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Technical Trading and Testing of Intra-day Market Efficiency in the Foreign Exchange Market

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Abstract*: Due to the growing interest of investors in intra-day trading it is necessary to pay even more attention to the analysis of the microstructure of financial markets. This article analyses the behaviour of the exchange rate EUR/USD at short intervals. The base aim of this paper is to verify the possibility to reach the "above average return" through automated trading systems based on technical analysis. In the case that, the selected strategies will be achieved above average profits, it is possible to reject the efficient market hypothesis in its weak form. Otherwise, it can be argued that it could not disprove the hypothesis of efficient market in a very short time intervals and movement of the exchange rate EUR/USD is not predictable.*

Keywords: Foreign exchange market · Fast-frequency data · Market efficiency · Technical analysis · Automatic trading systems

JEL Classification: G14 · G15

1 Introduction

The efficient market hypothesis is based on the assumption that the current price of a financial asset fully reflects all available information (Fama, 1969). Randomness of price changes, unpredictable movements in financial asset prices and the inability to achieve "above average profits" are among the main consequences of this theory. With the development of IT technology, at the end of the last millennium, trading on foreign exchange markets spread between retail investors and the issue of an effective spot foreign exchange market becomes even more relevant. In addition, brokers offer their clients margin accounts with a multiple financial leverage that allows for trade over very short time intervals and profit on small movements in exchange rates.

The hypothesis of a weak market efficiency can be tested by statistical tests which verify the randomness of exchange rate changes or through automated trading systems (ATS), which test the possibility of achieving "above-average returns." Automated trading systems are programmes that allow trading of financial assets, based on pre-defined rules. Trading rules are often based on technical analysis, but also may contain elements of risk-and money-management. Automated trading systems are used by investors in real trading and allow back-testing of their own trading strategies using historical data.

Authors such as Cornell & Dietrich (1978), Logue & Sweeney (1977), Dooley & Shafer (1984), Sweeney (1986) and Levich & Thomas (1993) in their papers used a simple trading system based on technical analysis to analyse the behaviour of exchange rates and which pointed to the possibility of achieving "above-average profits" in the application of these systems. LeBaron (1999) or Saacke (2002) sees a connection between successful trading systems based on technical analysis in the context of interventions on the foreign exchange markets. These authors point to the increased abil-

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ity of technical indicators to predict future movements in exchange rates during central bank interventions. Another possible explanation is provided by Dooley& Shafer (1984). These authors argue that movements in exchange rates are influenced by the behaviour of investors who are influenced by fundamental factors and the pursuit of profit arising from speculation, which, then, leads to the formation of graphic formations and movements in exchange rates that are, thus, more predictable.

Another possible explanation is often provided by the authors of the papers. In their study points to the oversimplification (absence of transaction costs, exclusion of a risk premium, the problem of limited sample data) that may not reflect the real situation on the market. Some published papers are trying to eliminate this simplification, such as Lee & Sodoikhuu (2012), who studied the behaviour of currency pairs EUR, JPY, GBP to USD in the period between 2003 and 2009. They concluded in their work that a system based on filter rules after transaction costs does not provide above-average returns and foreign exchange market satisfies the conditions of weakly efficient market.

On the other hand, there is still sufficient number of authors who believe that foreign exchange markets behave inefficiently (Surajaras & Sweeney (1992), Neely & Weller (2001). For example Okunev & White (2003) applied the trading system using technical analysis indicators (momentum) on a monthly exchange rates AUD, FRF, CAD, DEM, CHF, GBP from 1975 to 2000 and concluded that even simple trading systems based on technical analysis may lead to above-average profits, which could not be explained by risk premium or transaction costs.

Olson (2004), Qi & Wu (2005) suggested that foreign exchange markets may show signs of inefficient behaviour, but only within a short period. They divided monitored period into several shorter intervals in their articles and pointed to the declining performance of trading strategies based on technical analysis and the problem of appropriate choice of data.

