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Market Efficiency of Euro Exchange Rates and Trading Strategies

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Abstract

This paper tests the hypothesis on market efficiency for returns on the euro against fifteen currencies while assuming predictability of returns, dependent on the sign and magnitude of endogenous shocks. Considering the properties of exchange rate returns, the quantile autoregression approach was selected in empirical analysis. Based on the research data sample, consisting of daily exchange rates between January first, 1999, and April thirty, 2020, the paper suggests profitable trading strategies depending on a currency pair. In the case of six out of fifteen currency pairs, exchange rate returns were found non-predictable or almost non-predictable. In the case of nine considered currency pairs, there was a significant linkage between current and past exchange rate returns, found as dependent on the sign and magnitude of endogenous shocks in exchange rate returns. Finally, the paper considered possible factors of inefficiency and suggested further research of the topic.

Keywords: quantile autoregression, market efficiency, foreign exchange, euro

Introduction

Financial markets have become increasingly integrated due to the growing process of globalization and integration. The role of exchange rate as an international financial transmission mechanism and its influence on competitiveness of an economy among others make the topic extremely important for any economy. There are many theoretical approaches dedicated to determine and explain behaviour of exchange rates. This paper belongs to the empirical literature grounded on efficient market theory originally developed by Fama (1965). The efficient market hypothesis assumes that changes in exchange rate dynamics arise due to new information. Therefore, based on the efficient market hypothesis, exchange rate dynamics should be unpredictable and behave as a pure random walk process. However, empirical literature provides mixed findings regarding the validity of efficient market hypothesis (Katusiime et al., 2015). A well-known and frequently documented property of exchange rates dynamics, referred to as the phenomenon

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of clustering volatility, is that high volatility periods tend to be followed by high volatility periods, and low volatility periods tend to be followed by the low ones. Empirical literature directed towards the phenomenon of clustering volatility mainly relies on the various specification of conditional heteroskedasticity models based on Engle's (1982) ARCH and Bollerslev's (1986) GARCH model. Furthermore, exchange rates distribution was often skewed and exhibited excess kurtosis, referred to as fat tails of empirical distribution. Therefore, the property of clustering volatility and potential asymmetries in exchange rates dynamic and fat tails of its distribution point out the need to examine the dependence structure between current and past returns across different quantiles of residuals distribution. This paper aims to examine the dependence structure of returns depending on the size and sign of its endogenous shocks. Consequently, working hypothesis of this paper assumes that efficiency of returns in daily euro-exchange rates depend on the sign and magnitude of its endogenous shocks. Taking into account aforementioned properties of exchange rate series, the quantile autoregression approach proposed by Koenker and Xao (2004, 2006) seems to be well suited to exhibit the property of persistence in exchange rate dynamics. Despite the suitability of the approach, the quantile autoregression specification was employed to examine dynamics of nominal exchange rates with high-frequency data only in papers from Kuck et al. (2015) and Kuck and Maderitsch (2019). Following the quantile autoregression approach, Kuck et al. (2015) illustrated temporal dependence patterns for daily exchange rate returns of the USD/EUR, USD/JPY, USD/GBP, USD/AUD, USD/CHF and USD/CAD between 1999 and 2014. Based on estimates from this paper, trading strategies were derived for each currency pair. In short memory patterns, very active trading is a preferred strategy, while in the case of persistence, a buy-and-hold strategy yields higher returns. Therefore, the research additionally aims to contribute to the existing body of literature with suggestions of trading strategies on foreign exchange markets for the considered pairs of currencies.

The remainder of the paper is organized as follows: section 2 briefly summarizes existing literature related to the considered topic. Section 3 illustrates employed methodology, Section 4 provides research data and empirical results, while Section 5 gives implications and discussion. The final section provides an overview of the main findings of the research.

