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EXPLAINING AND FORECASTING THE EURO/DOLLAR EXCHANGE RATE. USING THRESHOLD MODELS TO CAPTURE NON-LINEARITIES TRIGGERED BY BUSINESS CYCLE DEVELOPMENTS AND EQUITY MARKETS DYNAMICS

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ABSTRACT

In this paper, I build a linear econometric ECM model based on the differentials of short interest rates, GDP growth expectations and inflation, in order to explain the euro/dollar exchange rate dynamics and provide reliable forecasts. Despite the good performance of the adopted specification, some behavioural aspects remain unexplained. The introduction of non-linear threshold dynamics within the base linear formulation provides a better understanding of “abnormal” features other than simple deviations from long-run equilibrium levels, allowing for the possibility of asymmetric behaviour in the exchange rate. Empirical evidence of this is found in the actual dynamics of the euro during its first one-and-a-half years of life. The non-linear specification shows better performances than the linear model with respect to both in-sample fitting and out-of-sample forecasting, thus showing that, even though fundamentals hold in explaining the euro/dollar exchange rate dynamics, these may work also through some non-linear mechanism.

1. INTRODUCTION[1]

When the euro was introduced on 1 January 1999 few observers expected it would have experienced such a prolonged depreciation against the US dollar; in fact, the euro dropped by about 27% from its introduction to September 2000. Both its status as a young currency and its somehow peculiar behaviour require a deeper understanding of the factors driving its dynamics. In this respect, the first natural question that arises is whether the euro is not driven by fundamentals and to what extent its developments were predictable. Ex post the answer is yes, in the sense that the euro/dollar exchange rate evolved in line with GDP growth and short term interest rate differentials between the euro area and the United States. Hence, in the presence of correct expectations on fundamentals, the weakening of the euro would have not been a surprise. However the magnitude of the depreciation could be debated, raising the doubt of an undervaluation of the euro with respect to the dollar.

A behavioural linear ECM model is hence specified, which is aimed at both finding the main determinants of the euro/dollar exchange rate and obtaining reliable forecasts. The hypothesis is tested that short interest rate differentials, expected GDP growth differentials and inflation rate differentials possibly drive the long term dynamics of the euro/dollar exchange rate, on the ground of empirical evidence. The adopted specification can be judged as satisfactory, as it beats the random walk and provides the correct positioning with respect to 1-month forward rates in more than 50% of cases[2]. However, the linear model is not able to capture outliers and some

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[1] *Acknowledgements: I acknowledge useful input from Jeremy Berkowitz, Todd E. Clark, Rodolfo Dozio, Michael W. McCracken, Luca Mezzomo, Domenico Sartore and Timo Teräsvirta. Any remaining errors and inaccuracies are mine. The opinions expressed do not necessarily represent those of Banca Commerciale Italiana.*

[2] *From an exquisitely market-oriented perspective, it is important for a model to provide forecasts which make possible financial gains with respect to the forward (exchange rate) prediction. If, for instance, the exchange rate appreciates, and the model forecasts a larger appreciation than the forward exchange rate does, it is convenient to enter a long position* at *the forward price, and close the position with a sale at the final spot market price. In this case,*

possibly “abnormal” features of the euro/dollar exchange rate (if compared with the base model assumptions), as these are not simply related to a problem of temporary deviation from equilibrium levels.

The presence of non-linearity is hence assumed to be the main cause of these peculiarities, and a set of alternative threshold regression models is built, maintaining, apart from the introduction of non-linear dynamics, the same structure of the linear model. The non-linear specification proposed allows the possibility of taking into account asymmetric responses of the euro/dollar exchange rate to similar impulses, depending on some “state” condition being in place. The better in-sample fitting and out-of-sample forecast performance exhibited relative to the linear model seems to confirm this hypothesis, showing that, for instance i) monetary policy interventions may make sense only when a significant degree of undervaluation of the euro, which puts at risk the inflation stability condition, is underway, while the same consideration does not necessarily hold in the opposite case, ii) the euro seems to be more vulnerable when GDP growth differentials are unfavourable while, in the opposite situation, positive factors may amplify their upward influence by reinforcing their cross effects, iii) extraordinarily positive stock market performances may temporarily decouple exchange rate dynamics from macroeconomic fundamentals. Evidence of these general findings is present in the actual behaviour of the euro/dollar exchange rate already during its first one and a half years of life.

2. THE “YOUNG CURRENCY PROBLEM” AND THE DATA

The choice of the data used for the models presented in the following has required some assumptions as far as the period preceding 1 January 1999 is concerned, since the euro was introduced on that date.

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the indications provided by the model are good within a speculative context. The “good performance” condition with respect to the forward exchange rate prediction can be summarised as follows:

$$(M_t - F_t) \times (A_t - F_t) > 0,$$

where M_t is the model forecast for time t, F_t is the forward exchange rate and A_t is the actual value of the exchange rate.

The basic assumption is that before the introduction of the single currency the "natural" substitute of the euro-area as the counterpart of the United States was Germany. This is also consistent with the fact that German interest rates played a major role in the convergence process which took place in the run-up to the European Economic and Monetary Union. As a consequence, the DEM/USD exchange rate corrected for the EUR/DEM parity is used before 1999. Short interest rates are 3-month interbank rates for both Germany and the US. Both exchange and interest rate data are monthly averages of daily data. GDP data are GDP annual growth rate expectations, taken from Consensus Economics Inc., which collects every month the predictions of "over 200 prominent financial and economic forecasters" on a range of macroeconomic and financial variables (available in the publication *Consensus Forecasts*). These data are a valid proxy for aggregate expectations of GDP growth. Monthly data taken from *Consensus Forecasts* are then used to calculate weighted monthly averages of expected growth for the current and the following year, where the weights for the current year decrease as year-end approaches, while the weights for the following year correspondingly increase. German GDP growth data are used until December 1997, while for 1998 a weighted average of German and aggregate euro area data is employed, where the weights for German growth decrease as year-end approaches, while the weights for the euro area growth correspondingly increase. Finally, inflation data are annual inflation rates of CPI, both for Germany, the euro-area and the US. The same procedure as for the GDP series is applied here to German and euro area inflation data in 1998, in order to smooth the transition path.

Monthly data are used, from January 1992 to August 2000. In-sample estimation results cover the full period while, when the models are used to obtain forecasts, estimation is conducted on a reduced sample, ending in December 1998, and the remaining data form the forecast set.

3. A LINEAR MODEL BASED ON ECONOMIC FUNDAMENTALS

The model proposed here is aimed at seeking the key determinants of the euro/dollar exchange rate, with the main purpose of producing forecasts for a sufficiently large forecasting horizon even in a more than 1-step ahead prediction framework. It is based on economic fundamentals, in order to capture the trend developments of the exchange rate in line with a base macroeconomic scenario, and exploits the idea of a long-run “equilibrium” relation between the exchange rate and its determinants.

As it is variously shown in the literature, the key assumption which is tested here is that the main driving forces of the exchange rate are the differentials of interest rates, GDP growth and inflation rate between the two areas involved. However, both economic growth and inflation enter in this model in a slightly different way with respect to the traditional approach. In fact, following a relatively new research line already in use in financial markets, the hypothesis considered here is that the exchange rate is driven by the differentials of the expectations of GDP growth, in place of the actual differentials, thus reflecting the fact that inevitably market participants take their decisions using a forward-looking approach. The other point is quite similar since, turning to the inflation rate differential, this enters the model 1-period lagged, thus taking into account a sort of “announcement” effect, since inflation figures are usually available with a 1-month lag.

Consequently, the long-run relation is as follows:

$$EURDOL_t = \alpha_0 + \alpha_1 SR_t + \alpha_2 GDP_t + \alpha_3 CPI_{t-1} + u_t,$$

where $EURDOL_t$ is the euro/dollar exchange rate, SR_t is the short interest rate differential, GDP_t is the expected GDP growth differential and CPI_{t-1} is the inflation rate differential 1-time lagged, and u_t is a disturbance term. All differentials are between the euro area variable and the correspondent US variable, hence the short rate differential is the difference between the euro area interest rates and the US interest rates, and so on.

According to economic theory, the coefficients α_1 and α_2 should have a positive sign, while α_3 should be negative. In fact, i) higher short rates, as opposed to long rates, which incorporate an inflation premium, should favour a currency, since they make financial investments attractive in relative terms, through a liquidity effect

(MacDonald, 1994), ii) higher GDP growth, as far as it hints at solid economic conditions of the business cycle, should benefit a currency by attracting flows of business investments, while iii) higher inflation should negatively affect a currency, by discouraging both financial and business investments, due to a lack of confidence with respect to the healthy state of economic fundamentals.

