rate, R4 and R5 perform somewhat better so that the loss is only 0.38 per cent higher than that of the optimal unrestricted rule. If we allow for a separate weighting of the current and the lagged real exchange rate (R6) we get the best result in terms of the loss function. Note that the improvement of the last three rules mainly stems from a reduction of the variance of the inflation rate. As for policy rule R7, according to which the nominal interest rate responds to the level of the nominal exchange rate, the optimisation resulted in a coefficient on the exchange rate of zero ( $f_s = 0$ ). Thus, the policy rule is identical with R1. This result is not very surprising given the non-stationarity of the nominal exchange rate in open economy macro models.

Table 3

### 2.3 Explaining the mixed results in favour of open economy policy rules from numerical simulations of calibrated models

The figures in Table 3 show that the benefit from additionally responding to exchange rate movements is rather limited. The economic rationale behind this result can be directly derived from the exchange rate model underlying the open economy models. According to UIP the current exchange rate moves in response to current and future expected movements in the domestic and foreign nominal interest rate as well as in response to disturbances to UIP (see equation (5)). Let us assume for a moment that, in addition to a constant foreign interest rate, there is no disturbance to UIP. Thus, the only remaining determinant of the exchange rate is the domestic nominal interest rate, and hence the operating target of the central bank. From this it directly follows that the contemporaneous movement of the nominal exchange rate contains no extra information for the decision making process of the central bank. Thus, under such a setting policy rules R1 and R2 would be identical, with no feedback from  $q_t$  on  $i_t$  (see Table 4). As a result, if the exchange rate is not an independent source of disturbance, there is no additional informational value to be had from also responding to the exchange rate itself. The exchange rate is fully determined by the policy

instrument, and hence endogenous with respect to the decision-making process of the central bank. In the case of UIP disturbances, the informational content of the current real exchange rate can even be quantified. Table 3 shows that the use of R2 instead of R1 lowers the loss by exactly 1 per cent, given the calibration of the UIP shock in the previous Section.

Table 4

The improvement of the performance when the central bank responds to the lagged exchange rate (R3 to R6 which all produce an identical outcome) cannot be explained by informational advantages, but by gains from commitment. Such gains typically occur in models with forward-looking behaviour by improving the short-run trade-off between output and inflation. For a closed economy Woodford (1999) showed that under commitment the interest rate response in the case of supply shocks is more gradual compared to that associated with discretionary policy.<sup>4</sup> Specifically, he showed that in order to manipulate private sector expectations optimal policy under commitment almost always involves responses to lagged states of the economy (the so-called ‘history-dependence’ of optimal policy under commitment). On the level of simple policy rules this gain from commitment can be realised in approximation by interest rate rules which are not only a function of current output and inflation, but also of the lagged interest rate. In an open-economy setting this so-called interest rate smoothing behaviour can be replicated by responding to a lagged exchange rate term.<sup>5</sup> With  $f_{q(-1)} < 0$  an appreciation in  $t-1$  leads to an increase in the interest rate in  $t$ . As UIP perfectly holds, the appreciation in  $t-1$  has been triggered by an increase in the interest rate in  $t-1$ . Thus, responding to  $q_{t-1}$  is identical to responding to  $i_{t-1}$ . This is also confirmed by the results shown in Table 4 according to which R3 produces the same economic outcome as the interest rate smoothing policy rule presented in the last row of the Table. Note that R4, R5, and R6 only represent transformations of R3 (and hence the interest rate smoothing policy rule) which yield exactly the same outcome in terms of the dynamics of the system.

As has been stressed by Leitimo et al. (2002) who use a model that is identical to our baseline model, the reason for inertia in our baseline model is that inflation is affected by the change in the

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<sup>4</sup> In contrast to this, if demand shocks occur (i.e. if complete stabilisation of each of the goal variables is simultaneously possible) there is no difference in the optimal responses under discretion and under commitment (see also Clarida et al., 1999). In open economy models, this result does not hold in general. A positive demand shock, followed by an increase in the interest rate, results in an exchange rate appreciation, which in isolation contributes to lower inflation. Thus, in open economy models there is also a trade off between inflation and output stabilisation when demand shocks occur.

<sup>5</sup> Note that in our baseline model the only forward-looking agents are the foreign exchange market participants, whereas price setters and consumers are assumed to be fully backward-looking.

exchange rate. In an alternative specification, where only the level of the exchange rate enters the inflation equation

$$\pi_{t+1} = \pi_t + \gamma_y Y_t + \gamma_q Q_t + \varepsilon_{t+1}^\pi \quad (9)$$

the additional gain from using an interest rate smoothing policy rule disappears and the open economy policy rules is indeed identical to the closed economy policy rule (see Table 5).

Table 5

### 3 Uncertainty about how the market determines the exchange rate

A well-known result of the empirical literature on exchange rates is that the short- and medium-run behaviour of exchange rates is not very well understood. In particular, the empirical evidence on the two parity conditions – purchasing power parity and uncovered interest parity – which not only constitute a major building block for monetary and portfolio balance models of exchange rate determination but also for standard open economy macro models is not very supportive in systems of market determined exchange rates. This finding introduces an important uncertainty for the monetary policy maker who has to take decisions in an open economy environment where the exchange rate influences inflation and output. Thus, when setting up an economic model on the basis of which one implements monetary policy, one has to be aware of the fact that this model is not a true description of private agents' behaviour. This concerns in particular domestic (foreign) firms selling goods to the foreign (domestic) market and international investors shifting funds from one currency into another.

In the present study we assume that the pricing behaviour of firms, and hence the degree of pass-through, is known by the monetary policy maker. Thus, deviations from PPP do not introduce any uncertainty into the decision-making process (for a discussion of the impact of an uncertain degree of pass-through on the conduct of monetary policy see Adolfson, 2001, 2002, and Hunt and Isard, 2003).

The focus of this paper rather is on uncertainty originating from the international financial markets. In this Section we concentrate on how possible deviations from UIP and the resulting uncertainty about the true behaviour enter our open economy macro model. In this context, exchange rate uncertainty is defined as the risk that instead of UIP another exchange rate model is a better description of exchange rate behaviour at a certain moment in time. We modify the baseline model so as to account for the possibility that another exchange rate specification is a more realistic description of actual exchange rate behaviour. Specifically, we replace the UIP equation (3) with six

alternative exchange rate specifications enumerated by (3.i), with  $i = 1, 2, \dots, 6$ . These alternatives to UIP that have been proposed in several papers dealing with the evaluation of monetary policy rules in an open economy environment. Apart from the exchange rate model, the model's remaining equations (the IS equation, the Phillips curve and the relationship between the nominal and the real exchange rate) are always identical with the baseline model (equations (1), (2) and (4)).

One possibility is to model the empirical deviations from UIP as though they are a structural shock process, interpretable as time-varying risk premium (see Section 3.1). This is the line mostly taken in open economy macroeconomics as it corresponds particularly to the standard approach to explaining the UIP puzzle by an international asset pricing model with risk averse agents. Another strand of research concentrates on models that respond to the rejection of UIP by replacing it with an alternative exchange rate equation that continues to posit a relationship between interest rates and exchange rates. And this relationship is above all based on empirical findings which yield somewhat more stable results than UIP estimations (see Sections 3.2 and 3.3). As an alternative to the efficient market hypothesis, many studies allow for deviations from the rational expectations hypothesis by introducing the processes of backward-looking expectations (see Sections 3.4 and 3.5). Finally, we introduce a purely random exchange rate behaviour that excludes any macroeconomic determinant other than its own lagged value (see Section 3.6).

### 3.1 Exchange rate uncertainty 1 (U1): Time-varying and persistent risk premium shocks

The standard way of modelling deviations from strict UIP in open-economy macro models is to include a foreign exchange risk premium  $u_t^s$  that follows an AR(1) process

$$u_t^s = \rho_s u_{t-1}^s + \varepsilon_t^s \quad (3.1)$$

Due to this popularity within the economic profession the exchange rate specification in our baseline model is similar to that of numerous other studies. In particular, we assumed a known and constant  $\rho_s$ , taking a value of 0.3. However, the empirical determination of the degree of persistence often leads to mixed results. Table 6 summarises the UIP specifications that can be found in various simulation studies for the open economy.