Brief Literature Overview

The literature review provides recent findings regarding the validity of foreign exchange market efficiency. The contemporary empirical literature on the link between exchange rate dynamics and efficient market hypothesis is viable. It brings various evidence from all over the globe while revealing diversity in the properties of exchange rate dynamics. Since the topic represents an empirical issue, the results always depend on data selection and econometric model specification. Ca'Zorzi et al. (2017) employed a dynamic stochastic general equilibrium (DSGE) approach and found DSGE models well suited to forecast real exchange rate. However, DSGE model forecasts of nominal exchange rate underperform random walk. Eichenbaum et al. (2017) found that the current real exchange rate improves to forecast changes in the nominal exchange rate in countries with monetary policy targeting inflation and floating exchange rates regimes. However, the finding does not hold for countries with quasi-fixed, crawling-peg, and heavily managed floating exchange rate regimes. Based on the assumption of interest rate parity, Engel et al. (2018) found inflation significant to forecast changes in U.S. dollar exchange rates while the interest-rate differential was not significant. Engel and Wu (2018) pointed out that economic fundamentals could well explain nominal exchange rate dynamics. Furthermore, the evidence suggested that liquidity yields were significant in explaining exchange rate movements for all G10 countries. Della Corte et al. (2016) established the relationship between a country's major commodity export price and its nominal exchange rate. Cheung et al. (2018) provided an exhaustive analyzis of forecasting power for the competing models to predict nominal exchange rates and point out that there was no one specific model to outperform the others. Belbute et al. (2017) examined persistence of official and informal Kwanza/USD exchange rates. The results indicated persistence in the two exchange rates in levels first differences, while the persistence in the official market was significantly lower than in the informal exchange rate. Juselius and Assenmacher (2017) illustrated that Swiss US nominal exchange fluctuates with long persistent swings. Salazar (2017) showed that over time the nominal exchange rate in Chile exhibited long and persistent swings around relative prices. Juselius (2017) explained the persistence of swings with imperfect knowledge, reflexivity, and feedback mechanisms. Consistently with imperfect knowledge expectations, Juselius and Stillwagon (2018) examined exchange rates for the US and UK and showed that the nominal exchange rate had moved away from equilibrium over the medium run, whereas over the long run the nominal exchange rate was adjusted. Li et al. (2016) employed the multifractal detrended cross-correlation analyzis (MF-DCCA) and analyzed cross-correlation between crude oil market and five selected exchange rate markets. The results revealed a strong multi-fractality between crude oil market and exchange rate markets in the short term and in the long term. Furthermore, the cross-correlations between the exchange rates and crude oil returns were found persistent. Katusiime et al. (2015) examined market efficiency and trading rule profitability in the foreign exchange market in Uganda from January 1994 to June 2012. The results illustrated the pricing inefficiency of the foreign exchange market except for a few brief episodes of efficiency while pointing out the buy-and-hold strategy as a preferred strategy on the foreign exchange market in Uganda. Hsu et al. (2016) analyzed technical trading rules in the foreign exchange market daily data over 45 years for 30 developed and emerging market currencies. The results supported a predictable foreign exchange market with potential excess profitability for developed and emerging currencies. Sensoy et al. (2016) examined efficient market hypothesis under the framework of fractional integration for several developed and emerging economies. The results indicated strong rejection of market efficiency, mostly in emerging countries, while exchange rates of developed countries are found less inefficient. However, the results always depend on data selection and model specification. The Brief literature overview illustrates that contemporary empirical literature still struggles to establish an unambiguous connection between efficient market hypothesis and exchange rate dynamics. Therefore, this paper makes a step ahead and illustrates efficiency euro-exchange rates for endogenous shocks of different sign and magnitude.

Methodology

An efficient market hypothesis (EMH) can be mathematically formulated with the help of the martingale theory. Based on martingale theory, if a time series $\{y_t\}$ was a martingale with respect to its past, then its future value could not be predicted based on its current and past values. Therefore, equation (1) should hold for all *t*.

$$E(y_{t+1} \mid y_1,...,y_t) = y_t \quad (1)$$

Consequently, the development of time series y_t can be described as a random walk process in equation (2):

$$y_{t+1} = y_t + \varepsilon_t \quad (2)$$

Where y_t is a time series at its levels. Based on equation (2), the development of returns was presented in equation (3):

$$y_{t+1} - y_t = \varepsilon_t \quad (3)$$

Therefore, to validate EMH one can estimate specifications in equation (4) or (5). Afterward, in the case of market efficiency, statistical tests should confirm the hypothesis of $\rho = 1$ or $\rho - 1 = 0$.

