

# A STUDY ON EXCHANGE RATE DYNAMICS AND MARKET EFFICIENCY

APPLICATIONS OF TECHNICAL ANALYSIS TO THE ITALIAN LIRA - US DOLLAR EXCHANGE RATE

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## 1. Introduction

Empirical evidence on exchange rate economics is contradictory. During the 1970s there was high confidence in Purchasing Power Parity (PPP) theories and monetary explanations of the exchange rate. Nevertheless, these models have given unsatisfactory results in the explanation of the movements of the major exchange rates, particularly in the short run.

Opposite theories on the cause of the relative strength/weakness of major currencies have been developed. During the first half of the 1980s Keynesian theories were brushed up; the Mundell-Fleming model explanation of the dollar's strength in the period 1980-85 was the US budget deficit. After the collapse of the dollar in 1985, other models were introduced predicting that the only way the US could stop the decline of the dollar was by reducing the budget deficit.

Moreover the deviations from the equilibrium condition in the goods market (i.e. from what predicted by the PPP) proved generally to be greater than expected. This lack of efficacy was accounted for and explained by the overshooting model.<sup>1</sup> Such a model however, though capable of explaining the high volatility of exchange rates (maintaining the equilibrium assumption), has shown low predictive properties, which reduces considerably its usefulness in an *ex ante* perspective.

Note also that a number of studies have shown that the equilibrium condition in the asset market is often violated.<sup>2</sup> This deviation, to be explained endogenously, would have implied inefficient market or non-rational expectations.

Because of the poor econometric performance of economic theories and of the economists' predilection for market efficiency and rational expectations, the model of random walk for exchange

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<sup>1</sup> Dornbusch (1976).

<sup>2</sup> For a survey, see Boothe and Longworth (1986).

rates has become popular. In a sense, the diffusion of the random walk model stems thus from the weakness of structural models. However, still now the contention that the exchange rate follows (approximately) a random walk is not solved.<sup>3</sup>

The random walk assumption implies market efficiency in its weak form which means that *no extra profit can be earned by exploiting information about the past exchange rate values*.<sup>4</sup>

The theoretical explanation of the random walk model is that agents take all relevant information into account to forecast the future path of the exchange rate; efficient arbitrage between the future and the present then fixes the current exchange rate. Exchange rates reflect thus all relevant and available information. According to such a theory only unforeseen events ("*news*") can lead to a discrete change in the current exchange rate. Since news is by definition unpredictable, so are, according to the efficiency market assumption, exchange rate changes.<sup>5</sup> (Dornbusch 1976, Mussa 1984).

## 2. Overview of the study

This study explores the process of determination of the exchange rate Italian lira - US dollar and, indirectly, the hypothesis of weak efficiency of the market. It covers the period from 14 March 1991 to 30 June 1994 (daily data).<sup>6</sup>

The sample is divided into two sub-samples: 14 Mar. 1991 - 17 Jan. 1994, 18 Jan. 1994 - 30 Jun. 1994. The first sub-sample is used to analyse and to model exchange rate dynamics; the second sub-sample is used to simulate and test the models *discovered* in the first sub-sample.

The first sub-sample period is particularly delicate because of the exit of the lira from the EMS in September 1992. To perform more accurate investigations, it has thus been furtherly divided into two periods delimited by the exit of the lira from the EMS.

The study focuses first on the Random Walk (RW) hypothesis. Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) tests are performed and the autocorrelation functions are analysed. The conclusion is not unambiguous, the RW hypothesis being not rejected for the period 14 Mar. 1991 - 17 Jan 1994 as a whole, but being questionable for the two separate sub-periods divided by the exit of the lira from the EMS (14 Mar. 1991 - 16 Sep. 1992, 1 Oct. 1992 - 17 Jan. 1994). Moreover the

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<sup>3</sup> Mussa (1979).

<sup>4</sup> About the inefficiency of exchange market in its semistrong form as defined by Fama (1970) ("*the deviations of exchange rates from uncovered interest parity are due to a time-varying risk premium*") the consensus is greater.

<sup>5</sup> Dornbusch (1976), Mussa (1984).

<sup>6</sup> For a test of market efficiency one should adjust exchange rate with the interest rate differential. In this paper the exchange rate series is not adjusted due to a lack of data. Note anyway that Schulmeister (1987) analysing both adjusted and unadjusted reaches the same conclusions; moreover Schulmeister (1983) points out that test statistics are not substantially altered by the adjustment.

RW hypothesis is strongly rejected for the period immediately after the exit of the lira from the EMS (1 Oct. 1992 - 22 Dec. 1992).<sup>7</sup>

Notice however that DF and ADF tests are not very powerful.

The analysis goes on in the attempt to determine some trading rules capable to improve the forecasts of the exchange rates. The trading rules considered are based only on the information concerning past values of the lira-dollar exchange rate.

The idea is that if it is possible to find trading rules that are consistently profitable over a reasonable period, then the market is not efficient.

Even though market efficiency should imply that no trading rule could be profitable, evidently, testing a very large number of trading rules, some of them could give, *ex post*, significant profits.

In the financial literature *ex post* analyses are largely developed. In such a perspective, a number of studies have found evidence of profit-making opportunities in the exchange market. For instance Logue and Sweeney (1978) have found that while data of the franc-dollar spot rate (in the period 1970 - 1974) seemed to be white noise using spectral analysis, there was a number of trading rules that yielded positive profits. The same authors however, in a subsequent work, testing the same trading rules considered in Logue and Sweeney (1977) on different periods and different currencies concluded that markets can be considered weakly efficient.<sup>8</sup>

The approach proposed in the present work is to test the profitability of trading rules in an *ex ante* perspective: the trading rules that are tested are not automatically taken from the literature but are, in a sense, "*discovered*" in the study itself, selecting those trading rules which, in the analysis of the first sub-sample period, show good statistical forecasting properties; only in a second step, their performance is tested over a simulation period (the second sub-sample).

The simultaneous investigation of the RW hypothesis and the profitability of trading rules deserves a short digression.

According to the RW model, the best forecast of tomorrow's exchange rate is today's exchange rate. However, most of the RW tests (among which, those used in this work) are based on the assumption of linearity in the alternative hypotheses.