According to estimation results, the coefficients have the correct signs and are statistically significant according to the |2| t-value criterion. The coefficient estimates have been obtained using the Johansen methodology for testing the presence of cointegration between the considered variables, since all series individually taken have been found to be I(1) processes. Given that this is a long-run equation, variables involved must be cointegrated.

According to the results of the Johansen test procedure, the cointegration condition is met, but the test indicates the presence of two cointegrating relations. However, for the purposes of this paper, the assumption is made of weak exogeneity for all the explanatory variables with respect to the exchange rate, since the main focus here is on the exchange rate dynamics conditional on a given macroeconomic scenario.

At this point, a univariate Error Correction Mechanism (ECM) including the long-run relation and some dynamic terms is specified for the euro/dollar exchange rate:

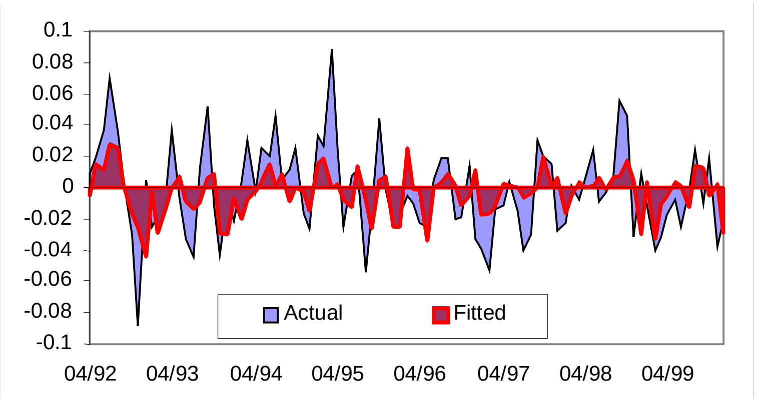
$$\Delta EURDOL_t = \beta_1 \Delta EURDOL_{t-1} + \beta_2 \Delta EURDOL_{t-2} + \beta_3 ECM_{t-1} + \beta_4 \Delta SR_t + \beta_5 \Delta GDP_t + \beta_6 \Delta CPI_t + \beta_7 \Delta SR_{t-1} + \ldots + \beta_i \Delta GDP_{t-1} + \ldots + \ldots + \beta_k \Delta CPI_{t-1} + \ldots + \ldots + \varepsilon_t,$$

where the ECM term contains the above long-run relation. All the other variables are differenced, hence $\Delta x_t = x_t - x_{t-1}$. Using the general-to-specific methodology, only two dynamic terms for the exogenous variables resulted to be significant.

Also here, estimation results show that all coefficients have the correct signs and are significant. In particular, the autoregressive component is relevant, which is not a surprise for exchange rates but, above all, the ECM term is significant, thus indicating that both economic fundamentals and any deviation from the long-run equilibrium level play a key role in the determination of the exchange rate dynamics. Among the exogenous dynamic terms, only the widening or the narrowing of the expected GDP growth differential resulted to be significant throughout the variables-selection cycle.

Preliminary output statistics are in favour of a goodness-of-fit judgement, as it can be easily seen even from the graph below, which plots the actual and fitted values of the euro/dollar exchange rate changes together:

EUR/USD – FITTED AND ACTUAL MONTHLY CHANGES



The model is able to reproduce quite closely the developments of the exchange rate, even capturing the direction of changes, which is very important in this contest, also from an operative point of view. However, it does not perform so well in dimensional terms, since larger variations generally remain unexplained, which is not a surprise within the linear framework, an issue that will be analysed more carefully in the following. This is not a surprise even looking at the R^2 value, which is relatively good if compared with empirical evidence in the applied literature, but is not so high in absolute terms.

Finally, estimated residuals are checked. Autocorrelations and partial autocorrelations confirm the outcome of the h-Durbin test of uncorrelated residuals.

Even the hypotheses of serial correlation and heteroskedasticity are strongly rejected, while normality is accepted.

The Chow tests do not detect any structural change at the time when the euro was introduced. However, both the shorter dimension of the second period used for testing and the procedure employed in order to smooth the transition from German to euro data may have contributed to this outcome. In any case, even bringing the break point backwards in time no structural changes are individuated.

The only test which fails is the Ramsey test, thus indicating that the linear specification needs some improvement. At this point, the possibility of taking into account the presence of non-linearity may make sense.

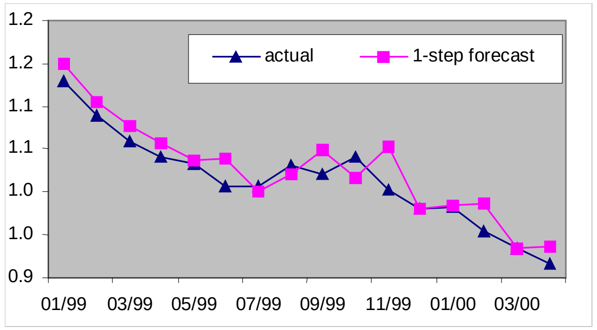
But before passing to non-linear analysis, forecasts from the model are obtained and an interpretation of it is provided.

3.1 INTERPRETATION OF THE LINEAR MODEL AND FORECASTS

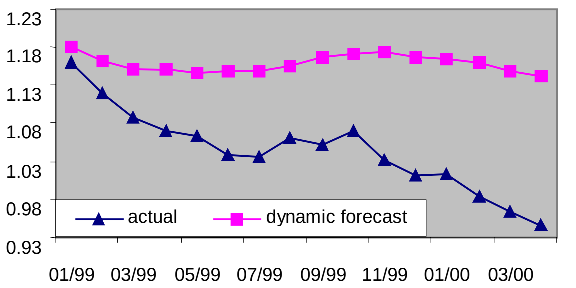
Overall, the linear model can be considered good, both from an econometric point of view and for the applied purposes of market operators.

It shows that fundamentals work in describing the exchange rate dynamics, both in static terms, when the possibility of temporary deviations from the long-run equilibrium is allowed, and in dynamic terms, especially when it is demonstrated that changes in the relative GDP growth expectations are highly significant in determining the direction of the exchange rate. This is what the values and the statistics of the ECM and ΔGDP coefficients say.

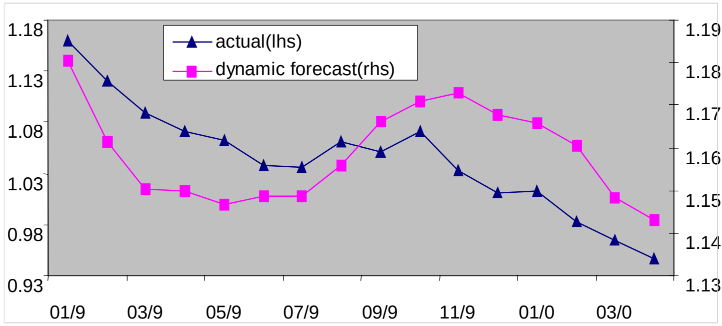
But this can also be clear looking at the out-of-sample properties of the model, i.e. by examining its forecasting performance. 1-step and multi-step ahead predictions are obtained, taking parameters estimated up to December 1998 in both cases. As far as the exogenous variables are concerned, actual values have been employed. This is consistent with exact expectations on the underlying macroeconomic scenario, and has the double advantage of i) avoiding any distortion related to not-correct forecasts on the exogenous variables, and ii) showing whether the euro/dollar exchange rate movements were really unpredictable even when economists and analysts were able to predict macroeconomic fundamentals.



	actual	1-step forecast
01/99	1.1605	1.1803
02/99	1.1200	1.1345
03/99	1.0884	1.1065
04/99	1.0707	1.0868
05/99	1.0626	1.0672
06/99	1.0375	1.0686
07/99	1.0359	1.0302
08/99	1.0605	1.0512
09/99	1.0510	1.0789
10/99	1.0699	1.0458
11/99	1.0325	1.0839
12/99	1.0109	1.0112
01/00	1.0128	1.0150
02/00	0.9836	1.0159
03/00	0.9649	0.9638
04/00	0.9462	0.9663



