Daily abnormal price changes and trading strategies in the FOREX

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Received 6 November 2019
Revised 4 February 2020
Accepted 22 March 2020

Abstract

Purpose – This paper explores abnormal price changes in the FOREX by using both daily and intraday data on the EURUSD, USDJPY, USDCAD, AUDUSD and EURJPY exchange rates over the period 01.01.2008–31.12.2018.
Design/methodology/approach – It applies a dynamic trigger approach to detect abnormal price changes and then various statistical methods, including cumulative abnormal returns analysis, to test the following hypotheses: the intraday behaviour of hourly returns on overreaction days is different from that on normal days (H1), there are detectable patterns in intraday price dynamics on days with abnormal price changes (H2) and on the following days (H3).
Findings – The results suggest that there are statistically significant differences between intraday dynamics on days with abnormal price changes and normal days respectively; also, prices tend to change in the direction of the abnormal change during that day, but move in the opposite direction on the following day. Finally, there exist trading strategies that generate abnormal profits by exploiting the detected anomalies, which can be seen as evidence of market inefficiency.
Originality/value – New evidence on abnormal price changes and related trading strategies in the FOREX.

Keywords FOREX, Anomalies, Overreactions, Abnormal returns, Patterns, Abnormal price changes
Paper type Research paper

1. Introduction

Abnormal price changes in financial markets are of interest to both academics and practitioners. According to the Efficient Market Hypothesis (EMH) (Fama, 1965; Samuelson, 1965) prices should follow a random walk and there should be no detectable pattern; they should fully reflect all available information and be unpredictable. The main implication of the EMH is that traders should not be able to "beat" the market and make abnormal profits.

However, since the 1980 a number of papers have been published reporting against the EMH, specifically showing that there exist market anomalies that can be exploited through appropriate trading strategies (Lehmann, 1990; Jegadeesh and Titman, 1993; Pritamani and Singhal, 2001; Caporale *et al.*, 2018 and many others). The existing literature has tried to gain a deeper understanding of such anomalies by analysing their drivers (Mynhardt and Plastun, 2013), the existence of market overreactions (De Bondt and Thaler, 1985), possible patterns in price behaviour resulting from them (Bremer *et al.*, 1997; Ferri and Min, 1996; Caporale *et al.*, 2018) and their effects on market participants (Savor, 2012; Feldman *et al.*, 2012). The latter seek to exploit them by developing profitable trading strategies (Lehmann, 1990; Jegadeesh and Titman, 1993; Pritamani and Singhal, 2001; Caporale *et al.*, 2018).

JEL Classification — C63, G12, G17

Alex Plastun gratefully acknowledges financial support from the Ministry of Education and Science of Ukraine (0117U003936).

Journal of Economic Studies
Emerald Publishing Limited
0144-3585
DOI 10.1108/JES-11-2019-0503

The aim of the present paper is to examine whether daily abnormal price changes create market anomalies and are exploitable by means of suitable trading strategies in the case of the Foreign Exchange market (FOREX), focusing in particular on the EURUSD, USDJPY, USDCAD, AUDUSD and EURJPY exchange rates over the period 01.01.2008–31.12.2018 and using both daily and intraday data. The FOREX is normally thought to be one of the most efficient financial markets and therefore it is particularly interesting to examine whether there is any evidence against its efficiency. Moreover, it is open round the clock. Finally, most of the previous literature focuses on overreactions in the stock market whilst there are hardly any studies about their presence in the FOREX.

Our analysis provides a deeper understanding of and new insights into market behaviour in the presence of daily abnormal price changes, which are defined by using a dynamic trigger approach (Wong, 1997) and are classified as positive and negative. Then various hypotheses of interest are tested to establish whether or not the intraday behaviour of hourly returns on days with abnormal price changes differs from that on normal days, and whether or not there are detectable patterns in intraday price dynamics on days with abnormal price changes and on the following days. For this purpose a variety of statistical methods are used, including cumulative abnormal returns. Finally, a trading simulation approach is used to establish whether or not any detected anomalies can be exploited to generate profits by designing appropriate trading strategies. This type of analysis recognises that trading is an integral part of the process through which exchange rates are determined and evolve and provides crucial information for understanding asset price dynamics and the degree of market efficiency.