$$y_{t+1} = \rho \cdot y_t + \varepsilon_t \quad (4)$$

$$y_{t+1} - y_t = (\rho - 1) \cdot y_t + \varepsilon_t \quad (5)$$

When statistical tests confirm the hypothesis of $\rho = 1$ in a time series, the stochastic process is called the unit root process, and a time series embodies a stochastic trend. Econometric literature developed a range of different tests to validate the existence of unit root in a time series. However, contemporary econometric literature often points out the low power of the unit root test. To overcome the biasness of results from unit root tests, several unit root tests with different assumptions under null hypothesis were employed. Augmented Dickey–Fuller (1979) (ADF test), Phillips–Perron (1988) (PP test), the Generalized Least Squares and Dickey-Fuller test (DF-GLS) test from Elliot et al. (1996) (ERS test) and Kwiatkowski et al. (1992) (KPSS test) were considered. However, exchange rate series are well known for the phenomenon of clustering volatility often tested and confirmed using ARCH tests following (Engle, 1982). Therefore, the nature of exchange rate series might be nonlinear, and standard linear unit root tests might be inadequate. Recent empirical literature (Kuck et al., 2015; Kuck and Maderitsch, 2019) successfully implemented Quantile Autoregression (QAR) approach from Koenker and Xiao (2004, 2006) and revealed nonlinear and asymmetric nature of exchange rate returns development while Bošnjak et al. (2019) revealed properties of CDS returns. Following Koenker and Xiao (2004, 2006) autoregression coefficient $\alpha(\tau)$ in equation (6) is supposed to depend on sign and magnitude of endogenous shock $\varepsilon(\tau)$. Consequently, the autoregression coefficient $\alpha(\tau)$ is estimated for each of the observed quantile of endogenous shock $\varepsilon(\tau)$ following specification in equation (6):

$$Q_{y_t}(\tau \mid \Delta y_t) = \alpha(\tau) \cdot \Delta y_{t-1} + \varepsilon(\tau) \quad (6)$$

Where: $Q_{y_t}(\tau \Delta y_{t-1})$ corresponds to the τ-th conditional quantile of the observed series returns, $\varepsilon(\tau)$ presents τ-th quantile of a residual-term (ε_t) and $\alpha(\tau)$ denotes quantile (τ) dependent autoregressive coefficient. Therefore, the term $\varepsilon(\tau)$ illustrates the sign and magnitude of endogenous shocks, while the term $\alpha(\tau)$ shows its dependence structure suitable to judge on dependence structure or persistence of endogenous shocks depending on its sign and magnitude.

Research Data and Empirical Results

Data sample in this research consists of daily exchange rates for EUR/USD, EUR/JPY, EUR/GBP, EUR/EUD, EUR/CAD, EUR/CZK, EUR/DKK, EUR/HUF, PLN, EUR/SEK, EUR/NOK EUR/HKD, EUR/HRK, EUR/CNY, and EUR/RUB mid-exchange rates retrieved from European Central Bank (ECB). The daily exchange rates for EUR/HRK, EUR/CNY and EUR/RUB range from April first 2005 up to the end of April 2020 while data for all the other exchange rates under consideration range from January fourth 1999 up to the end of April 2020. Daily exchange rate series were observed in (natural) log values. An increase in the exchange rate presents an appreciation of the euro, and positive endogenous shocks indicate appreciation shocks. Correspondingly, a decrease in the exchange rate presents depreciation of the euro, and negative endogenous shocks indicate depreciation shocks. Hence, endogenous shocks within 0.10 quantile are considered as the highest euro depreciation shocks, while endogenous shocks above 0.90 quantile are considered as the highest euro appreciation shocks. Endogenous shocks around the median are considered endogenous shocks of the smallest magnitude, while other endogenous shocks are considered moderate in its magnitude. Following the methodological procedure, unit root tests were performed, and results were reported in Table 0-A in the Appendix. All of the employed unit root tests unambiguously indicate unit root existence in the exchange rate levels, while exchange rate returns being stationary. Therefore, the exchange rate tended to persist at its level, while exchange rate returns illustrated mean reverting property. However, mean reversion of exchange rate returns does not necessarily indicate the efficiency of the foreign exchange market. Figure 1 in the Appendix illustrates the empirical density function for each of the considered currency pairs. Empirical density function clearly illustrates excess kurtosis at point zero, indicating the departure of empirical distribution from normality while zero-returns of the exchange rate being highly likely. QAR approach is consistent with the empirical properties of exchange rate returns, and QAR estimates for fifteen currency pairs were examined. Table 1 summarizes estimates for EUR/CNY, EUR/USD, EUR/JPY, EUR/GBP, and EUR/HKD exchange rate returns.