Currently, scientists are turning attention to analysing the foreign exchange market microstructure and using advanced methods to study the behaviour of exchange rates in very short time intervals. Neely & Weller (2003) published their work on this topic. They used genetic programming and linear forecasting model to predict the development of half-hour exchange rate changes on currency pairs CHF, DEM, JPY and GBP against the U.S. dollar during 1996. The created models that take into account the trading hours and transaction costs, failed to provide an above-average return and weakly efficient market hypothesis was not rejected during intra-day trading. The method of genetic programming was also used by Dempster, Payne, Romahi & Thompson (2001), who used a 15-minute exchange rate changes to predict the behaviour of the exchange rate GBP/USD. If the model included transaction costs, this method was not able to achieve above-average profits. The same conclusion was reached also by Curcio, Goodhart, Guillaume & Payne (1997), who applied the filter tests on "tick by tick" data for currency pairs DEM, JPY, GBP against USD. These authors divided their observations into two periods and concluded that using of filter tests on the high-frequency data does not provide the investor above-average profits.

However, the work of other authors suggest a possible inefficiency of the foreign exchange market. Omrane & Oppens (2004) focused their work on finding the presence of graphical formations on the EUR/USD intra-daily exchange rates. Their work confirmed the existence of these patterns and their ability to predict the movements of the exchange rate, but due to transaction costs dispute the use of these patterns in creating profitable trading systems. Kozhan & Salmon (2010) used a "tick by tick" data for the currency pair GBP/USD for different time periods between 2003 and 2008 and concluded that it was possible to use genetic programming to achieve significantly above-average returns in 2003 which, however, disappeared in 2008. This result suggests that the foreign exchange market can temporarily show signs of inefficient behaviour, but not in long period.

2 Methods and Resources

Data

The data used are from the data center MetaQuotes Software Corp. and are available through the trading platform Metatrader of X-Trade Brokers Czech Republic. To test the profitability of strategies will be used daily, 4-hour, an 1-hour and 5-minute spot exchange rate EUR/USD. In the trading strategies are used the bid-ask courses. Each of time series contained approximately 10,000 values, it represented for the 5-minute values the time period from 01.01.2011 to 28.02.2011, for the 1-hour values the time period from 03.07.2009 to 28.02.2011 and for the 4-hourly values the interval from 22.09.2004 to 28.02.2011. The daily time interval contains 2000 values only. The data come from the interval from 11.08.2003 to 28.02.2011

Strategies based on exponential moving average (EMA)

Moving averages are among the most popular trend indicators. These indicators show the average price of the underlying asset for a given period of time. Exponential moving average (EMA) compared to conventional simple moving average (SMA) puts more importance on recent prices compared to previous prices. It can be calculated as follows:

$$EMA_t = p_t * k + EMA_{t-1} * (1 - k) \tag{1}$$

EMA_t a EMA_{t-1} represent the value of the indicator at time t, p_t is the current price of the instrument and k represents the percentage of used prices:

$$k = 2/(T + 1). \tag{2}$$

The first calculated value EMA_0 is derived from a simple moving average, where T denotes the length of the period for which the moving average is calculated:

$$EMA_0 = SMA_0 = \frac{1}{T}\sum_{t=1}^{T} p_t. \tag{3}$$

The most common trading strategies used for testing above-average returns is the mutual crossing of two moving averages, when one is computed for longer and the other for a shorter time interval, see Brock, Lakonishok & Lebaron (1992). Buying signal occurs when EMA_{short} based on a shorter time interval crosses and rises above EMA_{long}, which is calculated from a longer period of time:

$$EMA_{short} > EMA_{long}\,. \tag{4}$$

Sell signal (open short position or closing a long position) is exactly the opposite of the buying signal:

$$EMA_{short} < EMA_{long}. \tag{5}$$

In this work are using several strategies with different length of moving averages. Used strategies and length of moving averages are as follows: EMA_6/EMA_{12}, EMA_9/EMA_{18}, EMA_{10}/EMA_{20} and EMA_{12}/EMA_{24}. Numbers indicate the length of the moving average period for which the indicator is calculated.

