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Fernando Alexandre

John Difrill

Fabio Spagnolo

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Inflation Targeting and Exchange Rate Co-ordination

Fernando Alexandre,[*] John Driffill[†]and Fabio Spagnolo[‡]

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Abstract

In a linear rational expectations two-country model, using an aggregate demand-aggregate supply framework, we analyze the effects of the adoption of an inflation targeting regime on exchange rate volatility and the possible scope for policy coordination. This analysis is conducted using optimized interest rate policy rules within a calibrated model. Rules for interest rates that respond either to exchange rates or to portfolio shocks give improved performance and permit gains from international coordination. Optimized Taylor Rules perform relatively well.

Key Words: Inflation Targeting; Taylor Rule; Exchange Rate Coordination; Rational Expectations;

JEL Classification: E17; E52; E61; F42.

[*]Department of Economics, Birkbeck College and University of Minho (email: falexandre@econ.bbk.ac.uk)

[†]Department of Economics, Birkbeck College (email: jdriffill@econ.bbk.ac.uk)

[‡]Department of Economics, Birkbeck College (email: fspagnolo@econ.bbk.ac.uk)

1 Introduction

Inflation targeting has become part of the new orthodoxy on monetary policy. The ingredients are delegation of monetary policy to an independent central bank, use of short-term interest rates as the instrument of policy, inflation targeting, and floating exchange rates. Individual countries set interest rates independently to meet their own inflation targets; there is no coordination of policies among countries. This appears to have become a successful recipe for macroeconomic management, at least in so far as inflation has been low in most of the developed world from the mid-1990s, there has been growth in some countries, most obviously the US, and exchange rate fluctuations have been the cause of only moderate and intermittent concerns. International coordination of economic policy is conspicuously almost completely absent from the agenda, both among policy makers, and in the scholarly world.[1]

There is an interesting contrast to be drawn between this new millenial orthodoxy and the one that prevailed around twenty years ago. Then floating exchange rates ruled, but the nominal anchor was to be provided by control of the money supply. Whether because the economic conditions of the times were more agitated, or whether because control of monetary aggregates was a less good model for policy, exchange rates were highly volatile in the early 1980s. The swings in the value of the major currencies were the cause of great concern, provoked policy intervention, and stimulated much scholarly analysis. The then young CEPR made international economic policy coordination one of the themes of its research programme in international macroeconomics[2].

The arguments in favour of policy coordination made at that time were based on there being spillovers of the effects of policy between countries under floating exchange rates. Countries responding independently to a common adverse supply shock would be inclined to rely on the exchange rate appreciation induced by a tightening of monetary policy. The overall result was likely to be too much monetary tightening. In other circumstances, in response to other shocks, independent, uncoordinated policy actions might be too weak. Coordinated actions by

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[1]Coordinated policy actions are sporadic. There was concerted intervention to support the Euro in autumn 2000. There has been concern about the effects of the value of the Yen on Japanese recovery prospects, but no real action.

[2]Some of the results of the research were published in Buiter and Marston (1994). Later Canzoneri and Henderson (1991) produced a synthesis and overview of the subject.

all countries are able in principle to achieve better results for all.

It remains true under a policy that uses setting of short-term interest rates to achieve an inflation target in an environment of floating exchange rates that the spillover effects remain. One of the principle channels of policy transmission in open economies is the exchange rate effect on the consumer price index of an interest rate change. Nevertheless there has been relatively little discussion of international coordination of policy to date. This may be because exchange rate volatility is more generally accepted now than it was twenty years ago. In fact exchange rates are currently much less volatile than they were then. It may be because the earlier literature concluded that the gains to be had from coordination were modest.

There has been extensive analysis of inflation targeting in open economies, for example Ball (1999), Svensson (2000) and Sutherland (2000). Indeed, most of the inflation targetters are small open economies. But there has been little on coordination. The idea of introducing policy responses to asset price bubbles has been mooted by Checchetti et al (2000), largely in response to movements in stock prices and real estate, the US stock market, Japan, South East Asia, and so on, with passing observations on exchange rates.

Against this background, the purpose of this paper is to explore possible effects of coordination of policy among countries that target inflation using interest rates as instruments of policy. While the principal explicit inflation-targetters are small open economies – New Zealand, Canada, Sweden, the United Kingdom, Australia, Spain – we have modeled a world of just two identical economies.

Our analysis is developed using an aggregate demand-aggregate supply framework that combines features of the widely used New Keynesian model of output and inflation with open-economy effects. In our analysis we will take the view of Batini and Haldane (1999) and McCallum and Nelson (1999b), among others, who describe as an inflation targeting strategy the use of a simple monetary policy rule that sets the policy instrument as a function of the deviations of the inflation forecast, for a defined horizon, from the target. In our analysis that implies that the monetary authorities use an inflation forecast monetary policy rule – the policy instrument reacts to deviations of expected inflation from target – to minimize an expected loss.

Using simulation analysis, the questions we try to answer, in the context of our linear rational expectations model, are these. What happens to exchange rate volatility when either or both countries change from a regime where policymakers react directly to deviations of inflation and output from target to an inflation forecast rule? Does adding a response to the exchange rate directly or to a portfolio shock reduce exchange rate volatility and improve economic performance? Does the establishment of some sort of co-ordination between countries result in a

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better outcome for the exchange rate stability and welfare?

Before developing a model, however, we turn to data on inflation and exchange rates for a number of inflation targetters, to review briefly the various experiences of these countries, and to provide a little more empirical context for the analysis of policies.

2 A Brief Review of Recent Experience

In order to review briefly the experiences that countries have had under inflation targeting and alternative frameworks for monetary policy, Figures 1 to 4 show the paths of the inflation rate and the trade-weighted exchange rate for eight countries: Australia, Canada, Finland, Germany, New Zealand, Spain, Sweden, and the United Kingdom. The data run from 1985 to 2000, and cover periods in which these countries have employed a variety of different frameworks for monetary policy, and have taken part in a variety of exchange rate regimes. The figures show, in addition to the economic data, a line labelled "filter probabilities – regime 1". This refers to an estimated division of the data into two "regimes" based on the mean and variance of each series. The procedure for estimating the regimes is set out in detail in the appendix. It allows for a data-determined division of the data into (for example) high variance and low variance periods.

New Zealand was one of the first countries to adopt inflation targeting, following the Reserve Bank Act of 1989. Figure 2 shows that for New Zealand's inflation there was a fairly clear change of regime in 1990. In fact the mean and the variance of inflation fell at that time. The adoption of inflation targeting has (at least superficially) been successful in this respect. Figure 4 shows that there was concurrently a change in regime for New Zealand's exchange rate. Its volatility fell significantly. New Zealand's experience may suggest that inflation targeting might be capable of achieving both greater price stability and greater exchange rate stability.

The experience of Sweden has been very different. Sweden adopted inflation targeting after the succession of speculative attacks on the Exchange Rate Mechanism of the European Monetary System in 1992, after which its exchange rate been floating, so it is unsurprising that the volatility of Sweden's exchange rate rose at the end of 1992. The visual impression of the data is confirmed by the estimated pattern of regimes, with a clear shift to a high volatility regime at the end of 1992. Nevertheless, the mean and variance of Sweden's inflation have fallen, though more slowly, since the introduction of inflation targeting.

Canada exhibits a yet different pattern. While Canadian inflation fell in 1991, a visual impression confirmed by the estimated division of the data in Figure 1 into two regimes, with

a switch in 1991, the volatility of the exchange rate has been more or less unchanged. The adoption of inflation targets in Canada in 1991 has been associated with lower and more stable inflation.

Space does not permit a full discussion of the eight cases illustrated in the figures. This very brief sketch is intended to serve as a reminder that the experiences of the small open economies that have adopted inflation targeting have been very varied and affected by numerous conditions specific to each country. The data suggest that the adoption of inflation targeting has not been associated with systematically more or less variable exchange rates than the regime that preceded it. This may explain the relative lack of concern in policy circles about exchange rate coordination. Most countries in the mid 1990s achieved lower and less variable inflation. The data do not throw any light on the issue of whether coordinated responses to exchange rate movements could allow countries to achieve better outcomes in terms of exchange rate, output, and employment volatility, without prejudicing inflation performance. Of course this review of the data does not enable causal connections to be inferred. We turn now to a simulation analysis of whether coordinated policy might be able to offer better outcomes.

3 Description of the Model

The analysis is conducted in an aggregate demand and aggregate supply framework that contains elements of the widely used New Keynesian model of output and inflation, combined with open-economy effects. This framework has emerged, in the last decade, as broadly consensual and highly useful in the analysis of monetary policy rules (see, for example, Rudebusch: 2000; Taylor: 1999). As argued by Ball (1999), one advantage of this framework is its simplicity and realism in the description of the monetary transmission mechanism.

