ABSTRACT

In this paper we propose a new transmission mechanism to examine the impact of central bank intervention on exchange rates. Within a heterogeneous expectations exchange rate model intervention operations are supposed to temporarily improve either chartist or fundamentalist forecasts, which forces portfolio managers to adjust their foreign currency positions. The empirical examination of the hypothesis is done by applying a markov regime-switching approach to daily US-dollar/DEM forward rates and intervention data of the Deutsche Bundesbank and the Federal Reserve from 1979 to 1992. It is shown that the performance of simple chartist trading rules was strong whenever these central banks intervened on the foreign exchange market. A similar coincidence cannot be found within the more sophisticated fundamentalist approach.
1. Introduction

The recent concerted and unilateral intervention carried out to stop the depreciation of the Euro again revealed central bank's persuasion that buying and selling foreign currency was an effective policy tool in order to influence exchange rates. Especially in the mid 1980s, when the US dollar was perceived to be overvalued against other major currencies, the G5 and G7 meetings decided that coordinated multilateral policies were necessary to depreciate the US dollar and to restore equilibrium in current account balances. In addition, central bank intervention should be employed to 'calm disorderly markets' or support other central banks in their foreign exchange market operations. Beyond the question whether exchange rates should be a target of economic policy, it remains unclear why interventions – typically sterilized – affect exchange rates. One approach stresses the fact that central bank intervention changes the relative supply of outstanding domestic and foreign bonds. As long as domestic and foreign assets are imperfect substitutes intervention will affect the risk premium and subsequent portfolio reallocations change the exchange rates. In another explanation proposed by Mussa (1981) intervention is supposed to reveal information about the future path of monetary policy inducing expectation revisions and a revaluation of exchange rates. Of course, in this scenario intervention has to be perceived by market participants, so only reported activity can be examined.

In this paper another transmission mechanism focussing on the impact of central bank intervention on exchange rate expectations of market participants is proposed. As stated in Dooley and Shafer (1983) intervention operations may introduce trends into the evolution of exchange rates that can be exploited by means of chartist forecasting techniques. LeBaron (1999) provided support for this argumentation showing that the profitability of a simple trading rule based on moving averages was magnified whenever the Federal Reserve intervened on the foreign exchange market. Neely and Weller (1997) stressed that these excess returns are not due to the predictive power of the intervention signal itself, but result from strengthening chartists ability to identify

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3 The so-called portfolio balance channel is examined by Dominguez and Frankel (1993a) and Baillie and Osterberg (1997a).
4 Kaminsky and Lewis (1996) provide an empirical investigation of the signalling channel. Although they found that intervention contains useful information to predict future monetary policy, the signals were of the wrong sign on average.
empirical regularities in the exchange rate history. Apart from providing the rationale for the application of trading rules, intervention may as well improve the performance of expectation based on fundamentals, especially when central banks try to correct current exchange rate misalignments. As is documented in micro survey studies chartist and fundamentalist techniques are used depending on whether short term or long term forecasts are to be made (Dominguez, 1986; Allen and Taylor, 1989).

To allow for different forecasting strategies the impact of central bank intervention is investigated applying a heterogeneous expectations exchange rate model. Following Frankel and Froot (1986) the excess demand for foreign currency is assumed to be a function of the relative success of chartist and fundamentalist forecasting techniques. As is stated above the performance of chartist or fundamentalist predictions is expected to be temporarily improved by central bank intervention – thereby altering the time series properties of exchange rates. The empirical examination of the hypothesis is done by applying the Markov regime-switching approach originally proposed by Hamilton (1989) to daily Deutsche Bundesbank and Federal Reserve intervention data from 1979 to 1992. Considering the results of Neely and Weller (1997) intervention data is used only to construct a dummy variable distinguishing between intervention and no-intervention periods. Statistically significant estimates of dummy coefficients lead to the conclusion that an impact of central bank intervention on exchange rate expectation cannot be rejected. Furthermore, we re-examine the effects of intervention on exchange rate volatility, where empirical work has reported quite mixed results. The parameter estimates of the Markov switching model suggest that the inconclusive evidence is due to a regime dependent correlation between the intervention and volatility.

