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A test of significance of the predictive power of the moving average trading rule of technical analysis based on sensitivity analysis: application to the NYSE, the Athens Stock Exchange and the Vienna Stock Exchange. Implications for weak-form market efficiency testing

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In this article, an alternative testing procedure for the significance of the predictive power of the Moving Average (MA) trading rule of technical analysis is proposed and applied to the New York Stock Exchange (NYSE), the Athens Stock Exchange (ASE) and the Vienna Stock Exchange (VSE). In contrast to existing methodologies, for which significance testing is performed considering exclusively one combination of MA lengths each time, the one proposed in this article takes into account the variability of the performance of the MA trading rule by considering jointly the rule's cumulative returns using MAs at all lengths. More reliable testing of the hypothesis of weak-form market efficiency and more straightforward interpretation of results by investors are among the advantages of the proposed approach over the existing one. An application of the proposed methodology to capital markets for the period 1993 to 2005 shows that weak-form market efficiency is clearly accepted for the NYSE, is rejected for the ASE except for the last sub-period (2001 to 2005), while for the VSE, it is rejected for the first sub-period (1993 to 1997) and accepted for the other two sub-periods.

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I. Introduction

The possibility that asset prices may be predictable is a subject of great challenge for academics and of great interest for investors. Until the early 1990s the general consensus was that, except for some 'anomalies', markets are by and large efficient, i.e. prices fully reflect all the available information and, therefore, cannot be predicted (Fama, 1970, 1991; Elton and Gruber, 1995). More recent empirical tests, however, concluded that, to an extent, prices may be predictable. Methodologically, one of the common approaches for the empirical testing of the efficient markets hypothesis in its weak-form, i.e. when the available information set includes only past prices, is to examine, whether or not, there is predictive power in the trading rules of technical analysis (Brock *et al.*, 1992; Hudson *et al.*, 1996; Mills, 1997). The most celebrated of these rules is that of the Moving Average (MA). In one of its versions, at first two noncentred MAs with different length are created from the time series of stock prices:

$$\mathrm{MAL}_t = \left(\frac{1}{N}\sum_{i=0}^{N-1}\theta_i B^i P_t\right)$$

$$\mathrm{MAS}_t = \left(\frac{1}{M}\sum_{i=0}^{M-1}\theta_i B^i P_t\right) \quad \text{with } N > M$$

where MAL_t represents the relatively longer MA with length N, calculated at time t, MAS_t the relatively shorter MA with length M, P_t the stock price at time t, θ_i are nontime varying parameters and B the backward shift operator, i.e. $B^i P_t = P_{t-1}$.

Buy signals are (sequentially) generated at the times τ_j^B, where

$$\tau_j^B \equiv \inf\left\{t : t > \tau_j^B, \mathrm{MAL}_t - \mathrm{MAS}_t > DP_{t-1}\right\} \quad (1)$$

Sell signals are (sequentially) generated at the times τ_j^S, where

$$\tau_j^S \equiv \inf\left\{t : t > \tau_j^S, \mathrm{MAS}_t - \mathrm{MAL}_t > DP_{t-1}\right\} \quad (2)$$

were the initial times τ_0^B, τ_0^S are set equal to zero and D is the so-called 'band' (a pre-specified nonnegative constant).

In most of the research papers on this subject, the hypothesis of efficient markets in its weak-form is tested by the comparison of the performance of the trading rule relative to that of the passive investment strategy (buy and hold). However, in most cases, the selection of the MA lengths is rather arbitrary. Indeed, although several scholars, in order to weaken the dependence of the results on the chosen length of the MA, examine several cases with MAs with different lengths (see, e.g. Brock *et al.*, 1992; Hudson *et al.*, 1996; Mills, 1997), the choice of the lengths of the MAs is usually based upon the popularity that some specific combinations of MA lengths enjoy among market analysts (e.g. Brock *et al.*, 1992; Bessembinder and Chan, 1995).

For this reason, in our previous work (Milionis and Papanagiotou, 2009) we performed a sensitivity analysis of the trading rule's performance to discover a possible functional dependence of the cumulative returns of the MA trading rule on the length of the longer MA (the shorter MA was kept equal to the price series itself, the length of the longer MA varied from 5 to 100 with unit step, no filter was used, i.e. the value of the parameter D in Equations 1 and 2 was set equal to zero and all θ_i parameters were set equal to one). We found that such a functional relationship cannot be fitted as the series of cumulative returns corresponding to successive values for the length of the longer MA have a large variability and on several occasions these series were nonstationary or 'near unit root' (see Milionis and Papanagiotou, 2009 for further details). That means that either there is no specific level around which trading rule cumulative returns fluctuate or there exist long swings away from a certain level.

Although these findings of Milionis and Papanagiotou (2009) do not cast any doubt on the validity of the results *themselves* regarding the predictive performance of the MA trading rule for *specific* combinations of MA lengths as presented in previous published papers, they do have direct implication for weak-form market efficiency testing. Indeed, given the high variability of the performance of the MA trading rule as a function of the length of the longer MA, as documented in Milionis and Papanagiotou (2009), by just finding out that trading rules with some specific combinations of MA lengths can, or cannot, beat the market is not enough information to safely conclude for or against weak-form market efficiency. However, as stressed in that paper, the sensitivity analysis of the trading rule's performance could potentially serve as a background for the development of a suitable methodology for testing more reliably the predictive power of the MA trading rule and for drawing conclusions about the validity of the hypothesis of weak-form market efficiency. In contrast to the existing methodologies, which are based on exclusively one combination of MA lengths each time, such a methodology would have the advantage of taking into account the sensitivity of the trading rule cumulative returns by considering jointly the rule's cumulative returns using MAs at all lengths.

The development and application of such a methodology is the purpose of this study, which can be considered as both a self-contained study on the significance testing of the MA trading rule's predictive performance, and as an extension of our previous study (Milionis and Papanagiotou, 2009) on the sensitivity analysis of the performance of that trading rule. Hence, we recommend the reader to first look at our previous paper. The capital markets which will be considered are, as in Milionis and Papanagiotou (2009), the New York Stock Exchange (NYSE), the Athens Stock Exchange (ASE) and the Vienna Stock Exchange (VSE). The justifications for the selection of these markets as well as further details are extensively discussed in Milionis and Papanagiotou (2009).

For the NYSE, it has been found that the MA trading rule performs significantly better than the buy and hold investment strategy, but its predictive performance has weakened over the most recent time period (Brock *et al.*, 1992; Cai *et al.*, 2005). As far as VSE is concerned, existing research work has shown that the hypothesis of weak-form market efficiency is rejected. Huber (1997) comes to this conclusion using daily closing prices for the seven most actively traded shares, the Wiener Boerse Kammer Index and the Austrian Traded Index (ATX) for the period January 1986 to August 1992 and employing the multiple variance ratio test of Chow and Denning. Shmilovici *et al.* (2003), using a universal coding method, showed that the stochastic complexity of the time series of daily ATX index prices for the period November 1992 to December 2001 is significantly lower than that of a random series, as they find significant compression above the random compression thresholds for all the window lengths they used; hence, they also rejected the weak-form market efficiency hypothesis for VSE. Similar research work for ASE leads most of the times to the conclusion of rejection of market efficiency (e.g. Milionis *et al.*, 1998; Niarchos and Alexakis, 1998; Panagiotidis, 2005) with only one occasion (Laopodis, 2004) where the efficient market hypothesis was not rejected.

The rest of this article is structured as follows: in the next section we develop the new testing procedure; in Section III we present the results from the application of the method to the NYSE, VSE and ASE; finally, a summary of the most important of our findings and conclusions are presented in Section IV.