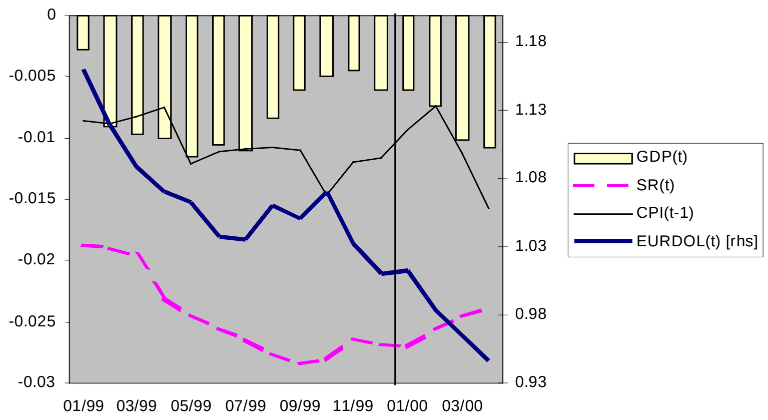
	actual	dynamic forecast
01/99	1.1605	1.1803
02/99	1.1200	1.1615
03/99	1.0884	1.1504
04/99	1.0707	1.1500
05/99	1.0626	1.1467
06/99	1.0375	1.1488
07/99	1.0359	1.1486
08/99	1.0605	1.1560
09/99	1.0510	1.1660
10/99	1.0699	1.1707
11/99	1.0325	1.1729
12/99	1.0109	1.1677
01/00	1.0128	1.1656
02/00	0.9836	1.1607
03/00	0.9649	1.1483
04/00	0.9462	1.1430



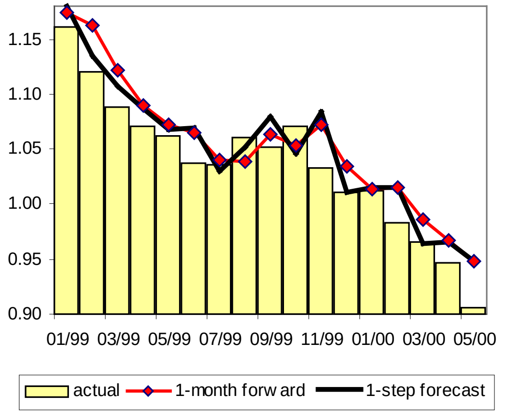
The good forecasting performance of the model is evident, especially in terms of precision and direction of change, when looking at the 1-step forecasts (as also quantitative methods of forecasting performance evaluation will show a few sections below). But it is perhaps even more relevant that the full path of the euro/dollar exchange rate, with a first downward phase, a second stage of up-trending and a final phase of further depreciation, is well captured. As for the smaller precision of multi-step predictions (especially when the time horizon is brought forward), this might also be interpreted as a gauge of the under-valuation of the euro (widely reckoned by analysts and institutional players, such as the European Central Bank itself) with respect to the dollar. In fact this model has the double merit of taking account of dynamics (which is consistent with a depreciating/appreciating euro when GDP growth differential widened/narrowed) and the long-run equilibrium level, which, apart from the direction of changes, measures the sign and magnitude of the deviation from equilibrium.

The conclusion is that if economists and analysts had been good enough at forecasting the macroeconomic environment, they would have been able to partly predict the depreciation of the euro against the dollar.

But is this effectively true, and did both the actual and forecast euro-dollar exchange rate go in line with fundamentals? The following graph hints to a positive answer.



Finally, as far as the forecasting performance of the model with respect to the forward rates is concerned, this is acceptable (see the graph below), since the percentage of successful indications with respect to the forward predictions is 53%.



4. NON-LINEARITIES IN THE EURO/DOLLAR EXCHANGE RATE

Even though the above-built linear model provides a satisfactory specification for the euro/dollar exchange rates, some already-mentioned elements hint at the possibility that some form of non-linearity is present in the euro-dollar dynamics. These elements are i) the incapability of capturing larger variations, ii) the negative outcome of the RESET test, iii) the finding that the ECM term in the dynamic equation is not equally significant across time, even though this result might be distorted by the fact that estimating sub-sets of the full database reduces the dimension of the samples. However this evidence allows nothing more than conjectures, hence some formal linearity tests have to be performed in order to derive more reliable conclusions.

The form of non linearity which is taken into account here is the threshold-type non-linearity (Tong et al., 1980). A simple but general two-regimes threshold regression model is as follows:

$$y_t = \begin{cases} a_0 + a_1 y_{t-1} + \ldots + a_j x_t + \ldots + a_m z_t + \ldots + \sigma_1 \varepsilon_t & \text{if } w_{t-d} \leq s_1 \\ b_0 + b_1 y_{t-1} + \ldots + b_j x_t + \ldots + b_m z_t + \ldots + \sigma_2 \varepsilon_t & \text{if } w_{t-d} > s_1 \end{cases}$$

where w_{t-d} is the threshold variable (which could be a lagged endogenous variable or an exogenous variable), d is the lag parameter, s_1 is the threshold value. This model is non-linear across time, but is locally linear in the dimensional space of the threshold variable. The threshold value individuates, time by time, the break-point between the two regimes, thus causing, deterministically, the transition across regimes. Of course, more regimes can be individuated.

The linearity tests applied here are the threshold test and the general non-linearity test (Tsay, 1989), which are specifically designed to detect threshold-type non-linearity:

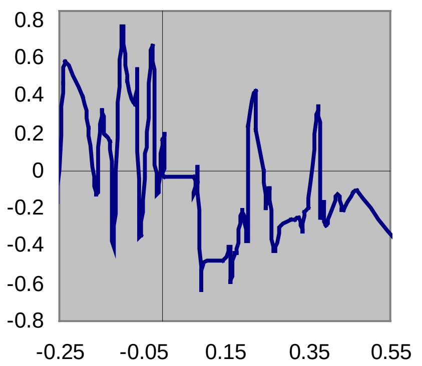
AR order	THRESHOLD TEST		GENERAL NON-LINEARITY TEST	
	Test statistic	Prob.	Test statistic	Prob.
1	1.1818	0.3119	0.7172	0.6307
2	14.0274	$2.1193\ 10^{-7}$	4.3470	0.00013
3	4.7037	0.0019	3.1524	0.0011
4	14.6812	$5.0426\ 10^{-10}$	7.4811	$1.7452\ 10^{-9}$
5	22.7911	$7.0718\ 10^{-15}$	12.5225	$6.8414\ 10^{-15}$

As the table shows, the null of linearity is rejected if autoregressive dynamics of at least 2-order is considered. However, in line with the specification of the linear model and with the results obtained from the autocorrelation analysis of the euro/dollar changes, only the first two autoregressive terms are considered, since higher-order terms were not significant.

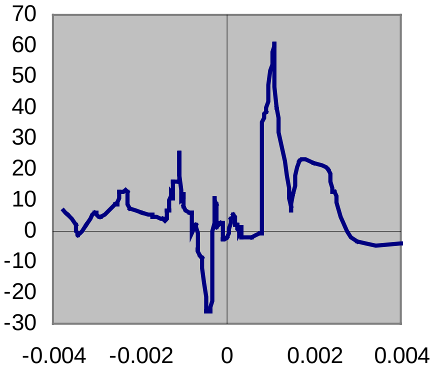
These tests are specifically designed for the case in which the threshold variable is a lagged variable, hence their implementation depends on the delay parameter which is specified. Consequently the table above refers only to the case where the threshold variable is $\Delta EURDOL_{t-1}$, since different alternatives seem to be less straightforward from the point of view of economic theory. In fact, as it will be seen in the following, simultaneous (not lagged) exogenous threshold variables are entertained here (with the obvious exception of the ECM term). In fact, the focus here is on the static relation between the euro/dollar exchange rate and its key determinants.

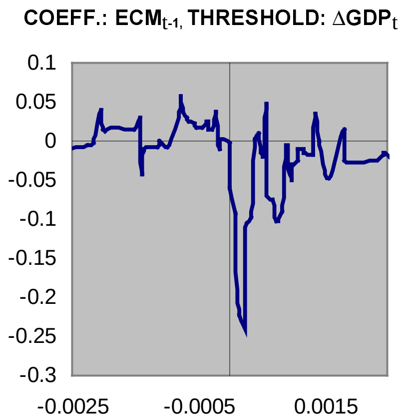
However this is not a problem, since another way of detecting threshold-type non-linearities which are tied to specific threshold variables is provided by the recursive local fitting approach (RLF). This is a recursive estimation of the regression coefficients which is conducted in the space of the threshold variable. Results can be shown through scatterplot graphs, which plot recursive estimates of the coefficients against the ordered threshold variable. If non-linearity is present, estimates should appear initially stable, then should show some unstable behaviour in the form of a jump, and finally might become stable again. In this case two regimes are individuated, but the extension to more regimes is straightforward. The RLF regression involves the same six regressors of the linear case, that is: $\Delta EURDOL_{t-1}$, $\Delta EURDOL_{t-2}$, ECM_{t-1}, ΔSR_t, ΔGDP_t, ΔCPI_{t-1}. Five regressions are then performed, which use $\Delta EURDOL_{t-1}$, ECM_{t-1}, ΔSR_t, ΔGDP_t, ΔCPI_{t-1} respectively as the threshold variable. In each case 5 graphs are plotted, one for every coefficient.

