Markov Switching Regimes in a Monetary Exchange Rate Model*

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Abstract:

This paper extends the real interest differential (RID) model of Frankel (1979) by introducing Markov regime switches for three exchange rates, over the years 1973 - 2000. Evidence of a non-linear relationship between exchange rates and underlying fundamentals is provided. It turns out that one of the estimated regimes represents exactly the RID case. The key fundamental which determines regimes turns out to be the interest rate. The established relationship is shown to be stable in several respects: regimes are highly persistent, provide a much better description of the data than alternatives and are robust towards several modifications.

JEL classification: F31

Keywords: Markov switching model, monetary model of the exchange rate, real interest differential model (Frankel 1979)

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Introduction

Exchange rate modelling has received a new lease of life as a result of simple monetary models having well-defined long-run properties (see, for example, MacDonald and Taylor, 1994). Knowing that fundamentals matter in the long-run (see also Mark, 1995, MacDonald, 1999), attention has shifted to shorter-term horizons. Although the verdict on the importance of fundamentals is still ambivalent (see, for example, Frankel and Rose, 1995) new approaches, many of them building on non-linear relationships between fundamentals and exchange rates, seem to offer more hope at this horizon. In this paper we contribute to these efforts by re-examining the monetary model in a time-varying coefficients context using a Markov switching approach. Amongst other things, we show that for a relevant sample of exchange rates regime switching properties provide substantial explanatory power beyond a constant coefficients approach.

The poor explanatory power of structural exchange rate models (see, for example, Frankel and Rose, 1995) provides a natural motivation to search for a more sophisticated modelling of the fundamental determinants of exchange rates. Many of these approaches incorporate non-linearities, which have been indicated for exchange rates for some time now (see, for example, Hsieh, 1989). There are at least four strands in the literature, each postulating a characteristic link: first, linear models can be modified by allowing for the non-linear formulation of coefficients (see, for example, Meese and Rose, 1991). Second, the relation between fundamentals and exchange rates can be expressed in an error correction framework, based on statistically derived cointegration vectors (MacDonald and Taylor, 1994; MacDonald and Marsh, 1997). Third, a similar idea of the long-term stable influences and short-term dynamics is captured in threshold approaches which assume mean-reverting properties of exchange rates (e.g. Kilian and Taylor, 2003). Fourth, there has been a presumption in the literature that coefficients may be time-varying (some general thoughts on unstable processes are given in Hendry and Clements, 2003). Whereas earlier studies assume these coefficients evolve smoothly (Wolff, 1987, Schinasi and Swamy, 1989), we draw on the idea of changing regimes. This approach seems to be more appealing for two reasons. First, it fits in with the observation that exchange rate models perform well for some sub-periods, whereas they do not for other periods (Meese, 1986, 1990; Faust et al., 2003), and, second, there is recent empirical support for the view that fairly sudden regime changes occur (Frydman and Goldberg, 2001).

The power of the Markov switching approach for exchange rate modelling was first demonstrated by Engel and Hamilton (1990) and Engel (1994). These studies used a time series approach, with two regimes, and applied their models to three currencies. Despite the success of these studies in capturing the dynamic evolution of exchange rates there are very few studies which have applied the Markov-switching approach to a fundamental exchange rate model. The exceptions are Marsh (2000), who uses a Markov switching model for daily exchange rate data, with interest rate differentials as the only fundamental. He concludes that this approach does not provide superior forecasts for exchange rates in comparison with a pure time series Markov Switching Model. Bessec (2003) uses a Markov switching error correction model to describe adjustments to PPP in the European Monetary System. Clarida et al. (2003) apply a Markov switching multivariate model to weekly spot and forward rates of four major exchange rates. They come to the conclusion that allowing for regime switches in an error correction framework provides forecasts which significantly outperform linear models. De Grauwe and Vansteenkiste (2001) use monthly data for high and low inflation countries' exchange rates for the period 1973 to 1998. Regressing the exchange rate on a set of fundamentals, they show that the coefficients switch significantly between the two states examined for high inflation countries but not for industrialised countries.

In this paper we demonstrate significant regime changes in a monetary exchange rate model for the three most important currency markets, namely the bilateral US-Dollar values of the D-Mark, Yen and Pound (see Bank for international Settlements, 2002). Our paper differs from the study of De Grauwe and Vansteenkiste (2001) – which is similar in that it considers fundamentals – in several respects: first, the use of a regime switching approach in modelling exchange rate fundamentals is explicitly based on a market microstructure approach. This provides a substantial motivation for applying regime changes to the major markets. Second, the modelling follows Frankel's (1979) real interest rate differential exchange rate approach, which has been a widely used variant of the monetary approach. Third, our findings are seen to be robust to several modifications. Fourth, the Markov switching monetary exchange rate model does not systematically provide forecasting power. In summary, our results can be seen as further evidence in favour of non-linear modelling of fundamentals.

The paper is structured as follows: Section 1 motivates the approach of time-varying fundamentals and in particular regime switching fundamentals by referring to the market microstructure literature. In Section 2 the Markov switching methodology is described. Section 3 presents the estimation results for three major exchange rates, which are further discussed in Section 4. Robustness checks are performed in Section 5 and Section 6 summarizes our main findings.

1. On the regime switching character of fundamentals.

Traditional applications of the monetary exchange rate model rely on a single state relationship between fundamentals and exchange rates. As we have noted, our application of the monetary model relaxes the assumption of a single state. The monetary models can be derived on an ad hoc basis, using Cagan style money demand functions or from an optimising model. In this paper we use the extended monetary model, first established by Frankel (1979), and referred to as the "real interest rate difference model (RID)". This model nests both the flexible price and the sticky price monetary model, within it, and may be represented by the following equation:

$$e_t = c + \alpha(m_t - m_t^*) + \beta(y_t - y_t^*) + \gamma(i_t^s - i_t^{s*}) + \delta(i_t^l - i_t^{l*}) + \varepsilon_t \quad (1)$$

where e_t denotes the log of the spot rate at time t, defined as the home currency price of a unit of foreign currency (in our study the US-Dollar is the foreign currency), m_t the log of the money supply, y_t is the log of output, i_t^s is the short-term interest rate, which captures liquidity effects in this model, and i_t^l is the long-term interest rate which captures expected inflation. The asterisk represents the foreign country which is the United States in our study. From a monetary perspective one would expect the estimated coefficient on the relative money supply term to be close to one and the income elasticity, β, should be estimated negative. The coefficient on the short-term interest rate is also expected to be negative, while the expected inflation term should exhibit a positive influence on the exchange rate.