Statistical test

The values of returns are calculated as the difference between the logarithms of the current closing rate and the previous closing rate.

$$r_t = ln\ p_t - ln\ p_{t-1} = ln\frac{p_t}{p_{t-1}} \cong \frac{p_t}{p_{t-1}} - 1 \tag{6}$$

Statistical tests use only the values of the period in which the strategy was active. The zero returns from the period, when there are no open trading positions, are not taken into account.

Statistical tests checked whether the strategies based on moving averages have higher returns than provides the market and whether these strategies achieve statistically significant profit. But at first the hypothesis of equality of variances of active and passive strategies will be tested.

$$H_0 : \sigma_1^2 = \sigma_2^2 \tag{7}$$

$$H_A : \sigma_1^2 \neq \sigma_2^2 \tag{8}$$

Levene's test was used for the analysis of variance. The test statistic, *W*, is defined as follows:

$$W = \frac{(N-k))}{(k-1)} \frac{\sum_{i=1}^{k} N_i \left(\overline{Z}_i - \overline{Z}_{..}\right)^2}{\sum_{i=1}^{k} \sum_{j=1}^{N_i} \left(\overline{Z}_{ij} - \overline{Z}_i\right)^2} \quad , \tag{8}$$

where *k* is the number of different groups to which the sampled cases belong. Z_{ij}, Z_i and Z are calculated as follows:

$$Z_{ij} = \left| r_{il} - \overline{r}_i \right|, \tag{9}$$

$$Z_i = \frac{1}{N_i} \sum_{j=1}^{N_i} Z_{ij} \, , \tag{10}$$

.

$$Z = \frac{1}{N} \sum_{i=1}^{k} \sum_{j=1}^{N_i} Z_{ij} \, . \tag{11}$$

The resulting statistic is compared to the critical value of the F-distribution with *k-1* and *N-k* degrees of freedom at the chosen level of significance α:

$$W > F_{\alpha,(k-1,N-k)} \, . \tag{12}$$

The null hypothesis H_0 is rejected if the value of the test statistic lies outside of the confidence interval.

Independent two-sample t-test is also used in this paper. This test compares means for two groups of cases - returns of active strategies and returns of „Buy and Hold" strategy.

Testing hypotheses can be written as follows:

$$, \qquad H_0 : \mu_1 \leq \mu_2 \tag{13}$$

$$H_A : \mu_1 > \mu_2 \, . \tag{14}$$

In the case that the null hypothesis about equality of variances could not be rejected, the t-test with the assumption of equality of variances of two distributions is used. The *t* statistic to test whether the means are different can be calculated as follows:

$$t = \frac{\left| \mu_2 - \mu_1 \right|}{\sqrt{\frac{(N_1 - 1)\sigma_1^2 + (N_2 - 1)\sigma_2^2}{(N_1 + N_2 - 2)}} \sqrt{\frac{1}{N_1} + \frac{1}{N_2}}} \tag{15}$$

The variables N_1 and N_2 represent the number of observations. N_1 is the number of periods for which the funds were bound in the active strategy and N_2 is the number of periods in the "Buy and Hold" strategy and also is equal to the sample size.

Alternative hypothesis H_A can be accepted, if the test statistic is found in the critical interval.

$$t \geq t_{1-\alpha}\left(N_1 + N_2 - 2\right) \tag{16}$$

In the case, that the null hypothesis about equality of variances is rejected, the t-test with the assumption of the different variances of two distributions is used.

$$t = \frac{\left|\mu_2 - \mu_1\right|}{\sqrt{\frac{\sigma_1^2}{N_1} + \frac{\delta_2^2}{N_2}}} \tag{17}$$

The critical interval has the following form, where the variable f denotes the number of degrees of freedom[2].