Table 6

Thus, as a first type of exchange rate uncertainty we allowed for variations of  $\rho_s$  within a range from 0 to 0.99. Note that the structure of the model under exchange rate uncertainty 1 is similar to that of the baseline model. The source of uncertainty solely arises from the estimation of an

important model parameter. Thus, while exchange rate uncertainty 1 can be attributed to parameter uncertainty, the other types of exchange rate uncertainty to be presented in Sections 3.2 to 3.6 refer to structural model uncertainty since we present alternative exchange rate equations that replace UIP.

### 3.2 Exchange rate uncertainty 2 (U2): The original Ball (1999) model for open economies

As an alternative to UIP, Ball (1999) proposed a static relationship between the real exchange rate  $q_t$  and the real interest rate  $r_t$  ( $= i_t - \pi_t$ ) of the following form:

$$q_t = -\alpha_i r_t + \varepsilon_t^q \quad (3.2)$$

It captures the idea that a rise in the interest rate makes domestic assets more attractive, leading to an appreciation of the domestic currency. Albeit simplified, his approach is mainly based on empirical findings on reduced-form exchange rate equations (see Section 3.3). Concerning the calibration of equation 0, Ball (1999) assumed an interest rate elasticity of the real exchange rate  $\alpha_i$  of 2 indicating that a one percentage point rise in the interest rate causes a 2 per cent appreciation. The origin of this value is discussed in more detail in Section 3.3. Similar to exchange rate uncertainty 1 we even increase the degree of uncertainty in our simulations by not only altering the exchange rate specification (from UIP equation (3) to equation (3.2)) but by allowing the parameter  $\alpha_i$  to vary within a range from 0 to 4.  $\varepsilon_t^q$  is assumed to be an i.i.d. white noise shock.

### 3.3 Exchange rate uncertainty 3 (U3): The empirical approach of Ryan and Thompson (2000)

In empirical models for small open economies researchers often found structural reduced-form equations of the exchange rate to be superior to UIP. In a recent study for Australia, Ryan and Thompson (2000, p. 13) summarise this result as follows: “A standard, forward-looking international arbitrage condition is conspicuous in its absence but has repeatedly failed to replicate the observed behaviour of the Australian dollar. Instead, a lagged real interest rate differential has consistently proved more successful.” Thus, in their quantitative simulations they replace UIP by

$$\Delta q_{t+1} = -\alpha_r (r_t - r_t^f) - \alpha_q q_t + \varepsilon_{t+1}^{\Delta q} \quad (3.3)$$

which can be solved for  $q_{t+1}$ :  $q_{t+1} = (1 - \alpha_q) q_t - \alpha_r (r_t - r_t^f) + \varepsilon_{t+1}^{\Delta q}$ . Accordingly, the current real exchange rate is determined by its own lagged realisation and the lagged real interest rate differential.  $r_t$  is the domestic real interest rate and  $r_t^f$  the foreign real rate.  $\varepsilon_{t+1}^{\Delta q}$  is a white noise

disturbance. Similar to the Ball (1999) approach higher domestic interest rates lead to an appreciation of the currency, however with a lag of one period. Additionally, the backward-looking elements favour a more gradual adjustment as opposed to (3.1).

The parameters that have to be determined for a quantitative analysis of uncertainty 3 are the interest rate elasticity  $\alpha_r$  and the exchange rate elasticity  $\alpha_q$  of the change in the real exchange rate. Ryan and Thompson (2000) estimated a macroeconomic model of the Australian economy on the basis of a single equation framework. For a period from 1985:Q1 to 1998:Q4 they arrive at the following specification for the real exchange rate equation:

$$\Delta q_t = -0.392(r_{t-1} - r_{t-1}^f) - 0.413q_{t-1} + 0.411tot_{t-1} + 1.263\Delta tot_{t-1} + \varepsilon_t^{\Delta q}$$

where tot is the terms of trade. Beechey et al. (2000) who estimated a model of the Australian economy similar to that of Ryan and Thompson (2000) (with an estimation period ending in 1999:Q3) find the following parameters:

$$\Delta q_t = -0.590(r_{t-1} - r_{t-1}^f) - 0.484q_{t-1} + 0.473tot_{t-1} + 1.290\Delta tot_{t-1} + \varepsilon_t^{\Delta q}.$$

Both studies base their estimation equations on a macroeconomic model for Australia that was developed by de Brouwer and O'Regan (1997). These authors get the following estimates:

$$\Delta q_t = -0.36dum_{t-1}(r_{t-1} - r_{t-1}^f) - 0.63(1 - dum_{t-1})(r_{t-1} - r_{t-1}^f) - 0.32q_{t-1} + 0.33tot_{t-1} + 1.32\Delta tot_{t-1} + \varepsilon_t^{\Delta q}$$

where dum is a variable that takes a value of one for 1980:Q3 to 1984:Q4 and zero otherwise. The total estimation period ranges from 1980:Q3 to 1996:Q3. The results of the three studies make clear that the elasticities are subject to a considerable degree of uncertainty. Note that in all estimations the interest rates are expressed in per cent per annum while the change of the real interest rate refers to a quarter of a year. Thus, if we want to equalise the length of the underlying periods, the interest rate elasticity has to be multiplied by four which yields a value between  $-2.52$  and  $-1.44$  for the abovementioned empirical studies.<sup>6</sup> These are the values that Ball (1999) had in mind when he set  $\alpha_r$  in his model to 2. The parameter  $\alpha_q$  roughly ranges between 0.3 and 0.5. Thus, in accordance with the previous Sections, exchange rate uncertainty 3 not only refers to the possibility that the UIP condition of the baseline model is not the true exchange rate equation, but also to uncertain

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<sup>6</sup> Recall that our model does not explicitly refer to any specific frequency. Because of the scarce lag structure it could at best be interpreted as an annual model (see Section 2.2).

parameters within this alternative specification. For simplicity we only allowed  $\alpha_r$  to vary between 0 and 4;  $\alpha_q$  was set to 0.5. For the reasons outlined in Section 2.2  $r_t^f$  has been set to zero.

### 3.4 Exchange rate uncertainty 4 (U4): Mixed expectations I (Dennis, 2000)

The problem with the empirical approaches of the last two Sections is that they fully reject the hypothesis of the exchange rate as an asset price since rational expectations are no longer part of the determinants of the current exchange rate. An attempt to simultaneously capture the features found in data based models on the one hand and the requirements implied by rationality and efficient market considerations on the other hand is to introduce mixed expectations. Dennis (2000) uses the following modified UIP condition:

$$s_t = \nu E_t s_{t+1} + (1-\nu)s_{t-1} - i_t + i_t^f + \varepsilon_t^s \quad (3.4)$$

The parameter  $\nu$  defines the degree of forward-looking and rational behaviour and  $\varepsilon_t^s$  is a white noise disturbance. If  $\nu$  approaches unity, expectations are predominantly forward-looking. If  $\nu$  approaches zero, expectations are predominantly static and backward-looking. In fact, (3.4) is a simplified version of the chartist-fundamentalist model proposed by De Grauwe and Dewachter (1993). Instead of using an elaborate moving average trading rule, however, the chartists in the specification of Dennis (2000) simply forecast the exchange rate in  $t+1$  by its realisation in  $t-1$ .

Again changes in the foreign interest rate are ignored in our simulations. Uncertainty occurs with respect to the degree of backward-looking behaviour  $(1-\nu)$  in the foreign exchange market. Dennis (2000) only considered the extreme cases of  $\nu=1$  and  $\nu=0$ . In our simulations, however, we allowed  $\nu$  to vary over the entire spectrum from 1 to 0.