The rest of the paper is organized as follows. We next outline the intervention augmented heterogeneous expectation exchange rate model and its corresponding regime-switching specification. Section 3 reports and discusses the estimation results and the test statistics. Section 4 provides the conclusions of the paper.

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5 Dominguez (1998) estimates GARCH(1,1) models and shows that overt intervention was able to reduce volatility in certain periods. But in general, intervention seemed to have an increasing effect on the conditional variance of exchange rate changes (Baillie and Osterberg, 1997b).
2. Central bank interventions in a heterogeneous expectation exchange rate model

In the standard chartist and fundamentalist (c&f) model originally suggested by Frankel and Froot (1986) the (log of the) exchange rate \( e_t \) is driven by the decisions of portfolio managers. They buy and sell foreign currency in response to changes in the expected rate of appreciation \( E_t[\Delta e_{t+1}] \) and a set of contemporaneous variables included in a vector \( z_t \). Thus, the exchange rate can be written as:

\[
e_t = aE_t[\Delta e_{t+1}] + b z_t,
\]

(1)

where the vector of elasticities of the contemporaneous variables (\( b \)) and the elasticity of exchange rate expectation (\( a \)) should be constant over time. Under the rational expectations hypothesis equation (1) has the well known forward looking solution that \( e_t \) is the weighted sum of current and expected future market fundamentals. In contrast to this, Frankel and Froot (1986) assumed that portfolio managers generate their exchange rate expectations using a mixture of chartist \( E_t^c[\Delta e_{t+1}] \) and fundamentalist \( E_t^f[\Delta e_{t+1}] \) forecasts:

\[
E_t[\Delta e_{t+1}] = \omega_t E_t^f[\Delta e_{t+1}] + (1 - \omega_t) E_t^c[\Delta e_{t+1}].
\]

(2)

\( \omega_t \), denoting the weight given to fundamentalist views at date \( t \), is dynamically updated by the portfolio managers in a rational Bayesian manner:

\[
\Delta \omega_t = \delta (\omega_{t-1}^* - \omega_{t-1})
\]

(3)

with:

\[
\omega_{t-1}^* = \frac{\Delta e_t - E_{t-1}^c[\Delta e_t]}{E_{t-1}^c[\Delta e_t] - E_{t-1}^e[\Delta e_t]},
\]

where \( \omega_{t-1}^* \) is the ex post calculated weight that must have been assigned to fundamentalist forecast in order to predict the current exchange rate change accurately. The value of \( \delta \) reflects the extent to which portfolio managers enclose new information in this adaptive process and proves responsible for the exchange rate dynamics. Concerning the expectation formation fundamentalists have in mind some kind of long-
run equilibrium $\tilde{e}$, to which the exchange rate reverts with a given speed $\theta$ over time, i.e.

$$E_t^f[\Delta e_{t+1}] = \theta_t (\tilde{e} - e_t) \quad (4)$$

This can be explained by the fact that agents have different beliefs about the equilibrium value of the exchange rate, which is certainly not observable. Kilian and Taylor (2001) conclude that the heterogeneity of beliefs will diminish when the exchange rate becomes increasingly overvalued and the supply of foreign exchange should rise. Accordingly to (4) fundamentalist expectation can be viewed as distributed symmetrically around $\tilde{e}$. We assume that the fundamental value $\tilde{e}_t$ can be described by purchasing power parity (PPP). Takagi (1991) provides evidence from survey data that foreign exchange market participants accept PPP as a valid relationship only in the long run implying low values for $\theta_t$. This view is recently supported by Taylor and Peel (2000) and Taylor et al. (2001) showing that due to its nonlinear dynamics the exchange rate reverts to the PPP level, but only in the long run. Furthermore, PPP as a measure of the fundamental exchange rate $\tilde{e}_t$ seems to be suitable for the investigation of central bank intervention, because the monetary authorities use it as a target level (Dominguez and Frankel, 1993b). If central bank operations on foreign exchange markets are in fact intended to bring back the exchange rate to its long run equilibrium, $\theta$ is supposed to increase whenever intervention occurs. Denoting the increase of $\theta$ by $\delta_\theta$, we can formulate $\theta$ as a function of a 0,1-intervention dummy $I_t$ as follows:

$$\theta_t = \theta + \delta_\theta I_t, \quad \theta, \delta_\theta > 0 \quad (4)$$