An abstract relation as simple as the monetary model is perhaps most useful as a long-run relationship, but is unlikely to capture the full dynamic interrelationships between fundamentals and exchange rates. One major criticism in this respect is the observation of foreign exchange market professionals that the importance of fundamental factors appears to change over time. What has been viewed as anecdotal evidence of the market in the past has recently become the subject of systematic market microstructure research (see, for example, Lyons, 2001). Three studies can be used to substantiate the claim of an unstable relationship between fundamentals and exchange rates. In similarly designed questionnaire surveys in the US (Cheung and Chinn, 2001) and in the UK (Cheung et al., 1999), foreign exchange dealers were asked which announcement of fundamentals they regarded as most important for their market. The fundamentals referred to were, unemployment, an interest rate, the inflation rate, the trade deficit, GDP, and a category "other". The response from these surveys is summarised in Table 1 and it reveals some interesting insights. First, fundamentals are of different importance to professionals, second, the relative importance of fundamentals between the two countries is very similar, but the difference over time is enormous. Indeed – as the lower part of Table 1 indicates – the difference over time is clearly larger than the difference between the two countries. To put this last finding into numbers, the average absolute difference between countries for the ten cases (five fundamentals times two points in time) is 5.7 percentage points, but the average absolute difference over time for ten cases (five fundamentals times two countries) is 15.4 percentage points and thus three times larger.

INSERT TABLE 1 ABOUT HERE.

These findings substantiate convincingly that market participants regard the importance of fundamentals as time-varying. What is not clear, however, are possible reasons for this instability. In this respect another questionnaire survey conducted in 1992, and analysed by Menkhoff (1998), provides further illumination. In this survey FX dealers and international fund managers in Germany were explicitly asked why fundamentals might attract different attention over time. Table 2 presents the exact question and response statements which the professionals were asked to evaluate with different degrees of (dis)agreement. Consistent with the evidence given above is the fact that the "no change over time" statement is denied by almost 85% of respondents.

INSERT TABLE 2 ABOUT HERE.

Interestingly, moreover, is the evaluation of the other two statements which formulate alternative sources of instability. The first alternative stresses that changing attention reflects the "most urgent problem", whereas the second alternative regards changing attention as a sign of "fashions", that is of non-fundamental influences. Although both answers attract clear agreement, the "most urgent problem" alternative receives even more than 85% agreement, and the "fashions" alternative more than 75%. In addition, the latter responses show more extreme responses at both ends of the spectrum, thereby indicating less consensus. We interpret these additional findings as not only supporting time-varying importance of fundamentals, but also as linking changing importance to fundamental real world problems. Changing fundamental scenarios can in principle be detected by a regime switching approach.

The identification of regimes is simplified by the limited number of relevant fundamentals that is quite stable over time and that can be related to the monetary model. Regarding the number of fundamentals, the list in Table 1 includes a category "other" which would capture further factors but which hardly received any attention by respondents. This is confirmed by the German survey study which includes a list of ten fundamentals. Fundamentals being related to the monetary model receive the highest ranks.

These results, however, do not indicate where the regime switches come from. There would seem to be two main explanations: First, the traders could cause the regime switches themselves. That is, the exchange rate is driven by those fundamentals which are given most attention to by the traders and the exchange rate therefore reflects the traders' views. These are not necessarily related to changes in the fundamentals' importance. Second, another possible explanation could be that the time series processes governing the fundamentals evolve over time. In this case the traders' assessments will change, too, but they would just reflect the actually differing importance of fundamentals[1].

However, survey evidence on the behaviour of foreign exchange participants strongly suggests that instability over time in the relationship between fundamentals and exchange rates matters. The modelling of time-varying fundamentals is thus

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[1] As one referee has stated, the RID model is a semi-reduced form. Frydman and Goldberg (2002) argue that the regime switches may occur through structural changes in the economy, e.g. instabilities of the money demand function, or through changes in expectation functions, although this would not be consistent with rational expectations.

more than justified from this literature and the particular regime-switching approach seems to be reasonable.

2. The Markov switching methodology

The Markov Switching Model (MSM) has been popularised by Hamilton (1989), although it was originally motivated by Goldfeld and Quandt (1973). For our aim it is convenient to consider it as a switching regression (for this particular form of the MSM see Hamilton, 1994, chapter 19):

$$r_t = \begin{cases} \beta_1 \cdot z_t + \varepsilon_t, \text{if } s_t = 1 \\ \beta_2 \cdot z_t + \varepsilon_t, \text{if } s_t = 2 \end{cases} \tag{2}$$

where r_t is the time series to be explained, in our case the 12-months percentage change of an exchange rate, z_t is a vector of exogenous regressors, β_i is a vector of real numbers, whose values depend on the non-observable state variable s_t, and ε_t is Gaussian white noise. The state variable s_t is assumed to follow an ergodic first-order Markov process and is characterised by the matrix Π consisting of the transition probabilities p_{ij} from state i to state j:

$$\Pi = \begin{bmatrix} p_{11} p_{21} \\ p_{12} p_{22} \end{bmatrix}, \ p_{ij}=\Pr(s_t=j|s_{t-1}=i) \tag{3}$$

Once the coefficients of the model and the transition matrix have been estimated, the probability $\Pr(s_t=j \mid r_1,..., r_T)$ of being in state j, based on the knowledge of the complete series, can be calculated for each date (for details of the algorithm see Kim and Nelson, 1999). This series of probabilities will be referred to as the *smoothed probabilities*, in contrast to the series of probabilities $\Pr(s_t=j \mid r_1,..., r_t)$ of being in state j based on the information up to date t - the *filter probabilities* - which is also calculated. It is straightforward to show that for the last date, that is t=T, the smoothed probability equals the filter probability.

In our investigation the vector z_t of fundamentals in equation (2) is chosen according to the real interest differential monetary model (RID), as presented in the previous section. In this context, the set of fundamentals covers relative changes in money supply (Δm_t), industrial production (Δy_t), the money market interest rate (Δi_t^s), as the short term interest rate, and the government bond yield (Δi_t^l) as the long term interest rate. Equation (1) can therefore be rewritten as:

$$r_t = \begin{cases} c_1 + \alpha_1 \cdot \Delta m_t + \beta_1 \cdot \Delta y_t + \gamma_1 \cdot \Delta i_t^s + \delta_1 \cdot \Delta i_t^l + \varepsilon_t, s_t = 1 \\ c_2 + \alpha_2 \cdot \Delta m_t + \beta_2 \cdot \Delta y_t + \gamma_2 \cdot \Delta i_t^s + \delta_2 \cdot \Delta i_t^l + \varepsilon_t, s_t = 2 \end{cases}, \qquad (3)$$

with state-depending coefficients. For comparative purposes the RID variant of the monetary model is also estimated with constant coefficients, which serves as a benchmark model and the null hypothesis for the tests.