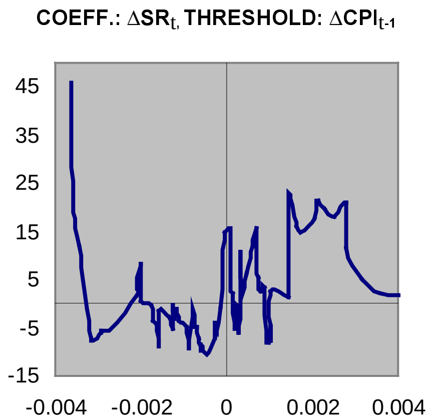
COEFF.: $\Delta EURDOL_{t-2}$, THRESHOLD: ECM_{t-1}



COEFF.: ΔGDP_t, THRESHOLD: ΔSR_t







As the above graphs show (not all graphs are reported here, but only some which are among the most significant), a break is evident almost in every scatterplot, and is usually located around the zero-value, hence individuating two regimes for each regression. When the threshold variable is i) $\Delta EURDOL_{t-1}$, the first (second) regime describes the case of a weakening (strengthening) exchange rate, ii) ECM_{t-1}, the first (second) regime describes the case of an undervalued (overvalued) exchange rate, iii) ΔSR_t, the first (second) regime describes the case of narrowing (widening) interest rate differentials, iv) ΔGDP_t, the first (second) regime describes the case of narrowing (widening) GDP growth differentials, v) ΔCPI_{t-1}, the first (second) regime describes the case of narrowing (widening) inflation differentials.

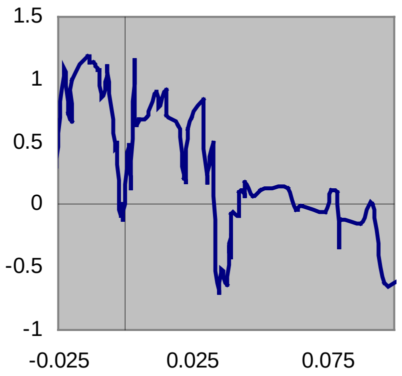
This means that the coefficients of the same variables may be different depending on what financial and/or macroeconomic conditions are in place, i.e. depending on which regime is active, using the model's syntax. This introduces the possibility of an asymmetric reaction of the exchange rate to identical qualitative/quantitative impulses.

4.1 HOW TO TAKE THE ROLE OF THE STOCK MARKET INTO ACCOUNT

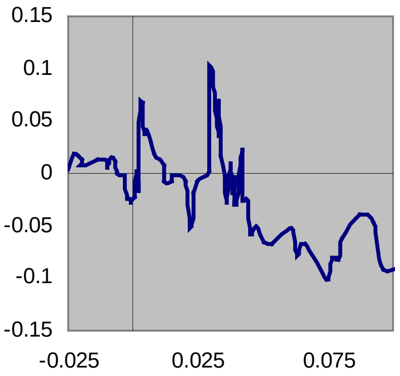
Up to now the analysis has considered only macro-variables. However, the question sometimes arises whether international stock exchange developments could exert some influence on the exchange rate. Given the leading role of the US equity market within the international environment, Nasdaq monthly percentage variations are employed here, since they exhibit a larger correlation with the euro/dollar dynamics than the S&P and the Dow Jones indexes. This issue became especially pressing beginning with November 1999, when the euro started an uninterrupted depreciating path to hit its historical lows in May 2000. The extraordinarily large gains posted by Nasdaq stocks in November, attracting flows of capitals towards the US market, cast the doubt that this could add even more to the euro weakness.

In order to take into account the role of the equity prices, an experiment is conducted here using stock yields as the threshold variable, without introducing them as an explanatory variable in the regression. If it comes out to be significant, this solution has the advantage of not requiring detailed expectations as far as the bourse's performance is concerned, but simply to express whether it is expected to fall below or go above a given threshold value. Scatterplots are shown below:

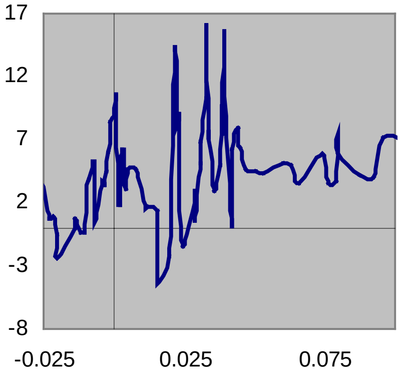
COEFF.: ΔEUR_{t-1}, THRESHOLD: ΔNAS_t



COEFF.: ECM_{t-1}, THRESHOLD: ΔNAS_t



COEFF.: ΔGDP_t, THRESHOLD: ΔNAS_t



All scatterplots show a major break, often with a clear parameter shift, around 3%, thus discriminating two regimes, i.e. where the first one includes losses and "normal" gains, and the second one only considerable gains.

4.2 NON-LINEAR ESTIMATION RESULTS

Six non-linear threshold models are specified here, which use the same explanatory variables of the linear model, as the following formulation shows:

$$\Delta EURDOL_t = \begin{cases} a_1\Delta EURDOL_{t-1} + a_2\Delta EURDOL_{t-2} + a_3 ECM_{t-1} + a_4\Delta SR_t + \\ a_5\Delta GDP_t + a_6\Delta CPI_{t-1} + \sigma_1\varepsilon_t & \text{if } w_{t-d} \leq s_1 \\ b_1\Delta EURDOL_{t-1} + b_2\Delta EURDOL_{t-2} + b_3 ECM_{t-1} + b_4\Delta SR_t + \\ b_5\Delta GDP_t + b_6\Delta CPI_{t-1} + \sigma_2\varepsilon_t & \text{if } w_{t-d} > s_1 \end{cases}$$

The threshold variable w_{t-d} is respectively i) in model [1] $\Delta EURDOL_{t-1}$, ii) in model [2] ECM_{t-1}, iii) in model [3] ΔSR_t, iv) in model [4] ΔGDP_t, v) in model [5] ΔCPI_t, and vi) in model ΔNAS_t. For each model, after having individuated from the scatterplots a plausible range for the threshold value, the correct specification is chosen according to the Akaike or the Schwarz criteria and the final estimation is hence conducted (Tsay, 1989). Estimation results are shown in the tables below:

MODEL [1]

threshold variable: ΔEURDOLt-1				
	regime 1		regime 2	
variable	coeff.	t-value	coeff.	t-value
$\Delta EURDOL_{t-1}$	0.2913	1.4019	0.2813	2.1997
$\Delta EURDOL_{t-2}$	0.0870	0.3591	-0.2849	-2.6520
ECM_{t-1}	-0.0281	-0.9750	-0.0119	-1.5646
ΔSR_t	7.7291	2.4625	-1.2397	-0.7226
ΔGDP_t	1.3526	0.2767	3.8326	2.9645
ΔCPI_{t-1}	1.2308	0.8886	-0.9090	-0.7817
eq. std. err	0.0297		0.0232	
R^2	0.4229		0.2331	
AIC crit.	-6.8345		-7.4170	
Schwarz crit.	-6.5107		-7.1768	
threshold	overall AIC		overall Schwarz	
0.004157	-14.2515		-13.6875	

MODEL [2]

threshold variable: ECMt-1				
	regime 1		regime 2	
variable	coeff.	t-value	coeff.	t-value
$\Delta EURDOL_{t-1}$	0.1470	0.2911	0.2377	2.2588
$\Delta EURDOL_{t-2}$	0.1762	0.4703	-0.2731	-2.7675
ECM_{t-1}	-0.0416	-0.9618	-0.0104	-1.4187
ΔSR_t	7.9624	2.0880	-0.6649	-0.4231
ΔGDP_t	3.3573	0.3773	3.9602	3.2000
ΔCPI_{t-1}	2.1976	1.2618	-1.3688	-1.3184
eq. std. err	0.0340		0.0227	
R^2	0.4881		0.2327	
AIC crit.	-6.4922		-7.4739	
Schwarz crit.	-6.1437		-7.2543	
threshold	overall AIC		overall Schwarz	
-0.1008	-13.9662		-13.398	