The model has the following structure:

$$y_t = \alpha_1 E_t y_{t+1} - \alpha_2 r_t + \alpha_3 q_{t-1} + \alpha_4 y^*_{t-1} + \alpha_5 y_{t-1} + v_t + z_t \tag{1}$$

$$y^*_t = \alpha_1 E_t y^*_{t+1} - \alpha_2 r^*_t - \alpha_3 q_{t-1} + \alpha_4 y_{t-1} + \alpha_5 y^*_{t-1} + v^*_t + z_t \tag{2}$$

$$\pi_t = \beta_1 \pi_{t-1} + (1 - \beta_1) E_t \pi_{t+1} + \beta_2 y_{t-1} + \beta_3 (q_t - q_{t-1}) + \epsilon_t + \eta_t \tag{3}$$

$$\pi^*_t = \beta_1 \pi^*_{t-1} + (1 - \beta_1) E_t \pi^*_{t+1} + \beta_2 y^*_{t-1} - \beta_3 (q_t - q_{t-1}) + \epsilon^*_t + \eta_t \tag{4}$$

$$r_t = r^*_t + E_t q_{t+1} - q_t + \xi_t \tag{5}$$

$$r_t = i_t - E_t \pi_{t+1} \tag{6}$$

$$r^*_t = i^*_t - E_t \pi^*_{t+1} \tag{7}$$

$$\xi_t \;=\; \psi\xi_{t-1} + \theta_t \tag{8}$$

All the variables in the model are log deviations around the steady state, with the exception of nominal interest rates that are in levels. Variables with an asterisk (*) refer to the foreign economy.

Equations (1) and (2) are dynamic IS curves, of the kind derived by McCallum and Nelson (1999a), with open-economy elements. These authors show that the IS curves can be derived as the linear reduced-form of a fully optimising general equilibrium model. They include a leading term for output that captures the effects of expected income on today's spending. This feature of the IS specification is particularly important in our model, where today's shocks to the foreign economy can be passed through expectations of today's home income. The inclusion of lagged output on the right-hand side of the IS equations, although its theoretical derivation is less clear-cut, is widely agreed to account for adjustment costs that result in some output inertia observable in the data. However, at this stage we set $\alpha_5 = 0$.

Output also depends negatively on the interest rate, and positively on a currency depreciation, in the usual way. The exchange rate is defined as the price of foreign currency in terms of domestic money, such that an increase in q represents a real depreciation of the domestic currency. The inclusion of the foreign country income in the IS curve of each country reflects the 'locomotive' effect of one country on the other. Finally, white noise shocks to the IS curve are considered, ν (ν^*) the country-specific demand shock and z the common shock.

Equations (3) and (4), representing the supply side of the economy, are open-economy Phillips curves. The inclusion of expected and lagged inflation on the right-hand side of the inflation equation, in the New Keynesian form, is strongly supported by several authors (Svensson: 1999; Ball: 1999; McCallum: 1997). The dependence of inflation on its own lagged value, reflects inflation persistence, which may result from elements of backward-lookingness in the wage-setting process (see Batini and Haldane:1999; Fuhrer and Moore: 1995). However, there is no agreement on the degree of inflation persistence (see section on calibration). Inflation also depends on the output gap with a lag. Additionally, the inflation equations include an open-economy term as in Ball (1999). Inflation depends on the lagged change in the exchange rate because changes in exchange rates are passed directly to inflation via the price of imported goods.[3] Finally, ε (ε^*) represents the country-specific supply shock and η the common shock. These shocks are assumed to be white noise.

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[3]Ball (1999) shows that aggregate inflation can be represented as a weighted average of domestic and imported inflation, with weights given by the share of imports and domestic goods in the price index. The inflation rate depends on changes in the exchange rate, which directly influences import prices that enter the definition of the

Equation (5), the uncovered interest parity (UIP), is expressed in terms of real exchange rates. This condition includes a term, ξ, that can be interpreted as a portfolio shock, assumed to follow an auto-regressive process of order one, as in equation (8).

Equations (6) and (7) represent the Fisher identity linking the real interest rate, the nominal interest rate and the expected inflation rate. It is required because central banks can only control nominal interest rates, i, but consumption and investment decisions, and therefore aggregate demand, are based on the *ex ante* real interest rate.

The policy of the monetary authorities is modelled by interest rate rules (see section on optimised policy rules). Thus the LM curve is redundant; the demand for money is always accommodated at unchanged interest rates.

4 The monetary transmission mechanism in the model

Because the model's lag structure is fundamental to the analysis to be performed below, the operation of the monetary transmission mechanism is worthy of some words of explanation. An open economy differs from the closed economy case because of the existence of an additional channel: the exchange rate. In a closed economy the real interest rate is the only channel from monetary policy to the real economy and prices. This channel is captured in our simple model in the following way. An increase in the domestic interest rate, for instance, changes the real interest rate, raising the cost of capital, and thereby causing a move in aggregate demand – equation (1). This change in aggregate demand is then transmitted to inflation through the output gap term - equation (3). In this model there is the additional channel of exchange rates, which can work in two different ways: first, indirectly through its effect on exports and consequent impact on the output gap. Second, there is a direct effect of exchange rates changes on inflation through their effect on the cost of imported products. The exchange rate also has an important role in the transmission of shocks between countries.

Given the described lag structure, monetary policy affects the country's current output and it affects inflation with one lag, through the traditional real interest rate channel, in accordance with the empirical evidence that monetary policy affects output more rapidly than inflation.

Consumer Price Index (CPI) in the following way,

$$\pi = \Gamma \pi^{\mathsf{d}} + (1 - \Gamma)\pi^{\mathsf{m}}$$

That is, aggregate inflation is an average of the domestic, π^{d}, and import, π^{m}, inflation and where $(1 - \Gamma)$ is the weight of import goods in the price index.

And, via the exchange rate channel, it affects current inflation directly and indirectly, through its effect on exports demand, with two lags.

5 Calibration of the model

The parameter values draw upon the work of several authors mentioned below. There is a lack of consensus in the literature concerning the values that the parameters should take.

One of the most uncertain parameters in this model is the inflation persistence coefficient, β_1. As mentioned above, although the value of this parameter is not theoretically clearly determined, the existence of adjustment costs and overlapping price and wage contracts make it realistic to assume some inflation persistence. Rudebusch (2000) refers to several studies (Fair: 1993; Fuhrer: 1997; Chadha et al: 1992; Brayton et al: 1997), and concludes that a plausible range for β_1 would be [0.4,1]. In view of the range of plausible values for β_1 we perform sensitivity analysis below.

Although there is some empirical evidence supporting the inclusion of lagged output in the IS equation, the uncertainty surrounding an appropriate value and the fact that there is no agreement on its theoretical derivation, leads us to set $\alpha_1 = 1$ and $\alpha_5 = 0$, as suggested by McCallum and Nelson (1999a).

Another highly uncertain parameter is the real interest rate coefficient, α_2. Batini and Nelson (2000) note that its value varies widely in studies of policy rules: for quarterly data, it ranges from 0.2 in Estrella and Fuhrer (1998) and McCallum and Nelson (1999b), to 6 in Rotemberg and Woodford (1999). Although such a wide range invites sensitivity analysis, we follow Ball (1999) and set $\alpha_2 = 0.6$.

The open-economy coefficients, α_3, α_4 and β_3, and their foreign economy counterparts, depend on the economies' degree of openness. The coefficient β_3 should reflect the weight of imported prices in the CPI. Again, we follow Ball (1999) and we set α_3 and β_3 equal to 0.2. The effect of lagged output on the other country's demand, given by α_4, is related to exports. We set it equal to 0.1.

The parameter on the output gap in the inflation equation is set equal to 0.4, as in Ball (1999). The autoregressive parameter in the portfolio shock is assumed to be equal to 0.8.

Demand Equation	Supply Equation
$\alpha_1 = 1$	$\beta_1 = 0.9$
$\alpha_2 = 0.6$	$\beta_2 = 0.4$
$\alpha_3 = 0.2$	$\beta_3 = 0.2$
$\alpha_4 = 0.1$	

We assume that shocks to output, exchange rates and inflation have all a variance of 1[4].

6   Loss function and simple policy rules

6.1   The welfare function

In the search for policy parameters we assume that policy makers seek to minimize the expected value of a loss function that is given by a weighted sum of the unconditional variances of output, inflation and the policy instrument:

$$E[L_t] = Var[\pi_t] + \omega_1 Var[y_t] + \omega_2 Var[i_t - i_{t-1}] \qquad (9)$$

The same weight is given to the variance of output and inflation, with $\omega_1 = 1$, and only half of this weight is given to the interest rate volatility term, $\omega_2 = 0.5$, following Rudebusch and Svensson (1999) and Rudebusch (2000). The inclusion of an interest rate smoothing term in the expected loss reduces volatility of the policy instrument. Weerapana (2000) mentions that, in the context of an open economy, the non-inclusion of an interest rate volatility term would generate considerable fluctuations in interest rates as the policy makers use them to eliminate the negative effects of exchange rates. On the other hand, Woodford (1998) provides arguments for the smoothing of interest rates, based on the idea that high interest rate volatility may damage the policy makers' credibility.

6.2   Classes of optimized policy rules

We consider five different classes of optimized simple interest rate policy rules. The exclusive use of interest rate rules for policy rests on the evidence that virtually all industrialized countries' central banks use some short-term (nominal) interest rate as their policy instrument (Walsh: 1998). Simple rules can have some advantages when compared to optimal rules, as argued

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[4]When calculating the optimal policy parameters we varied those variances, and the results appeared fairly robust.

by Batini and Haldane (1999), in the context of forward-looking rules. First, simple rules can be more robust in the presence of uncertainty about the actual model of the economy, as is always the case, than optimal rules that are functions of all predetermined state variables of the model (Taylor, 1999). Second, simple rules, when including forward-looking variables, can perform almost as well as optimal rules in output and inflation stabilization, and still enhance transparency and make the central bank more accountable resulting, therefore, in higher credibility. Finally, as emphasized by Ryan and Thompson (2000), and very importantly in the context of our work, simple rules allow experiences with different aspects of the monetary policy operating framework. However, because they do not use all the information available they will not in general be optimal (see Black et al: 1997).