Testing a MSM against a linear alternative is not straightforward because under the null hypothesis of a constant coefficient model without regime switches, only one regime governs the exchange rate and the transition probabilities are not identified. Garcia (1998) gives asymptotic critical values for Hansen's (1992, 1996) test for a couple of simple MSMs with two regimes. The set of models discussed by Garcia, however, does not include a model with exogenous regressors and a constant variance over the two regimes as used in our investigation. So his critical values are not valid for our model.

We therefore rely on Wald tests as used by, for instance, Engel and Hamilton (1990), Engel (1994) and Dewachter (1997). The Wald tests allow for testing two hypotheses. The first one tests against the null of $p_{11}+p_{22} = 1$; that is, it tests for systematically alternating regimes (as opposed to arbitrarily switching between regimes). The second one tests against the null of identical parameters in the different states. The latter test also facilitates testing which coefficients differ for the regimes. Both tests in combination test for Markov switching against the null hypothesis of a linear model. However, due to the problems mentioned above, the results have to be interpreted with caution.

3. Data and estimation results

For the estimation we use monthly data from January 1974 to October 2000[1] for four industrialised countries (the United States, Germany, United Kingdom, Japan) from the IFS database by the International Monetary Fund[2]. The estimation was performed in GAUSS.

For the German money stock and industrial production, possible structural breaks due to German reunification in 1990 merit some additional consideration. For M2 a structural break is detected in June 1990, which means the money stock is shifted upwards. In contrast, the series of industrial production does not show any significant break around reunification. This may be due to the low level of industrial production in Eastern Germany during reunification, compared to Western Germany. Therefore structural breaks have been considered only for the series for M2. The calculations have been performed using both, the corrected and the original series. As

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[1] For Germany a shorter series up to December 1998 was used due to the introduction of the EURO in January 1999.

[2] The following series have been used (replace ccc by country code): ccc.RF.ZF (exchange rate); ccc.39MBC (money for Germany and the US), ccc.59MC.ZF (money for the UK), ccc.34.BZF (money for Japan), ccc.66...CZF (industrial production), ccc.60B...ZF (short term interest rate); ccc.61...ZF (government bond yield). The UK does not report an M2 money series, which we use for Germany, Japan and the US. Therefore for the UK we use M0 as the money stock variable.

the results do not substantially differ, we subsequently rely on the results for the original series. This approach may be justified by the consideration that the increase in money supply, not being accompanied by an increase in output, would also have affected the exchange rate.

Each fundamental is calculated as the difference of the percentage change during the last twelve months in the home country versus the percentage change for the same horizon in the United States. This approach is applied for two reasons: first, it avoids seasonal effects in the data and reduces the noise from short-term movements in the exchange rates and the fundamentals and therefore promises more stable results[1]. A major disadvantage of this approach is that it leads to some serial correlation in the residuals. This autocorrelation is considerable, but dies out after few months. We therefore rely on heteroskedasticity and autocorrelation consistent standard errors (Newey and West, 1987). These do not only correct for autocorrelation but also for heteroskedasticity and we do not need the form of autocorrelation to be more precisely specified. Second, Frankel's model is based on a version of purchasing power parity PPP (Frankel, 1979, p. 612). Absolute PPP, however, is not a particularly useful construct, due to well-known market imperfections. Therefore, it is straightforward to work with changes in exchange rates and fundamentals, as is done in empirical work on PPP.

For example, the relative change in the money supply is calculated as (the other fundamentals are calculated analogously):

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[1] The use of quarterly data, instead of overlapping annual changes, does not substantially change the results, although it severely lowers the significance of the results, due to noise in the higher frequency data and the lower number of observations which available for estimation. The results are not given here, but available from the authors on request.

$$\Delta m_t = \frac{m_t^{home} - m_{t-12}^{home}}{m_{t-12}^{home}} - \frac{m_t^{USA} - m_{t-12}^{USA}}{m_{t-12}^{USA}} \quad (5)$$

Table 3 shows the estimation results for the constant coefficients RID for the exchange rates of the Deutsche Mark (DEM), the Japanese Yen (JPY) and the Pound Sterling (GBP), all against the US Dollar (USD).

INSERT TABLE 3 ABOUT HERE.

The results are heterogeneous and hardly consistent with theory. The expected signs from the theoretical model are given in the last column for comparison. First, we note that the coefficient on the money supply term is significant, but wrongly signed, relative to the theoretically derived expectation, for the Deutsche Mark and the Pound Sterling, whereas it is correctly signed, although not significant, for the Yen. Second, the sign of the coefficient on the short-term interest rate differential is significantly positive for the Deutsche Mark, significantly negative for the Yen and insignificant for the Pound. The long-term interest rate differential has the correct sign and is significant only for the Pound, but not for the other exchange rates. Only for the coefficient on industrial production do we find the correct sign and significance in accordance with theory. These results are in line with early empirical findings. For example, Dornbusch (1980), Boothe and Glassmann (1987) find that the initial relationship reported by Frankel breaks down as soon as the sample is extended beyond 1978.

The results are substantially better when the restriction of constant coefficients is abandoned. Table 4 provides estimation results for the real interest differential model with Markov switching coefficients.

INSERT TABLE 4 ABOUT HERE.

It is worth mentioning that the MSM distinguishes regimes which are highly persistent. The probability of remaining in the present state is always between 91 and 97 per cent, most probabilities being close to 95 per cent. The smoothed probabilities are given in Figure 1 in graphical form and show the comparatively low number of regime switches due to the high persistence: there are 7 periods where the process is in state 1 for the DEM/USD, 11 for the JPY/USD and 10 for the GBP/USD.

INSERT FIGURE 1 ABOUT HERE.