$$\left|t\right| \geq t_{1-\alpha}\left(f\right) \tag{18}$$

The one-sample t-test was also used in this paper. This test examines the hypothesis of profitability active strategies. Test hypothesis are defined as follow:

$$H_0 : \mu_1 \leq 0\,, \tag{19}$$
$$H_A : \mu_1 > 0. \tag{20}$$

Test statistic is given by the following formula:

$$t = \frac{\left(\mu_1 - 0\right)}{\sigma_1}\sqrt{N_1}\,. \tag{21}$$

The null hypothesis of non-profit active strategy will be rejected if the test criterion is outside the confidence interval:

$$\left|t\right| \geq t_{1-\frac{\alpha}{2}}\left(n-1\right). \tag{22}$$

Trading account and profit of strategies

The real trading account was developed to better illustrate the profitability of trading strategies The gains and losses of individual strategies will be recorded in this account. The margin account was

[2] Degrees of freedom can be calculated as follow:

$$f = \frac{\left(\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}\right)^2}{\frac{\left(\frac{\sigma_1^2}{N_1}\right)^2}{N_1 - 1} + \frac{\left(\frac{\sigma_2^2}{N_2}\right)^2}{N_2 - 1}}$$

created with an initial deposit 10 000 USD and the invested amount was set at 10,000 units of base currency. The incomes of individual transactions were summed for every strategy and converted using simple interest on an annual rate of return.

3 Results

Table 1 revealed the descriptive characteristics of the 5-minute, 1-hour, 4-hour and daily changes in the exchange rate, defined as the difference between the logarithms of the closing exchange rates of a current and previous period. Probability distribution of changes in foreign currency exchange rates for all observed returns is symmetric, but shows high level of kurtosis compared to normal distribution, which is apparent from the histograms in Figure 1 to 4. Changes in exchange rates exhibit extreme number of small changes and higher number of extreme values compared to normal distribution. The highest level of kurtosis was observed in one-hour foreign exchange rate and the lowest value was recorded in daily returns. The last column contains the Jarque-Bera test statistics, which rejected the null hypothesis of normal distribution of returns.

Table 1 Descriptive statistics for ln exchange rate returns of EUR/USD

Time interval	Number of obs.	$\bar{r}$	σ	Skewness	Kurtosis	Jargue-Bera test
5 min	9999	0.000003	0.000176	0.265319	6.000739	15101.47*
1 hour	9999	-0.000001	0.000625	-1.229088	42.873753	767552.58*
4 hour	9999	0.000005	0.001173	-0.166935	8.977062	33583.20*
1 day	1999	0.000042	0.002914	-0.001480	2.104297	365.93*