The different classes of optimized simple rules we analyze are: an optimized Taylor rule, an optimized Taylor rule with an exchange rate term, an optimized forward-looking rule, an optimized forward looking rule with an exchange rate term and an optimized forward looking rule with a portfolio shock.

6.2.1 Optimized Taylor Rule

The best-known example of a simple rule is the Taylor rule, after Taylor (1993), in which the interest rate reacts to deviations of output and inflation from the target:

$$i_t = \lambda_1 y_t + \lambda_2 \pi_t \tag{10}$$

$$i_t^* = \rho_1 y_t^* + \rho_2 \pi_t^* \tag{11}$$

The main arguments for Taylor rules rest on their simplicity, with the transparency and accountability that the central bank gains thereby, and on the fact that they describe actual monetary policy in several countries since the mid eighties (see, for example, Taylor: 1993). Hereafter these rules will be referred to as OTH and OTF for the home and foreign economies, respectively.

6.2.2 Optimized Taylor rule for an open-economy

Ball (1999), extending the Svensson (1997) and Ball (1997) model to an open economy, concludes that inflation targets and Taylor rules are sub-optimal; different rules are required because monetary policy affects the economy through the exchange rate as well as through interest rate channels. Therefore one might study the case of a policy rule that adds an exchange rate term

to the Taylor rule. This is equivalent to the use of a 'Monetary Conditions Index'[5] (an 'MCI')
as an instrument rule, that is, a weighted sum of the interest rate and the exchange rate:

$$i_t = \lambda_1 \pi_t + \lambda_2 y_t + \lambda_3 q_t \tag{12}$$

$$i_t^* = \rho_1 \pi_t^* + \rho_2 y_t^* - \rho_3 q_t \tag{13}$$

Hereafter these will be referred as OTQH and OTQF, respectively.

6.2.3 Forward-looking policy rule

Countries like New Zealand, Canada and the United Kingdom, as well as other inflation targeters,
base their monetary policy explicitly on inflation forecasts, using them as an intermediate target
(see Svensson: 1997; Batini and Haldane: 1999). Therefore, the behaviour of inflation targeters
might be better described by the following simple forward-looking monetary policy rule:

$$i_t = \gamma E_t \pi_{t+j} \tag{14}$$

$$i_t^* = \delta E_t \pi_{t+j}^* \tag{15}$$

where i is the policy instrument and γ is the feedback parameter; $E_t \pi_{t+j}$ is the expected value
for inflation in period $t + j$, conditional on the information at time t; and j defines the targeting
horizon with its length determined by the lags in monetary policy and the role given to goals
other than inflation. In our analysis, and given the lag structure of our model, we assume that
central banks set nominal interest rates in response to deviations of the inflation forecast one
period ahead from the target, therefore $j = 1$. These rules will be referred to as FWH and
FWF, for the home and the foreign economy, respectively, hereafter.

Svensson (1997) suggests that inflation forecasts should be seen as an intermediate target
in inflation-targeting regimes, in the sense that policy makers react to expected inflation in
order to attain the inflation target. In that sense, Batini and Haldane (1999) mention its
good performance when it is evaluated on the criteria for a good intermediate target[6]. First,
because inflation forecasts use all the information available - including lags in the transmission of
monetary policy - they are by definition the variables most closely correlated with the inflation
target and an adequate guide to the state of the economy. Secondly, because in their construction

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[5] A MCI emphasises the fact that monetary policy, in an open economy, has two main channels that affect
aggregate demand - interest and exchange rates - and that when changing interest rates its effects on the exchange
rates must be considered.

[6] The requirements of any intermediate target are: controllability, predictability and to be a good policy guide.

they encompass all the lags in the transmission of monetary policy, they are highly controllable by policy makers.

6.2.4 Forward-looking rule with an exchange rate term

In this specification the policy makers react not only to deviations of expected inflation from target but also to deviations of the exchange rate from its long run equilibrium:

$$i_t = \gamma_1 E_t \pi_{t+1} + \gamma_2 q_t \tag{16}$$

$$i_t^* = \delta_1 E_t \pi_{t+1}^* - \delta_2 q_t \tag{17}$$

The inclusion of an exchange rate term rests on the argument set forth in Cecchetti et al (2000) that "central banks can improve macroeconomic performance by reacting systematically to asset prices, over and above their reaction to inflation forecasts and output gaps." In our open economy model, because exchange rate fluctuations affect aggregate spending, through the export demand channel, and CPI through import prices, the reaction of the policy instrument to exchange rate deviations from its equilibrium level can then be justified on the argument that it could help in output and inflation stabilization. Hereafter, these rules are referred as FWQH and FWQF, respectively.

6.2.5 Forward-looking rule with a portfolio shock

Some authors, (see, for example, Smets: 1997; Freedman: 2000; and Cecchetti *et al*: 2000) argue that interest rates should offset exchange rate movements only when they result from portfolio adjustments. In their study on asset prices and monetary policy, Cecchetti *et al* (2000) claim that because a portfolio shock to the exchange rate can have long lasting effects on output and prices and therefore destabilize the economy, central banks should systematically react to it. Thus, we will consider policy rules where the monetary authorities react to a portfolio shock to the exchange rate (FWSH and FWSF, respectively, hereafter):

$$i_t = \varphi_1 E_t \pi_{t+1} + \varphi_2 \xi_t \tag{18}$$

$$i_t^* = \varkappa_1 E_t \pi_{t+1}^* - \varkappa_2 \xi_t \tag{19}$$

7 Solving the Model

Our multivariate linear rational expectations model is written in the Blanchard-Kahn form (Blanchard and Kahn: 1980) and then solved using the procedure described in Soderlind (1999), applying a Schur decomposition to the coefficient matrix[7].

The reduced-form solution of the model is of the form

$$X_{t+1} = BX_t + C\varepsilon_{t+1} \tag{20}$$

and the variance-covariance matrix of X, denoted by V, is given by,

$$vec(V) = [I - (B \otimes B)]^{-1} vec(\Omega) \tag{21}$$

where $\Omega = CV(\varepsilon)C'$[8]. The variance-covariance matrix of the shocks is the identity matrix in line with the specification above.

7.1 Non-cooperative and cooperative behaviour by policy makers

In our analysis, we consider both non-cooperative or cooperative behaviour among policy makers.

In the case of non-cooperative behaviour, parameter values are determined by looking for a Nash equilibrium in policy rules. We assume that each country knows the other's policy rule and optimizes taking it as given. Thus, for example, the domestic policy maker chooses optimal policy parameters (via a grid search), taking as given the policy rule of the foreign country. Knowing (and taking as given) the policy rule of the domestic policy maker, the foreign policy maker then adjusts his own policy rule in order to minimize his loss function. This process is iterated until convergence is attained.

In the co-operative case, we use again a grid search procedure to find the optimal policy parameters. But now it is assumed that the choice is made jointly with the objective of minimizing their joint loss function

$$E[L_t] = Var(y_t) + Var(y_t^*) + Var(\pi_t) + Var(\pi_t^*) + 0.5Var(\Delta i_t) + 0.5Var(\Delta i_t^*) \tag{22}$$

which is a sum of the individual countries' loss functions, reflecting the assumption of symmetry.

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[7]We ran all the programs in Gauss and used the implementation of the Schur decomposition made available by Soderlind at http://www.hhs.se//personal/psoderlind.

[8]See Hamilton (1994), page 265.

8   Sensitivity Analysis

Given the high degree of uncertainty surrounding some of the model's parameters, especially the inflation persistence coefficient, we computed optimal policy rules for different values of the coefficients, and examined the behaviour of the model. Following Rudebusch (2000), who defines [0.4,1] as a plausible range for β_1, we explored the consequences of assuming that β_1 takes extreme values of the range, $\beta_1 = 0.4$ and $\beta_1 = 0.9$, and also an intermediate value, $\beta_1 = 0.6$.

To find the optimal values of the policy parameters we perform grid search over a wide range of possible values and choose those that minimize the expected loss function. We look for the optimal parameters λ_1, λ_2, and ρ_1, ρ_2, of the Taylor rule; and, γ and δ, of the forward-looking policy rules, as set out in equations (10), (11) and (14), (15). In equilibrium they will be the same for both countries.

In the table below we present the resulting optimal policy parameters and the expected losses for different degrees of inflation persistence.

	Optimised Taylor Rules			Inflation Forecast Rule	
Inflation persistence	$\lambda_1 = \rho_1$	$\lambda_2 = \rho_2$	Loss	$\gamma = \delta$	Loss
$\beta_1 = 0.9$	2.2	1.3	9.086	2.0	9.462
$\beta_1 = 0.6$	1.9	1.3	8.681	2.3	8.769
$\beta_1 = 0.4$	1.6	1.3	7.439	2.6	7.641

We can conclude that the optimal policy parameters and the expected loss vary considerably with the degree of inflation persistence. For both classes of policy rules welfare increases with lower inflation persistence. The inflation reaction parameter in the Taylor rule increases with inflation persistence, reflecting the need for tougher policy reactions once inflation deviates from its steady state value. The forward-looking parameter decreases with the degree of inflation persistence.