Many of the trading rules used by technical analysts are, on the contrary, non-linear functions of past prices. Thus, independently from the RW tests, *technical analysis* may be a coherent determinant of expectations' formation and, consequently, may play a role in the determination of exchange rate dynamics.

In the literature, the consideration of non-linear alternative hypothesis to the RW model is only partly developed in the technical analysis framework. A growing number of studies analyse foreign

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<sup>7</sup> The 1st oct 1992 is the first day in which official values are reported after a lack of fifteen days, being the last official value referred to the 16th sep 1992.

<sup>8</sup> Logue, Sweeney and Willet (1978).

exchange markets in the framework of chaos theory, in which complex dynamic patterns are explained through deterministic non-linear difference equation models.<sup>9</sup>

According to the theory of chaos, the behaviour of the exchange rate lira-dollar (including the *jump* relative to the exit of the lira from the EMS) does not present peculiarities to be explained outside the chaotic framework itself: a certain pattern interrupted by sudden changes is indeed one of the typical characteristics of chaotic series.

In this study, on the contrary, the quick depreciation of lira begun in September 1992 is considered as an anomalous behaviour to be related to the structural and institutional break caused by the exit of the lira from the EMS. This exploration thus is intended to contribute to a theory of expectation formation and exchange rate determination and not to a purely mathematical explanation of exchange rate dynamics.

Technical analysis is, in fact, largely recognised to be an important instrument for the formation of expectations. Even though it exploits purely statistical regularities of time series, it is economically founded. In this perspective, if the depreciation of the lira has to be considered peculiar, it is because the theoretical and practical validity of all the economically based instruments of expectations forming are to be questioned during periods of institutional change.

### 3. The Random Walk hypothesis

In order to explore the RW hypothesis, unit root tests<sup>10</sup> and the analysis of the autocorrelation function have been carried out.<sup>11</sup> Results of the unit root tests are reported in Tab. 1; these tests lead not to reject the RW hypothesis for the period 14 Mar. - 17 Jan. 1994 (obss. 1-700), pointing out that the time series is first-order integrated (all the DF and ADF tests are in the non-critical zone)<sup>12</sup>. A rough visual inspection of the autocorrelation function leads to similar conclusions (the non-rejection of the RW hypothesis): the autocorrelation function of the series in levels decreases almost linearly, while that of the series of the first-order differences is not significantly different from zero for all lags different from zero).<sup>13</sup>

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<sup>9</sup> De Grauwe and Vansanten (1990, 1992), Hsieh (1989).

<sup>10</sup> Dickey and Fuller (1979).

<sup>11</sup> Both the series in levels (L) and the first-order differences (DL) have been considered; results are reported only for the former.

<sup>12</sup> ADF(n) tests have been carried out for each n=1,2,...,12. Results are presented only for the first four ADF tests because no significant modifications about conclusions have been obtained from the analysis of the other eight. The same consideration is true for all the following ADF tests.

<sup>13</sup> See, for instance, Chatfield (1989).

**Table 1 Unit root tests for variable L**

```

*****
statistic      sample      observations  without trend  with trend
DF             2 700      699          -.18467 (-2.8660)  -1.2522 (-3.4184)
ADF(1)        3 700      698          -.14330 (-2.8660)  -1.2384 (-3.4184)
ADF(2)        4 700      697          -.12677 (-2.8660)  -1.3343 (-3.4184)
ADF(3)        5 700      696          -.19267 (-2.8661)  -1.4076 (-3.4184)
ADF(4)        6 700      695          -.13338 (-2.8661)  -1.4871 (-3.4184)

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\*\*\*\*\*  
95% critical values in brackets.

The RW hypothesis has been tested also dividing the sample period into two sub-periods, namely 14 Mar. 1991 - 16 Sep. 1992 and 1 Oct. 1992 - 17 Jan. 1994 (obss. 1-383 and 384-700). In fact, the 17 Sep. 1992 is the day in which the Italian lira went out from the EMS under the pressure of "international speculation". These tests (Tabb. 2 and 3) confirm the conclusions reached in the analysis of the period as a whole.

**Table 2 Unit root tests for variable L**

```

*****
statistic      sample      observations  without trend  with trend
DF             2 383      382          -1.6870 (-2.8693)  -3.2617 (-3.4233)
ADF(1)        3 383      381          -1.6625 (-2.8693)  -3.2108 (-3.4233)
ADF(2)        4 383      380          -1.7394 (-2.8694)  -3.0317 (-3.4234)
ADF(3)        5 383      379          -1.6429 (-2.8694)  -2.9861 (-3.4234)
ADF(4)        6 383      378          -1.7170 (-2.8694)  -2.7247 (-3.4234)

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\*\*\*\*\*  
95% critical values in brackets.

**Table 3 Unit root tests for variable L**

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*****
statistic      sample      observations  without trend  with trend
DF             384 700    317          -2.4894 (-2.8708)  -2.9749 (-3.4255)
ADF(1)        384 700    317          -2.5214 (-2.8708)  -2.9491 (-3.4255)
ADF(2)        384 700    317          -2.5315 (-2.8708)  -2.9396 (-3.4255)
ADF(3)        384 700    317          -2.3538 (-2.8708)  -2.9026 (-3.4255)
ADF(4)        384 700    317          -2.3996 (-2.8708)  -2.9057 (-3.4255)

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\*\*\*\*\*

95% critical values in brackets.

However if we consider that the speculation against the lira became evident some days before the exit from the EMS and we thus divide the period into the two sub-periods (obss. 1-381; 382-700) the results are less unambiguous (Tabb. 4 and 5): even if some ADF tests do not reject the hypothesis of RW at critical level of 95%, some other ADF and the DF tests lead to reject that hypothesis.

**Table 4 Unit root tests for variable L**

```
*****
statistic      sample      observations  without trend  with trend
DF             2 381      380          -1.5324 (-2.8694)  -3.5362 (-3.4234)
ADF(1)        3 381      379          -1.4486 (-2.8694)  -3.4518 (-3.4234)
ADF(2)        4 381      378          -1.4239 (-2.8694)  -3.1573 (-3.4234)
ADF(3)        5 381      377          -1.2747 (-2.8694)  -3.0806 (-3.4234)
ADF(4)        6 381      376          -1.3019 (-2.8694)  -2.7737 (-3.4235)
*****
```

95% critical values in brackets.