II. Methodology and Data

The data used in this study are the daily closing prices of the Standard and Poor-500 Index (henceforth SP) of NYSE, the General index (henceforth GEN) of the ASE and the ATX index of the VSE for the period 27 April 1993 to 27 April 2005. As in Milionis and Papanagiotou (2009), the whole time period was subdivided into three sub-periods each of 4 years long (1993 to 1997, 1997 to 2001, 2001 to 2005).

In Milionis and Papanagiotou (2009), using stationarity testing procedures based on the Augmented Dickey–Fuller (ADF) tests as well as other approaches, it was found that on several occasions the series of trading rule cumulative returns for successive lengths (L) of the longer MA (henceforth R_L), for both costless and costly transactions (0.5% fee per transaction), contained a unit root in its dynamics. However, it is with the rest of the cases, i.e. those for which R_L is stationary that we will deal with in this study.

For these cases, a model of the following form will be estimated:

$$\Phi(B)R_L = c + \Theta(B)\varepsilon_L \tag{3}$$

where B is the so-called backward shift operator such that: $B^k Y_t = Y_{t-k}$;

$$\Phi(B) = 1 - \varphi_1 B - \cdots - \varphi_p B^p$$

is the autoregressive polynomial of order p with parameters $\varphi_1, \varphi_2, \ldots, \varphi_p$;

$$\Theta(B) = 1 - \theta_1 B - \cdots - \theta_q B^q$$

is the MA polynomial of order q with parameters $\theta_1, \theta_2, \ldots, \theta_q$; ε_L is a white noise process and c is a constant.

A linear trend will be added to Equation 3 for those cases where the existence of such a trend was found to be significant in the stationarity testing procedure in Milionis and Papanagiotou (2009). Each model of the general form described in Equation 3 will be created following the well-known Box–Jenkins model building approach (Box and Jenkins, 1976). As explained in the next section, in all cases, pure autoregressive models will be selected. Considering the general form of such a model:

$$R_L = c + \varphi_1 R_{L-1} + \varphi_2 R_{L-2} + \cdots + \varphi_p R_{L-p} + \varepsilon_L$$

it may be easily shown (e.g. Box and Jenkins, 1976) that the expected value of R_L is given by the following equation:

$$E(R_L) = \frac{c}{1 - \varphi_1 - \varphi_2 - \cdots - \varphi_p} \tag{4}$$

and its variance γ_0 is given by the following equation:

$$\gamma_0 = \frac{\sigma_\varepsilon^2}{1 - \varphi_1\rho_1 - \varphi_2\rho_2 - \cdots - \varphi_p\rho_p} \quad (5)$$

where, σ_ε^2 is the variance of the white noise process ε_L, and $\rho_1, \rho_2, \ldots, \rho_p$ are the autocorrelation coefficients at lag $1, 2, \ldots, p$, respectively. As the mean level around which the series fluctuates given by Equation 4 is constant, and the variance is finite and given by Equation 5, it is possible to draw confidence intervals above and below the series level (in the same way confidence intervals may be drawn around the trend if the process is trend stationary). Then, stating the null hypothesis (H_0) that the performance of the trading rule does not differ from the performance of the buy and hold strategy, a significance testing can be easily performed following the confidence interval approach: H_0 is accepted if the buy and hold return is within the confidence interval around the mean level of the trading rule performance. Another advantage of the proposed methodology over the existing one is that it can explicitly discriminate among three states: (1) the trading rule performs significantly better than the passive investment strategy; (2) the performance of the rule does not differ in a statistically significance sense than that of the passive investment strategy and (3) the performance of the trading rule is significantly lower than that of the passive investment strategy.

However, two points, one technical and one financial have not been taken into consideration in the above simplified approach. At first, calculating the confidence interval around the mean level in those cases where the series R_L is stationary by using Equation 5, it is assumed that the values of all the parameters in Equation 5 are exactly known. However, these values are sample estimates. A more strict treatment would require considering, in addition, the variances of the estimates of these parameters. It is usual practice in similar cases, however, to compute confidence intervals based on formulas such as Equation 5 (for further details, see Pindyck and Rubinfeld, 1998). The other point has to do with the treatment of the investment capital during the periods for which an investor who follows the trading rule signals is out of the market. At first, it is noted that due to differences in the regulatory framework in the three markets, investors do not have the same investment flexibility in all markets. For example, short selling was not allowed on ASE during the period under study. An obvious choice, common for all markets, would be for instance to invest the resulting capital after a sell order is executed to a deposit account; hence, the trading rule return would be increased accordingly. In that case interest rates should refer to local currencies, in which index prices also refer to. Hence, the significance testing can be performed both with and without explicit consideration of an investment in a deposit account during the out-of-the-market periods.

III. Results and Discussion

Figure 1 shows in common plot the variation of SP, GEN and ATX against time for the period that the data cover. The series have been adjusted so that all series start with the value of 100. From Fig. 1 it is evident that there are much more pronounced fluctuations in GEN than in the other two indices, with the most conspicuous the sharp increase and decline around mid-1999. Further, although SP and ATX both closed much higher at period-end, as compared to their first close, each one seems to wander in its own right, without much indication of a common behaviour.

This may be further researched quantitatively by examining whether or not the three index series are co-integrated. The results of such a co-integration analysis are shown in Table 1. From these results, it is evident that all series contain a unit root as the corresponding values of the ADF statistic are clearly below the critical values. Further, the value of the co-integration ADF statistic (Engle and Granger, 1987) for the residuals of the co-integration regression is smaller than the critical value given in MacKinnon (1991), so the hypothesis that the residuals of the co-integration regression contain a unit root cannot be rejected. Hence, there is clear evidence that the three index series are all $I(1)$, but are not co-integrated. Therefore, different behaviour in the application of the MA trading rule to the three indices may be possible.[1]

Using the results presented in Table 3 of Milionis and Papanagiotou (2009) regarding the decision on stationarity testing for the R_L series, an Autoregressive Integrated Moving Average (ARIMA(p, d, q)) model was estimated for each case. Where appropriate a linear trend was also added. It was observed that in all cases where the hypothesis of a unit root in the series R_L was rejected, the corresponding sample autocorrelation function tailed off having several consecutive significant spikes while the corresponding sample partial autocorrelation function cut off after the first one to three lags.

[1] Further details of other features of index returns are given in Milionis and Papanagiotou (2009).

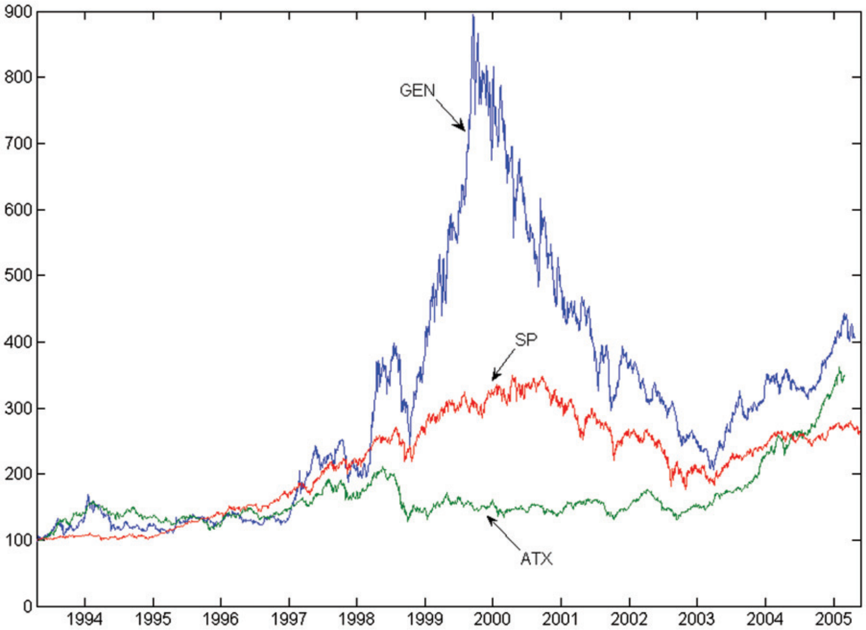

Fig. 1. Variation of SP-500, Athens General Index and Vienna ATX Index in common plot
Note: Prices are adjusted to begin from the value of 100.