For all exchange rates one regime is identified within which the estimates are fully consistent with Frankel's model: all coefficients are correctly signed and, in most cases, significant at least at the 10 per cent level. The RID regime is given in Table 4 as 'State 1' and covers, respectively, 47 and 57 per cent of the whole sample for the DEM/USD and the GBP/USD, but only 24 per cent for the JPY/USD. This finding is consistent with the notion that the RID model is a useful explanation of exchange rates in certain periods. There are other periods, however, where exchange rate determinants either have a clearly different degree of influence – leading to different coefficients – or have a different sign. According to the approach chosen there is always a second regime, that is 'State 2', which we now discuss.

A first insight in this respect is that the signs in state 2 are different from state 1 and are heterogeneous for the three exchange rates. Turning to each exchange rate, the DEM/USD and the JPY/USD are different concerning the significance of the parameters in state 2. Except for the constant, which is significant at the 1 per cent level for each single estimation, only the changes in output are significant at the 10 per cent level. This means that both rates are characterised by a regime 1 which is consistent with theory (but occurs less frequently for the case of the DEM/USD), and a second one which is hardly connected to any changes in the fundamentals considered here.

The picture is different for the GBP/USD rate, which also shows highly significant estimations in the second regime. But whilst the signs for changes in output are in accordance with the RID model for both rates, the GBP/USD shows a negative coefficient on the changes in the money supply. This particular result is contrary to our expectations.

In summary, the MSM has proved to be useful in several respects. First, there are two significant regimes which can be identified and this indicates the usefulness of a regime switching approach. Second, regimes have a length of roughly two years, which leaves open the possibility that they are caused by major real world economic issues whose impact lasts for some time. Third, one of these regimes has coefficients which conform to the RID model, confirming earlier findings of appropriate monetary exchange rate modelling in certain periods only. Fourth, the second regime reveals some complexity as coefficients have different signs from regime 1 and are heterogeneous for the three exchange rates. This complexity fits in with the failure of simple models to explain exchange rates. Despite these results, two more challenges have to be overcome: from a statistical viewpoint, does the MSM provide a superior modelling to alternatives, and from an economic viewpoint, can the regimes identified be linked to economic characteristics?

4. Discussion of results

Using a univariate exchange rate specification, Engel and Hamilton (1990) were the first to demonstrate the power of MSM in explaining exchange rate behaviour. One may thus expect that our fundamental-based version of the MSM provides a better fit to the data than competing models do.

INSERT TABLE 5 ABOUT HERE.

Table 5 shows some conventional measures of fit for the MSM with fundamentals, a standard MSM without fundamentals, a constant coefficients model and a simple random walk with drift. For all models the coefficients have been estimated based on the whole sample period and the expectations based on these models have been compared with realised exchange rate changes. The expected returns for the two Markov switching models are calculated as:

$$E[r_t] = \sum_{i=1}^{2} E[r_t \mid s_t = i] \cdot \Pr(s_t = i \mid r_1,..,r_T) \qquad (6)$$

Calculating the expected returns for the linear model and the random walk with drift is straightforward.

Both, MSM models, with and without fundamentals, generate lower errors than the classical models and the MSM with fundamentals performs best. Figure 2 shows plots of the estimated exchange rate changes from the constant coefficient model and the MSM with fundamentals in comparison with the actual exchange rate changes. The MSM tracks the data much better than the constant coefficient model.

INSERT FIGURE 2 ABOUT HERE.

Statistical superiority is, however, a necessary but not a sufficient condition for satisfying model adequacy. It is therefore of interest to determine if the regimes can be linked to some characteristics of the economic environments. As a first step in examining this issue we refer to the Wald tests, reported in Table 6, which allow us to better assess the significance of differences in the coefficients. It can be seen that the intercepts differ significantly between the states for all of the exchange rates. The many significant results for the slope coefficients show that the regime changes are in fact caused by different fundamentals for the exchange rates. In addition to the insights from Table 4, we are now in a position to say something about characteristic differences between regimes, indicating which differences in fundamentals are decisive.

INSERT TABLE 6 ABOUT HERE.

The DEM/USD and the JPY/USD differ in the coefficients for the short- and the long-term interest rates, whereas there is no significant difference in the coefficients for changes in money supply and production between the regimes. This means that the regime dependence is mainly driven by the assessment of interest rates, whereas the influence of money and output does not differ substantially. The case of the GBP/USD is somewhat different, as only long-term interest rates are also significantly different between regimes but not short-term rates. Some of the dynamics for this currency are instead captured by money supply and output. As an interim summary, the most important although not all relevant differences between regimes appear to be linked to differences in interest rate changes.

5. Robustness checks

To ensure our results are stable, and in particular to confirm the existence of two significantly different regimes, we check the robustness of our results. In particular, we vary four elements of our baseline model: the exact definition of variables, the differencing frequency (originally 12-month changes), the fundamental variables set and the sample period. Finally, we test for out-of-sample forecasting power.

First, we check, whether the results are related to the exact definition of fundamentals. For this reason several fundamentals are substituted for similarly defined ones. There are no major differences in the results, when M2 is substituted by M3 for the money supply. This also applies when other proxies for inflation expectations are used, such as realised inflation data. For both indices of producer and consumer prices, the results do not differ.

Second, using 6-months or 3-months changes, instead of 12-month changes, does not affect most of the signs of the estimated coefficients, but the coefficients mostly become insignificant. This may indicate that exchange rates fluctuate around the model-based estimations in the short run or that there are time lags of several months between changes in the fundamentals and those in the exchange rate.

Third, the set of fundamental variables is changed by omitting the second interest rate, thus converting the RID approach to the standard monetary model, and by adding a proxy for trade volume. Adding the relative percentage changes of imports and exports as a proxy for trade volume only slightly affects the values of the existing variables. However, imports as well as exports are significantly related to changes in the exchange rate for all rates and regimes other than regime 2 for the JPY/USD rate. Omitting the long-term interest rate does not substantially influence the coefficients of the remaining variables, but the fit of the model gets slightly worse.

Fourth, we re-estimate the results shortening the sample period successively for two years each[1]. For regime 1 this does not affect the signs of the estimated coefficients, but their size differs over time. While the influence of the money supply and the output variable becomes larger when the sample is shortened, there are only minor changes for the short-term interest rate. The long-term interest rate, which serves as our proxy for inflation expectations, finally becomes insignificant when the sample ends before 1990. For regime 2 the results are different: the coefficients for relative changes in the money supply and output become insignificant, whereas the interest rates do not change their sign, being highly significant. This behaviour suggests that the structure of our findings is somewhat sensitive with respect to the exact sample period. In particular, when sample periods differ markedly, some characteristics of the regimes may change and this is perhaps to be expected in light of the earlier literature claiming high instability in the exchange rate fundamentals relationship.