Given the high sensitivity of our results to the degree of inflation persistence, our results should be interpreted with caution. Despite the controversy as to the most likely figure, we assume a high level in our analysis, setting $\beta_1 = 0.9$.

9   Inflation targeting and exchange rate volatility

In this section we examine the effects on exchange rate volatility of changing from a regime where policy makers react directly to deviations of inflation and output from the target to an inflation

targeting regime, by one or both countries. We make this assessment for policy rules that react to domestic output and inflation and then for policy rules that also include an exchange rate term (see section on optimized policy rules).

Although some authors, for example Rudebusch and Svensson (1999), see inflation targeting as a monetary regime in which central bankers pursue an optimization exercise of a welfare function that penalizes deviations from the inflation target, we take the other view. Following Batini and Nelson (2000) and McCallum and Nelson (1999b), among others, an inflation targeting regime is defined as one in which the policy instrument reacts to deviations of expected inflation from target, for a given horizon. The performance of this rule will be compared with that of a regime where one or both countries follow a Taylor rule, reacting to deviations of output and inflation from the target, with and without an exchange rate term. Therefore, in this section, we analyze the effects on the volatility of the exchange rate when both countries change from a regime in which they react to output and inflation to an inflation targeting regime; and what happens if one country changes to a strict inflation targeting regime and the other keeps reacting to both inflation and output.

9.1   Policy rules without an exchange rate term

We assume here that policy makers do not react to exchange rate movements, in this sense behaving as if they were in a closed economy. We compare three scenarios. In the first scenario, both countries use an optimized Taylor rule (OTH/OTF). The policy rules are set out in equations (10) and (11) above. In the second scenario, the home country uses a rule based on an inflation forecast, while the foreign country continues to use an optimized Taylor rule (FWH/OTF). The rules are as set out in equations (14) and (11) above. And in the third scenario, both countries use policy rules based on inflation forecasts (FWH/FWF), as set out in equations (14) and (15) above. The parameters of the optimal rules are calculated assuming non-cooperative behaviour, employing the grid search procedure described in section 7 and are presented below in Table 1.

Table 1.   Optimal Parameters in Policy Rules

	OTH and OTF	FWH and OTF	FWH and FWF
Home	$\lambda_1 = 2.2; \lambda_2 = 1.3$	$\gamma = 2$	$\gamma = 2$
Foreign	$\rho_1 = 2.2; \rho_2 = 1.3$	$\rho_1 = 2.2; \rho_2 = 1.3$	$\delta = 2$

We compute the unconditional variance of the variables of the system in each of the three scenarios set out above, and we compute also the value of the loss functions for each case. Table

15

2 below contains the results.

Table 2.   Measures of macroeconomic performance under alternative policy rules.

	OTH and OTF	FWH and OTF	FWH and FWF
Var(i)	5.368	5.339	5.420
Var(i*)	5.368	5.388	5.420
Var(y)	3.283	3.894	3.898
Var(y*)	3.283	3.321	3.898
Var(π)	3.506	3.363	3.400
Var(π^*)	3.506	3.544	3.400
Var(q)	4.831	5.584	6.682
L	9.087	9.395	9.463
L*	9.087	9.138	9.463

When the home country alone changes from an optimized Taylor rule to an inflation targeting regime we have a higher volatility of output in both countries and a higher exchange rate volatility.   In this case, we do not have significant changes in the volatility of the policy instrument (the interest rate), and there is a decrease in the volatility of domestic inflation and an increase in the volatility of foreign inflation. The most relevant features of this case are the higher exchange rate variance and the negative spillover effects to the foreign country, which maintains the Taylor rule.

Comparing scenario 3, in which both countries change to an inflation targeting regime, to scenario 1, in which both use a Taylor rule, there is a higher volatility of the nominal interest rate and output and a lower inflation variance. A change to an inflation targeting regime by both countries produces higher exchange rate volatility, just as does a unilateral switch by the home country.

Another outcome of our simulations, in both cases, is that the adoption of an inflation targeting regime worsens the loss function of both countries. In Table 2 we present the values of the expected loss under different combinations of policy rules, with the optimal coefficients determined non-cooperatively, and use those values to compute pay-off matrices in Table 3 below.

Table 3. Payoff Matrix for a Game in policy rules

without Exchange Rate Response

Foreign→	Taylor rule		Forward rule	
Home↓	Domestic	Foreign	Domestic	Foreign
Taylor rule	9.087	9.087	9.138	9.395
Forward rule	9.395	9.138	9.463	9.463

In this case, where both countries do not react directly to the exchange rate, we can conclude that a strategy where both countries follow a Taylor rule is a Nash equilibrium.

9.2 Policy rules with an exchange rate term

Until now our analysis has ignored any possible reactions of policy makers to exchange rate movements. However, as mentioned above, in an open economy monetary policy has the extra channel of the exchange rate and, therefore, it maybe that including an exchange rate term improves macroeconomic performance. Thus we examine the properties of the system when policy makers react to the exchange rate. Their concern with exchange rate movements results exclusively from their individual welfare maximization. At this point we do not introduce coordinated responses to exchange rate movements. Again three scenarios are considered, as follows.

When both countries use optimized Taylor rules with an exchange rate term (OTQH/OTQF) the rules are as in equations (12) and (13) above. When only the home country uses an inflation forecast rule with an exchange rate term while the foreign country uses an optimized Taylor rule with an exchange rate term (FWQH/OTQF) the rules are given by equations (16) and (13). And when both countries use inflation forecast rules with exchange rate terms (FWQH/FWQF), the rules are (16) and (17).

Again, the optimal policy parameters are computed for the different cases and regimes assuming that policy makers behave non-cooperatively. The rules are presented below in table 4.

Table 4. Parameter values of optimal policy rules, rules including response to exchange rate

	OTQH vs. OTQF	FWQH vs. OTQF	FWQH vs. FWQF
Home	$\lambda_1 = 2; \lambda_2 = 1.1; \lambda_3 = 0.2$	$\gamma_1 = 1.8; \gamma_2 = 0.2$	$\gamma_1 = 1.83; \gamma_2 = 0.16$
Foreign	$\rho_1 = 2; \rho_2 = 1.1; \rho_3 = 0.2$	$\rho_1 = 2.1; \rho_2 = 1.8; \rho_3 = 0.2$	$\delta_1 = 1.83; \delta_2 = 0.16$

The resulting unconditional variance of the variables of the systems are set out below in table

5.

Table 5. Performance Measures under alternative policy combinations
with rules that respond to the exchange rate (q).

	OTQH and OTQF	FWQH and OTQF	FWQH and FWQF
Var(i)	5.005	5.198	5.800
Var(i*)	5.005	4.980	5.800
Var(y)	3.300	3.602	3.680
Var(y*)	3.300	2.450	3.680
Var(π)	3.605	3.489	3.650
Var(π^*)	3.605	4.645	3.650
Var(q)	3.967	4.297	8.663
L	9.009	9.415	9.447
L*	9.009	9.122	9.447

A change by the home country to inflation targeting with an exchange rate term, while the other country continues to use an optimized Taylor rule (with an exchange rate term), results in lower volatility of its inflation and in higher volatility of the policy instrument (the interest rate), output and the exchange rate. The foreign country has lower volatility of output and interest rate, and higher volatility of inflation. In this case both countries are worse off.

A change by both countries to an inflation targeting regime with an exchange rate term, with policy rules chosen non-cooperatively, results in higher volatility of the whole system and therefore in a higher loss. In the next section, we explore in more detail the potential benefits of reacting to exchange rate movements in an inflation targeting regime and the scope for co-operation.

Using the values of the losses for the different cases and regimes we can, as in the previous section, compute the payoff matrix, and this is set out in table 6.

Table 6. Payoff Matrix for a Game in Policy Rules
with Exchange Rate Response.

Foreign→	Taylor rule		Forward rule	
Home↓	Domestic	Foreign	Domestic	Foreign
Taylor rule	9.009	9.009	9.122	9.415
Forward rule	9.415	9.122	9.447	9.447

As before, we conclude that a strategy in which both countries follow a Taylor rule with an exchange rate term is a Nash equilibrium.

From the analysis in this section we can conclude that a change to an inflation targeting regime, both for the case in which policy makers do not react to the exchange rate, and for the case in which they do, results in higher volatility of the exchange rate and in a higher loss for both countries. We also conclude that a strategy where both countries follow a Taylor rule is a Nash equilibrium. Another interesting result is that the adoption of an inflation targeting regime by one country has negative spillover effects on the welfare of the other country, which maintains a Taylor rule.

In the next section, we analyze in more detail the benefits of reacting to the exchange rate in the context of an inflation targeting regime.

10 Portfolio shocks and inflation targeting

In the previous section we examined the effects of a policy response to exchange rate fluctuations, both in the case of optimized Taylor rules and in the case of inflation forecast targeting. In this section we turn our attention to the relative merits of a policy response to the exchange rate *per se* and a policy response only to the portfolio shocks that affect the exchange rate. This follows the suggestion of several authors (for example, Cecchetti et al: 2000; Freedman: 2000) that the policy instrument should only react to exchange rate movements that do not reflect fundamentals. In this section of the paper, we focus on inflation forecast rules rather than optimized Taylor rules[9].