Chartists are defined as market participants who believe that exchange rate time series exhibit regularities which can be detected by a wide range of so-called technical trading rules. To reduce the impact of data snooping biases brought on by searching for the best performer we employ a very simple type of trading rule following common practice (Takagi, 1991). Excess returns of moving average (MA) trading rules of daily U.S. dollar quotes for the DM, yen, pound sterling and Swiss franc is reported in Neely (1997) and LeBaron (1999). Lee et al. (2001) found MA trading rule profitability for Latin American currencies applying out of sample-tests. These studies show that the
length of the short run and long run moving average don’t have much influence on the trading rule profitability. To be concrete, chartists are supposed to expect that a future exchange rate increase is predicted by the proportion $\psi$ of the positive difference between the 14 day moving average ($\text{ma}_{14}$) and 200 day moving average ($\text{ma}_{200}$) and vice versa. Hence, their exchange rate expectation at date $t$ is $E_t^c(\Delta e_{t+1}) = \psi_t (\text{ma}_{14} - \text{ma}_{200})$. If a leaning against the wind strategy of central banks introduces trends into exchange rate dynamics, $\psi$ should rise whenever intervention occur. Denoting the increase of $\psi$ by $\delta_\psi$, we can formulate $\psi$ as a function of the intervention dummy $I_t$ as follows:

$$\psi_t = \psi + \delta_\psi I_t, \quad \psi, \delta_\psi > 0.$$  \hspace{1cm} (5)

Of course, neither the chartists, the fundamentalists, nor the portfolio managers have rational expectations about the future exchange rates. Within the model agents could do a better job in expected value terms, if they knew the complete model. But as long as market participants try to compensate the lack of a verified exchange rate model with different forecasting techniques, the imposed informational restrictions are a realistic description of the foreign exchange market.

In order to confront the C&F-model with exchange rate data, the econometric approach should be able to describe the conditional distribution of the exchange rate change by a mixture of (normal) distributions. As is stated in Clarida et al. (2001) the Markov regime-switching model suggested by Engel and Hamilton (1990) and developed further by, among others, Engel (1994), Vigfusson (1997) and Dewachter (2001) is a natural candidate to characterize exchange rate behavior. In our model, the conditional mean $\mu_t$ and the conditional variance $h_t$ of exchange rate changes $\Delta e_t$ are allowed to follow two different regimes indicated by an unobservable state variable $S_t$. The regime indicator $S_t$ is parameterised as a first-order Markov process and the switching or transition probabilities $P$ and $Q$ have the typical Markov structure:

$$\begin{align*}
\Pr[S_t=0|S_{t-1}=0] &= P \\
\Pr[S_t=1|S_{t-1}=0] &= 1-P \\
\Pr[S_t=1|S_{t-1}=1] &= Q \\
\Pr[S_t=0|S_{t-1}=1] &= 1-Q.
\end{align*}$$  \hspace{1cm} (7)
Thus, under conditional normality, an observed realisation $\Delta e_t$ is presumed to be drawn from a $N(\mu_{0t}, h_{0t})$ distribution if $S_t = 0$, whereas $\Delta e_t$ is distributed $N(\mu_{1t}, h_{1t})$ if $S_t = 1$.

The evolution of the log first differences of exchange rates can therefore be written as

$$
\Delta e_t = \mu_{0t} (1 - S_t) + \mu_{1t} S_t + \sqrt{h_{0t}} (1 - S_t) + h_{1t} S_t \cdot \varepsilon_t, \quad (8)
$$

where $\varepsilon_t$ is an i.i.d. standard normal variable. The parameter estimation of the mean ($\mu_t$) and variance ($h_t$) equations in the regime switching model are derived from maximisation of the log-likelihood function

$$
L = \sum_{t=1}^{T} \log \left[ p_{1t} \frac{1}{\sqrt{2\pi h_{1t}}} \exp \left\{ -\frac{(\Delta e_t - \mu_{1t})^2}{2h_{1t}} \right\} ight] \\
+ (1 - p_{1t}) \frac{1}{\sqrt{2\pi h_{2t}}} \exp \left\{ -\frac{(\Delta e_t - \mu_{2t})^2}{2h_{2t}} \right\}, \quad (9)
$$

$p_{1t} = Pr(S_t = 1| \Phi_{t-1})$ is the probability that the analysed process is in regime 1 at time $t$ and is updated by means of Bayesian inference using information available at time $t - 1$. Therefore, $p_{1t}$ and $(1 - p_{1t})$ can be regarded as weights assigned to regime dependent forecasts resulting from a rational learning process very similar to $\omega_t$ and (1 - $\omega_t$) in the theoretical exchange rate model outlined above.