### 3.5 Exchange rate uncertainty 5 (U5): Mixed expectations II (Leitemo and Söderström, 2001)

A somewhat more elaborate specification of backward-looking behaviour can be found in Leitemo and Söderström (2001). Instead of static expectations for the backward-looking part of the expectations, they assumed agents to form expectations adaptively. UIP then becomes

$$s_t = \nu E_t s_{t+1} + (1-\nu)\mathfrak{E}_t s_{t+1} - i_t + i_t^f + \varepsilon_t^s \quad (3.5)$$

where  $\mathfrak{E}$  is the adaptive expectations operator and  $\varepsilon_t^s$  a white noise disturbance. The parameter  $\nu$  again defines the degree of forward-looking behaviour on the international financial markets. If expectations are purely adaptive ( $\nu=0$ ) agents update their exchange rate expectations gradually in



the direction of the observed exchange rate. Thus,  $\epsilon_{t+1} = (1 - \xi)s_t + \xi\epsilon_{t-1}$ , where  $0 < \xi < 1$  measures the rate of updating.

Similar to the other types of uncertainty, the foreign interest rate is ignored. Uncertainty occurs with respect to the degree of rationality  $\upsilon$  and the rate  $\xi$  with which agents with adaptive expectations revise their expectations about the future exchange rate. Again  $\upsilon$  was allowed to vary between 0 and 1. Reasonable parameters for  $\xi$  were chosen on the basis of a study by Frankel and Froot (1987). Using survey data on exchange rate expectations for the US dollar against five major currencies they found statistically significant values of  $\xi$  ranging from 0.05 to 0.09. As the results of the simulations in Section 4 did not depend upon the value of  $\xi$ , we set it equal to 0.07.

### 3.6 Exchange rate uncertainty 6 (U6): The real exchange rate as a random variable

In one of the most widely cited papers in the international economics literature Messe and Rogoff (1983) demonstrated that a whole range of fundamentals-based nominal exchange rate models (flexible-price monetary models with and without current account effects, and a sticky-price monetary model) were unable to outperform a simple random walk in an out-of-sample forecasting exercise. Some years later, in Messe and Rogoff (1988) they regressed changes in the real exchange rates on real interest rate differentials to forecast the real exchange rates of three currencies against the dollar. Again they found that the forecasts from the random walk have lower root-mean-square error than those from their regressions in the majority of the post-sample fit experiments. However, the pure random walk of the real exchange rate has recently been rejected by studies using long-span data sets in favour of an AR(1) process with a high degree of persistence  $\alpha_q$ . Based on these findings which are still uncontested today (see e.g. Kilian and Taylor, 2003) we posit the following behavioural relationship of the real exchange rate:

$$q_{t+1} = \alpha_q q_t + \epsilon_{t+1}^q \quad (3.6)$$

Accordingly, the real exchange rate only depends on its own lagged value and a white noise disturbance  $\epsilon_{t+1}^q$ . In particular, no other macroeconomic variables, such as the domestic interest rate, have an influence on the exchange rate.

We allowed for additional uncertainty by assuming  $\alpha_q$  to take values between zero and unity. For reasons of non-stationarity, however, the pure random walk scenario in which  $\alpha_q = 1$  has to be excluded from the range of possible values. Thus, we only approximated the random walk by

defining the real exchange rate as a stationary AR(1) process with an autocorrelation coefficient approaching unity.

### **3.7 Summary**

Table 7 summarises the exchange rate specifications as well as the ranges of variation of the uncertain coefficients. Note that in all specifications the variances of the white noise shocks were set to unity.

Table 7

## **4 Monetary policy in an environment with exchange rate uncertainty**

In the previous Section we presented various approaches to replacing UIP with other exchange rate specifications that the authors of the cited studies deemed to be a better description of actual exchange rate behaviour. In this Section we assume that neither of the exchange rate specifications is perfectly true, but that there is a certain – but unknown – probability that instead of baseline UIP another specification is more realistic at a certain moment in time. Despite this knowledge, the policy maker continues to use the baseline model to determine his policy rules. Thus, he deems this model to be the most likely, even though he is aware of the fact that the UIP equation (3) is only an approximation of the true exchange rate generating model. The crucial question now is whether the conduct of monetary policy is affected by the uncertainty about the true exchange rate behaviour and whether there is a difference in the performance of the six policy rules which are derived on the basis of the baseline model in Section 2.

### **4.1 Consequences of exchange rate uncertainty for the monetary policy maker**

In our model, uncertainty about the true exchange rate specification impacts on the performance of monetary policy on two levels. On the first level, the exchange rate can be regarded as an own important source of shocks which directly (in the case of open economy policy rules) or indirectly (via inflation and output) trigger monetary policy actions. Thus, the exchange rate is not predominantly endogenous with respect to the interest rate, but vice versa. On the second level, the transmission of interest rate impulses via the exchange rate channel on the central bank's final targets is subject to a high degree of uncertainty which entails the risk that a central bank fails to pursue a successful stabilisation policy.

In the following we will illustrate the two levels of uncertainty with the dynamics of the system's variables following an exchange rate shock and an interest rate shock for a central bank that adopted

R1. For the sake of comparability, Figure 1 depicts the impulse responses for the baseline model. The left panel shows that a positive UIP shock leads to an immediate depreciation of the nominal (and the real) exchange rate. The depreciation stimulates inflation and output in  $t = 2$ , so that the central bank rises interest rates. Consequently, output and inflation quickly return to their target levels.<sup>7</sup> In the case of a positive interest rate shock (right panel), the nominal exchange rate appreciates in  $t = 1$ . As the contractionary monetary policy stance dampens output in  $t = 2$ , the central lowers interest rates so as to stabilise the path of the output gap.

Figure 1

Under exchange rate uncertainty, the central bank also observes an exchange rate depreciation following a positive shock to the exchange rate equation in  $t = 1$  which raises output and inflation above their target levels in  $t = 2$ . Again, the central bank pursues a contractionary policy, but the reaction of the exchange rate in  $t = 2$  crucially depends on the uncertainty scenario which is assumed to be ‘in action’ (see Figure 2). Compared with the baseline model, the nominal appreciation is stronger under U2 and U5, weaker under U3 and approximately the same under U1 and U4 (though starting from a higher level under U1). Under U6 the initial appreciation is even followed by a further rise in  $s_t$ . The different exchange rate developments in conjunction with the related interest rate responses then lead to fundamentally different paths for inflation and output.

Figure 2

The differences in the transmission of interest rate impulses are depicted in Figure 3 which shows the impact of a one-time unit shock to the interest rate in  $t = 1$  on the model’s macroeconomic variables. From  $t = 2$  on it is assumed that the central bank follows the optimal simple rule R1. The rise in the interest rate leads to an immediate appreciation under all exchange rate specifications, except for U3 and U6. However, the extent and the dynamics of the appreciation vary considerably, so that the transmission on  $\pi_t$  and  $y_t$  as well as the related response of  $i_t$  are different for each exchange rate specification. Under U3, the exchange rate reacts with a one period lag, while under U6 the nominal exchange rate appreciates gradually, although not directly in response to the interest rate impulse, but indirectly as the result of an inflation rate that is below target for a prolonged period of time in conjunction with a constant real exchange rate. Note that under U1 and U6 the

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<sup>7</sup> This example makes clear why in the baseline model open economy policy rules lead to slightly better outcomes. By following a policy rule like R2, the central bank already adjusts its interest rate in  $t = 1$  (since it directly responds to exchange rate movements). By doing so, the impact of the depreciation on  $\pi_t$  and  $y_t$  in  $t = 2$  is mitigated, and hence the loss reduced. However, as has been shown in Section 2.3, the informational gain from responding to exchange rate movements which are triggered by baseline UIP shocks was fairly small.

dynamics of the economy following an interest rate shock are independent from the parameterisation of the uncertainty scenario. Thus, the transmission of interest rate impulses under U1 is identical to that in the baseline model.

Figure 3

#### **4.2 Identifying policy rules that are robust to exchange rate uncertainty**

Section 2 showed that the performance of optimised simple rules in our baseline specification of the open economy model improves when some weight is put on the exchange rate in the policy rule. However, the improvement is only small compared to the outcome of the closed economy policy rule R1. This result seems to confirm the reluctance of many economists towards making policy rules more complicated by including exchange rate variables.