The results indicate strong momentum effect on the days with abnormal price changes and contrarian effect on the days after them. By specifying timing parameters for these effects it is possible to design profitable trading strategies based on the detected anomalies. Their presence in a market normally considered one of the most efficient is a very interesting finding. Future research could examine the same issue in less efficient markets such as stock markets, cryptocurrency and commodity markets.

The remainder of the paper is organised as follows. Section 2 contains a brief review of the literature on price overreactions and abnormal price changes in financial markets. Section 3 describes the methodology. Section 4 discusses the empirical results. Section 5 provides some concluding remarks.

2. Literature review

Abnormal price changes in financial markets were examined by De Bondt and Thaler (1985), who showed that the best (worst) performing portfolios in the NYSE over a three-year period tended to under(over)-perform in the following three years. Subsequently, numerous papers have analysed overreactions in different markets (stock market, FOREX, commodities etc.) and different countries (both developed and emerging), at different frequencies (daily, weekly, monthly etc.) and for different assets (exchange rates, stocks, oil, gold and many others). This led to developing the so-called overreaction hypothesis according to which if investors overreact in a given period, they will move in the opposite direction in the following period. A lot of empirical evidence supports this view – see, for instance, Brown *et al.* (1988), Atkins and Dyl (1990) and Ferri and Min (1996) for the US stock market, and Fung (1999) for the Hong Kong stock market.

More specifically, Brown *et al.* (1988) analysed NYSE data for the period 1946–1983 and found evidence of contrarian effect after large price movements. Atkins and Dyl (1990) examined daily price changes and detected contrarian effect after significant price changes, especially in the case of falling prices. Ferri and Min (1996) confirmed the presence of contrarian effect using S&P 500 data for the period 1962–1991. Fung (1999) used data from 33 stocks in the Hang Seng Index and found that "loser" portfolios on average outperform the "winner" portfolios by 9.9% 1 year after the formation periods.

Gunaratne and Yonesawa (1997) analysed return reversals after overreactions in the Tokyo stock exchange and reported that the extreme losers outperform the extreme winners by 11% per annum; Lobe and Rieks (2011) found evidence of overreaction in the Frankfurt stock exchange; Maher and Anokhi (2011) detected abnormal volatility patterns in the Indian stock market; Lerskullawat and Teerapan (2018) reported evidence of stock price overreaction in the Thai stock market; Cutler *et al.* (1991) found overreactions in the Gold market; and Larson and Madura (2001) in the case of the FOREX. Jegadeesh and Titman (1995) used the bid-ask bounce to explain price reversals. Not all studies provide evidence of price reversals after overreactions. For instance, Cox and Peterson (1994) did not find a negative correlation between abnormal returns on the day prices fall and the following three days.

Overreactions have been investigated much less in the case of the FOREX market. Andersen *et al.* (2003) found that the market reacts to news in an asymmetric fashion: bad news have a greater impact than good news. Kocenda and Moravcova (2018) provided evidence that exchange rates react not only after but also before the news release, but these reactions differ according to the origin, type and quality of the news. Wan and Kao (2009) explored the existence and price impact of contrarian behaviour in the foreign exchange markets and detected contrarian trading in the case of the British pound and the Japanese yen. Parikakis and Syriopoulos (2008) investigated patterns following excess 1-day fluctuations for various currencies and found that a contrarian strategy is profitable in all those markets.

Possible reasons for abnormal price changes include emotions and the herd effects (Griffin and Tversky, 1992; Madura and Richie, 2004), the existence of "noise" traders (Aiyagari and Gertler, 1999; Hong and Stein, 1999), overconfidence and other behavioural patterns (Barberis *et al.*, 1998; Daniel *et al.*, 1998), the use of technical and fundamental analysis by investors in making decisions (Duran and Caginalp, 2007), the degree of liquidity in the market (Jegadeesh and Titman, 1993), macroeconomic news announcements (Kocenda and Moravcova, 2018) and others.

Lehmann (1990), Jegadeesh and Titman (1993), Pritamani and Singhal (2001) and Caporale *et al.* (2018) showed that it is possible to generate abnormal returns adopting trading strategies based on abnormal price changes. More specifically, Jegadeesh and Titman (1993) tested the following trading strategy at the monthly data frequency: open positions in the direction, opposite to the previous movement. Profitability of such strategy is 2% per month. A similar strategy based on weekly data was analysed by Lehmann (1990), who also found 2% returns in a week.

Daily data were used by Caporale *et al.* (2018), who applied a trading robot approach to various financial markets including the United States showed that the reversal effect is exploitable in the stock market, whilst the momentum effect produces profits in the case of the FOREX and commodity markets.