**Table 5 Unit root tests for variable L**

```
*****
statistic      sample      observations  without trend  with trend
DF             382 700    319          -3.0327 (-2.8708)  -3.4801 (-3.4254)
ADF(1)        382 700    319          -3.0716 (-2.8708)  -3.4878 (-3.4254)
ADF(2)        382 700    319          -2.9983 (-2.8708)  -3.4634 (-3.4254)
ADF(3)        382 700    319          -2.8003 (-2.8708)  -3.4105 (-3.4254)
ADF(4)        382 700    319          -2.8415 (-2.8708)  -3.4125 (-3.4254)
*****
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95% critical values in brackets.

The exit from the EMS was probably not interpreted as the signal that speculation against lira would not have succeeded anymore (paid by BankItalia losses), but as a signal that Italian lira was overvalued. Such an interpretation is confirmed by the analysis of unit root tests for the period straddling the exit of the lira from the EMS, which seems to validate the idea that such an institutional change did not stop at all the speculation against the lira: indeed, from the point of view of the RW hypothesis, the period 14 Sep. 1992 - 2 Nov. 1992 (obss. 381-405) is rather anomalous (Tab. 6).

Table 6 **Unit root tests for variable L**

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*****
*
statistic      sample observations      without trend      with trend
DF             381 405      25      -4.1478 (-2.9850)      -3.7218 (-3.6027)
ADF(1)        381 405      25      -4.4159 (-2.9850)      -3.5347 (-3.6027)
ADF(2)        381 405      25      -4.6723 (-2.9850)      -3.4063 (-3.6027)
ADF(3)        381 405      25      -4.4661 (-2.9850)      -3.2953 (-3.6027)
ADF(4)        381 405      25      -4.3527 (-2.9850)      -3.3156 (-3.6027)
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*****
*
95% critical values in brackets.
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One possibility could be that there exists some systematic pattern in exchange rate movements that give rise to a sequence of upward and downward runs, which in the analysis of the period as a whole can look completely random even if they are not.

#### 4. The theory of technical analysis

Technical analysis of financial markets involves providing forecasts or trading advice on the basis of the inspection of past prices.<sup>14</sup> It is composed of both qualitative and quantitative analyses.<sup>15</sup> While the former contains an important subjective element, the latter is entirely based on statistical transformations of the prices' time series. These techniques produce clearly defined series of buy and sell signals and can therefore be econometrically tested.

Three types of technical analysis models are considered in this study: *Oscillators (O)*, *Relative Strength Indexes (RSI)*, and *Stochastics (ST)*.<sup>16</sup>

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<sup>14</sup> Some techniques, not considered in this paper, take into account also of the exchanged quantities.

<sup>15</sup> See Murphy (1986) and Kaufman (1978).

<sup>16</sup> A fourth kind of model has been considered and rejected as a predictor of the prices time series. It is the so called "*Market Momentum*" (MM). The time series of the MM(p) is calculated taking the differences of lag (p) of the price time series.

The investigation of the RW hypothesis through the autocorrelation function is sufficient to deduce that the (eventual) predictive power of such an index should be low. Note in fact, that analysing the significance of 100 different MM(p) (p=1,2,...,100) for the forecasting of future prices, would lead to consider 5 of these indexes being significant at a level of probability of 95%, even though the hypothesis of RW is true.

**OSCILLATOR**: It is the difference of a short term moving average and a long term moving average. The trading rule is as follows: buy when the short term moving average crosses the long term moving average from below (i.e. when the difference between the short term and the long term moving average becomes positive) and sell when the converse occurs (when the difference becomes negative).

Denoting a price at time t with  $X_t$ , the O formula is the following:

$$O(p,q)_t = \text{Average}(X_t, \dots, X_{t-p}) - \text{Average}(X_t, \dots, X_{t-q})$$

**RELATIVE STRENGTH INDEX**: This index and the following one (the stochastic) are intended to solve the problem of locating anomalous ("too fast") movements of the price in a given time horizon. Both the RSI and the ST have values in the range [0, 1]. There are different ways of using these indexes as trading rules. We will use them to determine the so called "overbought" and "oversold" market situations.

The market is considered overbought, according to an index, when the index is over the value 0.9 and oversold when the index is under 0.1. The underlying idea is that, independently from a possible trend, when price moves consistently in a direction, the probability of a correction increases.

The RSI formula is the following:

$$RSI(p)_t = \frac{\text{Sum}(U_t, \dots, U_{t-p})}{\text{Sum}(U_t, \dots, U_{t-p}) + \text{Sum}(D_t, \dots, D_{t-p})}$$

where  $U_t$  (Ups) is equal to  $X_t - X_{t-1}$  if  $X_t - X_{t-1} > 0$ ; equal to 0 otherwise  
and  $D_t$  (Downs) is equal to  $-(X_t - X_{t-1})$  if  $X_t - X_{t-1} < 0$ ; equal to 0 otherwise.

**STOCHASTIC**: This index is considered useful in non-directional movement periods. The idea is that when a price is very close to an upper or lower (flexible) bound it tends to correct in the opposite direction. Speculation according to such an index is then stabilising; in a sense it exploits the Keynesian idea that expectations are largely based on conventions, which leads to invert position when the price has gone far from the "conventional" price which market participant are used with; at the same time this "conventional" price, being derived by the price historical path, moves gradually while the actual price tends to vary in a certain range.

ST formula is the following:

$$ST(p)_t = \frac{X_t - \min(X_t, \dots, X_{t-p})}{\text{Max}(X_t, \dots, X_{t-p}) - \min(X_t, \dots, X_{t-p})}$$