Table 1. Results from testing for co-integration

Index	ADF statistic	Critical value at 5% level
SP	−0.08	−2.86
GEN	−1.14	−2.86
ATX	−0.58	−2.86
Co-integration statistic: −3.54		−3.75

Hence, in all cases pure autoregressive models were selected. The specification of each model is shown in Table 2[2] in which the original results of Table 3 of Milionis and Papanagiotou (2009) are also reproduced.

Cases for which

$$1.0 > \varphi_1 + \varphi_2 + \cdots + \varphi_p > 0.90$$

were loosely called 'near unit root' processes. For such processes, although they are stationary in the absence of a linear trend, i.e. they fluctuate around a certain mean level, long swings away from that level are possible.

Once the appropriate stochastic model for each case has been specified, for those cases where the R_L series is stationary (as is evident from Table 2, there are 12 such cases out of a total of 18 cases), it is possible to estimate the expected value and the confidence intervals around it, following the methodology outlined in the previous section and to proceed with the significance testing. In the same way, if a linear trend is included in the model, confidence intervals will be estimated around the trend.

Table 3 shows the results for the significance testing of the difference between the expected trading rule cumulative return and the buy and hold return for the case where no extra return at a risk free rate is added for the periods where an investor following the trading rule's signals is out-of-the-market. To further facilitate the exposition of the methodology and results, the significance testing procedure is also presented graphically for each market and each combination of transaction cost and time period in Fig. A1, in which the plots of the R_L series together with the corresponding buy and hold return, the expected value of R_L and the 95% confidence intervals are shown.

[2] It is noted that heteroscedasticity, extreme values and other nonlinearities may substantially affect the specification of an ARIMA model (see, for instance, Milionis, 2004). As ARIMA models are linear models, pre-adjustments ('linearization') of a time series may be performed before the specification of the model (see, for instance, Caporello *et al.*, 2001). Such pre-adjustments were not used in our analysis.

Table 2. Results from testing for stationarity and model specification

Index	Time period	Transaction cost	Result of stationatity test	Model specification
SP	1993 to 1997	0	Trend stationary series	$R_L = 14.62 + 0.09L + 0.80R_{L-1} - 0.22R_{L-4} + \varepsilon_L$
		0.5	Unit root	$R_L = 0.78 + R_{L-1} + \varepsilon_L$
	1997 to 2001	0	Stationary series	$R_L = -1.14 + 0.80R_{L-1} + \varepsilon_L$
		0.5	Unit root	$R_L = R_{L-1} + \varepsilon_L$
	2001 to 2005	0	Unit root	$\Delta R_L = 0.443\varepsilon_{L-7} + \varepsilon_L$
		0.5	Stationary series	$R_L = -3.48 + 0.85R_{L-1} + \varepsilon_L$
GEN	1993 to 1997	0	Stationary series	$R_L = 14.85 + 0.85R_{L-1} + \varepsilon_L$
		0.5	Unit root	$R_L = R_{L-1} + \varepsilon_L$
	1997 to 2001	0	Stationary series	$R_L = 37.95 + 0.85R_{L-1} - 0.34R_{L-2} + 0.26R_{L-3} + \varepsilon_L$
		0.5	Trend stationary series	$R_L = 82.20 + 0.59L + 0.86R_{L-1} - 0.38R_{L-2} + 0.27R_{L-3} + \varepsilon_L$
	2001 to 2005	0	Unit root	$R_L = R_{L-1} + \varepsilon_L$
		0.5	Stationary series (near unit root)	$R_L = 3.42 + 1.11R_{L-1} - 0.21R_{L-2} + \varepsilon_L$
ATX	1993 to 1997	0	Stationary series	$R_L = 10.60 + 0.76R_{L-1} + \varepsilon_L$
		0.5	Stationary series (near unit root)	$R_L = 1.68 + 0.92R_{L-1} + \varepsilon_L$
	1997 to 2001	0	Unit root	$R_L = R_{L-1} + \varepsilon_L$
		0.5	Stationary series	$R_L = -3.81 + 0.77R_{L-1} + \varepsilon_L$
	2001 to 2005	0	Stationary series (near unit root)	$R_L = 11.80 + 0.92R_{L-1} + \varepsilon_L$
		0.5	Stationary series (near unit root)	$R_L = 7.72 + 0.94R_{L-1} + \varepsilon_L$

Table 3. Results of the significance testing for the difference between the mean of the cumulative returns from the trading rule and the buy and hold return

Index	Time period	Transaction cost	$E(R_L)$	$\|\sigma^*1.96\|$	BH	H_0
SP	1993 to 1997	0			66.59	Rejected in favour of TR < BH
	1997 to 2001	0	−5.73	14.25	32.87	Rejected in favour of TR < BH
	2001 to 2005	0.5	−23.30	10.70	13.66	Rejected in favour of TR < BH
GEN	1993 to 1997	0	99.33	28.04	91.19	Accepted
	1997 to 2001	0	165.00	39.51	94.25	Rejected in favour of BH < TR
		0.5			93.28	Rejected for lag > 62 in favour of BH < TR
	2001 to 2005	0.5	34.26	18.14	26.99	Accepted
ATX	1993 to 1997	0	44.20	9.93	25.79	Rejected in favour of BH < TR
		0.5	21.10	17.15	25.16	Accepted
	1997 to 2001	0.5	−16.57	11.08	−12.74	Accepted
	2001 to 2005	0	147.60	21.89	143.58	Accepted
		0.5	120.80	27.44	142.37	Accepted

Notes: σ represents the square root of γ_0 and $|\sigma^*1.96|$ is the absolute value of the 95% confidence interval around $E(R_L)$. TR, trading rule; BH, buy and hold return.

From the results of Table 3 and Fig. A1 several interesting conclusions may be drawn. For the ASE (GEN index), it is very clear in the statistical sense that for the period 1997 to 2001 without transaction costs the trading rule performs better than the buy and hold strategy. The same is true even when transaction costs are considered, but, due to the existence of a linear trend in this case, only for lengths greater than 62. However, for the period 1993 to 1997 (without transaction costs) as well as for the period

Table 4. Results of the significance testing for the difference between the mean of the cumulative returns from the trading rule and the buy and hold return for SP and the period 1993 to 2005

Transaction cost	Result of stationatity test	Model specification	$E(R_L)$	$\|\sigma*1.96\|$	BH	H_0
0	Stationary series	$R_L = 10.16 + 1.06R_{L-1} - 0.23R_{L-2} + \varepsilon_L$	59.82	27.01	149.73	Rejected in favour of TR < BH
0.5	Unit root	$R_L = 0.72 + R_{L-1} + \varepsilon_L$			148.48	

Notes: σ represents the square root of γ_0 and $|\sigma*1.96|$ is the absolute value of the 95% confidence interval around $E(R_L)$. TR, trading rule; BH, buy and hold return.