By contrast, Cox and Peterson (1994) concluded that it is doubtful that large one-day price falls provide the opportunity for a short-term profitable trading strategy based on stock market overreaction given the relatively small size of price reversals and the presence of trading costs. Abnormal price changes and overreactions can also be used as a crisis identifier and a price predictor (Sandoval and Franca, 2012; Plastun *et al.*, 2018).

Overall, there is plenty of evidence against the EMH, especially its weak form (Fama, 1970). It is therefore particularly interesting to investigate its empirical relevance in the FOREX market, which is often considered to be one of the most efficient. None of the existing studies investigates intraday market behaviour during days with abnormal price changes and the following ones, and the related issue of whether detected anomalies can be exploited to generate profits in the specific case of the FOREX. Our study fills this gap and provides evidence on whether or not the intraday behaviour of hourly returns is different on days with abnormal price changes compared to normal days, and on whether there exist any detectable patterns (momentum or contrarian effects) in intraday price dynamics on days with abnormal price changes and on those following them.

3. Methodology

Our sample includes daily and hourly data from the FOREX for the following exchange rates: EURUSD, USDJPY, USDCAD, AUDUSD and EURJPY; the sample period is 01.01.2008-31.12.2018, and the data source is MetaQuotes Software Corp. The selected currencies are the most traded in the world. The sample period has been chosen to include a sufficient number of abnormal price changes to be able to construct a dataset suitable for performing *t*-tests as well as conducting trading simulations whilst avoiding data snooping.

To detect days with abnormal price changes we use a dynamic trigger approach (Wong, 1997; Caporale *et al.*, 2018) and define abnormal price changes on the basis of the number of standard deviations to be added to the average return.

In order to avoid distortions caused by price gaps, returns (R_i) are computed as follows:

$$R_i = \left(\frac{\text{Close}_i}{\text{Open}_i} - 1\right) \times 100\%, \tag{1}$$

where R_i– returns on the ith day in %;

Open_i – open price on the ith day;

Close_i – close price on the ith day.

Having calculated returns as in (1), a positive abnormal price change is defined by the following inequality:

$$R_i > (\overline{R}_n + k \times \delta_n) \tag{2}$$

and a negative abnormal price change is defined as:

$$R_i < (\overline{R}_n - k \times \delta_n) \tag{3}$$

where k is the number of standard deviations used to identify the abnormal price changes (specifically, $k = 2$); $\overline{R}_n$ is the average size of daily returns for period n and δ_n is the standard deviation of daily returns for period n.

Then the following hypotheses are tested:

H1. The intraday behaviour of hourly returns is different on days with abnormal price changes from that on normal days.

H2. There are detectable patterns in intraday price dynamics on days with abnormal price changes.

H3. There are detectable patterns in intraday price dynamics on the days following days with abnormal price changes.

To test these hypotheses we use the following methods:

(1) Visual inspection and average analysis;

(2) Student's *t*-tests;

(3) A cumulative abnormal returns approach;

(4) A trading simulation approach.

The reasons for choosing these methods are the following. Average analysis provides preliminary but not conclusive evidence on whether there are differences between returns on days with abnormal price changes and those on normal days. To establish whether or

not the detected differences are statistically significant Student's t-tests are carried out for Hypothesis 1, the null (H0) being that both sets of data (hourly returns on the days with abnormal price changes and in the full sample respectively) belong to the same population, a rejection of the null suggesting the presence of a statistical anomaly in the price behaviour on the days with abnormal price changes. The test is carried out at the 95% confidence level, and the degrees of freedom are $N-1$ (N being equal to $N1+N2$). Given the size of our dataset, it is legitimate to argue that normality holds, and therefore these are valid statistical tests.

The cumulative abnormal returns approach is based on MacKinlay (1997) and is standard for event studies. Abnormal returns are defined as follows:

$$AR_t = R_t - E(R_t) \tag{4}$$

where R_t is the return at time t and $E(R_t)$ is corresponding average return computed over the whole sample period as follows:

$$E(R_t) = \left(\frac{1}{T}\right)\sum_{i=1}^{T} R_i \tag{5}$$

where T is the sample size.

The cumulative abnormal return denoted as CAR_i is simply the sum of the abnormal returns:

$$\mathrm{CAR}_i = \sum_{i=1}^{24} AR_i \tag{6}$$

Extreme values of CAR correspond to the biggest anomalies in price behaviour. A change of direction represents evidence of the appearance (disappearance) of an anomaly.