As illustrated in Table 1, estimates for EUR/CNY, EUR/USD, EUR/GBP, and EUR/HKD exchange rate returns were martingales and fully in line with assumptions based on efficient market hypothesis. The linkage between past and current returns for these four currency pairs was not distinguishable from zero. However, the estimates for EUR/JPY exchange rate returns suggest some dependence between current and past returns. Negative endogenous shocks in EUR/JPY exchange rate returns of the highest magnitude were followed by negative returns. Therefore, depreciation of EUR against JPY was expected to last for some short period. As $\alpha(\tau)$ was a negative sign for endogenous shocks above the median, positive endogenous shocks were followed by negative endogenous shocks. Hence, the appreciation of EUR against JPY was followed by the depreciation of EUR against JPY. Furthermore, appreciation of higher magnitude was followed by the depreciation of higher magnitude since $\alpha(\tau)$ increases in its absolute values as the quantile increases. Table 2 presents estimates for EUR/AUD, EUR/CZK, EUR/DKK, EUR/HUF and EUR/PLN exchange rate returns.

Table 1. Euro returns against CNY, USD, JPY, GBP and HKD

Quantile	Estimates of (standard errors)				
	EUR/CNY	EUR/USD	EUR/JPY	EUR/GBP	EUR/HKD
0.10	-0.02052 (0.03108)	0.01063 (0.02601)	0.06935** 0.02804)	0.02859 (0.02123)	-0.00991 (0.02582)
0.20	-0.03427 (0.02272)	-0.01695 (0.02078)	0.04132** (0.01836)	0.00750 (0.01650)	-0.02208 (0.02110)
0.30	-0.03351 (0.01689)	-0.01720 (0.01484)	0.01815 (0.01506)	0.01491 (0.01490)	-0.01965 (0.01515)
0.40	-0.01853 (0.01626)	-0.01136 (0.01412)	-0.00073 (0.00811)	0.00159 (0.01294)	-0.01504 (0.01401)
0.50	-0.02968 (0.01474)	-0.01080 (0.01298)	-0.01102 (0.01262)	-0.00830 (0.01319)	-0.01169 (0.01246)
0.60	-0.01710 (0.01459)	-0.00843 (0.01310)	-0.02374* (0.01252)	0.00259 (0.01364)	-0.01178 (0.01337)
0.70	-0.01367 (0.01710)	0.00835 (0.01550)	-0.04059*** (0.01357)	0.01818 (0.01605)	0.00713 (0.01495)
0.80	-0.02798 (0.01904)	0.01101 (0.01971)	-0.04700*** (0.01619)	0.01230 (0.01833)	0.00508 (0.01982)
0.90	0.00670 (0.03056)	0.02201 (0.02650)	-0.07761*** (0.02207)	0.03183 (0.02549)	0.02302 (0.02677)

Source: Own estimates; Note: ***, ** and * denotes significance at levels of 1%, 5% and 10%, respectively