This finding raises doubts about the ability of the RID model with Markov switching coefficients to provide out-of-sample forecasts which significantly outperform those of a random walk. To explicitly assess the models forecastability, we estimate the model over a rolling sample of ten years and calculate the conditional expectations of the returns for the next one to 12 months. The forecasts of the Markov switching RID model are then compared to those generated by the competing models using the asymptotic test by Diebold and Mariano (1995)[2]. The monetary model with time-varying coefficients is outperformed by random walk forecasts in the short-run but improves the forecasts of the constant coefficient RID model in most cases (see the results in Table 7). Even the pure time series Markov switching model without fundamentals generates forecast errors exceeding those by the random walk. The fact that Markov switching models are able to describe the data well, but produce poor forecasts, is in line with many empirical works (Dacco and Satchell, 1999). This leads to the conclusion that, although the MSM captures most of the structural instability in the coefficients, there is still some additional source of time-variation left. It has, however, to be stated, that our results are strongly in favour of a non-linear relationship between exchange rates and macroeconomic fundamentals. These findings are in line with other recent studies as surveyed by Neely and Sarno (2002) or Cheung et al. (2002).

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[1] The results are given for the DEM/USD rate. Results for the other rates are similar and available from the authors on request.

[2] The Diebold-Mariano test allows to compare just the forecast of a model with the forecast of exactly one other model. Harvey and Newbold (2000) propose a modified Diebold-Mariano-type test, allowing to compare a forecast with the combined forecast of a group of competitors, which could be appealing in our case. However, as our results indicate that the Markov Switching RID does not outperform the Random Walk out of sample, one will always find a combination including the Random Walk forecast, which is not outperformed by the Markov Switching RID.

INSERT TABLE 7 ABOUT HERE.

6. Conclusions

In this paper we have re-examined the RID variant of the monetary model using a Markov-switching framework. The motivation for our work is based on three strands in the exchange rate literature: a number of studies indicate some influence of the monetary model's fundamentals on exchange rates, results from the market microstructure literature suggest a time-varying influence of a limited set of fundamentals on the exchange rate, and, finally, a MSM approach has proved much better at describing exchange rates than linear approaches. The overall results are highly supportive of our chosen approach.

First, there appear to be two highly persistent regimes that can be identified for the three exchange rates under investigation. Second, one of the regimes shows exactly the coefficients as forecast by the RID model. Third, the MSM significantly improves the quality of the estimation over some alternatives and the best model is the model combination of a RID approach with Markov switching regimes. The fundamentals that differentiate the two regimes are in large part but not only interest rates. Finally, we demonstrate that this outcome is quite robust against several modifications to sample periods, definitions, measurement and even the exact set of variables.

However, our results also show that there is always a second regime that is difficult to explain theoretically. Moreover, the other regimes are heterogeneous which is consistent with earlier literature indicating that there are complex influences in exchange rate determination. Finally, structural stability is not good enough to systematically produce out-of-sample forecasting ability.

Taking Rogoff's (2001) verdict as a benchmark that "explaining the yen, dollar and euro exchange rates is still a very difficult task, even ex post", we claim some progress. Fundamentals matter and despite limitations mentioned, our contribution is in line with high frequency studies which indicate some non-linear fundamental influences on exchange rates. It is up to further research in improving exchange rate explanation beyond the present promising indications.

References

Bank for International Settlements (2002), *Triennial Central Bank Survey, Foreign Exchange and Derivatives Market Activity in 2001*, Basel.

Bessec, Marie (2003), Mean-Reversion vs. Adjustment to PPP: The Two Regimes of Exchange Rate Dynamics under the EMS, 1979-1998, *Economic Modelling* 20, 141-164.

Boothe, Paul and Debra Glassmann (1987), Off the Mark: Lessons for Exchange Rate Modelling, *Oxford Economic Papers* 39, 443-457.

Cheung, Yin-Wong and Menzie D. Chinn (2001), Currency Traders and Exchange Rate Dynamics: A Survey of the US Market, *Journal of International Money and Finance* 20, 439-471.

--, -- and Ian W. Marsh (1999), How Do UK-Based Foreign Exchange Dealers Think Their Market Operates?, *CEPR Discussion Papers* 2230, London.

--, -- and Antonio G. Pascual (2002), Empirical Exchange Rate Models of the Nineties: Are Any Fit to Survive?, *NBER Working Paper Series* 9393, Cambridge, Massachusetts.

Clarida, Richard H., Lucio Sarno, Mark P. Taylor and Giorgio Valente (2003), The Out-of-Sample Success of Term Structure Models as Exchange Rate Predictors: A Step beyond, *Journal of International Economics* 60, 61-83.

Dacco, Roberto und Steve Satchell (1999), Why do Regime-switching Models Forecast so Badly?, *Journal of Forecasting* 18, 1-16.

De Grauwe, Paul and Isabel Vansteenkiste (2001), Exchange Rates and Fundamentals, *CESifo Discussion Papers* No. 577, Munich.

Dewachter, Hans (1997), Sign Predictions of Exchange Rate Changes: Charts as Proxies for Bayesian Inferences, *Weltwirtschaftliches Archiv* 133 (1), 39-55.

Diebold, Francis X. and Roberto S. Mariano (1995), Comparing Predictive Accuracy, *Journal of Business and Economic Statistics* 13, 253-262.

Dornbusch, Rudiger (1980), Exchange Rate Economics: Where Do We Stand?, *Brookings Papers on Economic Activity* 1, 143-194.

Engel, Charles (1994), Can the Markov Switching Model Forecast Exchange Rates?, *Journal of International Economics* 36, 151-165.

-- and James D. Hamilton (1990), Long Swings in the Dollar. Are they in the Data and Do Markets Know it?, *American Economic Review* 80, 689-713.

Faust, Jon, John H. Rogers and Jonathan H. Wright (2003), Exchange Rate Forecasting: The Errors We've Really Made, *Journal of International Economics* 60, 35-59.

Frankel Jeffrey A. (1979), On the Mark: A Theory of Floating Exchange Rate Based on Real Interest Differentials, *American Economic Review* 69 (4), 610-622.

-- and Andrew K. Rose (1995), Empirical Research on Nominal Exchange Rates, in: Gene Grossman and Kenneth Rogoff (eds.): *Handbook of International Economics*, Vol. III. Amsterdam et al.: North-Holland, 1689-1729.