To establish whether the detected anomalies can be exploited to generate abnormal profits a trading simulation approach is used which replicates the actions of a representative trader according to a given algorithm determining when a buy/sell position should be opened and then closed. It should be mentioned that the approach used here does not incorporate transaction costs (spread, fees to the broker or bank, swaps, etc.) and is only a proxy for actual trading. Nevertheless, it is informative about real trading given the fact that nowadays transaction costs are less and less important. Thanks to the development of Internet and high-frequency trading spreads tend to be small (at least in liquid markets such as FOREX), typically ranging between 0.01 and 0.02%. Banking and broker fees can affect profitability in the case of a small number of trades, but when there are dozens of trades (just like in our case) they become insignificant (this is the so-called scale effect in trading). Therefore our analysis can shed light on the profitability of the trading strategy based on detected anomaly despite the fact that it overlooks transaction costs.

The percentage result of the individual deal is computed as follows:

$$\%\ \text{result} = \frac{100\% \times P_{\text{close}}}{P_{\text{open}}} - 1 \tag{7}$$

where P_{open} – opening price for the trade

(1) P_{close} – closing price for the trade

Equation 9 holds in the case of long (buy) positions. For short (sell) ones P_{open} and P_{close} are reversed.

The sum of the results from each trade is the total financial result of trading. A strategy producing positive total profits implies that there exists an exploitable market anomaly.

Another important indicator of the degree of success of the trading strategy is the percentage of successful trades:

$$\%\ \text{successful}\quad \text{trades} = \frac{100\% \times \text{number of successful trades}}{\text{overall number of trades}} \tag{8}$$

If the trading strategy generates 50% or more profitable trades it can be considered profitable.

4. Empirical results

We start with the EURUSD series. The results are presented in Appendix A. Figures A1 and A2 show that returns on overreaction days differ from those on normal days; the *t*-test statistics confirm that these differences are statistically significant. This holds in the case of positive abnormal price changes for almost all the European and US trading sessions and half of the Asian session (the *t*-statistic is higher than the relevant critical value (Table A2)). As for negative abnormal price changes, the US session appears to be the most volatile (Table A3).

The cumulative abnormal returns analysis (Table A4 and Figure A3) indicates a stable pattern during the entire day of the abnormal price changes, since returns increase till 11.00 p.m. We also identify the average timing of the abnormal price changes (when the current daily return can be seen as an abnormal price change according to our definition): it is 7.00 p.m. in the case of positive abnormal price changes and 5.00 p.m. in the case of negative ones.

Concerning price behaviour on the day after the abnormal price change, average hourly returns after a positive abnormal price changes are much lower than on normal days during the first hours of the following day (Figure A4), and these differences are statistically significant (Table A5); the negative abnormal price changes results also provide evidence of contrarian movement (Figure A5 and Table A6).

The cumulative abnormal returns analysis suggests contrarian movements at specific times, namely from the start of the day till the beginning of the European session (Table A7). This is true for the both positive and negative abnormal price changes (see Figure A6).

The same type of analysis is carried out for USDJPY (Appendixes C and D), USDCAD (Appendixes E and F), AUDUSD (Appendices G and H) and EURJPY (Appendixes I and J). These results are presented in a supplementary file.

The complete set of results is summarised in Table 1 (for positive abnormal price changes) and Table 2 (for negative abnormal price changes). Differences in returns are treated as significant on the basis of the results from the average analysis. This confirms the presence of a price anomaly if the mean return on days with abnormal price changes is higher (lower) than that on normal days. Differences in returns are considered as statistically significant on the basis of the results of the Student's *t*-test. A rejection of the null hypothesis (data on overreaction days and normal days respectively belong to the same population) implies that the price anomaly is statistically significant. Patterns in cumulative abnormal returns dynamics are detected using the CAR measure, an increase of which suggests the existence of an anomaly. As for the timing of the abnormal price changes, this depends on when cumulative returns during the day exceed the abnormal price change threshold.

As can be seen, the results for the other exchange rates are generally very similar to those for EURUSD.