MODEL [3]

threshold variable: ΔSRt				
	regime 1		regime 2	
variable	coeff.	t-value	coeff.	t-value
$\Delta EURDOL_{t-1}$	0.3061	1.9936	0.2476	1.7484
$\Delta EURDOL_{t-2}$	-0.1379	-0.8456	-0.2747	-2.0299
ECM_{t-1}	-0.0046	-0.4240	-0.0140	-1.2651
ΔSR_t	0.3386	0.1765	6.6668	2.3900
ΔGDP_t	4.5741	2.1669	2.1331	1.1893
ΔCPI_{t-1}	0.9880	0.7054	-1.4526	-1.2482
eq. std. err	0.0284		0.0233	
R^2	0.2169		0.4215	
AIC crit.	-6.9936		-7.3679	
Schwarz crit.	-6.7259		-7.0811	
threshold	overall AIC		overall Schwarz	
-0.00035	-14.3614		-13.8070	

MODEL [4]

threshold variable: ΔGDPt				
	regime 1		regime 2	
variable	coeff.	t-value	coeff.	t-value
$\Delta EURDOL_{t-1}$	0.2836	2.0481	0.3393	2.0014
$\Delta EURDOL_{t-2}$	-0.0721	-0.4979	-0.3725	-2.4419
ECM_{t-1}	0.0048	0.4954	-0.0266	-2.0226
ΔSR_t	2.1375	0.9338	-0.8669	-0.3961
ΔGDP_t	2.9844	1.6620	5.8816	2.1515
ΔCPI_{t-1}	1.0133	0.9463	-1.7469	-1.1167
eq. std. err	0.0241		0.0281	
R^2	0.2388		0.2587	
AIC crit.	-7.2918		-7.0211	
Schwarz crit.	-6.9963		-6.7608	
threshold	overall AIC		overall Schwarz	
-0.00017	-14.3129		-13.7571	

MODEL [5]

threshold variable: ΔCPIt-1				
	regime 1		regime 2	
variable	coeff.	t-value	coeff.	t-value
$\Delta EURDOL_{t-1}$	0.3924	2.7495	0.1724	1.1039
$\Delta EURDOL_{t-2}$	-0.2162	-1.4118	-0.2630	-1.8009
ECM_{t-1}	-0.0122	-1.0751	0.0013	0.1187
ΔSR_t	0.0451	0.0220	3.3164	1.4931
ΔGDP_t	4.6955	2.3039	2.1848	1.1518
ΔCPI_{t-1}	0.7308	0.6359	-2.9461	-1.7796
eq. std. err	0.0288		0.0242	
R²	0.2802		0.2350	
AIC crit.	-6.9660		-7.2908	
Schwarz crit.	-6.9683		-7.0041	
threshold	overall AIC		overall Schwarz	
0.00019	-14.2569		-13.7025	

MODEL [6]

threshold variable: ΔNASt				
	regime 1		regime 2	
variable	coeff.	t-value	coeff.	t-value
$\Delta EURDOL_{t-1}$	0.4100	2.8123	0.0394	0.2204
$\Delta EURDOL_{t-2}$	-0.2941	-1.9448	-0.2135	-1.3560
ECM_{t-1}	-0.0066	-0.7770	-0.0543	-1.9658
ΔSR_t	0.5752	0.3372	3.5537	0.7892
ΔGDP_t	3.7700	1.9906	3.9469	1.4696
ΔCPI_{t-1}	-1.0528	-0.7835	2.5546	1.8309
eq. std. err	0.0277		0.0231	
R²	0.2576		0.3131	
AIC crit.	-7.0510		-7.2948	
Schwarz crit.	-6.8001		-6.9512	
threshold	overall AIC		overall Schwarz	
0.03764	-14.3459		-13.7514	

Estimates clearly show that, when different macroeconomic conditions occur, i.e. when one regime is activated in the place of the other, the same explanatory variables may play a different role. Specifically, a given determinant of the exchange rate may be significant in one regime and not significant in the other, or may have a different weight. It is therefore important to be able to recognise which regime is active, since the same event could have to be read in a different way. An inspection of the outcome of every model proposed follows here:

Model [1]: if at the previous time the exchange rate posted negative or small positive changes, the short rate differential has a relevant weight, which may reflect the potentially active role of monetary policy in defending a currency or, which is more consistent with the euro case, it reflects the major role of policy rates when euro weakness poses some threat to price stability. Instead, when some currency strengthening occurred at t-1, the autoregressive component and GDP growth differentials become relevant. However, given the same magnitude of the AR(1) and AR(2) coefficients, in the presence of two similar positive variations in a row, the prevailing role is played by GDP differentials. If, at time t-2, the exchange rate depreciated, this should instead strengthen at time t, unless GDP spreads are unfavourable.

Model [2]: the outcome of model [2] is even more relevant. In fact, it shows that if the euro is highly undervalued with respect to its long-run fundamental equilibrium level (i.e., the ECM term is negative), only the short rate differential may play a significant role. This confirms the importance of an active monetary policy when the euro is weaker with respect to some fundamental equilibria, therefore threatening price stability, not when it is weak per se. This is consistent with the way the ECB conducted monetary policy in the first months of 2000, and even with central bank officials' statements, who were prudent in linking a rate hike to a euro slide, unless this reflected some macroeconomic unbalance. When the undervaluation degree is small, or the euro is correctly priced or overvalued, again a potentially re-equilibrating role is played by the autoregressive components and by the relative business cycle conditions.

Model [3]: unfavourable interest rate developments are not relevant, unless the euro has a GDP growth disadvantage, because the only significant macro-variable is the GDP spread in this regime. When rates are favourable, these are highly important, hence potentially making a "strength position" of the currency to persist if this was in place at t-1.

Model [4]: when economic growth expectations worsen, the only significant variable is the AR(1) component, thus describing the possibility that, if some currency weakness is present, this might persist, unless expectations improve. In this case, this favourable factor plays a leading role. In addition, the significance of the autoregressive and the ECM terms means that if, in the previous time, a depreciation occurred which made the euro undervalued, this disequilibrium may be corrected. But it is worth noting that in this case just GDP relative growth expectations may give a key contribution to mark a turning point for the euro. This could reflect quite well the reversal in the second half of May, when the euro began a fast appreciation after having hit its historical lows, on some news pointing at the possibility of a gradual cooling-off of the US economy.

Model [5]: when inflation conditions are favourable, the relevance of the GDP term means that if this goes together with healthy business cycle conditions then the euro can appreciate; if, on the contrary, lower inflation is an indication of worse GDP expectations, the euro could instead weaken.

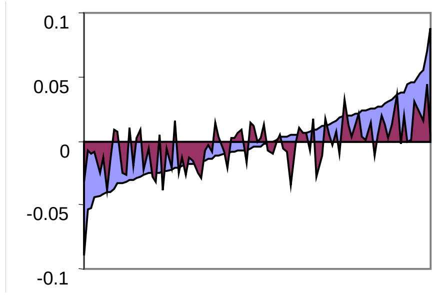
Model [6]: finally, when the US bourse has a negative or a “normal” positive performance, again GDP expectations play a relevant role. On the other side, when Nasdaq stocks post extraordinarily large gains, this should necessarily damage the single currency, since the ECM term is significant, thus potentially playing a defensive role. However, the fact that the other variables are not significant, with the only exception of inflation (which has, however, an incorrect sign), might indicate that neither the autoregressive dynamics nor fundamentals have some relevant weight, therefore eventually causing some instability to the currency.

Overall, empirical evidence shows that non-linear dynamics might explain some exchange rate behaviour which can be judged to be unusual if one has in mind that a given variable should exert a given influence independently of any “static situation” being in place, that is of the active regime.