Frydman, Roman and Michael D. Goldberg (2001), Macroeconomic Fundamentals and the DM/$ Exchange Rate: Temporal Instability and the Monetary Model, *International Journal of Finance and Economics* 6 (4), 421-435.

Garcia, Rene (1998), Asymptotic Null Distribution of the Likelihood Ratio Test in Markov Switching Models, *International Economic Review* 39 (3), 763-788.

Goldfeld S.M. and R.E. Quandt (1973), A Markov Model for Switching Regressions, *Journal of Econometrics* 1, 3-16.

Hamilton, James D. (1989), A New Approach to the Economic Analysis of Non-stationary Time Series and the Business Cycle, *Econometrica* 57 (2), 357-384.

-- (1994), *Time Series Analysis*, Princeton: Princeton University Press.

Hansen, Bruce E. (1992), The Likelihood Ratio Test under Nonstandard Conditions: Testing the Markov Switching Model of GNP, *Journal of Applied Econometrics* 7, 62-81.

-- (1996), Erratum: The Likelihood Ratio Test under Nonstandard Conditions: Testing the Markov Switching Model of GNP, *Journal of Applied Econometrics* 11, 195-198.

Harvey, David and Paul Newbold (2000), Tests for Multiple Forecast Encompassing, *Journal of Applied Econometrics*, 15, 471-482.

Hendry, David F. and Michael P. Clements (2003), Economic Forecasting: Some Lessons from Recent Research, *Economic Modelling* 20, 301-329.

Hsieh, David A. (1989), Testing for Non-linear Dependence in Daily Foreign Exchange Rate Changes, *Journal of Business* 62, 339-368.

Kilian, Lutz and Mark P. Taylor (2003*),* Why is it So Difficult to Beat the Random Walk Forecast of Exchange Rates?, *Journal of International Economics* 60, 85-107.

Kim, C.J. and Charles R. Nelson (1999), *State Space Models with Regime Switching: Classical and Gibbs Sampling Approaches with Applications*, Massachusetts: MIT Press.

Lyons, Richard (2001), *The Microstructure Approach to Exchange Rates*, Massachusetts: MIT Press.

MacDonald, Ronald (1999), Exchange Rate Behaviour: Are Fundamentals Important? *Economic Journal* 109 (459), 673-691.

-- and Ian W. Marsh (1997), On Fundamentals and Exchange Rates: A Casselian Perspective, *Review of Economics and Statistics* 79 (4), 655-664.

-- and Mark P. Taylor (1994), The Monetary Model of the Exchange Rate: Long-run Relationships, Short-run Dynamics and How to Beat a Random-Walk, *Journal of International Money and Finance* 13 (3), 267-276.

Mark, Nelson (1995), Exchange Rates and Fundamentals: Evidence on Long-horizon Predictability, *American Economic Review* 85 (1), 201-218.

Marsh, Ian W. (2000), High-frequency Markov Switching Models in the Foreign Exchange Market, *Journal of Forecasting* 19, 123-134.

Meese, Richard A. (1986), Testing for Bubbles in Exchange Markets: A Case of Sparkling Rates? *Journal of Political Economy* 94 (21), 345-373.

-- (1990), Currency Fluctuations in the Post-Bretton Woods Era, *Journal of Economic Perspectives* 4 (1), 117-134.

-- and Andrew K. Rose (1991), An Empirical Assessment of Nonlinearities in Models of Exchange Rate Determination, *Review of Economic Studies* 58 (3), 603-619.

Menkhoff, Lukas (1998), The Noise Trading Approach – Questionnaire Evidence from Foreign Exchange, *Journal of International Money and Finance* 17, 547-564.

Neely, Christopher J. and Lucio Sarno (2002), How well Do Monetary Fundamentals Forecast Exchange Rates?, *The Federal Reserve Bank of St. Louis Review* 84 (5), 51-74.

Newey, Whitney K. and Kenneth D. West (1987), A Simple, Semi-definite, Heteroskedasticity and Autocorrelation Conistent Covariance Matrix, *Econometrica*, 55, 703-708.

Rogoff, Kenneth (2001), The Failure of Empirical Exchange Rate Models: No Longer New, but still True, *Economic Policy Web Essay* 1 (1).

Schinasi, G.J. and P.A.V.B. Swamy (1989), The Out-of-Sample Forecasting Performance of Exchange Rate Models when Coefficients are Allowed to Change, *Journal of International Money and Finance* 8, 375-390.

Wolff, Christian (1987), Time-Varying Parameters and the Out-of-Sample Forecasting Performance of Structural Exchange Rate Models, *Journal of Business and Economic Statistics* 5, 87-97.

TABLE 1. The impact of economics announcements on the FX market

		Unemploy-ment rate	Interest rate	Inflation	Trade deficit	GDP	other	
USA	1996/97	33.0	30.9	18.3	9.9	2.1	4.2	
UK	1998	27.0	46.7	19.7	2.5	0.0	1.6	
USA	1991/92	16.3	22.8	10.9	37.5	3.8	0.5	
UK	1993	9.2	29.2	9.2	45.8	3.3	0.8	
Differences between countries:								
USA-UK	Now	6.0	-15.8	-1.4	7.4	+2.1	-	∅ 5.65
USA-UK	5y ago	7.1	-6.4	1.7	-8.3	+0.5	-	
Differences over time:								
Change USA		16.7	8.1	7.4	-27.6	-1.7	-	
Change UK		17.8	17.5	10.5	-43.3	-3.3	-	∅ 15.39

Data sources: Cheung and Chinn (2001) for USA, Cheung, Chinn and Marsh (1999) for UK

TABLE 2. Time-varying importance of fundamentals as seen by FX professionals

Question: Are economic variables regarded differently over time by market participants? Do you agree with the following statements?

( ) There are often variables in the foreground, which emphasise the actually most urgent problem.

( ) There are often variables in the foreground, which are just fashionable but not directly related to fundamental problems.

( ) The attention does not change over time.