Following the results presented in Table 2, each currency pair exhibited some form of dependence structure between past and current returns. Estimates for EUR/AUD exchange rate returns suggested predictability of appreciation of EUR against AUD. Based on estimates from Table 2, euro appreciation of a higher magnitude is supposed to be followed by appreciation. In contrast, behaviour of EUR/AUD exchange rate returns after euro-depreciation and its appreciation of the smallest magnitude was not predictable. In the case of EUR/CZK exchange rate returns, there was predictable behaviour after endogenous shocks of smaller magnitude, either positive or negative. Positive endogenous shocks of smaller magnitude were followed by positive returns, while negative returns followed negative endogenous shocks of smaller magnitude. After sizable magnitudes of endogenous shocks in EUR/CZK exchange rate returns, either positive or negative, there was no predictability of the next returns. Estimates for EUR/DKK exchange rate returns indicate no predictability of returns after euro-appreciation shocks of small magnitude and euro-depreciation shocks of the highest magnitude. In all other cases, depreciation was expected to follow depreciation shocks, while appreciation was expected to follow appreciation shocks. In the case of EUR/HUF exchange rate returns, predictability of returns was identified after depreciation shocks of higher magnitude and appreciation shocks of the highest magnitude. After euro-appreciation, shocks of the highest magnitude followed further euro-appreciation, while euro-depreciation shocks of higher magnitudes were followed by euro-appreciation as well. Following dependence structure between past and current returns for EUR/PLN exchange rate returns, appreciation of EUR against PLN could be predictable after positive endogenous shocks of a certain level and after the highest negative shocks. After endogenous shocks of small magnitude, the next-day return was not predictable. Table 3 summarizes estimates for EUR/SEK, EUR/NOK, EUR/RUB, EUR/CAD and EUR/HRK exchange rate returns.

Table 2. Euro returns against AUD, CZK, DKK, HUF and PLN

Quantile	Estimates of (standard errors)				
	EUR/AUD	EUR/CZK	EUR/DKK	EUR/HUF	EUR/PLN
0.10	-0.00233 (0.02645)	-0.02430 (0.02729)	0.03040 (0.02424)	-0.05618** (0.02441)	-0.05016* (0.02636)
0.20	-0.02476 (0.01525)	0.00165 (0.01647)	0.03175* (0.01826)	-0.03897** (0.01669)	-0.02630 (0.01619)
0.30	-0.01242 (0.01449)	0.01694 (0.01228)	0.02936*** (0.01103)	-0.02168** (0.01030)	-0.02508* (0.01316)
0.40	-0.00741 (0.01301)	0.01801* (0.01041)	0.03220*** (0.00523)	-0.00252 (0.01077)	-0.01180 (0.01081)
0.50	0.00110 (0.01249)	0.02762*** (0.00669)	0.00000 (0.01089)	0.00397 (0.00793)	0.01071 (0.00968)
0.60	0.01512 (0.01311)	0.02770*** (0.01021)	0.00043 (0.00640)	0.01152 (0.01109)	0.01554 (0.01144)
0.70	0.03479** (0.01525)	0.03663*** (0.01226)	0.04190*** (0.01261)	0.01179 (0.01285)	0.02909** (0.01377)
0.80	0.04016** (0.01799)	0.02854 (0.01766)	0.05302*** (0.01687)	0.01475 (0.01593)	0.04259** (0.01930)
0.90	0.05334* (0.02739)	0.02108 (0.02936)	0.06341*** (0.02273)	0.06631** (0.03120)	0.05008** (0.02439)

Note: ***, ** and * denotes significance at levels of 1%, 5% and 10%, respectively.
Source: Own estimates

Findings

The EFA results revealed two findings. *First, t*ime risk items were linked to the underlying online purchase processes (to the delivery and after-sales processes). Respondents perceived the items measuring the time aspect as part of the underlying processes and not as a separate "time" risk factor.

Second, the "counterfeit product" risk dimension did not become part of the financial factor model as it did for example in the survey of Zhang et al. in 2012. Additionally, this item does not correlate with any other analysed risk items. Consumers struggle to assess product originality. Nevertheless, this is a decidedly important product characteristic, especially if the product is a special and expensive brand. This issue seems to matter to Hungarian respondents particularly. This concern is not only a Hungarian topic. There is a rising number of internationally developed methods and patents to fight the selling of counterfeit products, e.g. Blockchain-based applications for product anti-counterfeiting (Ma, Li, Chen, X., Sun, Chen, Y. & Wang, 2016), or use of authentication keys and authentication server (US Patent US10558979B2, 2020).