For comparison purposes, we first specify the mean equations without taking into account foreign exchange market activities of central banks. However, the important results of the study are derived from mean equations that include intervention dummies as it is done in the second specification.

(1) The standard regime-switching-c&f model: RS-CF

The mean equation of the first regime represents the fundamentalist regime including the deviation of the exchange rate from its fundamental value $\tilde{e}_t$ described by purchasing power parity as outlined above. The second regime’s mean equation contains chartist expectations, i.e. the moving average trading consisting of the difference between $ma_{14}$ and $ma_{200}$:
\[
\mu_{0t} = \theta (\text{ppp}_{t-1} - e_{t-1}) \\
\mu_{1t} = \psi (\text{ma}_{14} - \text{ma}_{200}).
\]

The variance of \( \Delta e_t \), i.e. the volatility of \( e_t \), is assumed to be constant within regimes, \( h_{0t} = \sigma_F^2 \) and \( h_{1t} = \sigma_C^2 \), so that the only source of conditional heteroskedasticity is the regime-switching behavior.

(2) The intervention augmented regime-switching-c&f model: RS-CF-Int

To introduce Federal Reserve intervention into the regime-switching framework, we define that the dummy variable \( I_t = 1 \), if the Federal Reserve Bank intervenes at time \( t \) and \( I_t = 0 \), otherwise and rewrite the mean equations of the standard c&f model as follows:

\[
\mu_{0t} = \left( \theta + \delta_0 I_t \right) (\text{ppp}_{t-1} - e_{t-1}) \\
\mu_{1t} = \left( \psi_{14} + \delta_{14} I_t \right) (\text{ma}_{14} - \text{ma}_{200})
\]

As long as interventions do not occur, i.e. \( I_t = 0 \), this more general formulation boils down to the standard RS-CF model. More interestingly, if the foreign exchange intervention of the Federal Reserve had an impact on the forecasting performance of chartists and fundamentalists, a change of coefficients represented by significant estimates of the various \( \delta \)s should be observed. By introducing intervention dummies in the specification of second moments, \( h_{0t} = \sigma_F^2 + \delta_{\sigma_F} \cdot I_t \) and \( h_{1t} = \sigma_C^2 + \delta_{\sigma_C} \cdot I_t \), we are able to re-examine the relationship between central bank intervention and exchange rate volatility, where the existing literature provided mixed evidence (Baillie and Osterberg, 1997b and Dominguez, 1998).

3. Empirical Results

The models described above were estimated by maximum likelihood. Parameter estimates were obtained using the BFGS algorithm, and the reported t-statistics are based on heteroskedastic-consistent standard errors (White, 1982). The estimates are
derived from the daily DEM/US-Dollar forward exchange rate series kindly supplied by
the Deutsche Bundesbank. The purchasing power parity was constructed using monthly
observed consumer price indices. The intervention dummy series is based on
intervention data from the Deutsche Bundesbank and the Federal Reserve Bank.6 The
Fed intervention series only includes active trades made by the Federal Reserve for
reasons of influencing foreign exchange rates. Purchases and sales of the Deutsche
Bundesbank are reported whenever they changed their net foreign assets. The sample
extends from January 1979 to December 1992. The series of the forward exchange rate,
the PPP relation and the 200 day moving average are presented in upper graph, the
Federal Reserve purchases and sales of Dollars against DEM can be found in the middle
graph, and the Deutsche Bundesbank purchases and sales of Dollars against DEM in the
lower graph of Figure 1.