One simple reason why technical analysis can be an important determinant of the exchange rate is that it is used by foreign exchange rate dealers, which is the group of agents that influences most directly the process of exchange rate determination. A study of the "Group of thirty" points out that 97% of the bank respondents and 87% of the securities houses expressed the opinion that the use of technical models has had an increasingly significant impact on the market.<sup>17</sup> A questionnaire survey conducted on behalf of the Bank of England, among chief foreign exchange dealers revealed that at least 90% of respondents place some weight on technical analysis when forming views at one or more time horizons.<sup>18</sup> Moreover, this research pointed out a skew towards reliance on technical, as opposed to fundamentalist analysis at shorter horizons, which become steadily reversed as the length of horizon considered is increased. The authors also suggest that the large use of technical analysis can be self-fulfilling in the determination of short term exchange rate dynamics.

Buying and selling currencies *per se* is of course a zero-sum game. If banks and probably also securities houses, commodities firms and multinational industrial corporations, consistently win in this game (not only by using technical analysis), as it is affirmed in Group of Thirty (1985), who then is the loser? The answer is simple: all those market participants who buy or sell currencies for other reasons than short term profit maximisation. Particularly all those traders of goods and services who perceive and use foreign exchange markets for international payments, and Central Banks (whose objective functions are generally incompatible with short term profit maximisation). The latter, in specific circumstances, as in the period that led to the exit of the lira from the EMS, can have very consistent losses.

## 5. Methodology

Oscillators (O(p,q)), Relative Strength Indexes (RSI(p)), and Stochastics (ST(p)) have been calculated for different values of the parameters (p,q). Observe that the shorter the period of the statistics (parameters p and q), the more the statistics themselves are sensitive and the wider is their amplitude. To slow down the volatility and to reduce the number of false signals, a Moving Average (MA) has been calculated for the RSI and ST statistics.<sup>19</sup>

The variables considered are then the following:

O(p,q)	p = 1, 5, 15, 35, 50	q = 5, 15, 35, 50 for each p < q
MA(q)RSI(p)	p = 5, 10, 15, 20, 35, 50	q = 3, 5

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<sup>17</sup> Group of thirty (1985).

<sup>18</sup> Taylor and Allen (1992).

<sup>19</sup> The use of moving average is useful particularly when dealing with very short memory statistics. See, for instance, Murphy (1986).

MA(q)STp)                      p = 5, 10, 15, 20, 35, 50                      q = 3, 5

In order to obtain clear buy and sell signals, dummy variables (d) have been constructed for each of the variables considered. The variable tested are the following:

dO(p,q)	assuming the value 1	if O(p,q)>0 ;	-1	otherwise
d <sup>+</sup> MA(q)RSI(p)	assuming the value 1	if MA(q)RSI(p) > 0.9 ;	0	otherwise
d <sup>-</sup> MA(q)RSI(p)	assuming the value 1	if MA(q)RSI(p) < 0.1 ;	0	otherwise
d <sup>+</sup> MA(q)STp)	assuming the value 1	if MA(q)ST(p) > 0.9 ;	0	otherwise
d <sup>-</sup> MA(q)STp)	assuming the value 1	if MA(q)ST(p) < 0.1 ;	0	otherwise.

Each RSI and ST model gives rise to two predictors, namely an "overbought" (d<sup>+</sup>) and an "oversold" (d<sup>-</sup>) indicator. These two indicators do not necessarily have to be both significant for a certain model. Thus for each single RSI and ST (and for each RSI and ST filtered by a MA) four models have been considered: the first two models include both the overbought and oversold indicators (one of the models include also the constant term); in the other two models the overbought signal and the oversold signal are tested separately. Hence, the estimated models are the following:<sup>20</sup>

$$DL(t) = b dO(t-1) + e(t)$$

$$DL(t) = a \text{ const} + b d^+RSI(t-1) + c d^-RSI(t-1) + e(t)$$

$$DL(t) = b d^+RSI(t-1) + c d^-RSI(t-1) + e(t)$$

$$DL(t) = b d^+RSI(t-1) + e(t)$$

$$DL(t) = b d^-RSI(t-1) + e(t)$$

$$DL(t) = a \text{ const} + b d^+ST(t-1) + c d^-ST(t-1) + e(t)$$

$$DL(t) = b d^+ST(t-1) + c d^-ST(t-1) + e(t)$$

$$DL(t) = b d^+ST(t-1) + e(t)$$

$$DL(t) = b d^-ST(t-1) + e(t)$$

All the equations have been estimated with an AutoRegressive Conditional Heteroscedasticity (ARCH) model.<sup>21</sup> ARCH models are often used in financial market analyses because of the low likelihood of the homoscedasticity hypothesis; one of the stochastic characteristics of foreign exchange markets is indeed its varying volatility over time.<sup>22</sup> This varying volatility is explained in ARCH(p) models through the hypothesis that the conditional variance of the error term has an autoregressive structure of order p.

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<sup>20</sup> To reproduce exactly the rule *buy when the short term MA crosses from below the long term MA and sell in the opposite case*, the models based on O(p,q) variables do not include the constant.

<sup>21</sup> See, for instance, Greene (1993).

<sup>22</sup> Hsieh (1983).

Among ARCH(p) models, the choice of the model to adopt has been carried out testing, for each trading rule, the best order of the parameter p, considering also ARCH(p) models with some of the parameters explaining the conditional variance of the error term constrained to be equal to zero. The choice of the ARCH(p) model for each trading rule is based on purely statistical considerations.<sup>23</sup>

## 6. Empirical evidence

The sample period considered for the derivation of significant technical analysis instruments is 14 Mar. 1991 - 17 Jan. 1994 (obss. 1-700). The period 18 Jan. 1994 - 30 Jun. 1994 (obss. 701-811) is used to simulate the significance of these predictors and to test the performances of the given signals.

The results of such analyses are reported in par. 6.1 and 6.2 respectively. While the analysis of par. 6.2 involves only statistical considerations, the analysis of par. 6.1, the choice of the predictors, takes into account of both statistical and economical arguments.