10.1 Responding to the exchange rate itself

We first examine the effects of reacting directly to exchange rate, in the context of an inflation targeting regime. When policy makers follow the inflation forecast rules FWH and FWF respectively, the optimal policy parameters are $\gamma = \delta = 2$. When they introduce a response to the exchange rate the policy rules become FWQH and FWQF as set out in equations (16) and (17) above, and the optimal parameters become $\gamma_1 = \delta_1 = 1.83$; $\gamma_2 = \delta_2 = 0.16$.

This response to exchange rate movements results in higher volatility of the exchange rate and a slight improvement in welfare, relative to the situation in which they react only to deviations of the expected inflation from the target (see table 7 below).

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[9]In this case we ignore all the difficulties associated with the assessment of the kind of shock affecting the exchange rate.

Table 7. Performance Measures for Inflation Forecast Policy Rules

	Non-Cooperative Policies			Cooperative Policies	
	FW	FWQ	FWS	FWQ	FWS
Var(i)=Var(i^*)	5.420	5.800	4.815	5.584	4.612
Var(y)=Var(y^*)	3.898	3.680	3.646	3.729	3.507
Var(π)=Var(π^*)	3.400	3.650	3.473	3.632	3.713
Var(q)	6.682	8.663	5.070	7.566	4.457
L=L*	9.463	9.447	9.060	9.425	9.007

Note. FW denotes inflation forecast targeting with no response to exchange rate; FWQ
inflation forcast targeting with response to exchange rate; FWS inflation forecast targeting
with response to portfolio shocks. Both countries are using the same rule.

The reduction in the welfare loss results from a decrease in output volatility. On the other hand, the variance of inflation and of the policy instrument (the nominal interest rate) increases.

Therefore, we conclude that, in the context of an inflation targeting regime, the benefits of reacting non-cooperatively to the exchange rate, are not very great. Later we explore the scope for beneficial cooperation.

10.2 Responding to portfolio shocks

As mentioned above, there is a widespread view in the literature that the benefits of reacting or not reacting to a movement of the exchange rate depends crucially on the cause of its movement. Smets (1997), for example, suggests that the reason why the Bank of Canada used a MCI during the 90s was because the shocks hitting the exchange rate during that period were due to portfolio adjustments, and that under such circumstances it was beneficial to allow the induced changes in the exchange rate to modify the choice of interest rates. In order to explore this idea in this paper, we compare the variance of the system when policy makers react to a portfolio shock and with the variance of the system when they do not.

The policy rules that include responses to portfolio shocks are FWSH and FWSF set out in equations (18) and (19) above. The optimal coefficients are $\varphi_1 = \varkappa_1 = 1.72$ and $\varphi_2 = \varkappa_2 = 0.27$, respectively. We note that when they react to the portfolio shock rather than to the exchange rate, policy makers' responses to expected future inflation is less aggressive (the coefficient is

1.72 rather than 1.83), and they react more aggressively to a portfolio shock (coefficient 0.27) than to a movement of the exchange rate itself (coefficient 0.16).

The performance of the economy under these rules is set out in table 7. Reacting to the portfolio shock (column: Non-cooperative Policies, FWS) results in a better macroeconomic performance than does reacting to the exchange rate itself (column: Non-cooperative Policies, FWQ). The interest rate, output, inflation, and the exchange rate all become less volatile. There is an improvement in welfare. The value of the loss function falls from 9.447 to 9.060.

However, as compared with the inflation forecast rule (column: Non-cooperative Polices, FW), responding to portfolio shocks has not helped in stabilizing inflation. This result may appear to contradict the idea of some authors (see, for example, Mundell: 2000, cited in Cecchetti et al: 2000) that responding to a portfolio shock can help in inflation stabilization. However our result is likely to be a consequence of our assumed objective function, which puts equal weight on output stabilization and inflation stabilization, and also weights stabilizing the interest rate. The thing to note is that the increase in inflation variance (3.473 as against 3.400) is modest, compared with the reductions in the variances of output, interest rates, and the exchange rates. It is likely that another choice of policy parameters would maintain the inflation variance at the initial level and continue to bring substantial gains in the variances of the other variables. In particular it is striking that the reduction in loss that results from responding to portfolio shocks greatly exceeds that obtained by responding to the exchange rate itself.

Another striking result is that responding to portfolio shocks greatly reduces the variance of the exchange rate, as compared with the effects of no response, either to the shock or to the exchange rate, and of a response to the exchange rate. This may reinforce the attractiveness of this kind of policy rule, particularly if there are benefits to exchange rate stability that are not captured in the loss function used in this paper.

11   Inflation targeting and cooperation

The analysis so far has assumed the countries act independently of each other in choosing rules for their interest rates. That is, they are acting non-cooperatively. In this section we turn our attention to the scope for cooperative policy making to achieve better results. We stick with the situation of both countries using inflation forecast targets. Cooperative behaviour is modelled by having the policy makers in the two countries choose jointly the policy parameters that minimize their joint loss function. We first analyze the scope for cooperation when policy makers react explicitly neither to the exchange rate nor to the portfolio shock, and then we

consider policy rules that include these reactions.

11.1 Cooperative rules that respond only to domestic variables

In the setting analyzed in section 9.1, in which policy rules react only to domestic variables, co-operative behaviour by policy makers results in very similar optimal coefficients to the non-cooperative case. In the inflation targeting case, the case of most interest here, when the policy instrument reacts to deviations of expected inflation from the target, we find that the optimal policy parameter is equal to 2, both in the cooperative and non-cooperative cases. Despite the fact that, in the case of the forward-looking rule, the policy instrument is reacts implicitly to the exchange rate, there are no gains from cooperation.

11.2 Cooperative rules that respond to the exchange rate

When policy makers in the two countries cooperate on inflation forecast targeting, including an explicit response to the exchange rate, the policy rules have the form FWQH and FWQF set out in equations (16) and (17) above, and the optimal parameter values are $\gamma_1 = \delta_1 = 1.85$ and $\gamma_2 = \delta_1 = 0.09$ for expected inflation and the exchange rate, respectively.

From the outcome presented in table 7 above, we can conclude that co-operation (relative to non-cooperation) results in lower volatility of the exchange rate, of inflation and of the policy instrument. Output, however becomes more volatile. Globally this results in a very slight reduction in the welfare loss. In this case, we can conclude that, even if price stability were the only objective of policy makers, setting interest rates cooperatively and reacting to the exchange rate would be a better strategy than non-cooperation.

11.3 Co-operative rules that respond to a portfolio shock

Should the European Central Bank and the Federal Reserve Bank of the United States cooperate in the presence of, let us say, an irrational love by dollars? That is the kind of question we try to answer in this section. That is, we analyze whether there are any gains from reacting cooperatively to a portfolio shock rather than non-cooperatively.

The policy rules once again take the form set out in equations (18) and (19). The optimal policy parameters when both countries react co-operatively to a portfolio shock are, $\varphi_1 = \varkappa_1 = 1.56$ and $\varphi_2 = \varkappa_2 = 0.35$ for expected inflation and the portfolio shock, respectively. Note that when policy makers respond cooperatively to the portfolio shock rather than to the exchange rate itself, their response to the inflation forecast is less aggressive (coefficient 1.56 rather than

1.85), and the response to the portfolio shock is aggressive (coefficient 0.35) relative to the response to the exchange rate (coefficient 0.09). The performance measures for the case where both countries react to the portfolio shock co-operatively are set out in table 7 above.

We conclude that reacting cooperatively to a portfolio shock produces a better result than reacting non-cooperatively: the policy instrument, output and the exchange rate become less volatile. However, we should stress that although there is a reduction in the welfare loss, the inflation rate in this case becomes more volatile.

12   Conclusion

In this paper we have simulated the effects of various policy rules in a world consisting of two open economies with floating exchange rates. The questions we wish to address concern: (1) the effects of inflation targeting on exchange rate volatility; (2) the possibilities for reducing exchange rate volatility and improving economic performance by countries' modifying their policy rules to include responses either to movements in exchange rates or to the portfolio shocks that affect exchange rates; (3) the benefits of countries' coordinating their interest rate policies.

Modelling the introduction of inflation targeting as a shift from the use of an optimized Taylor rule to the use of an inflation forecast rule for interest rates, we find that exchange rate volatility rises substantially (by roughly one third) and economic performance generally worsens. Inflation becomes less variable, at the price of greater variability of output and interest rates.

In the context of countries using optimized Taylor rules for policy, introducing a response of interest rates to exchange rate movements brings about a small improvement in overall performance, made up of lower volatility of interest rates offset partly by higher volatility of output and inflation. The volatility of the exchange rate is significantly reduced. Of all the scenarios we simulated, this one, with countries using optimized Taylor rules augmented by a response to exchange rate movements, despite the absence of coordination of policy between countries, yields almost the best overall performance.

In the context of countries using inflation forecast rules, the introduction of a response of interest rates to the exchange rate brings only modest improvements in performance, whether policy is coordinated or not. Interestingly it does not bring about a reduction in exchange rate volatility. Greater benefits are produced by introducing a response to the portfolio shock. This has the effect of stabilizing exchange rates and interest rates. While the best overall performance (among our simulations) was produced by internationally coordinated inflation forecast rules augmented by responses to portfolio shocks, this only marginally exceeded the

performance of non-coordinated optimized Taylor rules also augmented by a response to the exchange rate.