* Significant at the 0.01 level.
Source: author´s calculation

Figure 1 Histogram of log returns EUR/USD 5-min

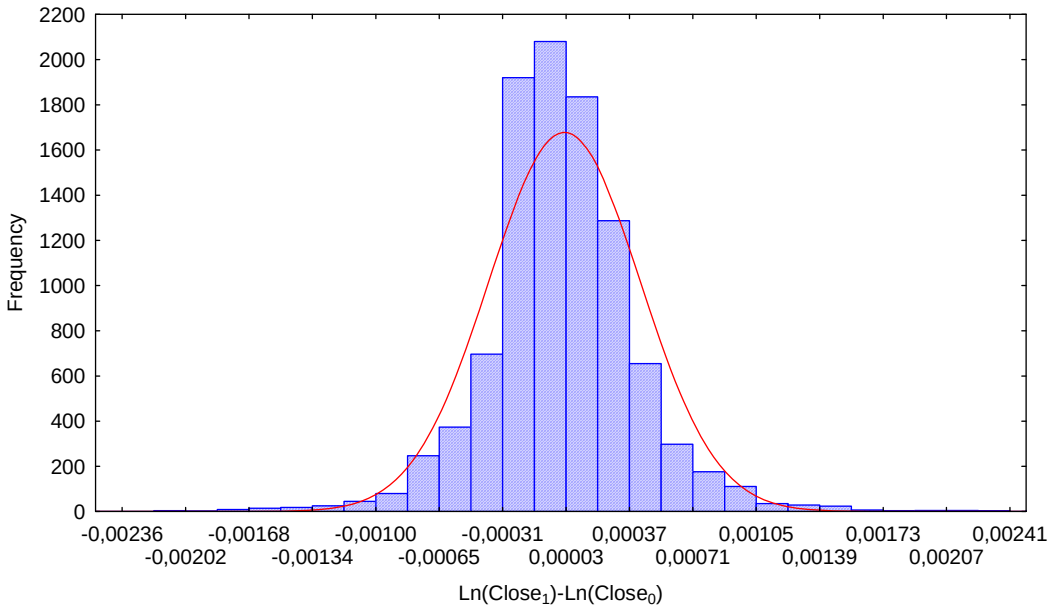


Figure 2 Histogram of log returns EUR/USD 1 hour

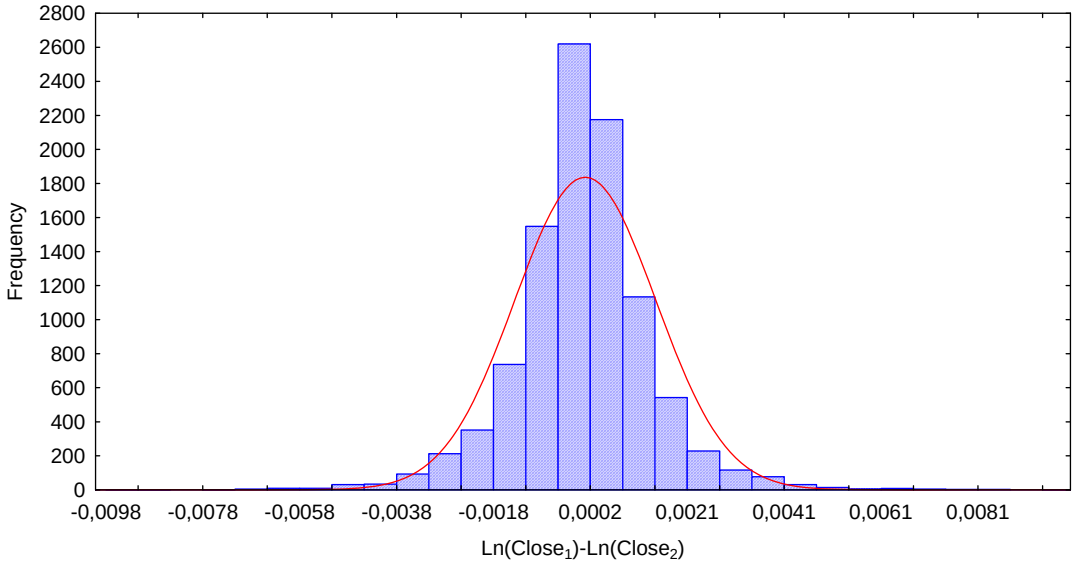


Figure 3 Histogram of log returns EUR/USD 4 hours

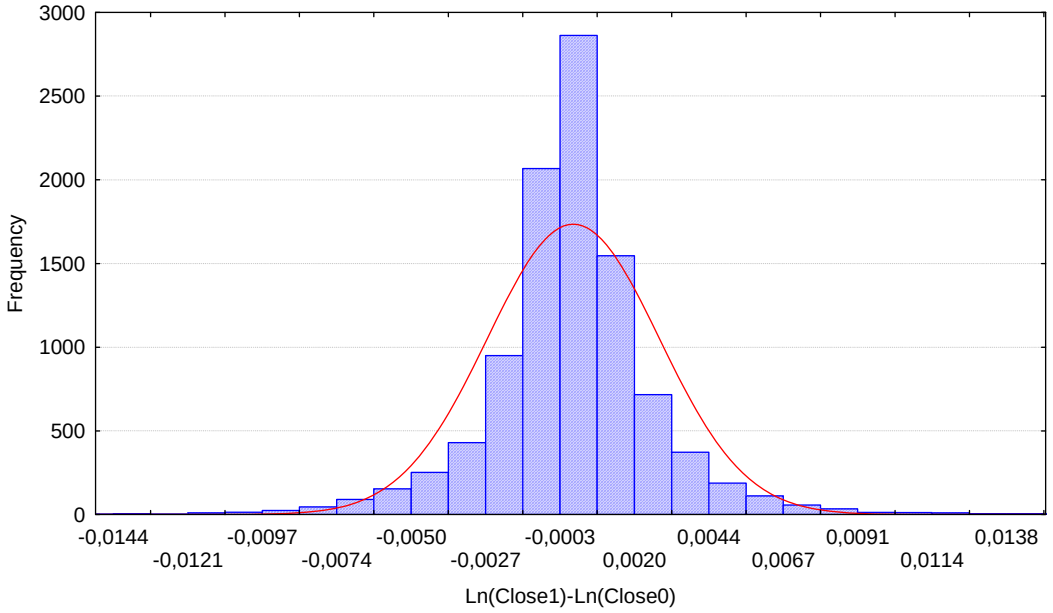
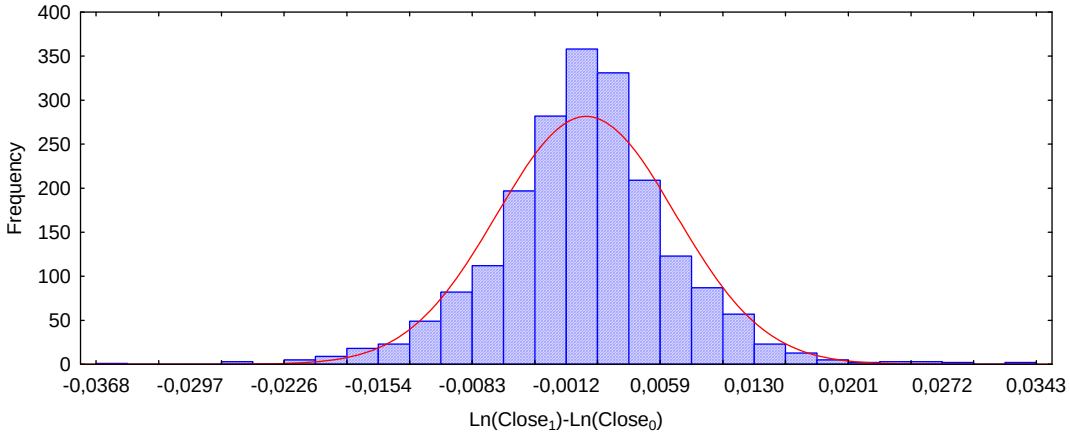


Figure 4 Histogram of log returns EUR/USD 1 day



Trading strategies

Trading strategies mentioned in this article examine the possibility of achieving above-average profits in the spot market for foreign currency pair EUR / USD using a five-minute, one-hourly, four-hourly and daily exchange rates. Trading strategies are based on the crossing of two exponential moving averages. There are four variants of this strategy, which differ from each other in the length of moving averages. The period length is determined by the index of moving average.

Table 2 Trading account and profitability of the strategies

Time interval		Exponential moving average				Buy & Hold
		EMA_6/EMA_{12}	EMA_9/EMA_{18}	EMA_{10}/EMA_{20}	EMA_{12}/EMA_{24}	
5 min	Number of trades	928	638	584	476	1
	Profit/loss (USD)	-3407.33	-2783.66	-2499.81	-2014.91	374.15
	Rate of ret. % p.a.	-207.9	-169.85	-152.53	-122.94	22.83
1 hour	Number of trades	736	472	430	358	1
	Profit/loss (USD)	-1805.11	902.17	460.95	379.26	-626.25
	Rate of ret. % p.a.	-10.72	5.36	2.74	2.25	-3.72
4 hour	Number of trades	698	488	442	376	1
	Profit/loss (USD)	-32.91	-2.33	-212.63	-265.54	-115.63
	Rate of ret. % p.a.	-0.05	0	-0.33	-0.41	-0.18
1 day	Number of trades	133	91	69	53	1
	Profit/loss (USD)	2214.62	4664.77	6209.63	5247.4	942.47
	Rate of ret. % p.a.	2.89	6.09	8.1	6.85	1.23