2001 to 2005 (with transaction costs) although the performance of the trading rule is on average greater than the buy and hold performance, the difference is not statistically significant as, due to the large variance, the buy and hold return falls within the upper confidence interval for the mean trading rule cumulative return.

For the VSE (ATX index) the trading rule 'beats the market' in the first period (without transaction costs), but in all other cases its performance does not differ statistically from the buy and hold performance.

For the NYSE (SP index) the situation appears to be different from the other two markets. Indeed, in all cases where a comparison is possible the trading rule not only cannot 'beat the market' but also its performance is significantly lower than that of the buy and hold strategy. This result provides strong evidence against the existence of predictive power in the trading rule (in fact, the strongest thus far in the literature). Therefore, it clearly suggests that the efficient market hypothesis in its weak-form cannot be rejected for NYSE.

As this result is very interesting and the changes occurred on NYSE during the period 1993 to 2005 are of much lesser importance than those on the ASE and the VSE (for details see Milionis and Papanagiotou, 2009), it is reasonable to consider the whole time period (1993 to 2005) as one period for NYSE and perform the same analysis. Once the total time period is considered, the R_L series is stationary for the no transaction costs case and a random walk with drift when transaction costs are considered. The details are given in Table 4. The results are also shown graphically in Fig. 2. In the left part of Fig. 2, together with the lines representing the buy and hold return and the trading rule cumulative return, the confidence intervals for the trading rule performance are also drawn. It is very clear that the performance of the trading rule is significantly (in the statistical sense) and substantially lower than the buy and hold return.

The result is even more astonishing in the presence of transaction costs. Although for this case the R_L series is nonstationary, hence, a statistical comparison is not directly possible. From Fig. 2 (right graph) it is evident that an investor who decided to trade on the basis of the trading rule signals with short MA lengths would end up loosing a substantial part of her/his initial investment capital even though during the time period under consideration the market was on average bullish!

It is also important to note that other researchers analysing the SP index for a time period partly overlapping with the time period considered in this study (Kwon and Kish, 2002; Cai *et al.*, 2005) find that the MA trading rule has no better performance than the buy and hold strategy. This is implemented by showing, for example, that returns during buy or sell periods (using the so-called variable length MA) do not differ from unconditional returns. This result however, if not properly interpreted, may lead investors to the erroneous conclusion that, whether they use the MA trading rule or stick to their original investment until the end of the investment period, the result does not differ as far as the final outcome of their investment is concerned. Apparently, this is radically different from what the method presented in this study predicts, at least as far as the so-called variable length MA, which was used in this study, is concerned.[3] Moreover, the implications that the results of our analysis may have for investors are direct and do not leave space for misinterpretation.

[3] This conclusion is certainly more reasonable, as in a bullish market if the average 'buy' return does not differ from the unconditional return then an investor who chooses the buy and hold strategy will be at the end better off than the investor who follows the trading rule, simply because the latter for some period will be out of a market, which gives on average positive returns; hence, will lose part of these returns.

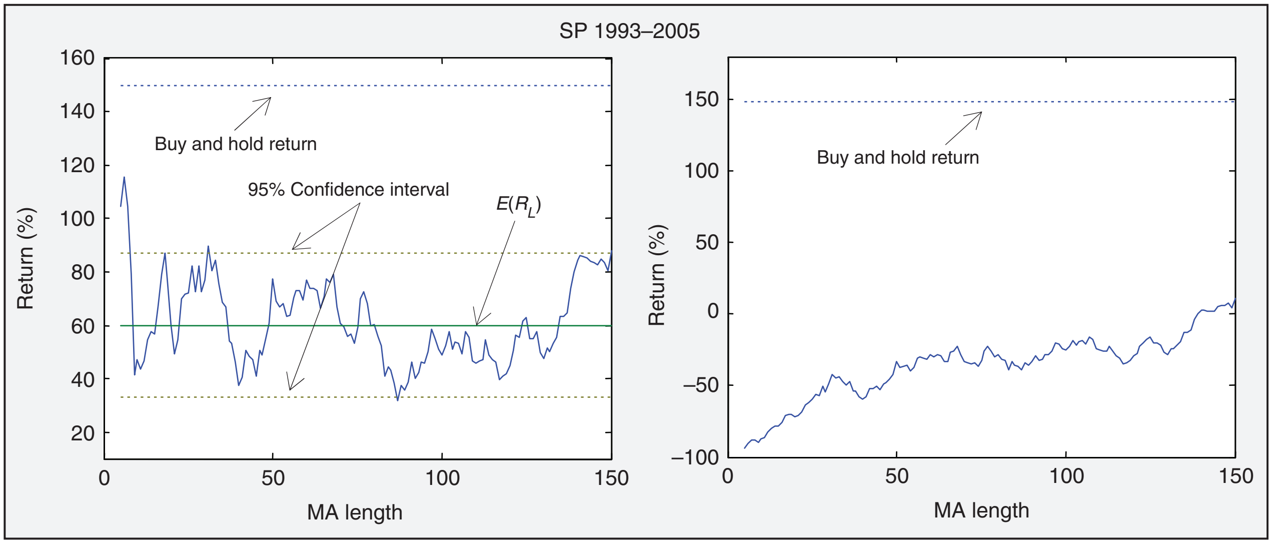

Fig. 2. Variation of the cumulative returns from the MA trading rule as a function of the MA length for SP with costless (left graph) and costly (right graph) transactions

Notes: Dash lines represent the total return from the buy and hold strategy and the estimated confidence interval on both sides of the mean level of trading rule cumulative return.

Table 5. Results of the significance testing for the difference between the mean of the cumulative returns from the trading rule and the buy and hold return

Index	Time period	Transaction cost	$E(R_L)$	$\lvert\sigma^*1.96\rvert$	BH	H_0
SP	1993 to 1997	0			66.59	Rejected in favour of TR < BH
	1997 to 2001	0	0	15.35	32.87	Rejected in favour of TR < BH
	2001 to 2005	0.5	−21.24	10.96	13.66	Rejected in favour of TR < BH
GEN	1993 to 1997	0	141.8	35.38	91.19	Rejected in favour of BH < TR
	1997 to 2001	0	205.1	46.28	94.25	Rejected in favour of BH < TR
		0.5			93.28	Rejected for lag > 19 in favour of BH < TR
	2001 to 2005	0.5	40.86	21.23	26.99	Accepted
ATX	1993 to 1997	0	53.10	10.82	25.79	Rejected in favour of BH < TR
		0.5	28.39	18.17	25.16	Accepted
	1997 to 2001	0.5	−11.15	11.81	−12.74	Accepted
	2001 to 2005	0	150.7	21.66	143.58	Accepted
		0.5	132.2	27.57	142.37	Accepted

Notes: σ represents the square root of γ_0 and $\lvert\sigma^*1.96\rvert$ is the absolute value of the 95% confidence interval around $E(R_L)$. An additional return due to investment in a deposit account during the out-of-the-market periods is included in TR. TR, trading rule; BH, buy and hold return.