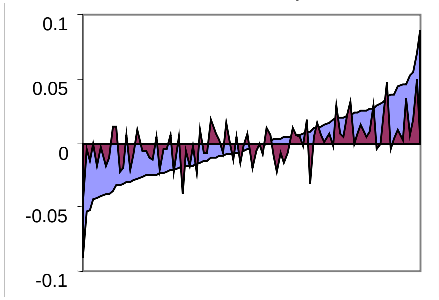
4.3 AN INSPECTION OF NON-LINEAR FITTING PROPERTIES

Fitted versus actual values graphs are another way of looking at the greater capability of non-linear threshold models to capture some exchange rate features which a linear model is not able to explain. Some improvement with respect to the linear specification is already evident from traditional fitting plots. However, it becomes even more evident if an alternative approach is used, as the following graphs shows:

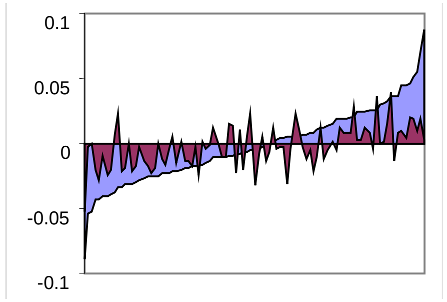
MODEL [2] ECM_{t-1}



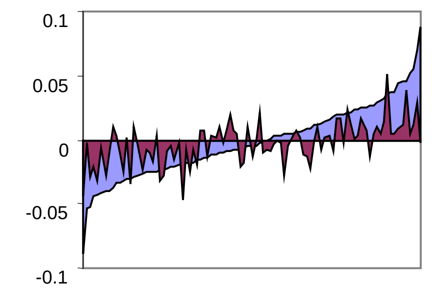
MODEL [3] ΔSR_t



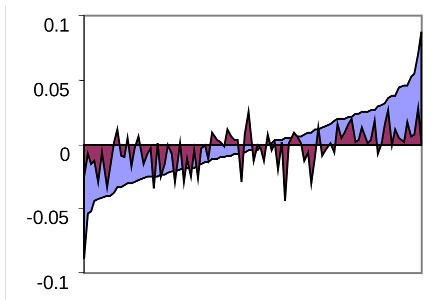
MODEL [4] ΔGDP_t



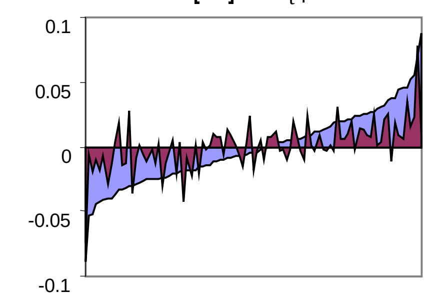
MODEL [6] ΔNAS_t



LINEAR MODEL



MODEL [6] ECM_{t-1}**



The above graphs plot fitted values of the euro/dollar changes together with actual values, but data are ordered according to the increasing magnitude of actual values. In this way it is possible to see whether outliers, or simply larger positive or negative changes, can be captured by the model. It is evident that almost all the non-linear models overperform the linear one as far as the capability of capturing outliers is concerned. This is a typical theoretical feature of threshold models, which gains support even here, where it is relevant given “extreme” dynamics exhibited by the euro/dollar exchange rate during its first one and a half years of life. Especially interesting is the case of the model using the ECM term as the threshold variable. In fact, simply choosing as the threshold a largely negative value (which is sub-optimal according to a rigorous use of the AIC or Schwarz criteria, but remains globally acceptable), the model performs even better with respect to both negative and positive extreme values. This indicates that discriminating between a situation of large undervaluation of the exchange rate and a “normal” situation might prove to be extremely important. This consideration should apply to the opposite case of a large overvaluation, but it is less relevant here, given the marked downward trend experienced by the euro from its introduction in January 1999 to May 2000.

4.4 NON-LINEAR VERSUS LINEAR FORECASTING PERFORMANCE

Non-linear out-of-sample forecasts from the six threshold models previously specified are obtained here, in order to judge whether the capability of the threshold specification in capturing both extreme values and the asymmetric behaviour of the euro/dollar exchange rate results in an even better forecasting performance.

As far as 1-step ahead forecasts are concerned, graphs are not shown here, since they are quite similar to the linear case, even though predictions generally prove to be more precise, even in terms of direction-of-change forecasting. The table below confirms this finding, since it contains some quantitative indicators of forecasting performance, that is the mean absolute error, the mean square error and the percentage of correct signs. Larger MAE and MSE indicate less precise forecasts, while higher percentages of correct signs indicate a better performance in terms of direction-of-change forecast.

1-STEP FORECASTS

	MAE	MSE	Correct signs %
Linear model	1.743%	0.051%	62%
$\Delta EURDOL_{t-1}$	1.615%	0.042%	80%
ECM_{t-1}	1.611%	0.041%	67%
ΔSR_{t}	1.819%	0.057%	67%
ΔGDP_{t}	1.609%	0.042%	73%
ΔCPI_{t-1}	1.654%	0.041%	67%
ΔNAS_{t}	1.485%	0.034%	73%
Random walk	1.98%	0.05%	-
Forward exchange rate	2.23%	0.06%	24%

It is evident that the non-linear specifications considered perform better than the linear one, both in terms of precision and of direction-of-change, with the only exception of the model using interest rate differentials as the threshold variable.

A comparison is also conducted with the random walk predictor, which is traditionally considered to be a benchmark in 1-step forecasting of exchange rates. The good result is that both the linear model and all the non-linear specifications entertained beat the random walk, thus contributing further evidence to that part of the applied literature according to which exchange rate movements may be approximated by, but are not, a random walk.

Finally, the “forward” model provides the worst indications, both in terms of predictive accuracy and in terms of direction-of-change predictability.

In order to assess whether the forecasting performance of the non-linear specification is significantly better than the linear one, two encompassing tests, i.e. the enc-t and the enc-reg test (Clark et al., 1999), are conducted against the null that the linear model encompasses the non-linear ones and vice-versa. The same test is applied even to the random walk predictor versus both the linear and the non-linear models.

	ENC-T encompassing test	ENC-REG encompassing test	ENC-T encompassing test	ENC-REG encompassing test
	H_0: the linear model encompasses the non-linear model		H_0: the non-linear model encompasses the linear model	
ΔEURDOL$_{t-1}$	0.0195	0.0160	0.9237	0.9288
ECM$_{t-1}$	0.0094	0.0570	0.3680	0.4058
ΔSR$_t$	0.7226	0.7518	0.1003	0.0545
ΔGDP$_t$	0.0309	0.0757	0.5779	0.5589
ΔCPI$_{t-1}$	0.0414	0.0608	0.6610	0.6445
ΔNAS$_t$	0.0198	0.0168	0.7725	0.7031
	H_0: the random walk model encompasses the non-linear model		H_0: the non-linear model encompasses the random walk model	
ΔEURDOL$_{t-1}$	0.0250	0.0280	0.3666	0.3907
ECM$_{t-1}$	0.0285	0.0238	0.0834	0.1708
ΔSR$_t$	0.1774	0.1252	0.0403	0.0554
ΔGDP$_t$	0.0294	0.0426	0.3119	0.3427
ΔCPI$_{t-1}$	0.0373	0.0321	0.1589	0.2483
ΔNAS$_t$	0.0280	0.0128	0.3776	0.4230
	H_0: the random walk model encompasses the linear model		H_0: the linear model encompasses the random walk model	
	0.1345	0.0944	0.1454	0.1762

*** results are expressed as rejection frequencies*

These tests confirm the better performance of the non-linear formulation, with the only exception of model [3].

A final test is conducted here, which judges the goodness of a model not in terms of point forecasting performance, but in terms of density (distribution) forecasting ability (Berkowitz, 1998), which required some Monte Carlo simulations. In fact, non-linear models might not forecast better than linear ones in the case of point forecasts, but they might be preferable if precision is measured with forecast densities (Clements et al., 1999). The results of two likelihood tests (with one and three degrees of freedom, respectively) are shown in the following table:

model	LR(1 dof)	LR test (3 dof)
Linear model	0.0158	0.0139
Threshold Mod. [1]	0.0089	0.0109
Threshold Mod. [2]	0.0546	0.1223
Threshold Mod. [3]	0.0142	0.0496
Threshold Mod. [4]	0.0081	0.0187
Threshold Mod. [5]	0.0570	0.0268
Threshold Mod. [6]	0.2744	0.0727

*** results are expressed as rejection frequencies*

The table shows that only two threshold models pass the test of good density forecast performance, i.e. Mod. [2] or the model using the ECM term as the threshold variable, and Mod. [6], which uses Nasdaq stock yields as the threshold variable. This provides further evidence in favour of the above-mentioned finding, especially confirming the worse performance of the linear specification. As far as the other non-linear formulations are concerned, results might bring to the conclusion that the ECM-based threshold model overperforms the alternative models, as even previous results suggest. This means that the degree of disequilibrium of the exchange rate with respect to macroeconomic fundamentals played a relevant role, conditioning the dynamics of the euro/dollar exchange rate.