[Figure 1]

As can be seen in the lower graphs intervention of both the Federal Reserve and the
Deutsche Bundesbank were sporadic and clustered. The fraction of trading days that
intervention is going on is 0.134 and 0.249. The average intervention was −2.1 million
dollars indicating that buying and selling of the Federal Reserve has been relatively
balanced. In contrast, the average intervention of the Deutsche Bundesbank was −26.56
million DEM. Conditional on the intervention occurring the mean absolute value of
purchases or sales is 112.1 million dollars (Federal Reserve) and 158.3 million DEM
(Deutsche Bundesbank), respectively.

Table 1 contains the estimates of both the RS-CF and the RS-CF-Int model. As regards
the transition probabilities, the models differ slightly at best. P and Q range above 0.95
thereby indicating high persistence of regimes. The unconditional probability of the
fundamentalist regimes $P = \frac{1 - Q}{2 - P - Q}$ is lower than the one assigned to chartist
regimes. This is also reflected in the expected duration of regimes. The (first)
fundamentalist regimes are expected to last up to 33 trading days whereas the (second)
chartist regimes have a longer duration of at least 34 trading days. Significant estimates
of variances point to regime dependent heteroskedasticity capturing periods of high and

6 I am grateful to Blake LeBaron for making intervention data available to me.
low volatility: The second moment in the second regimes is three times as high as the variance in the first regimes. The estimates of chartist and fundamentalist coefficients $\psi$ and $\theta$ are statistically significant and of the correct sign.

[Table 1]

Table 2 reports Ljung-Box Q-statistics relating to the residuals as well as to the squared standardised residuals of the estimated models thereby testing for serial correlation and autoregressive conditional heteroskedasticity. The figures show that the model is able to capture the mean dynamics as well as conditional heteroskedasticity of short term exchange rates by regime-switching, and it can be concluded that the intervention augmented c&f model does a good job in modelling the DM/US-Dollar forward rate.  

[Table 2]

However, the most important results from these Markov switching procedures are significant parameter estimates of chartist and fundamentalist forecasting techniques within the heterogeneous expectations framework. As has been outlined in the theoretical model, central bank interventions are supposed to affect exchange rates by influencing chartist and fundamentalist forecasting success. Because the standard RS-CF model is nested in the more general RS-CF-Int model, the hypothesis can be examined by the values of the log-likelihood functions, the likelihood ratio test (LRT) statistic and the estimates of the various $\delta$s in Table 1.

As the LRT statistic suggests, the consideration of intervention dummies explain a significant improvement in the log-likelihood function. Hence, the hypothesis that exchange rate expectations are not affected by central bank interventions has to be rejected. Particularly, the results of parameter estimates give rise to the conclusion that foreign exchange activities of the Federal Reserve as well as the Deutsche Bundesbank

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7 The fact that regime classification might be driven by state-dependent heteroskedasticity does not weaken this conclusion. A typical finding in the regime-switching literature is that coefficients in the mean equations become insignificant when additionally allowing for variances depending on regimes. This phenomenon can be explained by the dominance of second moments in characterising the distribution of high frequency data. As Table 1 suggests, the case in our study is completely different. Because $\theta$ and $\psi$ are significant even in the presence of strong state dependent volatility, empirical support for the c&f model is strong.
could have supported moving average trading rules. The dummy coefficient $\delta_\psi$ for both central banks is highly significant and reports a large increase of $\psi$ whenever $I_t = 1$. However, the predictive ability of these rules can only be confined completely to periods of central bank activity in the case of the Deutsche Bundesbank. When looking at the link between central bank intervention and fundamentalist exchange rate expectations, we recognize no significant change of $\theta$. It seems that the contribution of the Federal Reserve and the Deutsche Bundesbank to bring back exchange rates to the ppp level is small if not deniable.

In the case of Federal Reserve intervention, the intervention dummy identifies fundamentalist dominated periods in which the exchange rate volatility is estimated nearly twice as high. The statistically significant coefficient $\delta_{\sigma_i}$ indicates an important structural break in the volatility of the fundamentalist regime. In contrast, if there is any change in volatility within the chartist regime, then it is obviously not correlated with central bank intervention. In the case of Deutsche Bundesbank intervention, the dummy identifies a structural break in the volatility of the chartist regime, but not in the fundamentalist regime. This result can be interpreted to be in favour of the heterogeneous expectation approach. The finding that the correlation between exchange rate volatility and central bank interventions is strongly regime dependent may explain the mixed evidence reported from conventional single regime frameworks.