As mentioned in the previous section, the above simplified analysis ignores the possibility of an enhanced trading rule performance owing to an extra return due to the investment in a deposit account during the period for which an investor who follows the trading rule's signals is out of the market. Hence, the significance testing was repeated this time taking into account this extra return. Due to its availability, the mean annualized 3-month money market interest rate was used as a suitable for the circumstances proxy for the interest rate of a deposit account (*Source*: World Federation of Exchanges). The results, corresponding to those of Tables 3 and 4, Figs 2 and A1, are presented in Tables 5 and 6, Figs 3 and A2, respectively. To have an idea of how the cumulative returns of the trading rule are affected (increased) by investment in a deposit account during the out-of -market periods, in the right part of Fig. 3 the buy and hold

Table 6. Results of the significance testing for the difference between the mean of the cumulative returns from the trading rule and the buy and hold return for SP and the period 1993 to 2005

Transaction cost	Result of stationatity test	Model specification	$E(R_L)$	$\|\sigma*1.96\|$	BH	H_0
0	Stationary series	$R_L = 19.06 + 1.06R_{L-1} - 0.22R_{L-2} + \varepsilon_L$	81.22	31.08	149.73	Rejected in favour of TR < BH
0.5	Unit root	$R_L = 0.79 + R_{L-1} + \varepsilon_L$			148.48	

Notes: σ represents the square root of γ_0 and $|\sigma*1.96|$ is the absolute value of the 95% confidence interval around $E(R_L)$. An additional return due to investment in a deposit account during the out-of-the-market periods is included in TR. TR, trading rule; BH, buy and hold return.

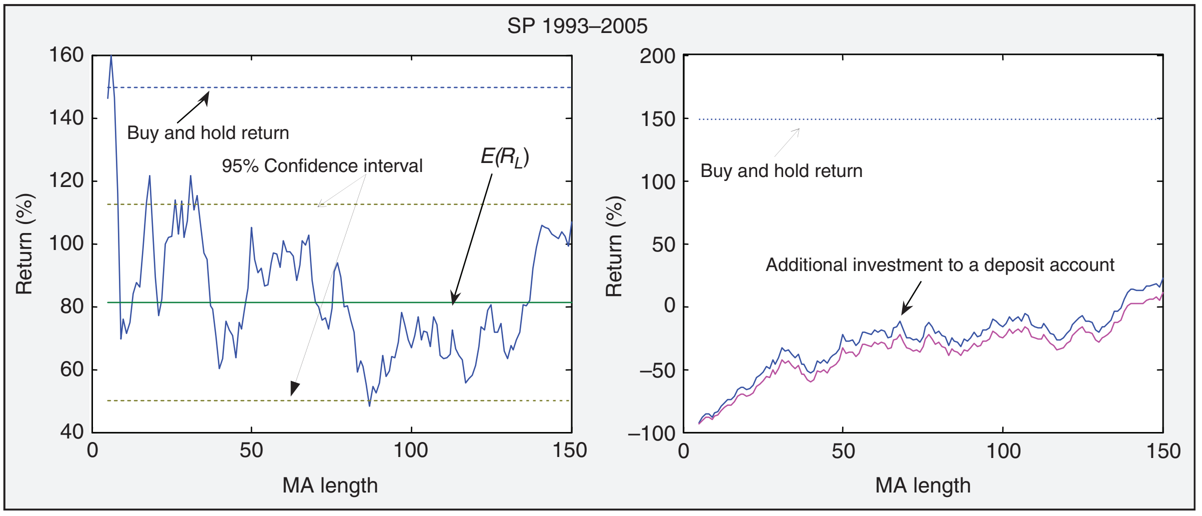

Fig. 3. Variation of the cumulative returns from the MA trading rule as a function of the MA length for SP with costless (left graph) and costly (right graph) transactions. Investing to a deposit account during the out-of-the-market periods is assumed
Notes: Dash lines represent the total return from the buy and hold strategy and the estimated confidence interval on both sides of the mean level of trading rule cumulative return.

return together with the cumulative returns from the trading rule, with and without investment in a deposit account, are drawn in the same plot.

Comparing these two sets of results, it is evident that although the returns from trading rule are increased with the extra investment in a deposit account, as expected, the results differ in the statistical sense in only two cases; (1) for the ASE (GEN) in the 1993 to 1997 period without transaction costs in which the returns from the trading rule are now significantly higher than the buy and hold return and (2) again for the ASE and for the 1997 to 2001 period with transaction costs in which trading rule returns are now significantly higher than buy and hold returns after the MA length of 19 (i.e. after a much shorter length than in the case with no interest rates). Hence, the weak-form market efficiency hypothesis for the ASE is even more confidently rejected. The clear evidence of predictive power of the trading rule in the ASE indicates that the sharp increase and decline of share prices around 1999 was possibly a pronounced speculative bubble.

For the VSE, the conclusions are essentially the same, while for NYSE, even after the inclusion of the extra return due to the investment at a risk free rate in the cumulative return on the trading rule, the later still remains substantially lower than the corresponding buy and hold return. Hence, our previous strong evidence against any predictive power of the trading rule for the NYSE as well as the conclusion of non rejection of the weak-form market efficiency hypothesis for the NYSE remain unchanged.

IV. Summary and Conclusions

The purpose of this study was at first to propose an alternative statistical procedure for testing the significance of the difference between the performance of the MA trading rule and the buy and hold return and in that way to test for the weak-form market efficiency hypothesis. In contrast to the existing methodologies, for which significance testing is performed considering exclusively one combination of MA lengths each time, the one proposed in this study takes into account the variability of the performance of the MA trading rule due to different length of the longer MA. This is obtained by considering jointly the rule's cumulative returns using MAs at all lengths. An additional return at a suitable risk free rate can be explicitly incorporated in the trading rule's cumulative returns representing investment during the out-of-the-market periods.

An important advantage of the proposed methodology over the existing one is that the conclusion deriving from this methodology for the acceptance or otherwise of the weak-form market efficiency hypothesis is more reliable. For this reason, for studies using the performance of the MA trading rule to test for weak-form market efficiency, we suggest that a sensitivity analysis for the performance of the trading rule similar to the one presented in this study be undertaken, even if a scholar wishes to proceed with a testing procedure different from that suggested in this study. At least a 'warning' should be denoted in cases where the series of successive cumulative returns from the trading rule are found to be nonstationary or very volatile. A further advantage of the proposed methodology is that the interpretation of the results for an investor is more straightforward.

The proposed methodology was applied to three different capital markets, namely the NYSE, the ASE and the VSE for a period of 12 years (1993 to 2005). Both costly and costless transactions as well as three consecutive sub-periods were considered.

The most important of the conclusions and findings are as follows: for the cases where changes in the performance of the MA trading rule as a function of the MA length can be assumed to occur around a mean level it was shown that, without transaction costs, the cumulative returns from the trading rules for the ASE and the VSE were significantly higher than the corresponding buy and hold return on some occasions; hence, the hypothesis of weak-form efficiency is rejected. However, the cumulative returns from the trading rule for the NYSE were found to be significantly lower than buy and hold return, so the weak-form efficiency hypothesis is not rejected. When transaction costs were considered, for the ASE, it was found that on some occasions the cumulative returns from the trading rule were still significantly higher than the corresponding buy and hold return, while on other occasions they did not differ significantly. The cumulative returns from the trading rule on the VSE did not differ significantly from the corresponding buy and hold return. By contrast, for the NYSE, if an investor used the trading rule in the presence of transaction costs she/he would lose a substantial part of her/his initial capital even though the buy and hold return was positive.

Hence, this study provides striking counterevidence for the existence of predictive power in the MA trading rule if applied to NYSE for the time period 1993 to 2005. At the same time, however, the NYSE is found to behave differently from both the ASE and the VSE in terms of the predictive performance of the MA trading rule. The ASE and the VSE show similar behaviour in the no transaction cost scenario, while in the presence of transaction costs an investor can still 'beat the market' on the ASE, but not on the VSE. More particularly, for the ASE, the findings of this study indicate that the sharp increase and decline of share prices around mid-1999 was possibly of a speculative nature.