In particular, it is argued that the fast movement of the exchange rate, when the position of the lira in the EMS became non-defendable, may be related to the situation of Italian fundamentals and to the expectations on them. Now, if it is true that these movements may be related to the tendency towards a new equilibrium value of the lira with respect to all the other currencies (in the sense that the lira was considered overvalued), then we should expect that the analysis of the first sample should lead to overestimate the goodness of *extrapolating* trading rules and to underestimate that of *stabilising* rules.

Moreover, as the exploration of the RW hypothesis pointed out, the period around the exit of the lira from the EMS is a very anomalous one, not only for its institutional change, but also from a statistical point of view.

To take into account of the possibility that the exit of the lira from the EMS may bias the properties of our models and may lead us to change a wrong predictive model, we have investigated both the first sub-sample as a whole and the first sub-sample deprived of the period of the exit of the lira from the EMS.

### 6.1. The choice of the models

The analysis has been conducted in a first stage testing every model in the sample period 14 Mar. 1991 - 17 Jan. 1994 (obss. 1-700) and at a second stage cutting the period 14 Sep. 1992 - 2 Nov. 1992 (obss. 381-405).<sup>24</sup> The implicit idea of the second stage analysis is that the trading rules considered may

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<sup>23</sup> The statistical properties considered are the t-statistics of the dependent variable and that of the parameters explaining the conditional variance of the error term (significance level at 10%). None of the estimated models shows problems of heteroscedasticity or serial correlation.

<sup>24</sup> The period to cut as "*anomalous*" has been derived by the analysis of the random walk hypothesis of par 3.

be appropriate in both the institutional contexts (before and after the presence of the lira in the EMS), but not during the period of transition.<sup>25</sup>

The analysis for the entire period outlines that none of the RSI(p) and the ST(p) considered gives significant results: the only statistically significant results obtained have the opposite sign with respect to what the theory says (which means that a buy signal is given when market is overbought and vice versa). Among O(p,q) models, significant results have been obtained for (p,q)=(1,15), (1,35), (1,50), (5,35), (5,50), (15,35), (15,50), while the following O(p,q) models have been rejected: (p,q)=(1,5), (5,15), (35,50). The best statistical performance of all the non-rejected models has been obtained with an ARCH(3) estimation model, in which the first parameter explaining the conditional variance of the error term is constrained to zero.<sup>26</sup>

The analysis for the period without the exit from the EMS does not lead to substantially different results. Small improvements are noted in the predictive significance of all RSI and ST but not such to make these models good predictors of short term exchange rate dynamics. Among O(p,q) models the only change is that O(1,15) is now rejected.

Results for not rejected models in both the entire and the "split" samples are as follows:

**GARCH(0,3) assuming a Normal distribution**  
converged after 21 iterations

\*\*\*\*\*

Dependent variable is **DL**

674 observations used for estimation from 2 to 675

\*\*\*\*\*

Regressor	Coefficient	Standard Error	T-Ratio [Prob]
<b>dO(1,35)(-1)</b>	.74246	.40906	1.8151 [.070]

\*\*\*\*\*

R-Squared	.0010181	R-Bar-Squared	.0010181
DW-statistic	2.0894		

\*\*\*\*\*

Parameters of GARCH explaining H-SQ, the conditional variance of the error term

\*\*\*\*\*

	Coefficient	Asymptotic T-Ratio
GARCH constant	93.4890	11.4148 [.000]
E-SQ(- 2)	.11963	2.2615 [.024]

<sup>25</sup> Tests for the profitability of trading rules stress that profitable models tends to be profitable also if the sample is divided in sub-samples, even though profitability of trading rules changes over time. Cf. Schulmeister (1987), Levich and Thomas (1993).

<sup>26</sup> All tests, except the DF and ADF, have been conducted at a level of significance of 10%.

E-SQ(- 3) .11225 2.1571 [.031]

\*\*\*\*\*

**GARCH(0,3)** assuming a Normal distribution  
converged after 19 iterations

\*\*\*\*\*

Dependent variable is **DL**

674 observations used for estimation from 2 to 675

\*\*\*\*\*

Regressor	Coefficient	Standard Error	T-Ratio [Prob]
<b>dO(1,50)(-1)</b>	.76070	.40466	1.8799 [.061]

\*\*\*\*\*

R-Squared	.0021832	R-Bar-Squared	.0021832
DW-statistic	2.0870		

\*\*\*\*\*

Parameters of GARCH explaining H-SQ, the conditional variance of the error term

\*\*\*\*\*

	Coefficient	Asymptotic T-Ratio
GARCH constant	93.9223	11.5279 [.000]
E-SQ(- 2)	.11615	2.2231 [.027]
E-SQ(- 3)	.11074	2.1476 [.032]

\*\*\*\*\*

**GARCH(0,3)** assuming a Normal distribution  
converged after 20 iterations

\*\*\*\*\*

Dependent variable is **DL**

674 observations used for estimation from 2 to 675

\*\*\*\*\*

Regressor	Coefficient	Standard Error	T-Ratio [Prob]
<b>dO(5,35)(-1)</b>	.94327	.40484	2.3300 [.020]

\*\*\*\*\*

R-Squared	.0039153	R-Bar-Squared	.0039153
DW-statistic	2.0821		

\*\*\*\*\*

Parameters of GARCH explaining H-SQ, the conditional variance of the error term

\*\*\*\*\*

	Coefficient	Asymptotic T-Ratio
--	-------------	--------------------

GARCH constant	93.0063	11.4448 [.000]
E-SQ(- 2)	.11955	2.2605 [.024]
E-SQ(- 3)	.11476	2.1905 [.029]

\*\*\*\*\*

**GARCH(0,3) assuming a Normal distribution**  
converged after 20 iterations

\*\*\*\*\*

Dependent variable is **DL**

674 observations used for estimation from 2 to 675

\*\*\*\*\*

Regressor	Coefficient	Standard Error	T-Ratio [Prob]
<b>dO(5,50)(-1)</b>	.73425	.40335	1.8204 [.069]

\*\*\*\*\*

R-Squared	.0021052	R-Bar-Squared	.0021052
DW-statistic	2.0756		

\*\*\*\*\*

Parameters of GARCH explaining H-SQ, the conditional variance of the error term

\*\*\*\*\*

	Coefficient	Asymptotic T-Ratio
GARCH constant	94.0282	11.5338 [.000]
E-SQ(- 2)	.11723	2.2268 [.026]
E-SQ(- 3)	.10889	2.1208 [.034]

\*\*\*\*\*

**GARCH(0,3) assuming a Normal distribution**  
converged after 21 iterations

\*\*\*\*\*

Dependent variable is **DL**

674 observations used for estimation from 2 to 675

\*\*\*\*\*

Regressor	Coefficient	Standard Error	T-Ratio [Prob]
<b>dO(15,35)(-1)</b>	.75905	.40487	1.8748 [.061]

\*\*\*\*\*

R-Squared	.0025469	R-Bar-Squared	.0025469
DW-statistic	2.0758		

\*\*\*\*\*

Parameters of GARCH explaining H-SQ, the conditional variance of the error term