The simulations suggest that modifying policy rules to include a response to portfolio shocks can bring about significant reductions in the volatility of interest rates and exchange rates, and an improvement in overall performance. In our simulations, the improvements in overall performance typically consist of lower variances of output and interest rates, partly offset by slightly higher inflation variance. Thus we have not shown that an improvement in every dimension of performance can be achieved. But it seems likely that a different selection of policy rules would be able to achieve this. Our policy rules have been chosen with reference to an objective function that weights output variance inflation variance equally, and gives weight to the variance of interest rate changes.

The simulations suggest that modest further gains can be obtained by international coordination of interest rate rules, when these contain some response either to exchange rates *per se* or to the portfolio shocks that affect them.

In the present paper the analysis has necessarily been limited in its scope, and suggests many questions for further exploration. The model has imposed numerous assumptions. We have tried to choose widely acceptable ones, but inevitably some are more contentious, and the results may be sensitive to some of these. Our sensitivity analysis reveals the sensitivity of the results to the assumed degree of inflation persistence. The question of the lag structure is particularly sensitive and worthy of further inquiry, as is the related issue of the transmission mechanism of interest rates.

We have restricted the paper to consideration of a small number of simple policy rules. While these have the virtue of simplicity and descriptive realism, they raise the problem of operating in a second best world. There are many possible alternative simple rules that might be compared. It would be interesting to explore the benchmark provided by the optimal state- or shock-contingent policy rules. Our results are based on a particular choice of objective function, and while this attempts to reproduce a consensus view of policy objectives, it would be useful to explore alternatives.

Notwithstanding these cautionary notes, we argue that the paper shows that augmenting interest rate policy rules by responses to the portfolio shocks that affect exchange rates may have beneficial effects. This reinforces the case for offsetting "irrational love of dollars" and other non-fundamental movements in exchange rates. It appears that this introduces a degree of surrogate international coordination, because, while there are additional gains for explicit international policy coordination, these are relatively small.

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13 Appendix

This section sets out in detail the method used to derive the estimates of the different regimes into which the data for inflation and exchange rates reported in Figreus 1 to 4 may be divided. We apply the methodology of Markov-switching models to describe the inflation and exchange rate processes for several countries since the mid 1980's. The motivation for using this approach comes from the work of Engel and Hamilton (1990), Engel and Hakkio (1997) and Evans and Wachtel (1993). Thus we consider the model

$$x_t = [\alpha_0(1 - s_t) + \alpha_1 s_t] + [\sigma_0(1 - s_t) + \sigma_1 s_t]u_t, \tag{A1}$$

where $\{s_t\}$ is a homogeneous Markov chain of order 1 with state space $\mathbb{S} = \{0, 1\}$ and transition probabilities $p = \Pr[s_t = 1 | s_{t-1} = 1]$ and $q = \Pr[s_t = 0 | s_{t-1} = 0]$; $\{u_t\}$ is a white noise with zero mean and unit variance, independent of $\{s_t\}$.

The specification of the mechanism governing transitions between the two regimes as a Markov process has the obvious advantage of requiring no a priori information about the location of the shifts in regime, letting the data select when and where these shifts occur, rather than imposing them.

Estimation of model (A1) is carried out by using the discrete version of the Kalman filter algorithm discussed in Hamilton (1994, Ch. 22). The inferred probabilities $\Pr[s_t = 1 | x_t, x_{t-1}, ..., x_1]$ of being in the regime represented by $s_t = 1$ at each point in the sample are then calculated. Regime 1 is attributed when the probability is above 0.5 and the duration is at least 2 periods.

The variables under investigation are the log changes in consumer prices, $\Delta p_t = \ln[p_t/p_{t-1}]$ and the log changes in foreign exchange rates, $EX_t = \ln[EXr_t/EXr_{t-1}]$.

We employ quarterly data for the inflation and monthly data for the exchange rate over the period 1985-2000 for eight countries: Australia, Canada, Finland, Germany, New Zealand, Spain, Sweden, United Kingdom.[10] For the inflation rate, mean and variance both depend

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[10]Data were obtained from Datastream.

on which regime is operative while for the exchange rate, only the variance is allowed to vary according to a hidden Markov chain.

Before estimating the model we directly test a single-regime model against a Markov-switching alternative. Although the two models are nested, the usual likelihood ratio statistic does not have a chi-squared asymptotic distribution since, under the null hypothesis of a single regime, the transition probabilities are unidentified and the information matrix is singular. To overcome these difficulties, we carry out the test using the standardised likelihood ratio test procedure developed by Hansen (1992, 1996). This procedure requires evaluation of the likelihood function across a grid of different values for the transition probabilities and for each state-dependent parameter. For inflation, from Table A1, the value of the standardised likelihood ratio statistics and related P-values under the null hypothesis (see Hansen (1996), for details) show strong evidence in favour of Markov regime switching for all the countries. Using exchange rates data, from Table A2, we find strong evidence in favour of Markov regime-switching for Finland, New Zealand, Spain, Sweden and United Kingdom; for the remaining countries the null hypothesis of linearity can not be rejected.

Starting with inflation, Tables A3 and A5 reports the ML estimates of α_i and σ_i $(i = 0, 1)$, along with the corresponding standard errors and portmanteau Q statistics for the residuals and their squares.

The main results suggest that, for all countries, the second half of the eighties and the early nineties, can be characterised by a high-inflation process with relatively high-volatility[11]. In contrast, the late nineties can be characterised as a process with a low-mean and smaller volatility. From Figures 1 and 2, the separation into regimes is very clear-cut, the probabilities are close to zero or one, and match the impression given by the series. Furthermore, with the only exception of United Kingdom, a serial correlation test on the standardized and squared standardized residuals indicates that the model is well-specified.

For Australia, the series starts with a period characterised by high-inflation, switches in 1990 to a low-inflation period; stays in that state till 1994 (beginning of inflation targeting), when it switches back to high-inflation state in 1995; from 1996 to 2000 it then moves back to a low-inflation regime.

Turning to Canada, it is obvious that there was a single change in regime in 1991 (year of adoption of inflation targets), the system remaining in the regime represented by $s_t = 0$ until the end of the sample period.

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[11] These results are in line with the work of Ball (1992) and Taylor (1981) which show that high inflation may be associated with high variability which reflects regime uncertainty.

The Reserve Bank Act 1989 makes New Zealand the first country to formally adopt an inflation target. The Act is part of a much wider reform process of New Zealand's economy, initiated in the mid eighties, with the aim of stabilising inflation, which had been well above that of its trading partners (Fischer, 1995) since the 70s. Tables A5 and A6, show that this change in regime is well captured by the simple model, with the filter indicating a period characterised by a high-inflation/high-variance (pre inflation targeting) to a low-inflation/low-variance (post inflation targeting) regime.

Finally, Sweden and the United Kingdom adopted inflation targeting after the foreign-exchange crisis of September 1992. Although there is some correspondence, it is interesting that the division into states does not match up neatly with the adoption of inflation targeting for each country.

The exchange rate process is allowed to switch between two distributions, one corresponding to a lower volatile period and the other to a higher volatile sample. The time series $\{EX_t\}$ satisfies, therefore, a model which allows for shifts in the variance (i.e. for periods of depreciation and appreciation), depending on the realized value of the state indicator s_t.

Results from Tables A7-A8 and Figure 3 confirm the findings obtained from the Hansen test thus indicating that for Australia, Canada, and Germany a simple Markov switching model specified as in (A1) is not able to capture the features of the data.

Table A9 records the results for New Zealand, Spain, Sweden and United Kingdom. For all countries, the estimates look reasonable and significant with the variances being significantly different in each regime. In New Zealand and Sweden, the filter probabilities, Figure A4, clearly show two distinct states associated to a pre and a post inflation targeting regime.

Finally, for United Kingdom the series starts by frequently jumping between the two regimes, before stabilizing to the low-volatility state (1987:06-1992:09). It then move to the high-volatility state (during the foreign-exchange crisis) and it switches back to the low-volatility state in 1993:08 where it remains apart from two periods in 1996-1997.

Table A1. Standardized LR Statistics for the Change in Consumer Price

	LR statistic	$M=0$	$M=1$	$M=2$	$M=3$	$M=4$
Australia	6.215	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Canada	2.855	(0.017)	(0.020)	(0.023)	(0.032)	(0.025)
Finland	2.877	(0.015)	(0.014)	(0.017)	(0.027)	(0.039)
Germany	2.299	(0.058)	(0.071)	(0.075)	(0.070)	(0.077)
New Zealand	11.710	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Spain	4.932	(0.000)	(0.002)	(0.003)	(0.009)	(0.013)
Sweden	3.822	(0.001)	(0.002)	(0.001)	(0.004)	(0.010)
United Kingdom	3.377	(0.003)	(0.002)	(0.004)	(0.005)	(0.006)

NOTES: See Hansen (1996) for details of the tests statistic, such as the definition of M.

p-values are in parentheses.

Table A2. Standardized LR Statistics for the Change in Exchange Rate

	LR statistic	$M=0$	$M=1$	$M=2$	$M=3$	$M=4$
Australia	1.800	(0.259)	(0.256)	(0.248)	(0.247)	(0.249)
Canada	1.493	(0.406)	(0.367)	(0.342)	(0.358)	(0.332)
Finland	8.600	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Germany	1.473	(0.316)	(0.315)	(0.325)	(0.303)	(0.307)
New Zealand	3.389	(0.002)	(0.001)	(0.002)	(0.004)	(0.004)
Spain	4.581	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
Sweden	10.213	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
United Kingdom	2.716	(0.006)	(0.007)	(0.004)	(0.011)	(0.010)

NOTES: See Hansen (1996) for details of the tests statistic, such as the definition of M.

p-values are in parentheses.