As illustrated in Table 3, each currency pair exhibited some dependence between past and current returns. Estimates for EUR/SEK exchange rate returns indicate predictability of euro appreciation after appreciation shocks of different magnitudes. There was no predictable depreciation neither behaviour of returns after any depreciation shocks of EUR against SEK. Therefore, EUR/SEC exchange rate returns exhibited asymmetries in their behaviour. In the case of EUR/NOK exchange rate returns. Appreciation of EUR against NOK was predictable after endogenous shocks of high magnitude, either positive or negative. Depreciation of EUR against NOK was not predictable, neither exchange rate returns after endogenous shocks of small magnitude. EUR/RUB exchange rate returns were predictable across quantiles except the two lowest. Appreciation of EUR against RUB was predictable after appreciation endogenous shocks at any quantile. Depreciation EUR against RUB was predictable as well, but not at the two highest quantiles of depreciation endogenous shocks. Predictable appreciation of EUR followed its appreciation endogenous shocks and predictable depreciation of EUR followed its depreciation endogenous shocks. Estimates for EUR/CAD and EUR/HRK exchange rate returns supported efficient market hypothesis across all quantiles except one quantile for each currency pair. Therefore, EUR/CAD and EUR/HRK exchange rate returns can be considered as almost efficient.

Implications and Discussion

Kuck et al. (2015) employed a quantile autoregression approach and following Baur (2013) and Brunnermeier et al. (2008), recognized currencies as funding or investment against US dollar. Research results from this paper suggest that four out of fifteen considered currency returns were entirely in line with the efficient market hypothesis, namely EUR/CNY, EUR/USD, EUR/GBP and EUR/HKD exchange rate returns. EUR/CAD and EUR/HRK exchange rate returns were found as almost in line with the efficient market hypothesis and not worth of special attention from traders.

Table 3. Euro returns against SEK, NOK, RUB, CAD and HRK

Quantile	Estimates of (standard errors)				
	EUR/SEK	EUR/NOK	EUR/RUB	EUR/CAD	EUR/HRK
0.10	-0.03391 (0.02275)	-0.09682*** (0.01990)	-0.02532 (0.02571)	-0.03856 (0.02667)	-0.00947 (0.02400)
0.20	-0.01689 (0.01871)	-0.03858** (0.01633)	-0.00817 (0.01597)	-0.03598* (0.01849)	-0.00473 (0.01921)
0.30	0.00360 (0.01572)	-0.02532* (0.01383)	0.03237*** (0.01065)	-0.01607 (0.01548)	0.01676 (0.01411)
0.40	0.01487 (0.01394)	-0.01613 (0.01188)	0.03827*** (0.01089)	-0.01446 (0.01357)	0.01622 (0.01071)
0.50	0.02600* (0.01329)	0.00415 (0.01153)	0.06462*** (0.00990)	-0.01901 (0.01327)	0.00000 (0.00816)
0.60	0.01546 (0.01352)	0.01097 (0.01208)	0.07447*** (0.01013)	-0.02030 (0.01424)	0.01011 (0.01145)
0.70	0.01765 (0.01441)	0.03744*** (0.01451)	0.08997*** (0.01178)	0.00026 (0.01547)	0.03132** (0.01354)
0.80	0.03597** (0.01741)	0.04526** (0.02063)	0.11038*** (0.01543)	0.01072 (0.02064)	0.02615 (0.02045)
0.90	0.05460** (0.02532)	0.08531*** (0.02474)	0.14544*** (0.03089)	0.03692 (0.02523)	0.00909 (0.03743)

Note: ***, ** and * denotes significance at levels of 1%, 5% and 10%, respectively.
Source: Own estimates