While a basic assumption underlying the analysis in Section 2 was that the central bank knows the behaviour of the private agents with certainty, now the central bank is assumed to operate in a world of uncertainty. The purpose of this Section is to find among the set of rules the policy rule which always guarantees the policy maker the best outcome, even though he is uncertain about the actual private agents' behaviour. The policy rule that performs best across a range of structural models is then called a robust policy rule since it best possibly insulates the economy from the negative consequences of both, exchange rate shocks and uncertain transmission of interest rate impulses via the exchange rate channel.

In the literature on model uncertainty one can typically find two methods on how to evaluate the competitive performance of simple interest rate rules across several structural models. Levin et al. (1999) took simple interest rate rules with parameters that were optimised in a baseline model for different preferences of the central bank towards inflation and output and compared the outcome of these rules in terms of the variances of the goal variables and the value of the loss function in structurally different models. The baseline model is defined as the model that the policy maker deems to be more likely than the alternative specifications.

The second method differs from the first mainly in its treatment of the optimised policy rule. While in the first approach the policy maker must rely on a particular parameterisation of a rule (with given numerical coefficients resulting from the optimisation in the baseline model) and then consider the performance of that given fixed rule across various models, Rudebusch (2001) optimises a simple rule for each model specification. He then calculates the performance of each rule within the rule-generating model and compares the results of one model with those of other specifications. In Rudebusch (2002) he also assesses the performance of various structurally

different optimised interest rate rules by setting up a ranking in terms of loss within each model under consideration. However, in the same paper he admits that “these results do not capture the model uncertainty faced by a policy maker” and that “the performance of a fixed rule across models is in the essence of the model robustness criterion championed by McCallum (1999)” (Rudebusch, 2002, p. 417). The same criticism has been pronounced by Stock (1999, p. 254) who argues that “the essence of policy robustness is whether a specific quantitative rule performs well under a model *other than that used to develop the policy.*”

We decided in favour of the first method as our goal is to show how uncertainty about the true exchange rate determination on the financial markets affects monetary policy that has committed itself to follow a time-invariant simple interest rate rule. In contrast to the approach of Levin et al. (1999), however, we did our analysis for one specific preference structure of the monetary policy maker, namely  $\lambda_\pi = \lambda_y = 1$ . The results are presented in Figure 4 which shows for each exchange rate specification the loss from all the policy rules in a single chart.

Figure 4

With a growing risk premium persistence (U1), the loss increases. While variations of  $\rho_s$  between 0 and 0.5 do not have a major impact on the value of the loss function, a  $\rho_s$  approaching unity makes the loss grow progressively.<sup>8</sup> The empirical approaches to the determination of the real exchange rate (U2 and U3) produce U-shaped loss curves. The loss reaches its minimum for an interest rate elasticity of the real exchange rate somewhere between zero and two. With a growing  $\alpha_{i/r}$  the loss increases much faster than with a falling  $\alpha_{i/r}$ . A notable exception is the outcome of R6 under U2. The resulting loss seems to be almost immune against uncertainty about  $\alpha_i$ . The introduction of mixed expectations (U4 and U5) reduces the loss resulting from the policy rules relative to the fully rational baseline case ( $\upsilon = 1$ ) up to a critical mass. The concrete results, however, depend on both, the policy rule and the exchange rate specification. Under U4, the performance of policy rules R2 and R6 becomes better the higher the degree of static (and hence backward-looking) expectations. In contrast to this, the loss curves of the other rules have a minimum which is at  $\upsilon = 0.5$  for R1,  $\upsilon = 0.7$  for R3, and  $\upsilon = 0.3$  for R4 and R5. An examination of U5 shows that for a growing degree of adaptive expectations (i.e. a lower  $\upsilon$ ) the behaviour of the loss curve of R1, R2 and R3 differs from that of R4, R5 and R6. The first group reaches a minimum loss at an  $\upsilon$  somewhere between

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<sup>8</sup> This explains why the concrete value of  $\rho_s$  (which we set to 0.3 in the baseline model) plays only a minor role for the determination of the policy rules – provided that  $\rho_s$  does not exceed a critical value.

0.4 and 0.7. If  $\upsilon$  is further reduced, the loss resulting from these rules quickly explodes. In contrast to this, the loss from the last three rules remains relatively low. With regard to a purely random real exchange rate (U6), loss increases with a growing  $\alpha_q$ . Except for R2 and R6, the loss becomes very high for a pure random walk.

Significant differences in the performance of the rules only occur for a large risk premium persistence (U1), a high interest rate elasticity of the exchange rate (U2 and U3), a high degree of backward-looking expectations (U4 and U5) and a near-random-walk behaviour of the real exchange rate (U6). In Table 8 we set up a ranking of the best and second best performing policy rule for each model specification. It shows that R6 performs very well under all types of exchange rate uncertainty. R2, R4 and R5 also seem to produce relatively good results. However, R2 performs worst under U3; and so do R4 and R5 under U2.

Table 8

In short, we get the following results:

1. The closed economy policy rule R1 according to which the central bank sets  $i_t$  independent of any exchange rate developments performs badly under market determined exchange rates with exchange rate uncertainty (second worst in all exchange rate specifications, except U5 in which it performs worst).
2. Policy rule R6 which is a specific variant of an open economy policy rule performs very well in all types of exchange rate uncertainty (three times second best, three times first best).
3. The remaining open economy policy rules lead to a very mixed performance which makes them not suitable for insulating the policy maker from the consequences of exchange rate uncertainty.

The reason why R6 performs so well across a range of exchange rate specifications is that current and past exchange rate movements provide the policy maker with an important information. At the time when an exchange rate disturbance occurs or when the exchange rate channel is triggered by adjustments in the interest rate, the policy maker takes these movements into account without any time lag. As a result, Figure 5 and Figure 6 show that the impact of exchange rate shocks and interest rate shocks on  $\pi_t$  and  $y_t$  are almost identical in all uncertainty scenarios. The difference between R6 and R1 becomes especially clear when we take a short look back to Figure 2 and Figure 3 where we depicted the impact of exchange rate shocks and the transmission of interest rate impulses under the assumption that the central bank follows R1. Under R1, the policy maker only

learns about the deviation of the exchange rate from the baseline model after the loss has already occurred.

Figure 5 and Figure 6

A final, but important issue that should be addressed when evaluating the performance of policy rules under a range of uncertainty scenarios is the question of whether the parameters that lead to differences in the performance of the rules are plausible (or realistic) or not. For U1 significant differences only occur for a risk premium persistence exceeding 0.6. A short look back to Table 6 shows that such high (annualised) values for  $\rho_s$  are rather an exception in the literature. Turning to the empirical approaches represented by U2 and U3 the parameters for which the performance of the rules shows important differences are much more realistic. Remember that the values for  $\alpha_i$  and  $\alpha_r$  that Ball (1999), Ryan and Thompson (2000) and the other authors had in mind when calibrating their models were around 2 (see Sections 3.2 and 3.3). Quantifying a plausible degree to which expectations are backward-looking (U4 and U5) is somewhat difficult as empirical work is not available. However, as significant differences already occur for values of  $\upsilon$  equal to 0.8 and lower (meaning that at least 20 per cent of the international investors do not form expectations rationally) we deem the contribution of U4 and U5 to the central bank's choice of a robust policy rule as highly relevant. The same applies to U6 where differences in the performance between R2, R4, R5 and R6 only appear for a high  $\alpha_q$ . Note that a value of  $\alpha_q$  approaching unity simulates the random walk behaviour of the real exchange rate often found in the empirical literature.