Table A3. Estimated Parameters for the Change in Consumer Price

	Australia		Canada		Finland		Germany	
α_0	1.482	(0.269)	1.489	(0.225)	1.438	(0.296)	1.065	(0.297)
α_1	7.445	(0.401)	4.632	(0.372)	4.713	(0.503)	3.255	(0.667)
σ_0	1.480	(0.200)	1.328	(0.158)	1.636	(0.200)	1.550	(0.207)
σ_1	1.949	(0.283)	1.818	(0.260)	2.301	(0.322)	2.984	(0.472)
p	0.942	(0.044)	0.980	(0.024)	0.979	(0.025)	0.933	(0.058)
q	0.953	(0.035)	0.983	(0.019)	0.981	(0.022)	0.971	(0.032)
$logL$	-126.76		-114.60		-127.48		-131.52	
$Q(1)$	0.461	(0.497)	0.745	(0.388)	0.141	(0.707)	0.075	(0.783)
$Q(3)$	1.072	(0.783)	6.262	(0.099)	6.804	(0.078)	0.669	(0.880)
$Q_2(1)$	2.962	(0.085)	0.102	(0.748)	1.288	(0.256)	0.931	(0.334)
$Q_2(3)$	3.583	(0.310)	3.204	(0.361)	1.549	(0.671)	2.022	(0.567)

NOTES: Standard errors for estimates and P-values for test statistics are in parentheses.

logL is the log-likelihood, $Q(k)$ is the residual Ljung–Box statistic at lag k, and $Q_2(k)$

is the squared-residual Ljung–Box statistic at lag k.

Table A4. Dating of Regime 1

Australia		Canada		Finland		Germany	
1985:2	1990:4	1985:2	1991:3	1985:2	1992:2	1989:1	1995:1
1995:1	1995:4						

NOTES: Regime 1 is attributed when the probability is above 0.5 and the duration is at least

2 periods.

Table A5. Estimated Parameters for the Change in Consumer Price

	New Zealand		Spain		Sweden		United Kingdom	
α_0	1.778	(0.301)	2.183	(0.333)	1.003	(0.451)	2.841	(0.397)
α_1	9.496	(1.555)	5.546	(0.403)	5.862	(0.875)	8.027	(1.439)
σ_0	1.711	(0.215)	0.947	(0.289)	2.320	(0.318)	2.509	(0.280)
σ_1	6.881	(1.067)	2.592	(0.275)	4.754	(0.589)	4.081	(0.839)
p	0.977	(0.030)	0.984	(0.017)	0.980	(0.025)	0.873	(0.106)
q	0.983	(0.019)	0.972	(0.038)	0.978	(0.028)	0.955	(0.033)
$logL$	-151.14		-131.44		-163.68		-154.83	
$Q(1)$	1.785	(0.181)	0.654	(0.418)	0.132	(0.716)	3.849	(0.049)
$Q(3)$	2.827	(0.419)	4.415	(0.220)	0.614	(0.893)	12.585	(0.005)
$Q_2(1)$	0.038	(0.843)	0.272	(0.601)	0.126	(0.721)	0.243	(0.621)
$Q_2(3)$	0.277	(0.964)	1.428	(0.698)	0.418	(0.936)	0.807	(0.847)

NOTES: Standard errors for estimates and P-values for test statistics are in parentheses.

logL is the log-likelihood, $Q(k)$ is the residual Ljung–Box statistic at lag k, and $Q_2(k)$

is the squared-residual Ljung–Box statistic at lag k.

Table A6. Dating of Regime 1

New Zealand		Spain		Sweden		United Kingdom	
1985:2	1990:4	1985:2	1996:4	1985:2	1992:2	1985:2	1985:3
				1993:1	1994:1	1988:4	1991:2

NOTES: Regime 1 is attributed when the probability is above 0.5 and the duration is at least

2 periods.

Table A7. Estimated Parameters for the Change in Exchange Rate

	Australia		Canada		Finland		Germany	
α	-0.070	(0.222)	-0.105	(0.093)	-0.057	(0.051)	0.064	(0.070)
σ_0	2.397	(0.255)	0.117	(0.147)	0.542	(0.045)	0.887	(0.056)
σ_1	5.042	(1.211)	1.403	(0.076)	2.892	(0.351)	2.184	(0.828)
p	0.376	(0.220)	0.995	(0.017)	0.732	(0.118)	0.362	(0.331)
q	0.851	(0.124)	0.375	(0.738)	0.909	(0.038)	0.964	(0.038)
$logL$	-453.02		-315.66		-258.92		-251.14	
$Q(1)$	2.311	(0.128)	0.567	(0.451)	0.328	(0.566)	0.055	(0.815)
$Q(6)$	5.819	(0.443)	2.139	(0.906)	3.297	(0.770)	5.114	(0.529)
$Q_2(1)$	1.177	(0.278)	1.269	(0.260)	0.114	(0.735)	0.489	(0.484)
$Q_2(6)$	4.499	(0.609)	6.363	(0.383)	0.222	(0.999)	1.594	(0.953)

NOTES: Standard errors for estimates and P-values for test statistics are in parentheses.
logL is the log-likelihood, $Q(k)$ is the residual Ljung–Box statistic at lag k, and $Q_2(k)$ is the squared-residual Ljung–Box statistic at lag k.

Table A8. Dating of Regime 1

Australia		Canada		Finland		Germany	
1985:03	1985:04	1985:03	2000:02	1989:04	1989:05	1992:10	1992:11
1986:07	1986:08			1992:10	1992:11		
1995:08	1995:09			1993:01	1993:03		
				1993:11	1993:12		
				1994:09	1995:01		
				1995:03	1995:04		
				1996:02	1996:06		
				1998:10	1998:11		

NOTES: Regime 1 is attributed when the probability is above 0.5 and the duration is at least 2 periods.

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Table A9. Estimated Parameters for the Change in Exchange Rate

	New Zealand		Spain		Sweden		United Kingdom	
α	-0.148	(0.164)	-0.053	(0.070)	-0.040	(0.055)	0.065	(0.140)
σ_0	1.922	(0.132)	0.822	(0.063)	0.554	(0.040)	1.466	(0.172)
σ_1	4.324	(0.495)	2.964	(0.557)	2.517	(0.199)	3.335	(0.540)
p	0.987	(0.018)	0.756	(0.156)	0.983	(0.013)	0.914	(0.065)
q	0.994	(0.006)	0.967	(0.025)	0.992	(0.008)	0.968	(0.027)
$logL$	-415.92		-265.50		-282.33		-374.18	
$Q(1)$	0.181	(0.670)	1.716	(0.190)	2.978	(0.084)	0.400	(0.526)
$Q(6)$	6.850	(0.334)	6.812	(0.338)	6.261	(0.394)	3.784	(0.705)
$Q_2(1)$	3.217	(0.072)	0.674	(0.411)	0.007	(0.929)	0.327	(0.567)
$Q_2(6)$	3.988	(0.407)	1.072	(0.982)	0.049	(0.998)	0.663	(0.995)

NOTES: Standard errors for estimates and P-values for test statistics are in parentheses.
logL is the log-likelihood, $Q(k)$ is the residual Ljung–Box statistic at lag k, and $Q_2(k)$
is the squared-residual Ljung–Box statistic at lag k.

Table A10. Dating of Regime 1

New Zealand		Spain		Sweden		United Kingdom	
1985:08	1989:12	1989:06	1989:07	1992:12	1999:10	1985:04	1985:10
		1992:10	1992:12			1986:01	1987:05
		1993:05	1994:03			1992:10	1993:07
						1996:11	1997:03
						1997:07	1997:12

NOTES: Regime 1 is attributed when the probability is above 0.5 and the duration is at least
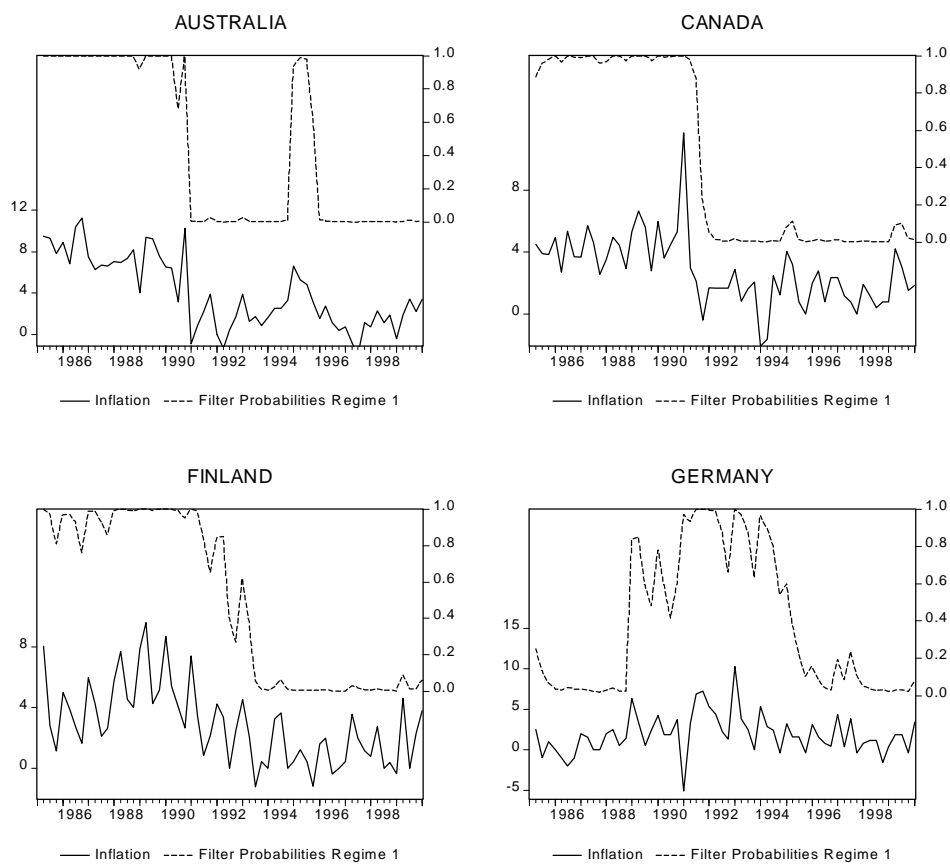2 periods.