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Appendix

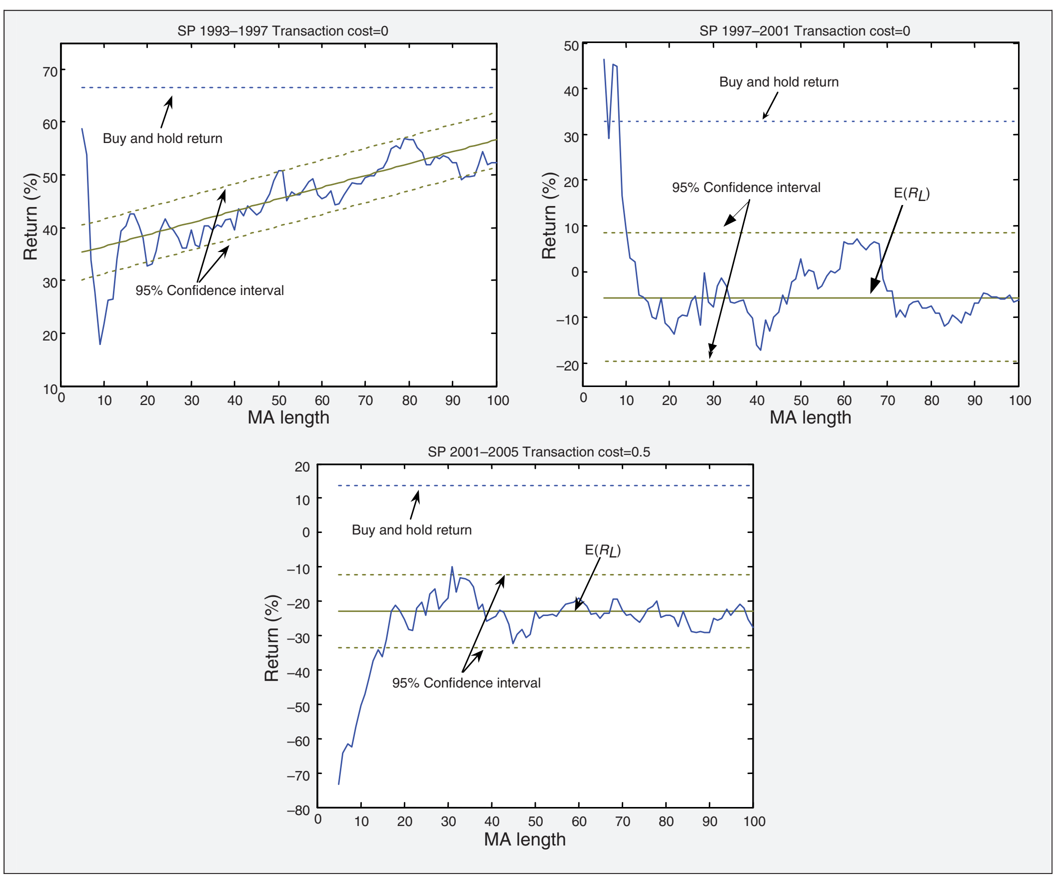

Fig. A1. Graphical representation of the significance testing procedure. No investment to a deposit account during the out-of-the-market periods (for details, see the legend of Fig. 2)