## 5 Conclusion

Standard open economy macro models are usually based on the assumption that the exchange rate is determined on an efficient foreign exchange market with forward-looking and rational behaviour on the part of the international financial markets' participants. Uncovered interest parity defines a known and reliable relationship between changes in the central bank's operating target and the exchange rate so that in addition to the interest rate channel a second important transmission channel of monetary impulses – the exchange rate channel – can be exploited by the central bank. The majority of the empirical literature, however, comes to the result that in the short and medium run (which is the most relevant for the conduct of monetary policy) the behaviour of exchange rates cannot be explained and predicted by any of the existing models. In particular, uncovered interest parity does not find much empirical support. This finding raises the question of how the conduct of

monetary policy in such an environment of uncertainty about the true determination of exchange rates is affected.

The intention of the present analysis is to provide a rationale for the observed widespread use of the so-called open economy policy rules according to which the interest rate directly responds to movements in the exchange rate. Our approach is based on a standard open economy macro model typically employed for the analysis of monetary policy strategies. The consequences market determined exchange rates are evaluated in terms of a social welfare function, or, to be more precise, in terms of an intertemporal loss function containing a central bank's final targets output and inflation. In order to take account of the poor empirical evidence of uncovered interest parity we question the basic assumption underlying most open economy macro models that the foreign exchange market is an efficient asset market with rational agents and we model the central bank's decision making process as being confronted by a high degree of exchange rate uncertainty. Exchange rate uncertainty is defined as the risk that instead of uncovered interest parity another exchange rate model is a better description of the exchange rate behaviour at a certain moment in time.

The main lesson that can be drawn from the analysis of monetary policy under market determined exchange rates and exchange rate uncertainty is that exchange rate uncertainty provides a rationale for adopting an open economy policy rule. This finding is in sharp contrast to the traditional literature on policy rules in open economies. Most of the studies conducted in this field only attach a minor importance to the possibility of interest rate feedback to the exchange rate movements. The study of Leitimo and Söderström (2001), for example, which is similar in topic to our study, comes to the conclusion that as long as there is no extreme parameterisations of the uncertainty scenario (which mainly corresponds to U5) closed economy policy rules seem to be an efficient and robust guide for monetary policy in an open economy. In comparison with their analysis we increased the degree of exchange rate uncertainty to account for the little knowledge about the true exchange rate behaviour by extending the set of possible exchange rate specifications. We showed that even with quite realistic parameters underlying the uncertainty scenarios the closed economy policy rule and some of the open economy policy rules perform poorly in terms of the loss they produce. By contrast, the use of an open economy policy rule with an important exchange rate feedback from contemporaneous and lagged movements in the real exchange rate (R6) performs reasonably well over all exchange rate specifications. Thus, in a world in which we allow for deviations from the assumption of perfectly functioning foreign exchange markets and in which we assume a central bank taking these deviations into account and behaving so as to reach its final targets, the rationale



for using open economy policy rules is the monetary policy maker's quest for a robust interest rate policy rule that performs comparatively well across a range of alternative exchange rate models.

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## Tables

**Table 1: A battery of simple policy rules**

	structure of the rule
R1	$i_t = f_\pi \pi_t + f_y y_t$
R2	$i_t = f_\pi \pi_t + f_y y_t + f_q q_t$
R3	$i_t = f_\pi \pi_t + f_y y_t + f_{q(-1)} q_{t-1}$
R4	$i_t = f_\pi \pi_t + f_y y_t + f_{\Delta q} \Delta q_t$
R5	$i_t = f_\pi \pi_t + f_y y_t + f_{\Delta s} \Delta s_t$
R6	$i_t = f_\pi \pi_t + f_y y_t + f_q q_t + f_{q(-1)} q_{t-1}$
R7	$i_t = f_\pi \pi_t + f_y y_t + f_s s_t$

**Table 2: Calibration of the Phillips curve and the IS equation**

Phillips curve		IS equation		
$\gamma_y$	$\gamma_q$	$\beta_y$	$\beta_i$	$\beta_q$
0.4	0.2	0.8	0.6	0.2

**Table 3: Performance of optimised rules in the baseline model**

structure of the rule	absolute loss	relative loss	Var( $\pi_t$ )	Var( $y_t$ )
R1: $i_t = 1.90\pi_t + 1.25y_t$	5.05	102.68	2.68	2.38
R2: $i_t = 2.23\pi_t + 1.56y_t + 0.27q_t$	5.00	101.68	2.68	2.32
R3: $i_t = 1.88\pi_t + 1.35y_t - 0.16q_{t-1}$	5.01	101.86	2.63	2.38
R4: $i_t = 2.17\pi_t + 1.69y_t + 0.26\Delta q_t$	4.94	100.38	2.60	2.33
R5: $i_t = 1.91\pi_t + 1.69y_t + 0.26\Delta s_t$	4.94	100.38	2.60	2.33
R6: $i_t = 2.29\pi_t + 1.78y_t + 0.36q_t - 0.23q_{t-1}$	4.93	100.20	2.62	2.31
R7: $i_t = 1.90\pi_t + 1.25y_t + 0 \cdot s_t$	5.05	102.68	2.68	2.38

Note: The relative loss refers to the loss from optimal unrestricted policy under commitment.

**Table 4: Optimised policy rules under a perfectly holding UIP condition and constant foreign interest rates**

structure of the rule	absolute loss	relative loss	Var( $\pi_t$ )	Var( $y_t$ )
R1: $i_t = 1.91\pi_t + 1.27y_t$	4.93	101.17	2.62	2.31
R2: $i_t = 1.91\pi_t + 1.27y_t + 0 \cdot q_t$	4.93	101.17	2.62	2.31
R3: $i_t = 1.85\pi_t + 1.35y_t - 0.20q_{t-1}$	4.88	100.30	2.57	2.31
R4: $i_t = 2.12\pi_t + 1.61y_t + 0.22\Delta q_t$	4.88	100.30	2.57	2.31
R5: $i_t = 1.90\pi_t + 1.61y_t + 0.22\Delta s_t$	4.88	100.30	2.57	2.31
R6: $i_t = 2.40\pi_t + 1.89y_t + 0.45q_t - 0.24q_{t-1}$	4.88	100.30	2.57	2.31
$i_t = 1.79\pi_t + 1.39y_t + 0.18i_{t-1}$	4.88	100.30	2.57	2.31

Note: The relative loss expresses the loss from the simple policy rule as a percentage of the loss from optimal unrestricted policy under commitment.

**Table 5: Optimised policy rules under a perfectly holding UIP condition, constant foreign interest rates and a modified Phillips curve relation**

structure of the rule	absolute loss	relative loss	Var( $\pi_t$ )	Var( $y_t$ )
R1: $i_t = 1.57\pi_t + 1.01y_t$	3.78	102.10	2.13	1.65
R2: $i_t = 1.57\pi_t + 1.01y_t + 0 \cdot q_t$	3.78	102.10	2.13	1.65
R3: $i_t = 1.55\pi_t + 1.01y_t - 0.03q_{t-1}$	3.78	102.10	2.13	1.65
R4: $i_t = 1.59\pi_t + 1.05y_t + 0.03\Delta q_t$	3.78	102.10	2.13	1.65
R5: $i_t = 1.56\pi_t + 1.05y_t + 0.03\Delta s_t$	3.78	102.10	2.13	1.65
R6: $i_t = 1.48\pi_t + 0.94y_t - 0.07q_t - 0.03q_{t-1}$	3.78	102.10	2.13	1.65

Note: The relative loss expresses the loss from the simple policy rule as a percentage of the loss from optimal unrestricted policy under commitment.