On the basis of the results presented in Tables 1 and 2 the following strategies are developed:

Strategy 1: when it becomes clear that the current day is a day with abnormal price change (see the timing of abnormal price change parameter in Tables 1 and 2) a position in the

Parameter/ Exchange rate	EURUSD	USDJPY	USDCAD	AUDUSD	EURJPY
Day of the abnormal price changes					
Are there significant differences in returns (day with abnormal price changes vs usual day)?	Yes	Yes	Yes	Yes	Yes
Are these differences statistically significant?	Yes. Observed during almost all the European and US trading sessions and half of the Asian session	Yes. Observed during almost the whole day	Yes. Observed during almost all the European and US trading sessions and half of the Asian session	Yes. Observed during almost the whole day	Yes. Observed during almost all the European and US trading sessions and half of the Asian session
Any patterns in cumulative abnormal returns dynamics?	Yes. CAR increase till the end of the day	Yes. CAR increase till the end of the day	Yes. CAR increase till the end of the day	Yes. CAR increase till the end of the day	Yes. CAR increase till the end of the day
Timing of abnormal price change	19:00	16:00	17:00	17:00	16:00
Day after the abnormal price changes					
Are there contrarian price movement on the day after the day with abnormal price changes?	Yes	Yes	No	Yes	Yes
Are these differences statistically significant?	Yes. At 00:00 and 2:00	Yes. At 01:00 and 4:00	No	Yes. At 0:00, 1:00 and 3:00	Yes. At 1:00, 2:00
Timing parameters of contrarian movements	Since the start of the day till the start of the European session (9:00)	Since the start of the day till the start of European session (7:00)	Not detected	Since the start of the day till the start of the European session (9:00)	CAR reaches maximum at the start of the European session (7:00), but stay there for the whole day

Table 1.
Overall results for the case of positive abnormal price changes

direction of abnormal price change should be opened. This position should then be closed at the end of the day.

Strategy 2: at the beginning of the day after the day with abnormal price change a position in the opposite direction to the abnormal price change should be opened. This position should then be closed according to the timing displayed in Tables 1 and 2 (see the timing parameters for the contrarian movements).

To establish whether or not the results obtained are statistically different from the random trading ones *t*-tests are carried out. They compare the means from two samples to see whether

Parameter/ Exchange rate	EURUSD	USDJPY	USDCAD	AUDUSD	EURJPY
Day of the overreaction					
Are there significant differences in returns (day with abnormal price changes vs usual day)?	Yes	Yes	Yes	Yes	Yes
Do these differences statistically significant?	Yes. Observed during almost all the European and US trading sessions and a half of the Asian session	Yes. Observed during almost the whole day	Yes. Observed during almost all the European and US trading sessions	Yes. Observed during almost all the Asian trading session	Yes. Observed during almost all the European and US trading sessions and a half of the Asian session
Any patterns in cumulative abnormal returns dynamics?	Yes. CAR increase till the end of the day	Yes. CAR increase till the end of the day	Yes. CAR increase till the end of the day	Yes. CAR increase till the end of the day	Yes. CAR increase till the end of the day
Timing of abnormal price change	17:00	17:00	19:00	16:00	16:00
Day after the overreaction					
Are there contrarian price movement on the day after the day with abnormal price changes?	Yes	Yes	Yes	Yes	Yes
Do these differences statistically significant?	Yes. At 00:00	Yes. At 00:00, 1:00, 3:00 and 14:00	Yes. At 00:00 and 6:00	No	No
Timing parameters of contrarian movements	Since the start of the day till the start of the European session (8:00)	CAR increase till the end of the day	Since the start of the day till the start of European session (9:00)	Since the start of the day till the start of European session (8:00)	CAR increase till the end of the day

Table 2.
Overall results for the case of negative abnormal price changes

or not they come from the same population. The first sample consists of the trading results from the trading strategy, and the second one of random trading results. The null hypothesis (H0) is that the mean is the same in both samples, and the alternative (H1) that it is not. The computed values of the *t*-test are compared with the critical ones at the 5% significance level. Failure to reject H0 implies that there are no advantages from exploiting the trading strategy being considered since the trading results do not differ from the random ones, whilst a rejection suggests that the adopted strategy can generate abnormal profits since the trading results are not random and therefore it is possible to "beat the market". As an example, the *t*-test results for EURJPY in the case of Strategy 1 are shown in Table 3.

The trading simulation results for the two strategies are presented in Table 4 (for positive abnormal price changes) and Table 5 (for negative abnormal price changes).