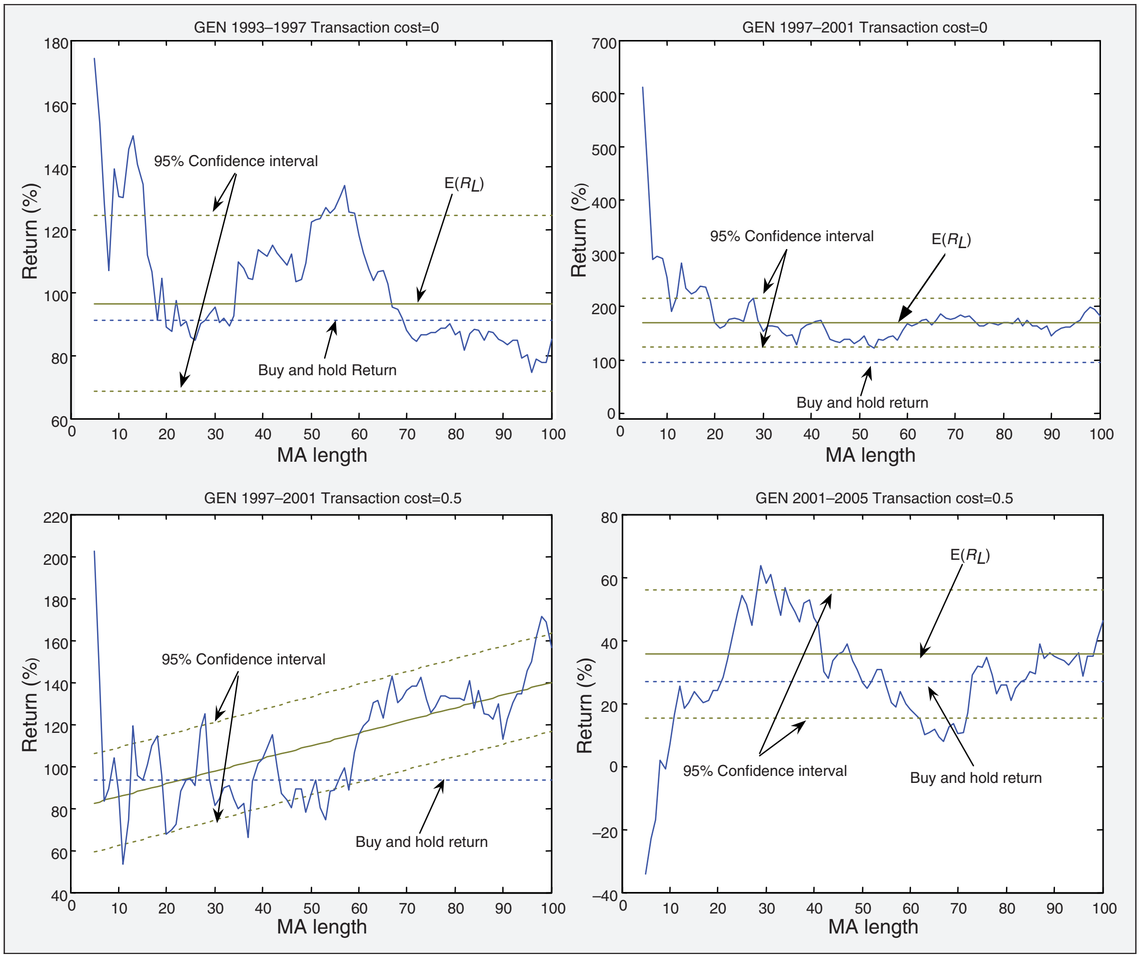

Fig. A1. Continued

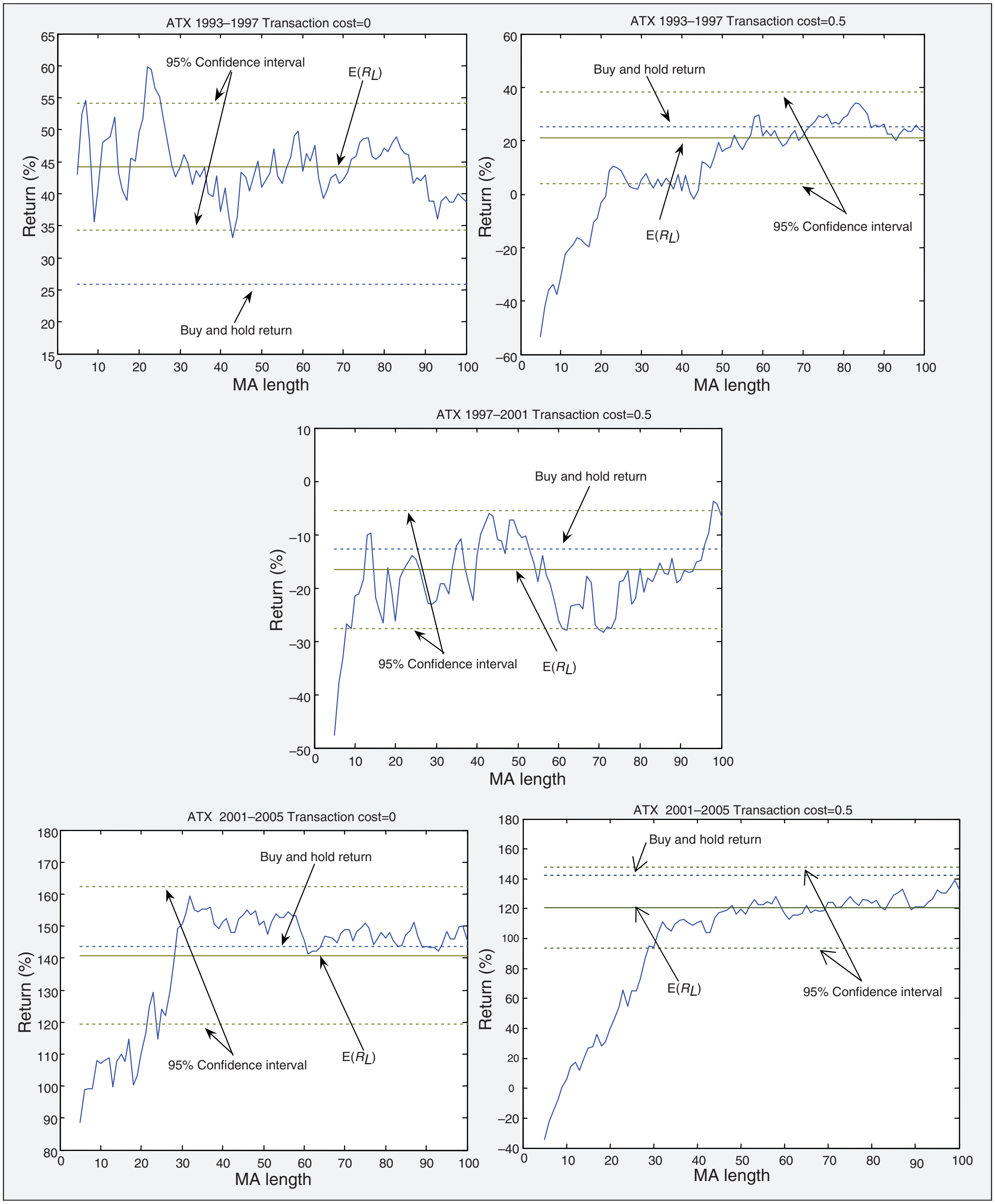

Fig. A1. Continued

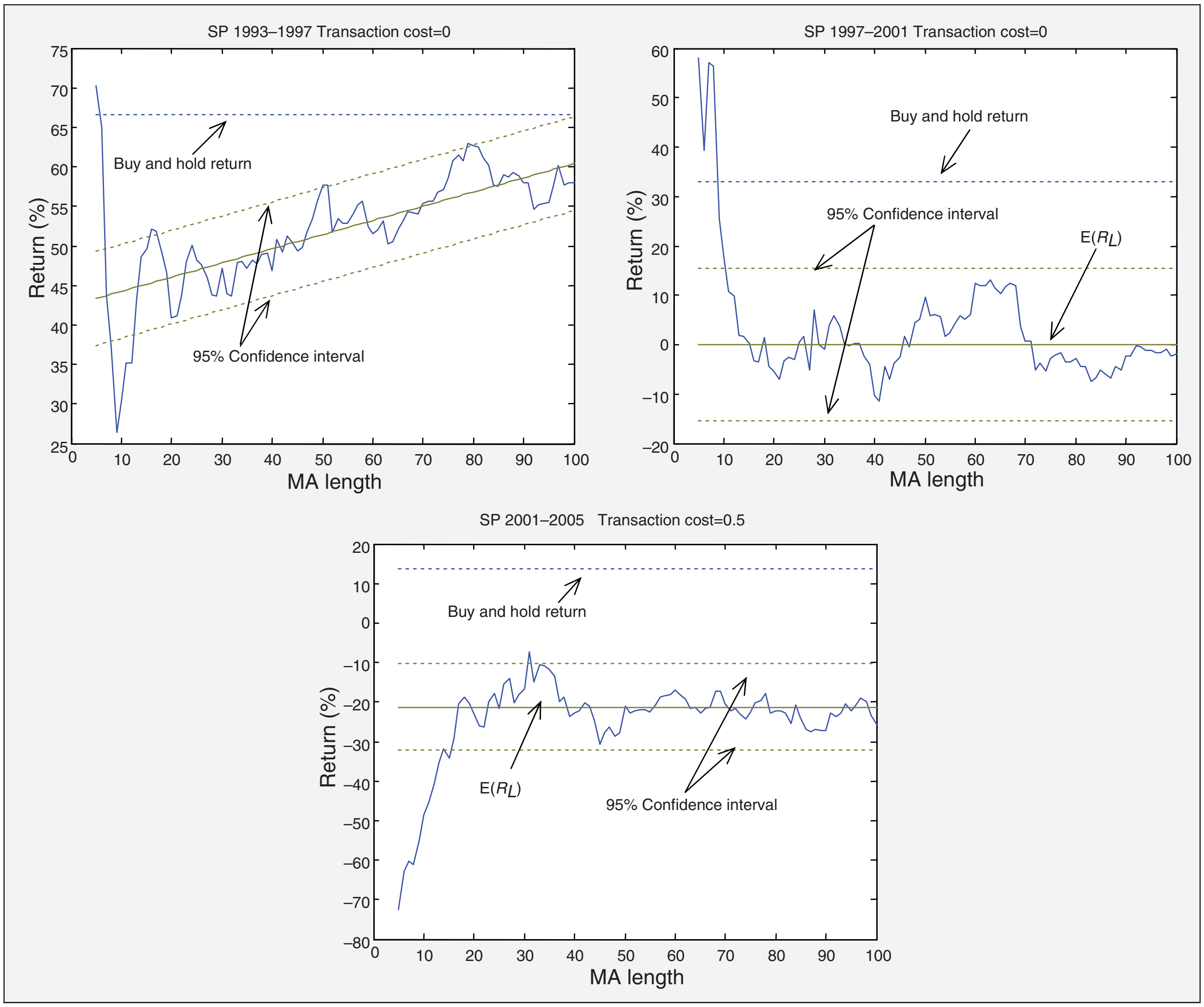

Fig. A2. Graphical representation of the significance testing procedure. Investing to a deposit account during the out-of-the-market periods is assumed (for details, see the legend of Fig. 2)