```

*****
                Coefficient          Asymptotic T-Ratio
GARCH constant    93.9586             11.4947 [.000]
E-SQ(- 2)        .11823             2.2537 [.025]
E-SQ(- 3)        .10829             2.1024 [.036]
*****

```

**GARCH(0,3)** assuming a Normal distribution  
converged after 20 iterations

```

*****
Dependent variable is DL
674 observations used for estimation from 2 to 675
*****

```

```

Regressor          Coefficient    Standard Error T-Ratio [Prob]
dO(15,50)(-1)    .89272 .40355      2.2122 [.027]
*****
R-Squared          .0039537          R-Bar-Squared    .0039537
DW -statistic     2.0777
*****

```

Parameters of GARCH explaining H-SQ, the conditional variance of the error term

```

*****
                Coefficient          Asymptotic T-Ratio
GARCH constant    93.3424             11.4719 [.000]
E-SQ(- 2)        .11569             2.2098 [.027]
E-SQ(- 3)        .11559             2.1812 [.030]
*****

```

## 6.2. Tests for market efficiency and trading rules performances

The six chosen models have been used to test market efficiency and the general performance of the trading rules in the period 18 Jan. 1994 - 30 Jun. 1994 (obss. 701-811). Two methods have been considered. The first one is based on the derivation of a forecasted exchange rate series to compare with the actual one (6.2.1). The second one is directly based on a test for the profitability of trading rules (6.2.2).

### 6.2.1. The construction of a forecasted series

The analysis is composed of the following steps:

-1- Every single model has been used to produce a series of forecastings. Forecasts have been derived using rolling ARCH models. The ARCH model used has been that derived in the analysis of the first part of the sample. The idea of rolling estimation is the following: at time  $t$  the model considered produces the forecast of the exchange rate at time  $t+1$ ; at time  $t+1$  the model is re-estimated to produce the forecast of time  $t+2$ , and so on. This kind of simulation is intended to reproduce a likely behaviour of a speculator who, once derived a model, uses it every day to produce buy and sell signals updating, day by day, his model with the new information obtained. This procedure can also be intended as a sort of stability analysis of the parameters of the model. If a parameter becomes non-significant the model is rejected (and, since that day onwards, is not used anymore).

-2- The six series have been combined to produce a unique series of forecasts. Two methods of combining forecasts have been considered: (a) the regression method; (b) the simple average.

-3- The forecasted series has been compared with the series of actual values. An OLS regression has been used to test the efficiency of the market: in the hypothesis of market efficiency no trading rules should improve the forecastings with respect to a RW model, so that actual and forecasted series should be orthogonal.

#### **FIRST STEP: ROLLING ARCH SIMULATION**

Two of the six models have caused significance problems in the rolling ARCH simulation, namely O(1,35) and O(15,35) in the final part of the forecasting sample. Once a model loses its statistical predictive properties, it is excluded by the process of combining forecasts. O(1,35) becomes statistically non-significant after obs. 779, O(15,35) becomes non-significant at the obs. 784.

#### **SECOND STEP: THE FORECASTED SERIES**

##### **(a) The Regression Method**

The regression method<sup>27</sup> has been implemented by dividing the sample relative to forecasts into two sub-periods. The first sub-period was to be used to derive the optimal weights of the linear combination of the six predictors; the second sub-period was to be used to simulate the performance of the combined forecasted series. Problems of multicollinearity among the six series in the first sub-period have prevented from implementing the whole procedure (different partitions of the forecast period have been considered).

The presence of multicollinearity suggests that combining forecasts based, not only on the same information, but also on the same way of processing the available information (in the sense that all the predictors are of O(p,q) type) cannot improve much the accuracy of each single forecast.

---

<sup>27</sup> For an analysis of the properties of the regression method, cf. Holden, Peel and Thompson (1990). By the way, notice that the Regression method can be seen as a generalisation of Bates and Granger (1969) variance-covariance method of combining two unbiased forecasts to produce a new forecast which is more accurate than either of its components.

### (b) The Simple Average Method

Even though the predictive power may be difficult to improve, two considerations suggest the use of a simple average of the six forecasted series.

-1- In the regression method the simple average is appropriate when the forecast errors have equal population variances.<sup>28</sup>

-2- If the optimal weights are unstable, forecasts will be expected to be poor; in general, the simple average will have non-optimal weights but may still give better forecasts than any system of time-varying weights.<sup>29</sup>

### THIRD STEP: A TEST FOR MARKET EFFICIENCY

Denoting with PR(t) the forecast of DL(t) the following models have been estimated with OLS:

$$DL(t) = a \text{ const} + b \text{ PR}(t) + e(t)$$
$$DL(t) = b \text{ PR}(t) + e(t)$$

Results are the following:

#### Ordinary Least Squares Estimation

```
*****
Dependent variable is DL
110 observations used for estimation from 802 to 811
*****
Regressor      Coefficient    Standard Error    T-Ratio [Prob]
CONST          -4.2361        2.4965            -1.6968 [.093]
PRDL(-1)      -5.2151        3.6682            -1.4217 [.158]
*****
R-Squared      .020208        R-Bar-Squared     .010210
S.E. of Regression  10.9047        F-statistic F( 1, 98)  2.0212 [.158]
DW-statistic   2.3091
*****
```

#### Diagnostic Tests<sup>30</sup>