	Most urgent problem	Fashions	No change over time
Agree fully	20.6	23.6	3.6
:	40.0	32.7	3.0
:	24.8	19.4	9.1
:	9.1	13.3	5.5
:	3.6	6.7	16.4
Disagree fully	1.8	4.2	62.4
Number n	165	165	165

Data source: Menkhoff (1998)

TABLE 3. Estimation results for the constant coefficient RID model

	DEM/USD	JPY/USD	GBP/USD	Expected signs
Intercept: c	-0.0166	0.0108**	0.0239	n.a.
Money : α	-0.1922*	0.0006**	-0.8296*	> 0
Industrial production: β	-0.5023*	-0.0627**	-0.4233	< 0
Short term interest rate: γ	0.0435**	-0.0292	-0.0006	< 0
Long term interest rate: δ	-0.0890	0.0112	0.1086	> 0

Asterisks refer to level of significance, *: ten per cent, **: five per cent, ***: one per cent Newey-West HAC standard errors

TABLE 4. Estimated coefficients for the MSM

	DEM/USD	JPY/USD	GBP/USD
State 1			
c_1	0.0893***	-0.0414***	-0.0688***
α_1	0.1600*	0.0082	0.2045
β_1	-0.5958***	-0.1845***	-0.7344***
γ_1	-0.0860***	-0.0272	-0.0006
δ_1	0.1654***	0.1172**	0.1762**
State 2			
c_2	-0.1179***	0.0282***	0.1290***
α_2	0.0390	0.0003*	-0.8722***
β_2	-0.3895	0.0204	-0.5401***
γ_2	0.0317	-0.0028	-0.0088***
δ_2	-0.1022	-0.0070	0.2810***
p_{11}	0.9494***	0.9137***	0.9697***
p_{22}	0.9556***	0.9726***	0.9590***
$P(s_t=1)$	0.4676	0.2410	0.5747
$P(s_t=2)$	0.5324	0.7590	0.4253
Expected duration of the regimes (in months)			
Regime 1	19.8	11.6	33.0
Regime 2	22.5	36.5	24.4

Asterisks refer to level of significance, *: ten per cent, **: five per cent, ***: one per cent, Newey-West HAC standard errors

TABLE 5. Fit of the MSM in comparison with competing models

	DEM/USD	JPY/USD	GBP/USD
Markov switching RID model			
RMSE	0.06075	0.02324	0.06042
MAE	0.04767	0.01822	0.04663
Pure Markov switching model			
RMSE	0.06527	0.02449	0.06486
MAE	0.04692	0.01995	0.05102
Constant coefficient RID model			
RMSE	0.11992	0.03821	0.11367
MAE	0.09872	0.02869	0.09059
Random walk with drift			
RMSE	0.12402	0.04123	0.12434
MAE	0.10230	0.03026	0.10167

RMSE: root mean squared error. MAE: mean average error

TABLE 6. Wald test results for transition probabilities and coefficients

H_0	DEM/USD	JPY/USD	GBP/USD
$p_{11}=1-p_{22}$	10.058***	7.300***	8.433***
$c_1=c_2$	8.745.685***	66.358***	1.829.783***
$\alpha_1=\alpha_2$	0.984	0.002	308.819.285***
$\beta_1=\beta_2$	0.980	1.023	23.680***
$\gamma_1=\gamma_2$	24.862***	8.276***	0.453
$\delta_1=\delta_2$	15.935***	4.809**	15.467***

The Wald statistics given in the table have been calculated using the asymptotic covariance matrix. Asterisks refer to level of significance. **: five per cent. ***: one per cent

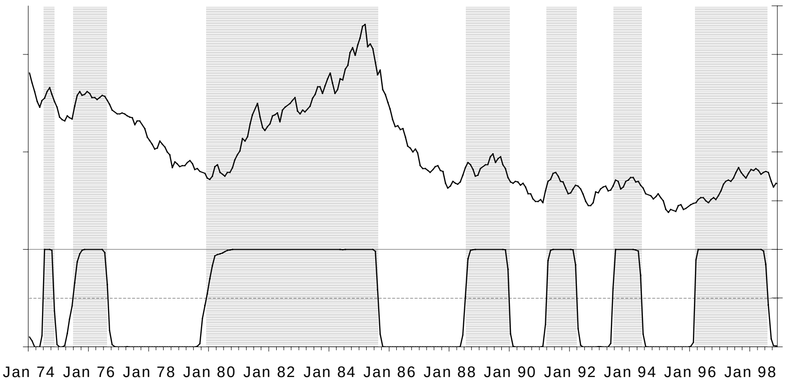
TABLE 7. Performance of out-of-sample forecasts based on competing models

	DEM/USD	JPY/USD	GBP/USD
Markov switching RID model			
1 month	0.0291	0.0093	0.0298
6 months	0.0945	0.0188	0.0754
12 months	0.1724	0.0379	0.1159
Pure Markov switching model			
1 month	0.0239 (-4.5914***)	0.0079 (-0.2062)	0.0250 (-3.2604***)
6 months	0.0817 (-2.5786**)	0.0147 (-0.3306)	0.0718 (-1.2023)
12 months	0.1239 (-1.9937*)	0.0234 (-0.4982)	0.1001 (-2.2351**)
Constant coefficient RID model			
1 month	0.0264 (-1.9279*)	0.0083 (-2.7424***)	0.0419 (5.2685***)
6 months	0.0936 (-0.3396)	0.0655 (3.6607***)	0.0983 (3.8782***)
12 months	0.1917 (0.0578)	0.2006 (3.5413***)	0.1835 (3.9745***)
Random walk			
1 month	0.0228 (-5.2933***)	0.0076 (-3.5322***)	0.0237 (-4.4309***)
6 months	0.0736 (-4.1238***)	0.0142 (-2.4539***)	0.0623 (-13.3567***)
12 months	0.1141 (-3.0134***)	0.0203 (-3.2203***)	0.0843 (-5.8335***)

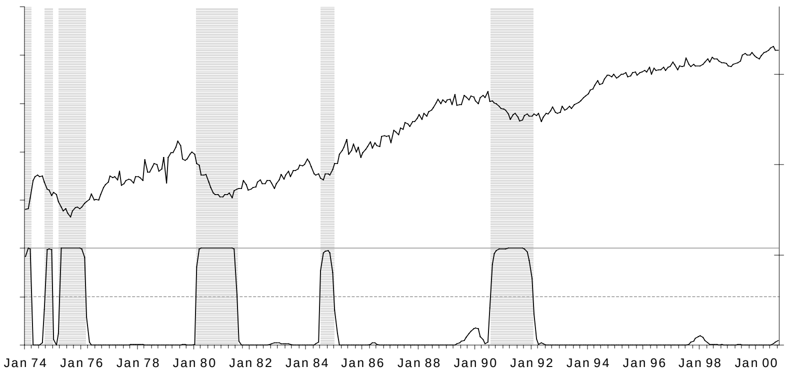
The alternatives are compared with the Markov switching RID model using the asymptotic test by Diebold and Mariano (1995) against the null hypothesis of no difference in forecast accuracy (using the absolute forecast error as loss function). The test statistic S_1 is given in parentheses. Positive values of S_1 indicate that the Markov switching RID model performs better than the alternative and vice versa. Asterisks refer to level of significance. **: five per cent. ***: one per cent