Notes: The initial account balance was 10 000 USD. Standard trade volume was 10,000 units of base currency. Rate of return - the annual rate in %. Length observed for the five-minute returns is 59 calendar days for hourly returns 606 calendar days, for four hours returns 2,351 calendar days and the daily returns 2,759 calendar days.
Source: author´s calculation

Table 2 includes returns of trading strategies based on moving averages. Revenues are affected by the initial deposit 10 000 USD, invested amount and the length of the period in which was used. All trading strategies applied to the five-minute exchange rates are unprofitable unlike the strategy "Buy &Hold", which achieved a profit of 374 USD, representing an annual yield rate of 22.8% p.a. It can be assumed that losses are mainly caused by the high number of transactions and total transaction costs, which are highest of all. Trading Strategies calculated from hourly exchange rates, in some cases, made a profit and also appreciated the initial deposit more than the strategy "Buy and Hold". The highest return in hourly exchange rates was achieved EMA_9/EMA_{18} strategy which reached rate of return 5,36% p. a. On the other hand trading strategy, which was used by four-hour currency exchange rates reported during six years only slight losses. The possibility of foreign exchange market inefficiencies suggests strategy calculated from the daily data, which in all cases were profitable and also exceeded market return. During the approximately eight years, EMA_{10}/EMA_{20} strategy achieved the highest appreciation, which showed an annual rate of return 8.1% p. a. However, the results in table 2 should be verified by statistical tests.

Table 3 Statistical tests of trading strategies

Time interval	Strategy	$\bar{r}$	σ	Number of obs.	Levene´s F-test (p- value)	Two-sample t-test (p-value)	One-sample t-test (p-value)
5 min	EMA6/EMA12	-0.000026	0.000570	8992	0.4671	1.0000	0.9999
	EMA8/EMA18	-0.000015	0.000558	9302	0.9060	0.9986	0.9960
	EMA10/EMA20	-0.000016	0.000559	9364	0.8289	0.9990	0.9972
	EMA12/EMA24	-0.000012	0.000554	9502	0.9379	0.9960	0.9851
	Buy &Hold	0.000009	0.000549	9999	X	X	X
1 hour	EMA6/EMA12	-0.000004	0.001908	9350	0.0972	0.5298	0.5798
	EMA9/EMA18	0.000014	0.001918	9601	0.3244	0.2840	0.2397
	EMA10/EMA20	0.000012	0.001918	9613	0.4083	0.3051	0.2672
	EMA12/EMA24	0.000014	0.001916	9637	0.5422	0.2820	0.2367
	Buy &Hold	-0.000002	0.001940	9999	X	X	X
4 hour	EMA6/EMA12	-0.000003	0.003610	9419	0.1273	0.5825	0.4490
	EMA8/EMA18	-0.000013	0.003668	9565	0.3224	0.7384	0.6823
	EMA10/EMA20	-0.000011	0.003633	9619	0.2717	0.3051	0.2672
	EMA12/EMA24	-0.000011	0.003637	9636	0.4730	0.6990	0.6218
	Buy &Hold	0.000016	0.003631	9999	X	X	X
1 day	EMA6/EMA12	0.000145	0.009295	1877	0.6259	0.4860	0.2600
	EMA9/EMA18	0.000278	0.009050	1936	0.6662	0.3081	0.0969
	EMA10/EMA20	0.000359	0.008864	1933	0.7027	0.2497	0.0408
	EMA12/EMA24	0.000284	0.000122	1974	0.9579	0.2831	0.0789
	Buy &Hold	0.000122	0.008862	1999	X	X	X