```
*****
```

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<sup>28</sup> Granger and Ramanathan (1984).

<sup>29</sup> Holden, Peel and Thompson (1990).

<sup>30</sup> A: Lagrange multiplier test of residual serial correlation. B: Ramsey's RESET test using the square of the fitted values. C: Based on a test of skewness and kurtosis of residuals. D: Based on the regression of squared residuals on squared fitted values.

Test Statistics	LM version	F Version
A:Serial Correlation	CHSQ(1) = 3.4021 [.065]	F(1, 97) = 3.4163 [.068]
B:Functional Form	CHSQ(1) = .0011860 [.973]	F(1, 97) = .0011504 [.973]
C:Normality	CHSQ(2) = 61.7681 [.000]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .89392 [.344]	F(1, 98) = .88394 [.349]

### Ordinary Least Squares Estimation

Dependent variable is **DL**

110 observations used for estimation from 802 to 811

Regressor	Coefficient	Standard Error	T-Ratio [Prob]
<b>PRDL(-1)</b>	.38411	1.6175	.23748 [.813]
R-Squared	-.0085788	R-Bar-Squared	-.0085788
S.E. of Regression	11.0077	F-statistic	NONE
DW - statistic	2.2999		

### Diagnostic Tests

Test Statistics	LM version	F Version
A:Serial Correlation	CHSQ(1) = 3.17789 [.075]	F(1, 98) = 3.2165 [.076]
B:Functional Form	CHSQ(1) = .37706 [.539]	F(1, 98) = .37092 [.544]
C:Normality	CHSQ(2) = 62.8055 [.000]	Not applicable
D:Heteroscedasticity	CHSQ(1) = .10961 [.741]	F(1, 98) = .10754 [.744]

The analysis of t-statistics on the coefficient  $b$  leads not to reject the hypothesis of orthogonality, which means that the market efficiency assumption is not to be rejected (note that including the constant the coefficient  $b$  takes the wrong sign with respect to what expected if technical analysis worked).

However, both models present problems from the point of view of diagnostic tests: normality hypothesis is rejected, serial correlation cannot be rejected at a significance level of 10% and CUSUMSQ test (not reported) leads to reject the hypothesis of constancy of the parameters of the two

models.<sup>31</sup> This, in turn, invalidates the significance of the t-test on the parameter of interest ( $b$ ) and, thus, the whole procedure of testing market efficiency through OLS regressions.<sup>32</sup>

Moreover, note that the use of technical analysis models to derive buy and sell signals does not coincide with the punctual forecasting of a price time series. The models considered are generally used for a different purpose: the objective is the prediction of some short-medium term movements of a certain consistency, able to compensate a (generally large) number of (small) losses deriving by a series of false signals. To put it roughly, out of *ten* predictions, technical analysts look for *two* good predictions that can overcompensate the losses of *eight* wrong predictions.<sup>33</sup>

The analysis of the distribution of OLS residuals is coherent with this observation: skewness and kurtosis are largely distant from those that we would expect if our predictive models had the characteristic of giving an (approximately) equal number of gains and losses of (approximately) the same amount. As a matter of fact, the normality test (based on skewness and kurtosis of residuals) leads to reject the normality assumption.

The unfulfilment of the assumptions on which the t-test is based leads us to our second method of testing market efficiency.

## 6.2.2. The profitability of trading rules

The profitability of trading rules has been analysed by testing the significance of the total gains obtained by the mechanical use of buy and sell signals.<sup>34</sup> Gains and losses are computed assuming that every operation (buy or sell) is done the day after an oscillator gives a signal; after the first signal, it is assumed that every time the oscillator changes signal the position is inverted (*short*  $\rightarrow$  *long*; *long*  $\rightarrow$  *short*); the last position (short or long, depending on the oscillator) is closed at the last price of the data set.

As a first step each model is tested singularly by a t-test, profits equal to zero being the null hypothesis. The small dimension of each sample suggests to test also the global significance of Oscillator models altogether.

### **TRADING RULES' PERFORMANCES**

Each of the six trading rules gives positive gains in the simulation period.

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<sup>31</sup> The CUSUM and CUSUMSQ tests are based on rolling regressions and are used to test the structural stability of the model.

<sup>32</sup> The OLS analysis has been carried out also for each of the six predictors separately. None of the models led to reject the null hypothesis of orthogonality between actual and forecasted values; however, also in this case, statistical results are so bad that the hypothesis of market efficiency should still be questioned.

<sup>33</sup> Murphy (1986).

<sup>34</sup> When a trading rule loses its statistical significance it is assumed that the position is closed the day after and that the trading rule is not utilised anymore.

Tab 7 reports buy and sell signals of the six models and the relative prices (liras per dollar).

**Tab 7. Simulation of the buy and sell operations according to Oscillator-type models**

Date	O(1,35)	O(1,50)	O(5,35)	O(5,50)	O(15,35)	O(15,50)
8 <sup>th</sup> feb	1699.25 B	1699.25 B				
10 <sup>th</sup> feb	1691.7 S	1691.7 S				
14 <sup>th</sup> feb	1684.61 B	1684.61 B	1684.61 B	1684.61 B		
15 <sup>th</sup> feb	1678.79 S	1678.79 S	1678.79 S	1678.79 S		
16 <sup>th</sup> Jun					1683.08 S	1683.08 S
6 <sup>th</sup> Jun	1620.6 B	1620.6 B				
7 <sup>th</sup> Jun			1617.61 B			
9 <sup>th</sup> Jun				1618.24 B		
10 <sup>th</sup> Jun						
13 <sup>th</sup> Jun					1599.18 B	
14 <sup>th</sup> Jun	1595.05 S	1595.05 S				
15 <sup>th</sup> Jun				1598.65 S		
20 <sup>th</sup> Jun	1584.43 B		1584.43 S			
21 <sup>st</sup> Jun	1583.26 S					
22 <sup>nd</sup> Jun	1575.75B*					
28 <sup>th</sup> Jun					1568.73 S	
29 <sup>th</sup> Jun					1562.82 B*	
30 <sup>th</sup> Jun		1585.99 B	1585.99 B	1585.99 B		1585.99 B

B: Buy

S: Sell

\*: Close the position because O(p,q) became insignificant the day before.

### AN INDIRECT TEST FOR MARKET EFFICIENCY

The  $t$ -test (at the significance level of 5%) outlines that gains are not significantly greater than zero neither for every single rule separately considered, nor for the set of rules altogether.

However, two considerations are necessary:

First, notice that to carry out a  $t$ -test, a normal distribution has been assumed even though previous analyses suggest to question such an assumption. Levich and Thomas (1993), with an alternative approach (the so called "*bootstrap approach*"), that does not require any assumptions on the distribution generating function of rates of profits, obtain significant results from some trading rules that, with a common  $t$ -test, would not be significant.<sup>35</sup>

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<sup>35</sup> In the "bootstrap methodology" the sequence of  $N$  observations on rates of profits are arranged in all its possible  $N!$  permutations to generate an empirical distribution. The significance of a rule is then analysed simulating its performance on each possible sequence; if there is no information in the original sequence of data, then the profits

Second, the significance level (conventionally fixed at 5%) is to be questioned: the significance level in this kind of analysis should be derived from the amount of risk effectively faced by speculators and from their loss function: notice for example, that in the hypothesis of risk neutrality (which implies a linear loss function) a 50% significance level may be used. Assuming risk aversion (convex loss function) the significance level should be lower: the higher the risk aversion, the lower the significance level.