**Table 6: Persistence of UIP shocks in the literature**

	frequency	$\rho_s$	annualised $\rho_s$
Dennis (2000)	a	0	0
Adolfson (2002)	a	0.8	0.8
Batini and Nelson (2000)	q	0.753 (estimated for UK)	0.32
Batini et al. (2001)	q	0.261 (estimated for UK with survey data)	0.005
Taylor (1993b)	q	0.5 (calibrated equally for all countries)	0.0625
Leitemo and Söderström (2001)	q	0.3 (calibrated at conventional values)	0.008
Svensson (2000)	q	0.8 (calibrated)	0.41

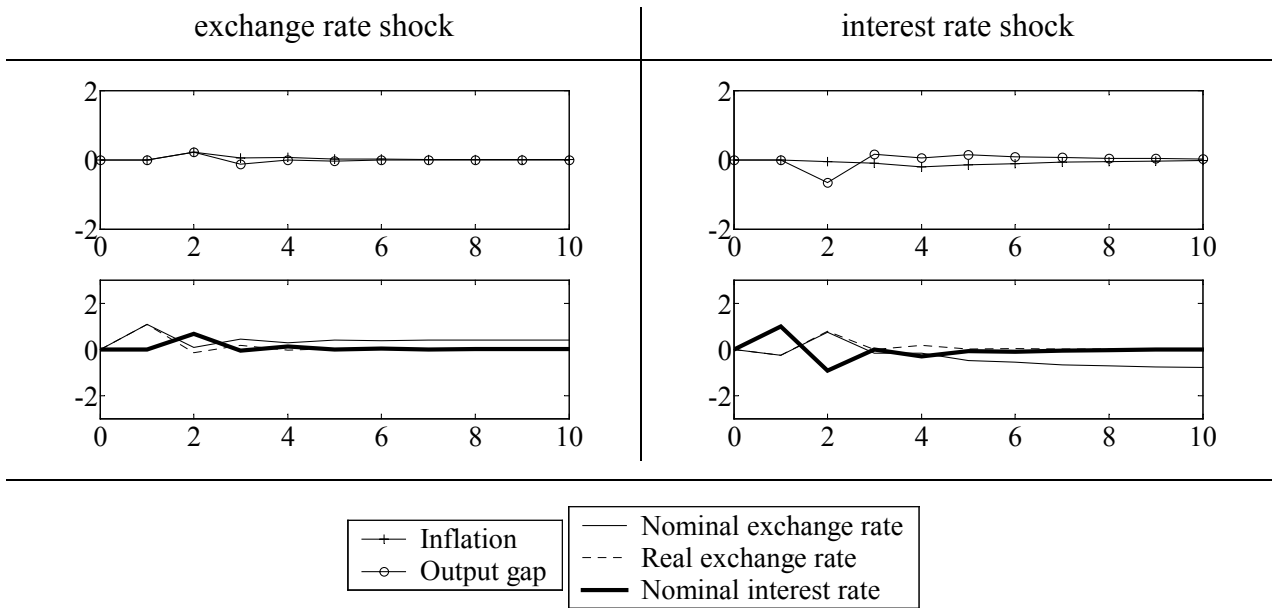
**Table 7: Summary of the different exchange rate specifications**

	exchange rate uncertainty	exchange rate specification	variation of
U1	UIP and risk premium	(3.1) $E_t s_{t+1} = s_t + i_t - i_t^f + u_t^s$ with $u_t^s = \rho_s u_{t-1}^s + \varepsilon_t^s$	$\rho_s \in [0; 1[$
U2	original Ball (1999)	(3.2) $q_t = -\alpha_i (i_t - \pi_t) + \varepsilon_t^q$	$\alpha_i \in [0; 4]$
U3	Ryan and Thompson (2000)	(3.3) $\Delta q_t = -\alpha_r (r_{t-1} - r_{t-1}^f) - \alpha_q q_{t-1} + \varepsilon_t^{\Delta q}$ with $\alpha_q = 0.5$	$\alpha_r \in [0; 4]$
U4	mixed expectations (I)	(3.4) $s_t = \nu E_t s_{t+1} + (1-\nu)s_{t-1} - i_t + i_t^f + \varepsilon_t^s$	$\nu \in ]0; 1]$
U5	mixed expectations (II)	(3.5) $s_t = \nu E_t s_{t+1} + (1-\nu)\mathbf{\epsilon}_t s_{t+1} - i_t + i_t^f + \varepsilon_t^s$ with $\mathbf{\epsilon}_t s_{t+1} = (1-\xi)s_t + \xi\mathbf{\epsilon}_{t-1} s_t$ and $\xi = 0.075$	$\nu \in ]0; 1]$
U6	random behaviour	(3.6) $q_t = \alpha_q q_{t-1} + \varepsilon_t^q$	$\alpha_q \in [0; 1[$

**Table 8: Ranking of the optimised simple rules**

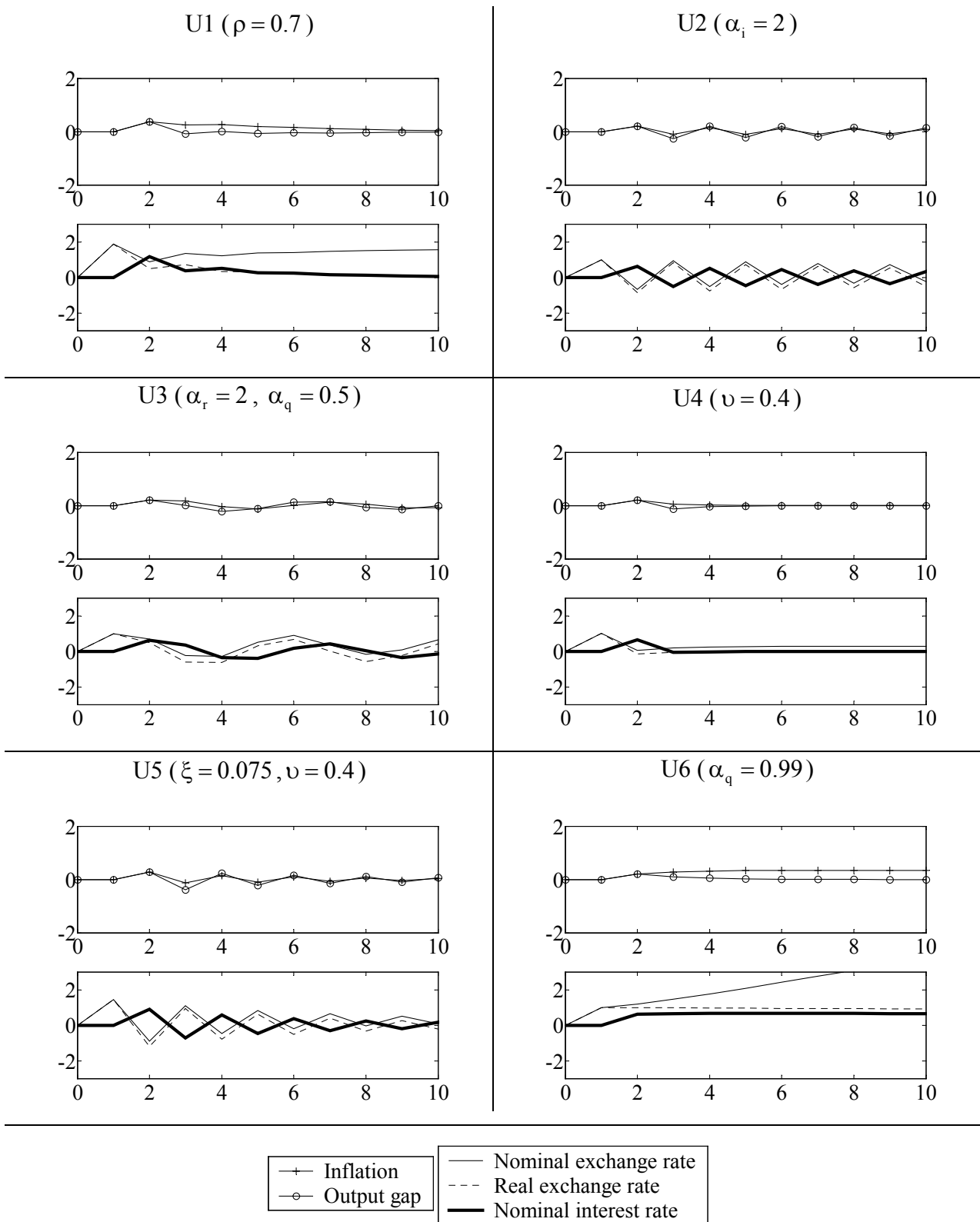
Exchange rate uncertainty	U1	U2	U3	U4	U5	U6
Best performing policy rule	R2	R6	R4 + R5	R2 + R6	R6	R2
Second best performing policy rule	R6	R2	R6	R4 + R5	R4 + R5	R6