Source: author´s calculation

Table 3 contains descriptive statistics and statistical test results, which verify the hypothesis above-average yield of trading strategies. The first column contains the length of the time interval, from which the yield are counted and the names of used trading strategy are in the second column. The average yield and standard deviation of trading strategies yield are given in the third and fourth

columns. Number of time intervals, in which the long or short position was open, indicates the fifth column. Sixth to eighth column contains the results of statistical tests. Levene´s test in all cases did not reject the null hypothesis about a different variance of the yields of active and „Buy and Hold“ strategy. Two-sample t-test for comparing two means confirmed, that trading strategies based on exponential moving averages do not provide higher returns on the currency pair EUR/USD than the market. Only the one-sample t-test confirmed on the significance level of 0.05, that the yield of the strategy EMA_{10}/EMA_{20} for daily exchange rates is significantly greater than 0.

4 Conclusion

This article examines the microstructure of the foreign exchange market and through high-frequency data analyses the behaviour of the spot exchange rate of EUR/USD. With the help of automated trading systems verifies the possibility of achieving "above average return" within a very short time intervals and tests the market efficiency hypothesis in its weak form on the foreign exchange market.

Distribution of the EUR/USD returns in exchange rates was symmetric for all observed lengths with higher degree of kurtosis compared to normal distribution. Degree of skewness for all lengths of returns was close to zero, indicating the absence of long-term trend. High degree of kurtosis (the highest rate of kurtosis was recorded for hourly returns) was the evidence of a large number of small price changes and continuous adaptation to new internal value.

A strategy based on exponential moving averages reached the highest losses on 5-minute exchange rates. This was caused by the low potential gains from one trade and high total transaction costs. The strategy based on longer moving averages reported better results. This is mainly due to the lower number of closed transactions and reduced transaction costs. However, this effect can be observed for all lengths of exchange rate EUR/USD. The best strategy (EMA_9/EMA_{18}) on 1-hourly exchange rates achieved rate of return 5,36 % p. a., which together with strategies EMA_{10}/EMA_{20} and EMA_{12}/EMA_{24} exceeded the return of the market (-3,72 % p. a.). All strategies based on the 4-hour exchange rate showed slight loss or the rate of return was close to zero.

The best results were achieved using daily exchange rate. Trading strategy EMA_{10}/EMA_{20}, after including transaction costs, reached the highest annual rate of return of all strategies (8,10 % p.a.) and also reached a higher return than the market (1,23 % p . a.). But this result was not confirmed by statistical test, which did not reject the null hypothesis about above-average profits of strategies compared to the market. The total return strategy EMA_{10}/EMA_{20} was probably influenced only by the high variance of daily returns. This result is confirmed by the final account balance when the strategy return is close to zero for the first six years and increasing of the final balance occurred between 2009 and 2011. This period is consistent with the beginning of the financial crisis and is therefore possible, that this trading strategy shows good results only during the period of central bank intervention.

In conclusion it is possible to say, that the strategies using only the crossing moving averages can´t achieve above average return on EUR/USD intra-daily market. This result also suggests that the exchange rate EUR/USD satisfies the conditions of weakly efficient market even within a very short period of time. On the other hand, it is necessary to mention the shortcomings of the selected strategy. The main disadvantage of this strategy can be seen in the continuous trading throughout the observed period, when long or short position is open. It is possible that the exchange rate EUR/USD behave inefficiently for a short time only and better timing of position would increase income of trading strategy. It remains also the question, whether the income of trading strategy based on moving averages could be increased by incorporating a larger number of parameters in the decision model (trading only in certain parts of the day or limiting losses by incorporating stop-loss

orders to trading strategy) and there is also the possibility, that the chosen strategy works only in times of central bank intervention. These issues will be the subject of further author's research.

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