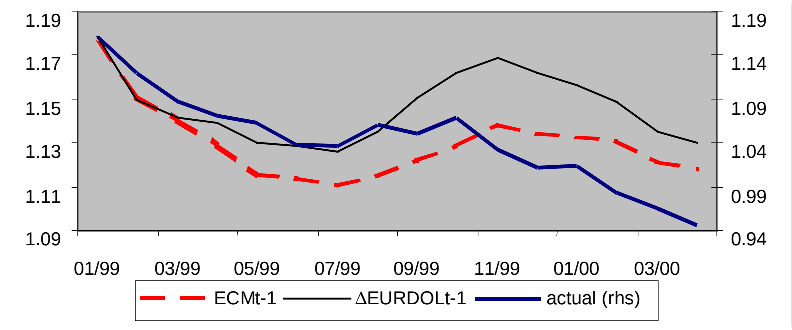
The encouraging results obtained for 1-step predictions find further support in the multi-step ahead forecasts performance.

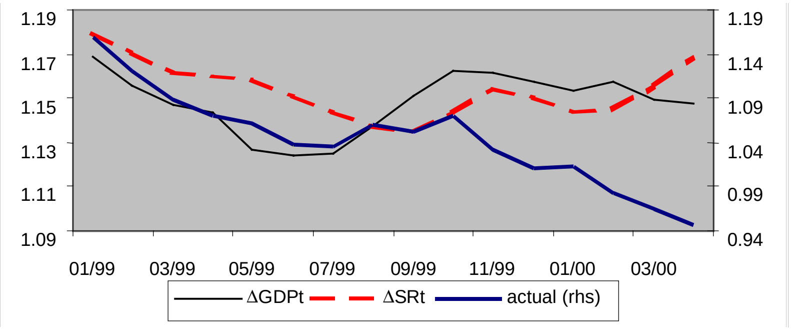
MULTI-STEP FORECASTS

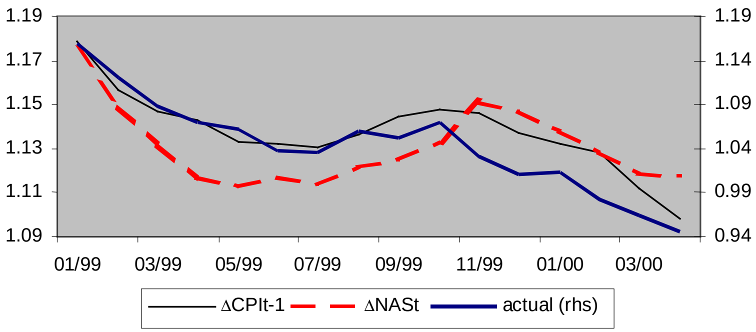
	MAE	MSE	Correct signs %
linear model	11.43%	1.55%	73%
ΔEURDOL$_{t-1}$	8.95%	1.01%	80%
ECM$_{t-1}$	7.89%	0.81%	80%
ΔSR$_t$	12.43%	1.82%	53%
ΔGDP$_t$	10.53%	1.35%	73%
ΔCPI$_{t-1}$	6.42%	0.57%	87%
ΔNAS$_t$	9.35%	0.82%	73%

	ENC-T encomp. test	ENC-REG encomp. test	ENC-T encomp. test	ENC-REG encomp. test
	H_0: the linear model encompasses the non-linear model		H_0: the non-linear model encompasses the linear model	
ΔEURDOL$_{t-1}$	0.0000	0.0005	1.0000	0.9992
ECM$_{t-1}$	0.0000	0.0002	1.0000	0.9996
ΔSR$_t$	0.1234	0.1109	0.7522	0.7637
ΔGDP$_t$	0.0000	0.0062	1.0000	0.9871
ΔCPI$_{t-1}$	0.0000	0.0001	1.0000	0.9999
ΔNAS$_t$	0.0000	0.0002	1.0000	0.9996

The most evident and significant element is that, apart from capturing quite well the direction-of-change dynamics, threshold models are even more precise than the linear one, even when forecasts are brought forward (i.e. from the 1-step to the 16-step ahead forecast case), with the usual exception of model [3]. The second-best performer is the ECM-lead model, thus offering further evidence in favour of the key role of fundamentals, especially in the sense of the existence of a long-run equilibrium relation, which leads exchange rate dynamics over a longer time horizon than the 1-step frame allows.







5. ECONOMIC INTERPRETATION OF NON-LINEAR RESULTS APPLIED TO THE EUROHISTORY

Among the major features of threshold models there are the capability of reproducing asymmetrical behaviours and of capturing outliers, which often characterise exchange rate movements. This a priori ability finds empirical evidence in the results obtained here.

Asymmetry takes the form of a different contribution and significance of a same variable, depending on which regime is active. For instance, it is shown here that when the undervaluation degree of a currency is relevant, thus putting the objective of price stability at risk, then monetary policy may play a role, through higher interest rates. This simply emerges from the significance of the short interest rate component when the exchange rate is below its long-run fundamental equilibrium level, while this same component turns out to be insignificant in the case of fair- or over-valuation. However, there is another important element. In fact, it is not sufficient that the exchange rate is undervalued to trigger a monetary policy action, but the undervaluation degree has to be sufficiently large in order to be considered an element of risk for the price stability objective. This concept is simply contained in the threshold value, which in fact in this case is estimated to be not zero, but around –10% in terms of deviation of the exchange rate from its equilibrium level. This is consistent with the conduct of monetary policy by the ECB in the first months of 2000, when it was made clear that it was not a weak euro per se which triggered any rate hike, but precisely a euro whose weakness could threaten price stability by contributing to macroeconomic unbalances.

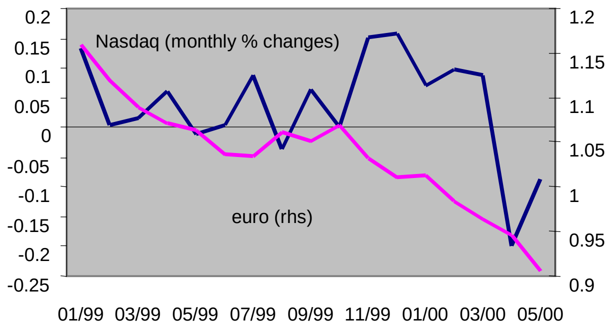
As far as the GDP growth differential is concerned, this comes into relevance in two ways. In fact, this is the variable which appears to be more frequently significant across all the non-linear specifications entertained. Moreover, it is relevant as the conditioning variable of the possible asymmetric reaction of the exchange rate to similar impulses depending on the relative state of business cycle expectations. In fact, regression estimates indicate that, when economic growth expectations are not in favour of the euro, the most significant variable is the AR(1) term, which may exert further pressure on the euro if this is already weaker, as it happened in the first half of 1999, when the euro fell much more rapidly than the worsening of relative GDP growth expectations indicated. This means that in the presence of unfavourable economic growth conditions, the euro is even more vulnerable than it would otherwise be. On the contrary, when the regime of favourable business cycle conditions is active, also the ECM term turns out to be relevant, with the possibility that upward influences could be reinforced even through the channel of the deviation-from-equilibrium correction. This exactly happened from July to October 1999 and might work in the same way in the second half of 2000, given the expected path of relative GDP growth (see the last graph of par. 3.1, also for the following consideration).

As far as the autoregressive dynamics are concerned, the asymmetric behaviour of the exchange rate is evident. In fact, if a downward trend prevails, only short rates are relevant, while GDP conditions do not weigh. The opposite occurs when the exchange rate is heading upwards. This was evident at the end of the summer of 1999, when, between unfavourable interest rates conditions and favourable cyclical conditions, these latter prevailed, pushing the euro up.

Interesting is also the interpretation of the CPI-lead model, where the significance of the GDP term when inflation conditions are favourable to the single currency makes it possible to distinguish whether lower inflation goes together with healthy business cycle conditions or is an indication of a weak cyclical evolution. The former case occurred in October 1999 and the latter case from February to April 2000.

Less relevant is instead the role of short rates as far as the non-linear behaviour is concerned, as forecast results show. But this might also be due to the "softer" dynamics of this variable during the period under examination.

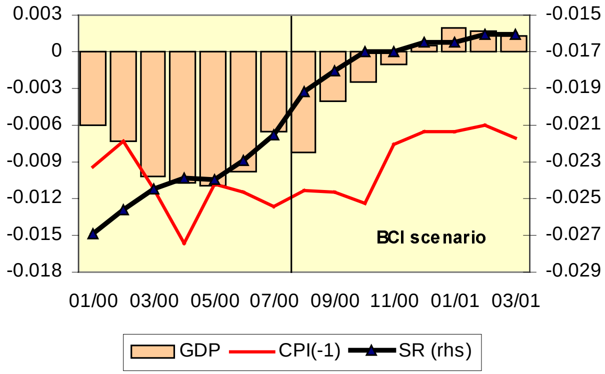
As far as the role of the stock market is concerned, the finding that, when the US bourse has a negative or a "normal" positive performance, GDP expectations are significant, might signal the possibility that even the relative weakness of the stock market in May 2000, together with some incipient signs of cooling-off of the US economy, may have given a contribution to a path-reversal of the euro.