As can be seen, the detected anomalies in most of cases can be exploited to generate abnormal profits from trading and "beat the market". These results are relevant to both academics interested in market efficiency and practitioners aiming to develop profitable strategies. Daily abnormal price changes can generate very specific patterns in price

Parameter	Value
Number of the trades	59
Total profit	45.50%
Average profit per trade	0.77%
Standard deviation	1.02%
t-test	5.81
t critical value (0.95%)	1.78
Null hypothesis	Rejected

Table 3. *t*-Test for evaluating the success of the trading strategy: EURJPY, positive abnormal price changes, Strategy 1

Instrument	Number of trades. Units	Number of successful trades. Units	Number of successful trades. %	Profit. %	Profit % per year	*t*-test calculated value	*t*-test status
Strategy 1							
EURUSD	67	47	70	31.59	3.16	5.87	Passed
USDJPY	58	54	93	35.07	3.51	7.62	Passed
USDCAD	76	49	64	42.71	4.27	9.17	Passed
AUDUSD	55	48	87	47.83	4.78	5.63	Passed
EURJPY	59	53	90	45.50	4.55	5.81	Passed
Strategy 2							
EURUSD	67	44	66	7.74	0.77	2.45	Passed
USDJPY	58	38	66	13.70	1.37	2.60	Passed
USDCAD	–	–	–	–	–	–	–
AUDUSD	55	37	67	22.95	2.29	3.03	Passed
EURJPY	59	37	63	21.14	2.11	2.39	Passed

Table 4. Trading simulation results for the case of positive abnormal price changes

Instrument	Number of trades. Units	Number of successful trades. Units	Number of successful trades. %	Profit. %	Profit % per year	*t*-test calculated value	*t*-test status
Strategy 1							
EURUSD	79	68	86	30.83	3.08	8.98	Passed
USDJPY	63	56	89	42.91	4.29	7.53	Passed
USDCAD	61	51	84	26.84	2.68	5.17	Passed
AUDUSD	66	60	91	73.83	7.38	8.54	Passed
EURJPY	77	64	83	54.76	5.48	7.38	Passed
Strategy 2							
EURUSD	79	40	50.6	5.1	0.5	1.23	Failed
USDJPY	62	38	61.3	20.2	2.0	2.49	Passed
USDCAD	61	37	60.7	5.6	0.6	1.25	Failed
AUDUSD	66	36	54.5	16.9	1.7	2.12	Passed
EURJPY	62	36	58.1	18.0	1.8	1.37	Failed

Table 5. Trading simulation results for the case of negative abnormal price changes

behaviour. On the day when they occur there is a strong momentum effect, whilst on the following day there is a contrarian effect.

5. Conclusions

This paper examines daily abnormal price changes in the FOREX using daily and intraday data on the EURUSD, USDJPY, USDCAD, AUDUSD and EURJPY exchange rates over the period 01.01.2008-31.12.2018. Positive and negative daily abnormal price changes are detected by means of a dynamic trigger approach. Intraday price behaviour during days with abnormal price changes and the following one is analysed applying various statistical methods such as cumulative abnormal returns analysis; market efficiency is then investigated applying a trading simulation approach. The intraday dimension of our analysis and the microstructure aspect of our trading analysis are both original contributions to this area of the literature.

To sum up, there are (in most cases statistically significant) differences between intraday dynamics on normal and days with abnormal price changes respectively. In particular, there is a strong momentum effect on days with abnormal price changes, i.e. prices tend to change only in the direction of the abnormal price changes during the whole day; in addition, usually the presence of a abnormal price movements becomes clear at the start of the US trading session. The overreaction hypothesis is supported by the evidence produced by our analysis: during the Asian trading session a strong contrarian pattern is present (i.e. on the day after the overreaction prices tend to go in the opposite direction). Contrarian movement is limited in time, since usually it lasts only till the start of the European session. Finally, there exist profitable trading strategies based on these anomalies, which represents evidence against market efficiency in the case of the analysed exchange rates.

The existence of detectable price patterns and of profitable trading strategies exploiting them is of interest not only to academics examining market efficiency but also to practitioners such as individual traders, institutional investors, hedge funds etc.: in an era of high-frequency trading and trading robots it is increasingly hard to spot arbitrage opportunities, and our analysis suggests that there might be some in the FOREX market. Future research could carry out a similar type of investigation in the case of other markets (cryptocurrency, commodity and stock markets), especially for the emerging economies.

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Appendix

The supplementary material is available online for this article.

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