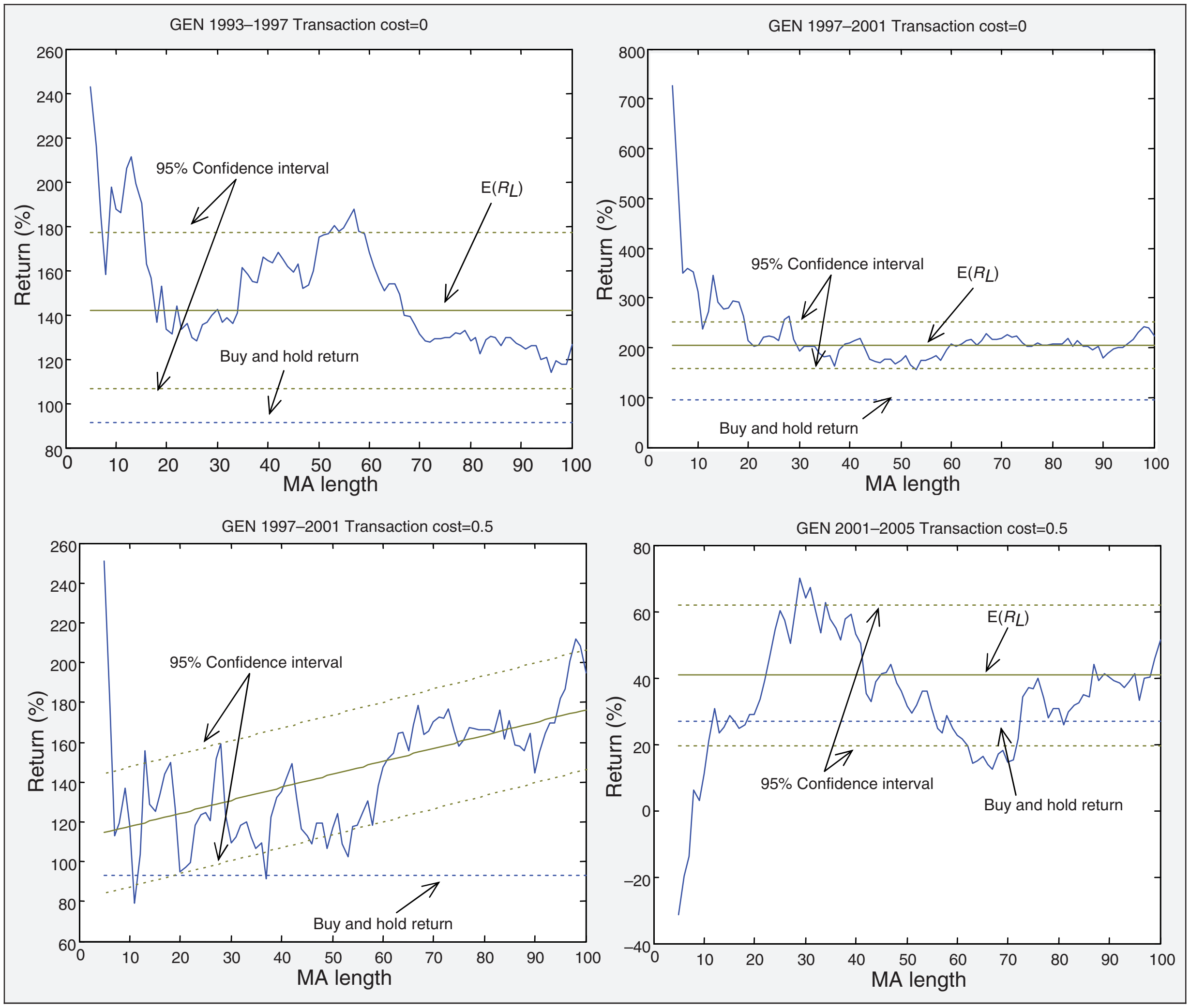

Fig. A2. Continued

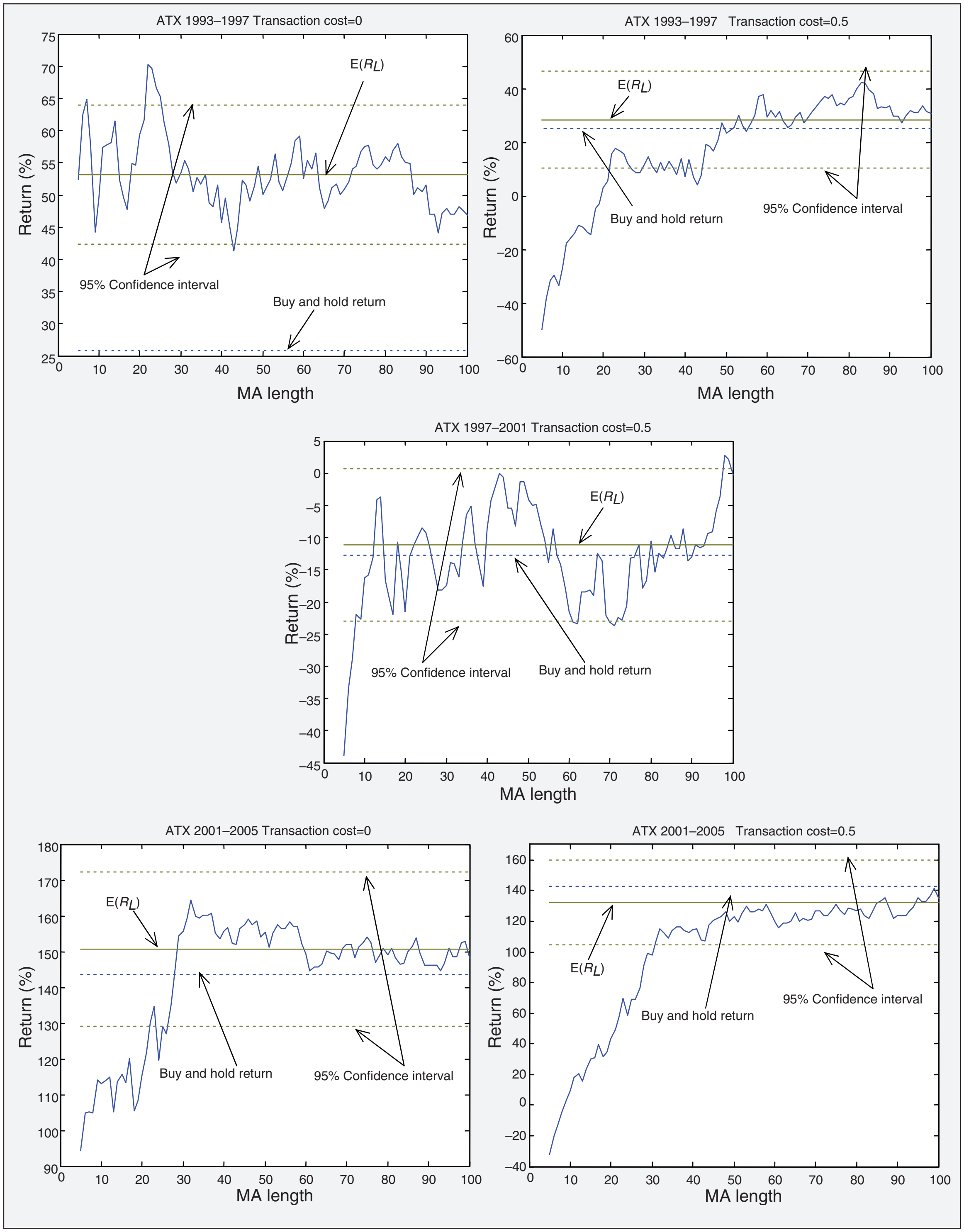

Fig. A2. Continued