3. Conclusion

Although there is evidence that monetary authorities tried to avoid misalignments and counter ‘disorderly markets’, the impact of central bank intervention on foreign exchange rates repeatedly turned out to be low when assessed by means of conventional single regime approaches. It becomes even more difficult to imagine a rational expectations model capable of explaining these results, when taking into account that intervention seems to increase the profitability of technical trading rules (LeBaron, 1999). Consequently, on the basis of the theoretical heterogeneous expectation framework, we estimate an intervention augmented two state Markov regime-switching model.
We show that the predictive power of simple chartist forecasting techniques was enhanced whenever the Federal Reserve or the Deutsche Bundesbank intervened on the foreign exchange market, whereas the more sophisticated fundamentalist approach approximated by the deviation of the current exchange rate from the ppp level was not strengthened in these periods. Obviously, the mixed evidence reported in the literature can be explained by regime dependence properties of intervention operations. If chartist analysis is associated with destabilizing effects on exchange rates and fundamentalist expectations with stabilizing effects, we cannot rule out a destabilizing impact of central bank intervention on exchange rates. This is confirmed by the finding that the intervention dummy identified periods in which the volatility is nearly doubled. Of course, we have to address a serious causality problem: Before quickly concluding that exchange rate volatility is due to intervention operations, ‘disorderly markets’, i.e. high volatility, may have challenged central bank activities. But as long as this reverse causality is not confirmed, central bank interventions are an ambiguous policy tool in influencing exchange rates.
Literature


Clarida, R; Sarno, L; Taylor, M.; Valente, G. (2001), The Out-of-Sample Success of Term Structure Models as Exchange Rate Predictors: A Step Beyond, Mimeo.


Fig. 1: DM/$ forward rate, PPP, 200 d moving averages and Central Bank Intervention

DM/Dollar Forward Rate, PPP, 200 d moving averages
Daily observations, 1979 - 1992

Federal Reserve Interventions
Purchases (+) and sales (-) of dollars

Deutsche Bundesbank Intervention
Purchases (+) and sales (-) of dollars
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>( \theta )</td>
<td>( 2.95 \cdot 10^{-3} (2.15)** )</td>
<td>( 2.43 \cdot 10^{-3} (1.81)* )</td>
<td>( 4.72 \cdot 10^{-3} (3.41)*** )</td>
</tr>
<tr>
<td>( \delta_\theta )</td>
<td>( 9.38 \cdot 10^{-3} (0.76) )</td>
<td>( -5.75 \cdot 10^{-3} (1.27) )</td>
<td></td>
</tr>
<tr>
<td>( \psi )</td>
<td>( 8.02 \cdot 10^{-3} (3.15)*** )</td>
<td>( 4.98 \cdot 10^{-3} (1.72)* )</td>
<td>( 1.99 \cdot 10^{-4} (0.06) )</td>
</tr>
<tr>
<td>( \delta_\psi )</td>
<td>( 3.69 \cdot 10^{-3} (2.87)*** )</td>
<td>( 3.17 \cdot 10^{-2} (5.46)*** )</td>
<td></td>
</tr>
<tr>
<td>( \sigma_F^2 )</td>
<td>( 8.89 \cdot 10^{-5} (13.76)*** )</td>
<td>( 8.25 \cdot 10^{-5} (13.57)*** )</td>
<td>( 8.17 \cdot 10^{-5} (9.60)*** )</td>
</tr>
<tr>
<td>( \delta_{\sigma_F} )</td>
<td>( 8.16 \cdot 10^{-5} (2.52)** )</td>
<td>( 2.45 \cdot 10^{-5} (1.44) )</td>
<td></td>
</tr>
<tr>
<td>( \sigma_C^2 )</td>
<td>( 2.27 \cdot 10^{-5} (11.13)*** )</td>
<td>( 2.31 \cdot 10^{-5} (10.07)*** )</td>
<td>( 1.99 \cdot 10^{-5} (6.92)*** )</td>
</tr>
<tr>
<td>( \delta_{\sigma_C} )</td>
<td>( 1.47 \cdot 10^{-6} (0.42) )</td>
<td>( 5.39 \cdot 10^{-6} (2.16)** )</td>
<td></td>
</tr>
<tr>
<td>( P )</td>
<td>( 0.9697 (139.70)*** )</td>
<td>( 0.9690 (111.75)*** )</td>
<td>( 0.9684 (104.13)*** )</td>
</tr>
<tr>
<td>( Q )</td>
<td>( 0.9741 (151.53)*** )</td>
<td>( 0.9753 (137.67)*** )</td>
<td>( 0.9708 (116.31)*** )</td>
</tr>
<tr>
<td>( \mathbf{F} )</td>
<td>( 0.46 )</td>
<td>( 0.44 )</td>
<td>( 0.48 )</td>
</tr>
<tr>
<td>( \mathbf{Q} )</td>
<td>( 0.54 )</td>
<td>( 0.56 )</td>
<td>( 0.52 )</td>
</tr>
<tr>
<td>( (1 - P)^{-1} )</td>
<td>( 33 )</td>
<td>( 32.26 )</td>
<td>( 31.65 )</td>
</tr>
<tr>
<td>( (1 - Q)^{-1} )</td>
<td>( 38.61 )</td>
<td>( 40.49 )</td>
<td>( 34.25 )</td>
</tr>
<tr>
<td>Log-Likelihood</td>
<td>( 13029.27 )</td>
<td>( 13054.42 )</td>
<td>( 13056.90 )</td>
</tr>
<tr>
<td>LRT</td>
<td>( 50.29 *** )</td>
<td>( 55.26 *** )</td>
<td></td>
</tr>
</tbody>
</table>