**Figures**

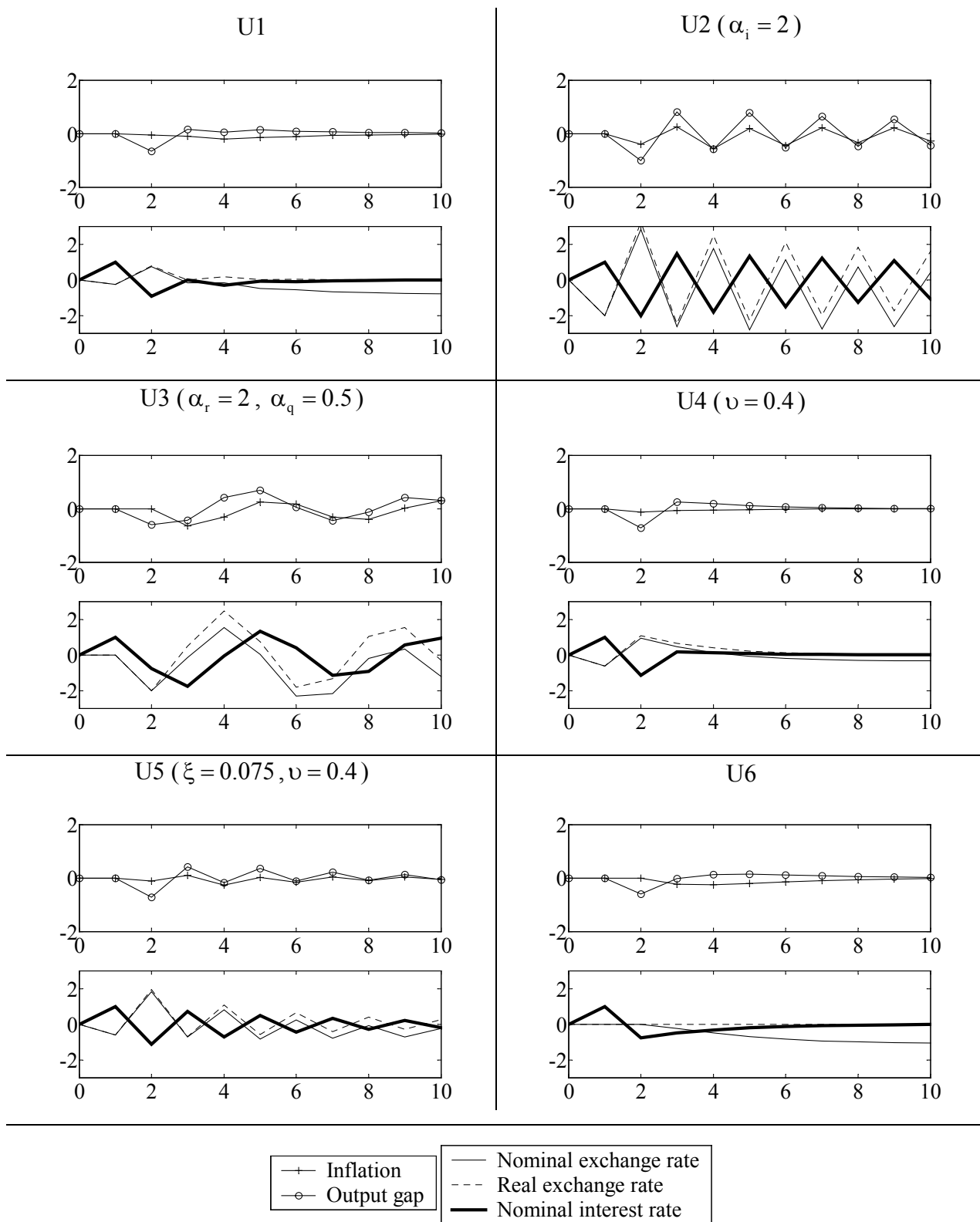


**Figure 1: Impact of unit shocks in the baseline model under the assumption that the central bank follows R1**

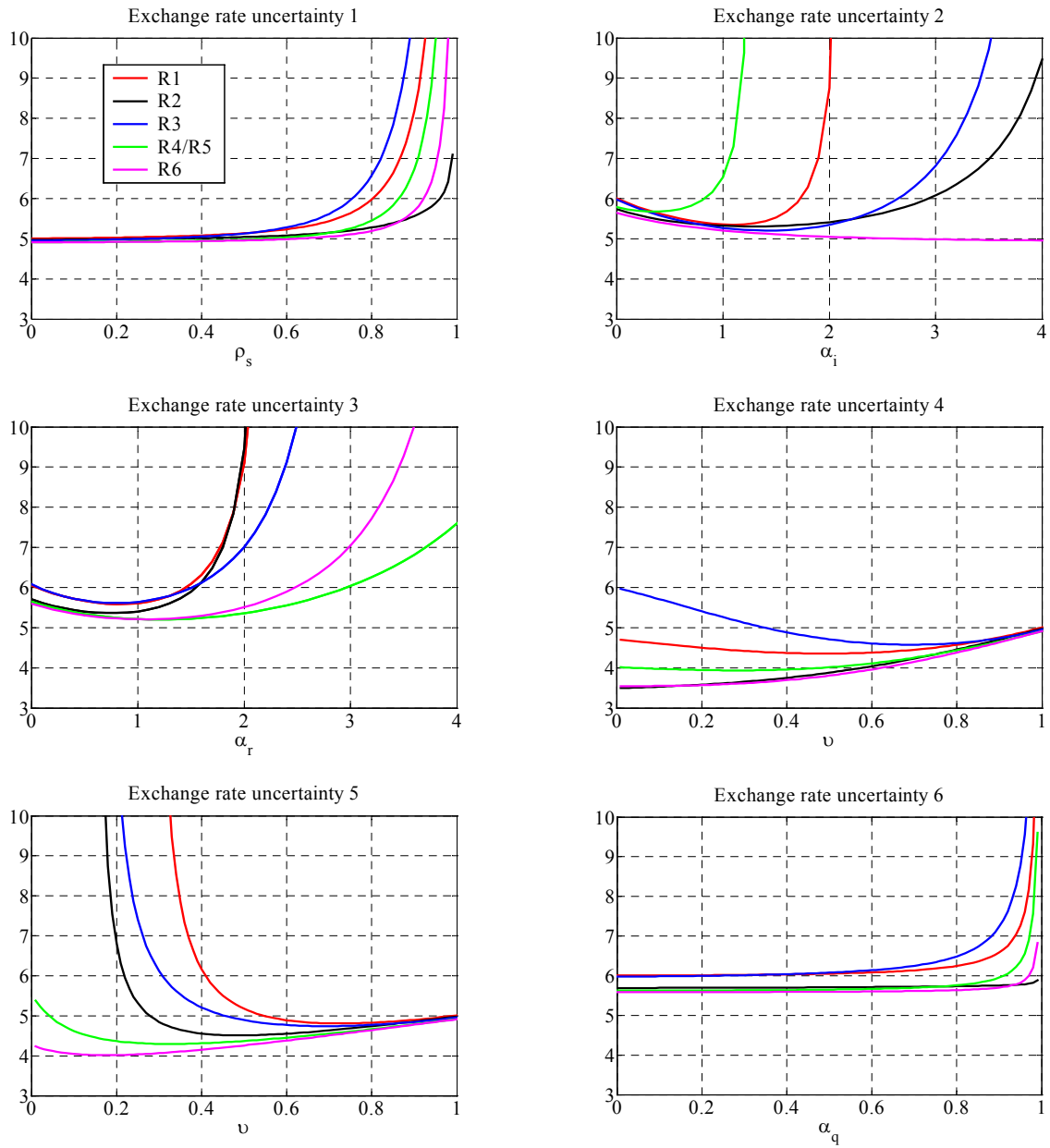




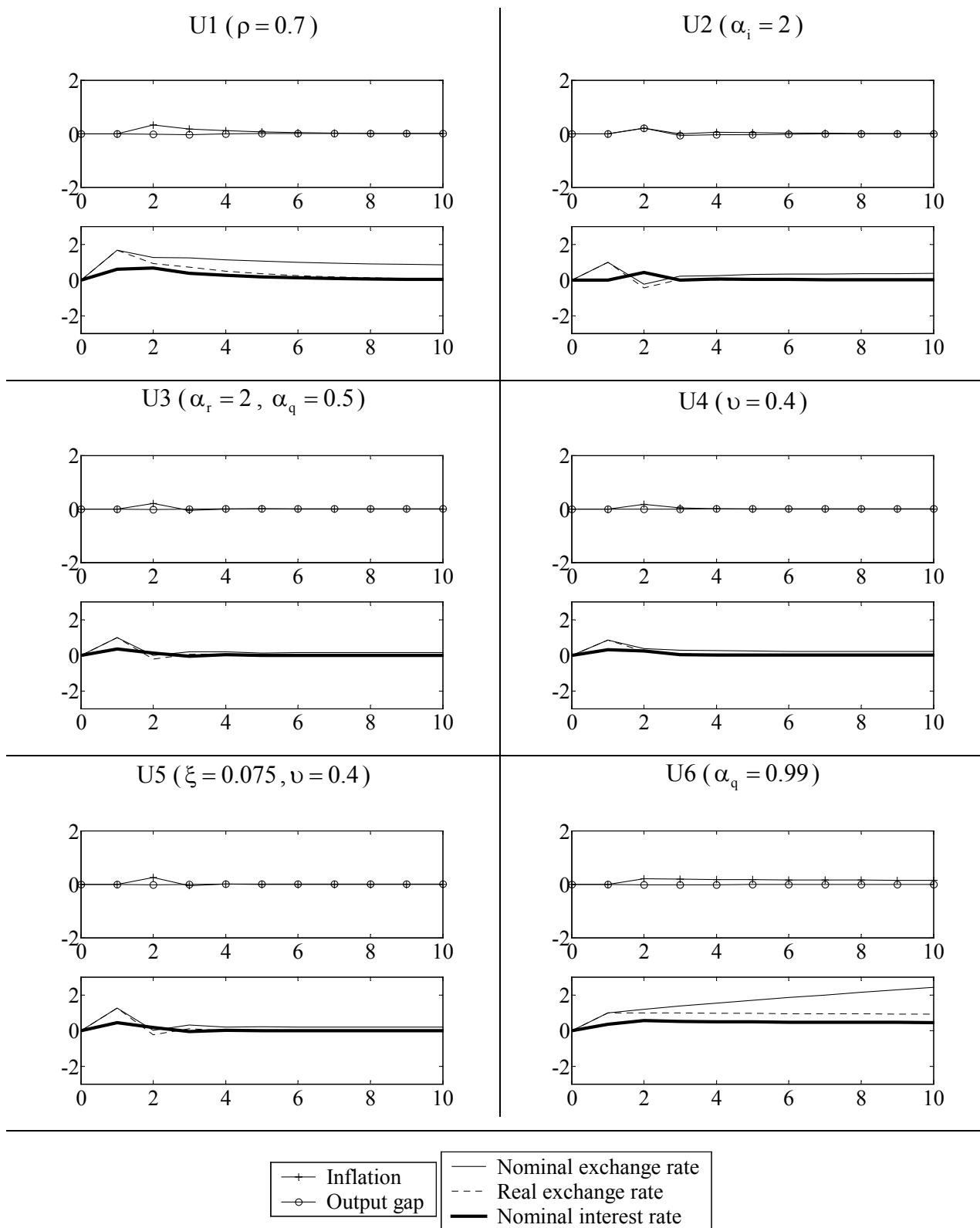
**Figure 2: Impact of a unit shock to the exchange rate equation under the assumption that the central bank follows R1**



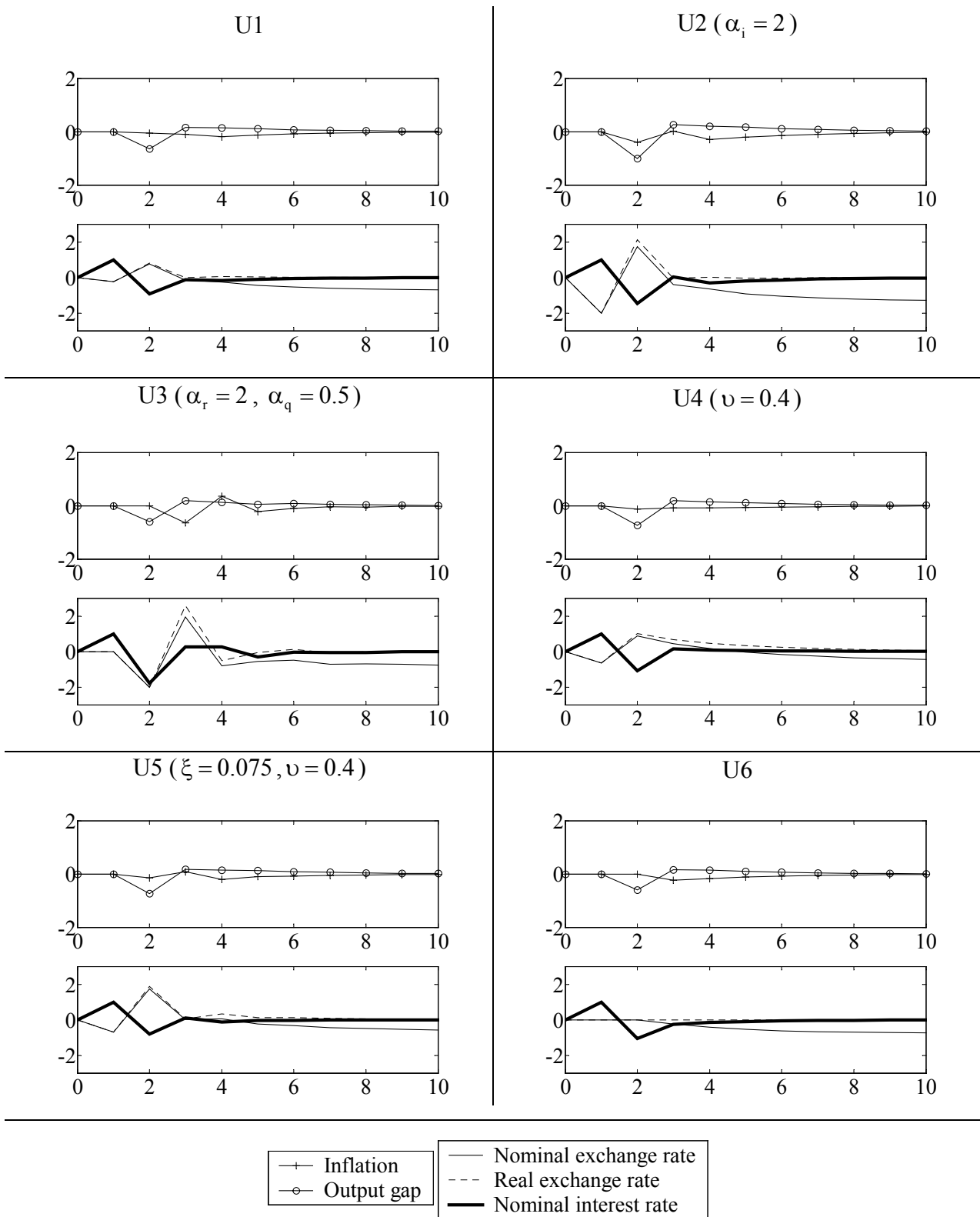
**Figure 3: Transmission of a unit interest rate shock with uncertainty about the true exchange rate model**



**Figure 4: Performance of the policy rules under exchange rate uncertainty**



**Figure 5: Impact of a unit shock to the exchange rate equation under the assumption that the central bank follows R6**



**Figure 6: Transmission of a unit interest rate shock with uncertainty about the true exchange rate model**