FIGURE 1. Smoothed Probabilities of being in State 1 (lower line) and Exchange Rate (upper line)

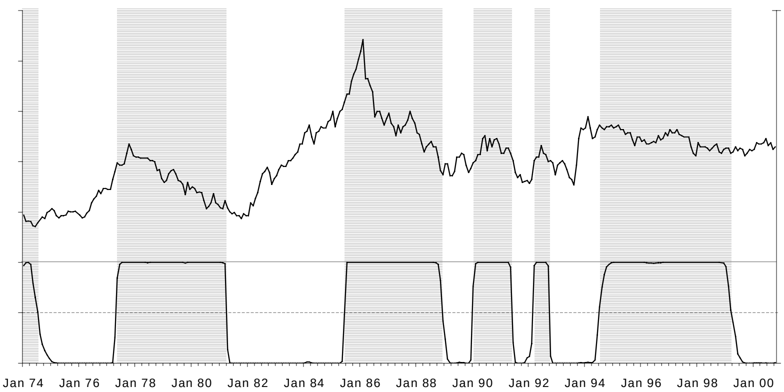
a) DEM/USD



b) JPY/USD



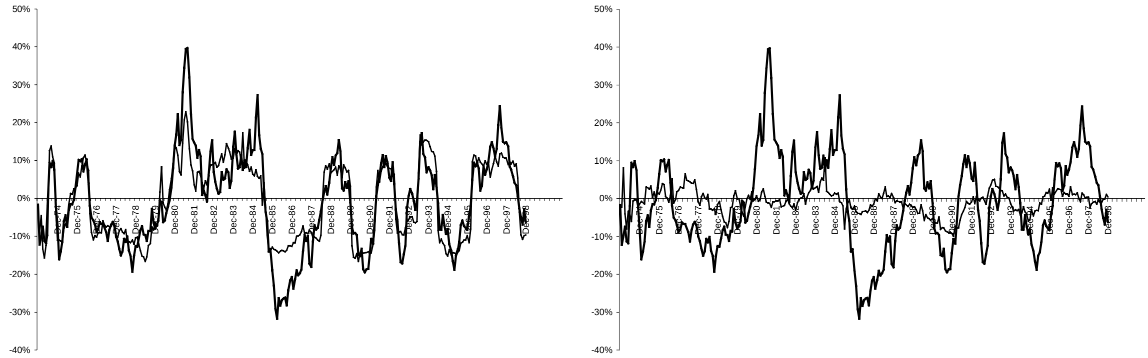
c) GBP/USD



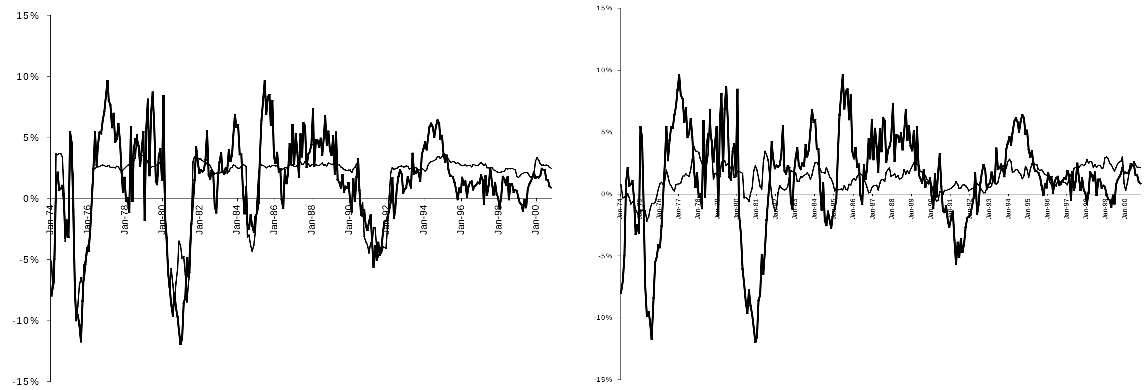
The grey areas mark periods for which the process is more likely to be in state 1 (in favour of the RID) than in state 2, that is $P(s_t=1|r_1,..,r_T)$ exceeds 0.5.

FIGURE 2. Fit of Estimated Models to actual percentage 12-months changes

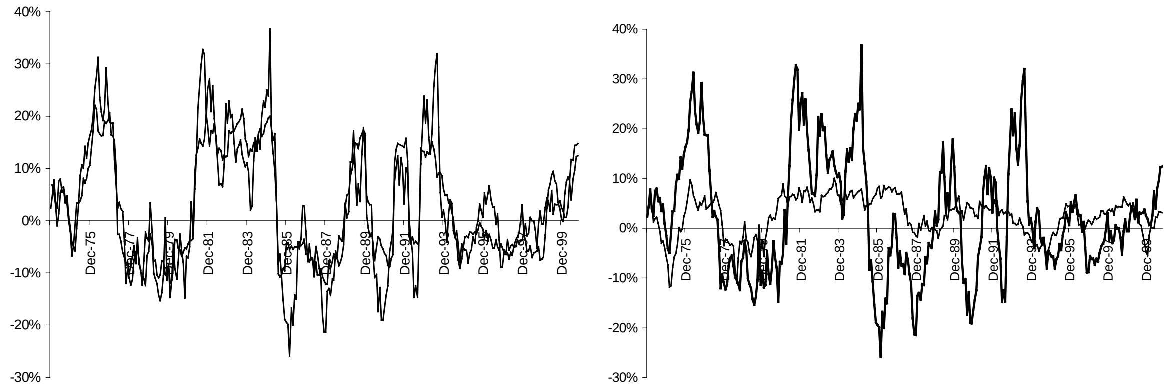
a) DEM/USD



b) JPY//USD



c) GBP/USD



Bold line: actual percentage change in exchange rate, thin line: fitted by RID with Markov switching coefficients (left hand figure), fitted by constant coefficient RID (right hand figure).