The latter consideration leads us to examine the significance level of trading rules' gains even though higher than the conventional level of 5%.

Taking into account transaction costs (that, for the kind of market participants that mostly use technical analysis, are estimated to be at 0.02% per trade), the overall profit from blindly following a trading rule becomes significant, according to a t-test, at the following probability level:

O(1,35): 0.298	O(1,50): 0.241
O(5,35): 0.418	O(5,50): 0.282
O(15,35): 0.313	O(15,50): <i>not computable</i> <sup>36</sup>
Six trading rules altogether: <sup>37</sup>	0.051.

These levels of significance imply that this kind of trading rules can be used by speculators not particularly risk averse and which globally do not face very high risk.

Thus, technical analysis is likely to be used by market participants such as banks, security houses and investment funds for two reasons.

First, given the high number of operations made by such agents, the global risk tends to be low.

Second, capital invested according to technical rules are only a fraction of the total investment of these currency dealers;<sup>38</sup> other fractions are invested according to criteria that lead to less variable (and less profitable) gains. In other words, the fraction invested according to technical analysis rules is likely to be among the most speculative part of the portfolio of these dealers; thus, in terms of a CAPM model<sup>39</sup>, technical analysis investments (characterised by high expected returns and high variance) can play an important role in the construction of the optimal portfolio.

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obtained from trading in the original series should not be significantly different from the profits available in the other series. Levich and Thomas (1993).

<sup>36</sup> This trading rule signalled only one speculation.

<sup>37</sup> Notice that to conduct a t-test on the overall profits of all the trading rules together it is necessary to assume the stochastic independency between the signals of different trading rules.

<sup>38</sup> Group of thirty (1985), Taylor and Allen (1992).

<sup>39</sup> For an analysis of the Capital Asset Pricing Model and the role of lotteries characterised by high rate of profits and high variance in the construction of the optimal portfolio, see Hirshleifer and Riley (1992).

In such a context, the use of technical analysis as an instrument of trading in the exchange rate market has to be related entirely to its features of high variability and high profitability.<sup>40</sup>

### **CONSIDERATIONS ON THE DISTRIBUTION OF GAINS**

A number of studies on the properties of profitable trading rules has pointed out that the distribution of the single rates of return has a negative median and is skewed to the right.<sup>41</sup>

Even though the significance of the analysis of the present work is not high (because of the small number of signals), such conclusions are confirmed: out of 26 operations (considering all trading rules together), 15 lead to losses and 11 to gains; the final positive gain of each trading rule is determined essentially by one big (outlying) gain for each trading rule; the distribution is skewed to the right and the median is negative.

## **7. Conclusions**

The main findings of this work are the following:

-1- The exchange rate movements between Italian lira and US dollar do not fit the random walk model; on the contrary, exchange rate dynamics can be efficiently characterised by a sequence of upwards and downwards trends.

-2- Technical analysis is not an efficient instrument to produce punctual forecastings of the exchange rate values: the forecasted series produced by technical analysis models is (close to be) orthogonal to the actual series. Nonetheless technical trading rules can be seen as a useful instrument to determine and exploit the sequence of upwards and downwards trends typical of currency markets.

-3- The foreign exchange market lira-dollar is thus not weakly efficient, since the profitability of currency speculation based on technical analysis stems exclusively from the exploitation of the information contained in past exchange rate values.

-4- Exploiting the information provided by technical analysis leads to positive (but highly variable) gains. Such an instrument can thus be coherently used by agents not highly risk averse (and/or by agents with a general strategy of differentiating risk, who use technical analysis to manage the speculative fraction of their portfolio).

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<sup>40</sup> When considering technical analysis's profitability for other kind of market participants (like for instance, individual speculators) some more caution notes are requested: risk aversion can be very different, diversifying instruments are generally limited and transaction costs are higher.

<sup>41</sup> Brock, Lakonishok and LeBaron (1991), Schulmeister (1987).

-5- The process of exchange rate expectations forming based on technical models can be considered rational in the sense that these expectations can be derived purely through a process of learning the "*profitable models*" (in the sense that the exercise developed in the present work may be performed by any agent).

-6- The profitability of extrapolative-type trading rules and the large use of technical analysis by important market-participants can give rise, in the short-medium term, to self-reinforcing patterns of exchange rate dynamics, which contribute to explain the upwards-downwards feature of exchange rate dynamics.

-7- Among the technical analysis trading rules considered, the following results have been obtained:

(a) Simple models of the type  $O(p,q)$  based essentially on a sort of extrapolative expectation method have given positive results: the kind of information they provide relates basically to the general short-medium term dynamics of the exchange rate, but cannot be used to provide accurate day by day forecastings.

(b) The present work (although the number of simulation is low) confirm what is well known in financial environment, that is to say that the use of trading rules of  $O(p,q)$  type leads to a high number of wrong signals (each of them leading to small losses) overcompensated by a small number of correct signals (some of which leading to very big gains). This is indeed one of the reason why technical analysis is not an instrument for day by day forecastings.

(c) RSI and ST models, inspired by the conception of the existence of a (moving) equilibrium, have been rejected as profitable methods of expectation forming. The idea of *overbought* and *oversold* markets (at least when exchanged quantities are not considered) is thus rejected.

(d) The multicollinearity of the forecasted series built by  $O(p,q)$  models suggests that each single predictor of  $O(p,q)$  type has the same informative power, which implies that single forecasts cannot be easily improved by combining them with each other. To improve such forecastings a different kind of information is needed.

(e) That all the  $O(p,q)$  models considered have the same informative content is coherent with the large use of such models in the very short term as well as in the short and the medium term.

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