On the contrary, when Nasdaq stocks perform extraordinarily well, the single currency should not necessarily be affected, thanks to the potentially balancing role of the ECM term. However, the minor role of autoregressive terms and fundamentals may potentially cause some instability to the currency, thus temporarily decoupling exchange rate dynamics from fundamentals, as it happened in November 1999, when both GDP growth expectations and short rate spreads were in favour of an appreciation of the euro. This instead started a sharp and uninterrupted fall which ended only in May 2000.

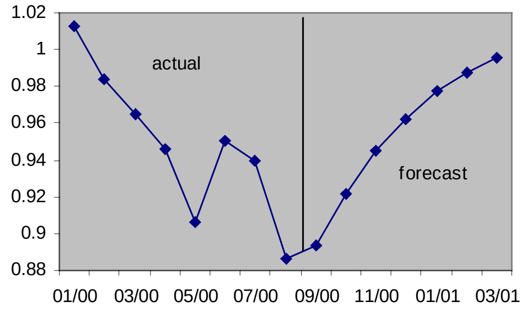
6. THE EURO: WHAT'S IN THE FUTURE?

We report the forecasts of the euro/dollar exchange rate for the remaining months of 2000 using both the linear ECM model and the ECM-based non-linear threshold specification (which is considered perhaps the most representative model among the non-linear specifications previously entertained, both for its good performance and for its interpretability from an economic perspective). The underlying macroeconomic scenario is provided by Banca Commerciale Italiana *(Quarterly macroeconomic outlook*, August 2000). This mainly involves a narrowing of both the (negative) GDP growth differentials and the short rate spreads throughout the second half of 2000 and the first quarter of 2001.



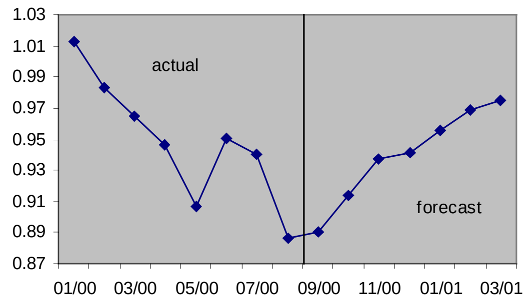
Consequently, the expected result should be that of an appreciation of the euro, as both models show, with the main difference that the non-linear formulation provides higher predictions:

LINEAR MODEL



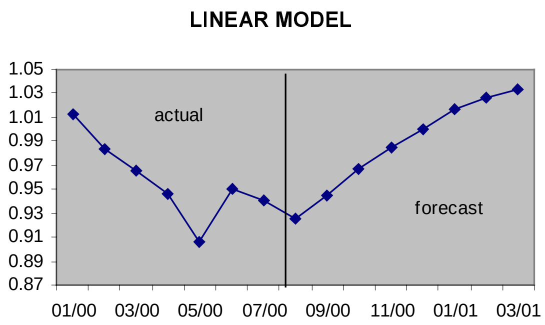
	euro/dollar
01/00	1.013
02/00	0.984
03/00	0.965
04/00	0.946
05/00	0.907
06/00	0.950
07/00	0.940
08/00	0.886
09/00	0.893
10/00	0.922
11/00	0.945
12/00	0.962
01/01	0.978
02/01	0.988
03/01	0.996

NON-LINEAR ECM-BASED MODEL



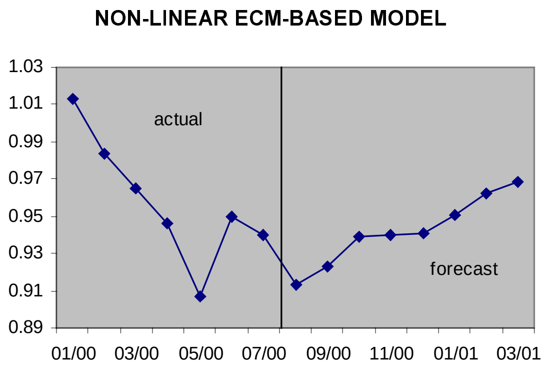
	euro/dollar
01/00	1.013
02/00	0.984
03/00	0.965
04/00	0.946
05/00	0.907
06/00	0.950
07/00	0.940
08/00	0.886
09/00	0.890
10/00	0.914
11/00	0.937
12/00	0.941
01/01	0.956
02/01	0.969
03/01	0.975

Previous results are obtained with data available up to August 2000. If estimations are instead stopped at July 2000, and the August euro/dollar exchange rate is considered an outlier (consequently, the September forecast is produced using the August prediction), there is the possibility that the euro/dollar exchange rate finally returns above parity with the linear model:



	euro/dollar
01/00	1.013
02/00	0.984
03/00	0.965
04/00	0.946
05/00	0.907
06/00	0.950
07/00	0.940
08/00	0.925
09/00	0.944
10/00	0.967
11/00	0.985
12/00	1.000
01/01	1.016
02/01	1.026
03/01	1.033

On the contrary, according to the non-linear formulation, the euro/dollar exchange rate at the end of the forecasting horizon would remain below parity. In addition, its final value would even be lower than in the previous (non-linear) case. This stems from the fact that the non-linear model allows for regime switches. In fact, using historical data up to August (which is the “outlier month”), the starting point for the following forecasts is lower. As a consequence, the euro/dollar predicted value remains lower (or, the other way round, “more undervalued”, given the new historical lows reached in August), thus triggering a shift into the first regime some time (two months in this case) before the same happens using data up to July. The correction with respect to the higher undervaluation degree (given by the value of the ECM term with respect to the threshold) and consequently the return to a level which is nearer to the equilibrium is quicker, thus allowing a higher final level at the end of the forecasting horizon.



	euro/dollar
01/00	1.013
02/00	0.984
03/00	0.965
04/00	0.946
05/00	0.907
06/00	0.950
07/00	0.940
08/00	0.913
09/00	0.923
10/00	0.939
11/00	0.940
12/00	0.941
01/01	0.950
02/01	0.962
03/01	0.969

Time will assess which model performs better in this case.

7. CONCLUDING REMARKS

Empirical evidence obtained in this work supports the hypothesis that economic fundamentals effectively drive the dynamics of the euro/dollar exchange rate, thus rejecting the random walk hypothesis. This is straightforward both looking at i) the euro/dollar exchange rate path exhibited after its introduction, which appears to be consistent with underlying fundamentals (hence contrasting the general disappointment of economists and analysts who were not able to forecast the depreciation of the euro), and ii) the good performance of the linear model, which is not only based on fundamentals, but also takes into account a long-run equilibrium relation.

The even better fitting and out-of-sample forecasting performance of the non-linear threshold models entertained here provides further support to this conclusion, adding evidence that not only fundamentals play a major role in the euro/dollar exchange rate dynamics, but also that their influence works through a non-linear mechanism. In fact, the same variable may exert a different influence on the exchange rate in dependence on which relevant “state” (or regime) of the macroeconomic scenario is in place, which allows the possibility of asymmetrical behaviours. Furthermore, and in contrast to linear models, threshold models are capable of capturing outliers, which are not extraneous to exchange rate dynamics.

Important is also the role of the threshold values, which describe quite well the fact that some effects may be produced on the exchange rate only when triggering factors are sufficiently significant. The main example, in this sense, is that it is not sufficient that the euro is weak to make the ECB raise rates, since it has to be sufficiently undervalued as to threaten the objective of stable inflation.

As for the possibility of an interaction between international stock market performances and the exchange rate, this can be taken into account through a non-linear structure, simply working as a sort of “disturbance” factor, which may cause, in extraordinary situations, some decoupling of exchange rate dynamics from fundamentals. This seems to produce some improvements in the understanding of the euro/dollar exchange rate, but without introducing the equity yields as an explanatory variable.

Finally, the choice of a sub-optimal threshold (biased towards smaller or larger values with respect to the optimal one according to a rigorous use of selection criteria), may improve the performances of a model, if this is consistent with the prevailing regime during the relevant period. This can become useful when scenario analysis is conducted, since a bias towards what is judged to be the most likely scenario is allowed.

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