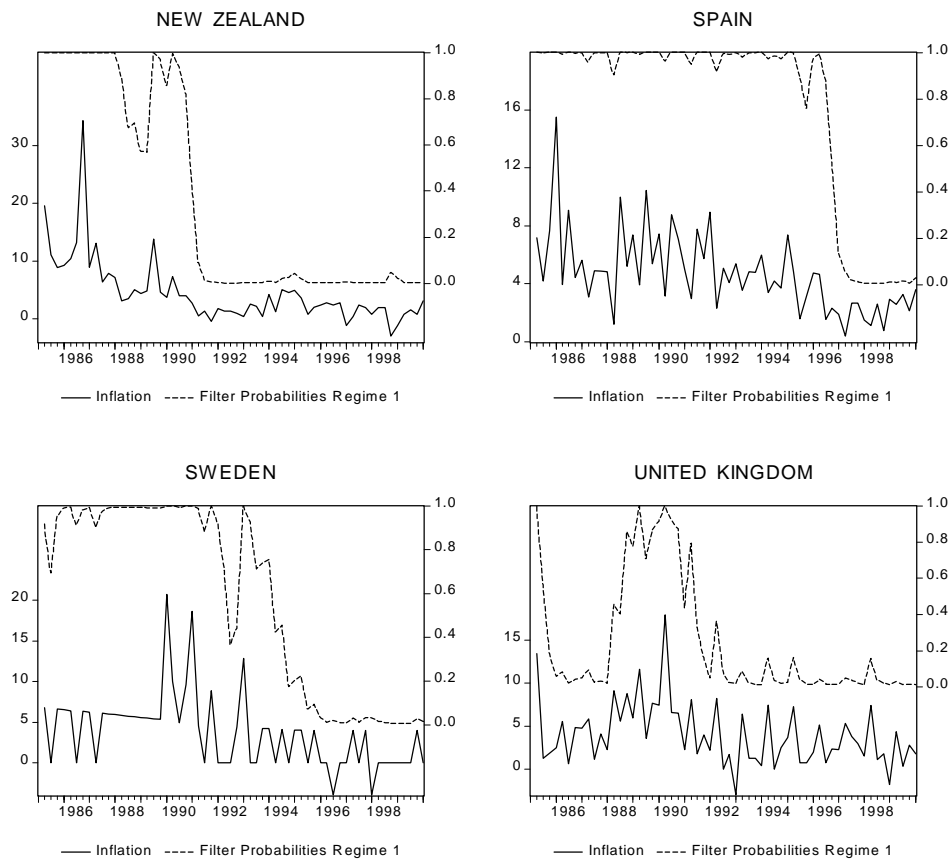Figure 1: Log changes in consumer prices (multiplied by 400)

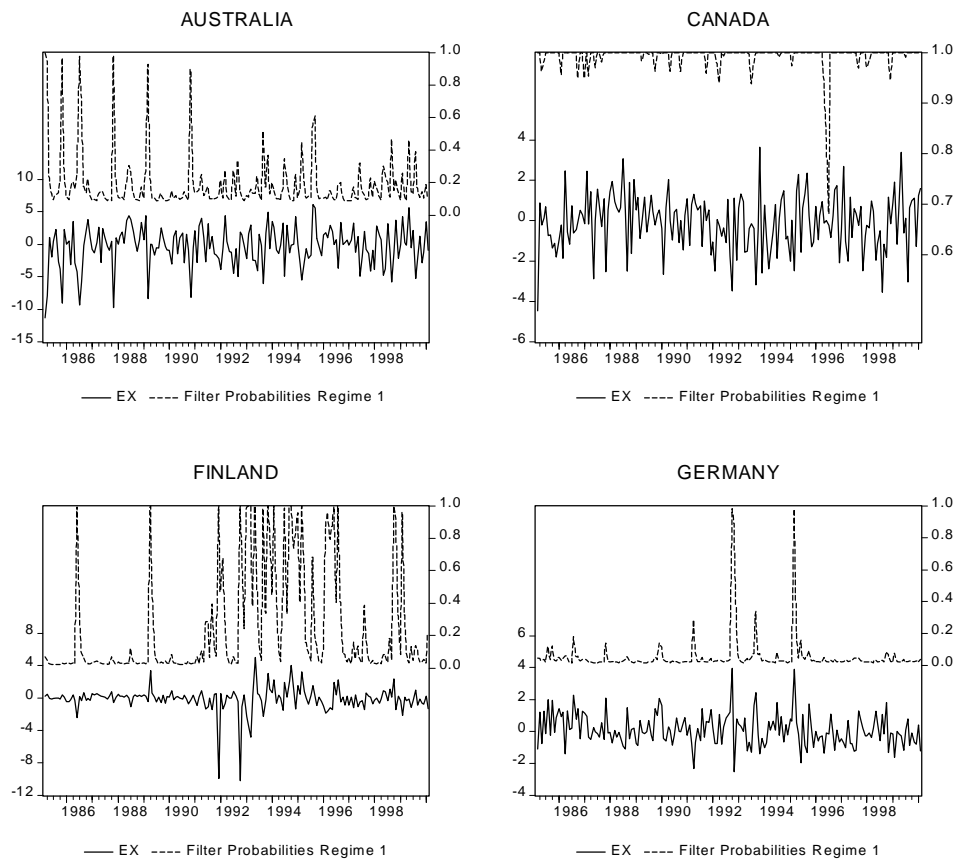Figure 2: Log changes in consumer prices (multiplied by 400)

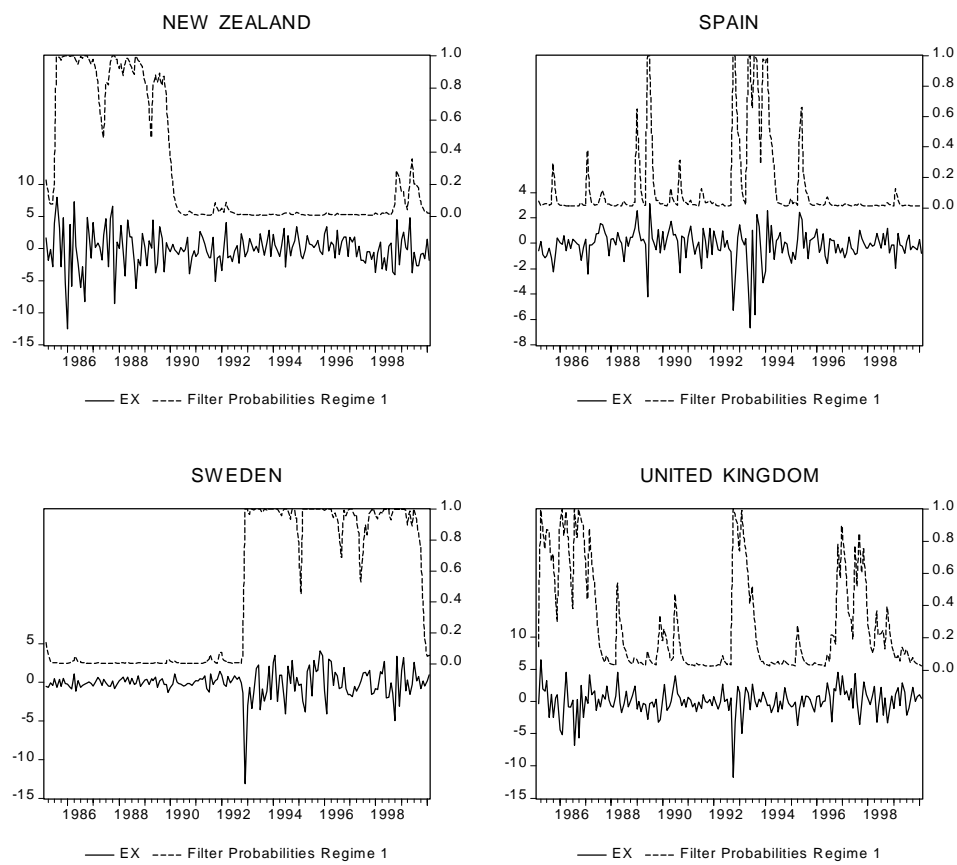Figure 3: Log changes in trade weighted exchange rate (multiplied by 100)

Figure 4: Log changes in trade weighted exchange rate (multiplied by 100)