Notes: The sample contains daily observations of the DM/Dollar forward exchange rate from January 1979 to December 1992. See text for meaning of symbols. t-statistics in parentheses are based on heteroskedastic-consistent standard errors. The likelihood ratio test statistic is asymptotically \( \chi^2 \) (df)-distributed with df indicating the numbers of restrictions. *, ** and *** denotes significance at the 90%, 95% and 99% level, respectively.
## Table 2

Specification Tests (Ljung-Box Q-Statistic)

<table>
<thead>
<tr>
<th></th>
<th>RS-CF</th>
<th>RS-CF-Int (FED)</th>
<th>RS-CF-Int (BBK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR(1)</td>
<td>0.67 (0.41)</td>
<td>0.58 (0.45)</td>
<td>1.32 (0.25)</td>
</tr>
<tr>
<td>AR(2)</td>
<td>0.71 (0.70)</td>
<td>0.63 (0.73)</td>
<td>1.38 (0.50)</td>
</tr>
<tr>
<td>AR(3)</td>
<td>4.61 (0.20)</td>
<td>4.55 (0.21)</td>
<td>5.17 (0.15)</td>
</tr>
<tr>
<td>AR(4)</td>
<td>7.38 (0.12)</td>
<td>7.19 (0.13)</td>
<td>7.37 (0.12)</td>
</tr>
<tr>
<td>AR(5)</td>
<td>9.25 (0.10)</td>
<td>9.20 (0.10)</td>
<td>8.69 (0.12)</td>
</tr>
<tr>
<td>ARCH(1)</td>
<td>0.12 (0.73)</td>
<td>0.42 (0.51)</td>
<td>0.01 (0.91)</td>
</tr>
<tr>
<td>ARCH(2)</td>
<td>0.21 (0.90)</td>
<td>0.93 (0.63)</td>
<td>0.09 (0.96)</td>
</tr>
<tr>
<td>ARCH(3)</td>
<td>2.52 (0.47)</td>
<td>2.37 (0.50)</td>
<td>2.50 (0.47)</td>
</tr>
<tr>
<td>ARCH(4)</td>
<td>6.54 (0.16)</td>
<td>5.93 (0.20)</td>
<td>6.27 (0.18)</td>
</tr>
<tr>
<td>ARCH(5)</td>
<td>6.54 (0.26)</td>
<td>5.97 (0.31)</td>
<td>6.30 (0.28)</td>
</tr>
</tbody>
</table>

**Notes:** AR(p) denotes the Ljung-Box statistic for serial correlation of the residuals out to p lags. ARCH(q) denotes the Ljung-Box statistic for serial correlation of the standardized squared residuals out to q lags. p-values are in parentheses.