However, for nine of the fifteen considered currencies, there could be some profitable trading strategies. Firstly, there was significant predictability of EUR/JPY exchange rate returns. Appreciation of EUR against JPY was followed by its depreciation and the depreciation of EUR against JPY was followed by the depreciation of EUR against JPY. Therefore, there was the predictability of EUR depreciation against JPY and in this case, JPY can be identified as an investment currency only. Due to the negative $\alpha(\tau)$coefficient for EUR depreciation of the high magnitude, the active trading strategy should be involved after EUR appreciation comparing to the case of EUR depreciation against JPY. EUR/HUF, EUR/PLN and EUR/NOK exchange rate returns exhibited similar dependence structure. After depreciation of EUR against these three currencies followed its predictable appreciation. Furthermore, the appreciation of EUR against these three currencies was predictable after the depreciation of EUR as well. Hence when considering these three currency pairs HUF, PLN and NOK could be considered as funding currencies only and a more active trading strategy should be in place after euro-depreciation endogenous shocks. AUD and SEK were found as funding currencies as well. However, appreciation of EUR against these two currencies was predictable after endogenous shocks of EUR appreciation only. Depending on the sign and magnitude of endogenous shocks, CZK, DKK and RUB were identified as both, investment and funding currencies. However, EUR/CZK exchange rate was more appropriate during calm periods of small endogenous shocks. Depreciation of EUR against CZK was followed after small depreciation shocks making CZK a suitable investment currency. Similarly, appreciation of EUR against CZK was followed after small appreciation shocks making CZK a suitable funding currency. DKK and RUB should be considered as investment and funding currencies. However, there were more opportunities for these two currencies to serve as investment currencies, particularly during periods of endogenous shocks of high magnitude or dynamic period on foreign exchange markets. Even though sources of foreign exchange market inefficiencies are beyond the scope of this research, to contextualize research findings from this paper, some facts are worth of mentioning. Research results from this paper provided different dependence structure of returns for different currency pairs. Therefore, it is reasonable to assume that there are various sources of inefficiency to be investigated. The sources of inefficiency might be examined within theories of exchange rate determination. Engel et al. (2018) identified inflation rate while not interest-rate differential as a predictor of changes in U.S. dollar exchange rates. Therefore, there might be market inefficiency of adjusting the exchange rate to the inflation rate while Purchasing Power Parity (PPP). A currency of a country might appreciate after an increase of its interest rate. Hence, Uncovered Interest Parity (UIP) might be another theory that provides a possible explanation. While examining the efficiency of the Korean foreign exchange market, Kang (2019) pointed out risk premia in the international financial market and of central bank interventions as the main drivers of foreign exchange market inefficiencies. Levich et al. (2019) suggested that after the financial and economic crises from 2008 foreign exchange market became more efficient and inefficiency was related to emerging market currencies. Findings from Levich et al. (2019) might be understood in the context of excess liquidity that emerged as a consequence of reaction from central banks to the crisis. Therefore, liquidity constraints might be related to foreign exchange market inefficiency as well. However, sources of inefficiency for currency pairs considered in this paper remain to be examined in further research.

Conclusions

Several conclusions can be drawn the research presented in this paper. Firstly and consistently with the existing body of literature, research findings from this paper suggested that empirical properties of foreign exchange rate series depart from normality. Secondly, the quantile autoregression approach is well suited to capture empirical properties of exchange rate series and reveal a specific form of dependence structure between current and previous returns for different sign and magnitude of endogenous shocks. Thirdly, in line with the efficient market hypothesis, six out of fifteen currency pairs exchange rate returns were found non-predictable or almost non-predictable. In the case of nine considered currency pairs there was a significant linkage between current and past exchange rate returns that was found to depend on the sign and magnitude of endogenous shocks in exchange rate returns. Some profitable trading strategies were suggested based on the structure of dependence between current and previous returns found in this paper. In the case of trading with EUR/JPY, JPY should be considered only as an investment currency, while more active trading strategies should be in place after EUR appreciation comparing to the case of EUR depreciation against JPY. HUF, PLN and NOK could be considered as funding currencies only and more active trading strategy should be involved after euro-depreciation endogenous shocks. AUD and SEK should be considered funding currencies, while CZK, DKK and RUB could be considered investment and funding currencies. Empirical findings from this paper suggest that the foreign exchange market efficiency depends on a currency pair in the first place. Depending on currency pairs, inefficiencies appeared across different quantiles of endogenous shocks suggesting various potential sources of foreign exchange market inefficiencies. Further research might be directed towards sources of foreign exchange inefficiencies and consider specific effects like market liquidity. Further research might also address foreign exchange market efficiency for specific time periods.

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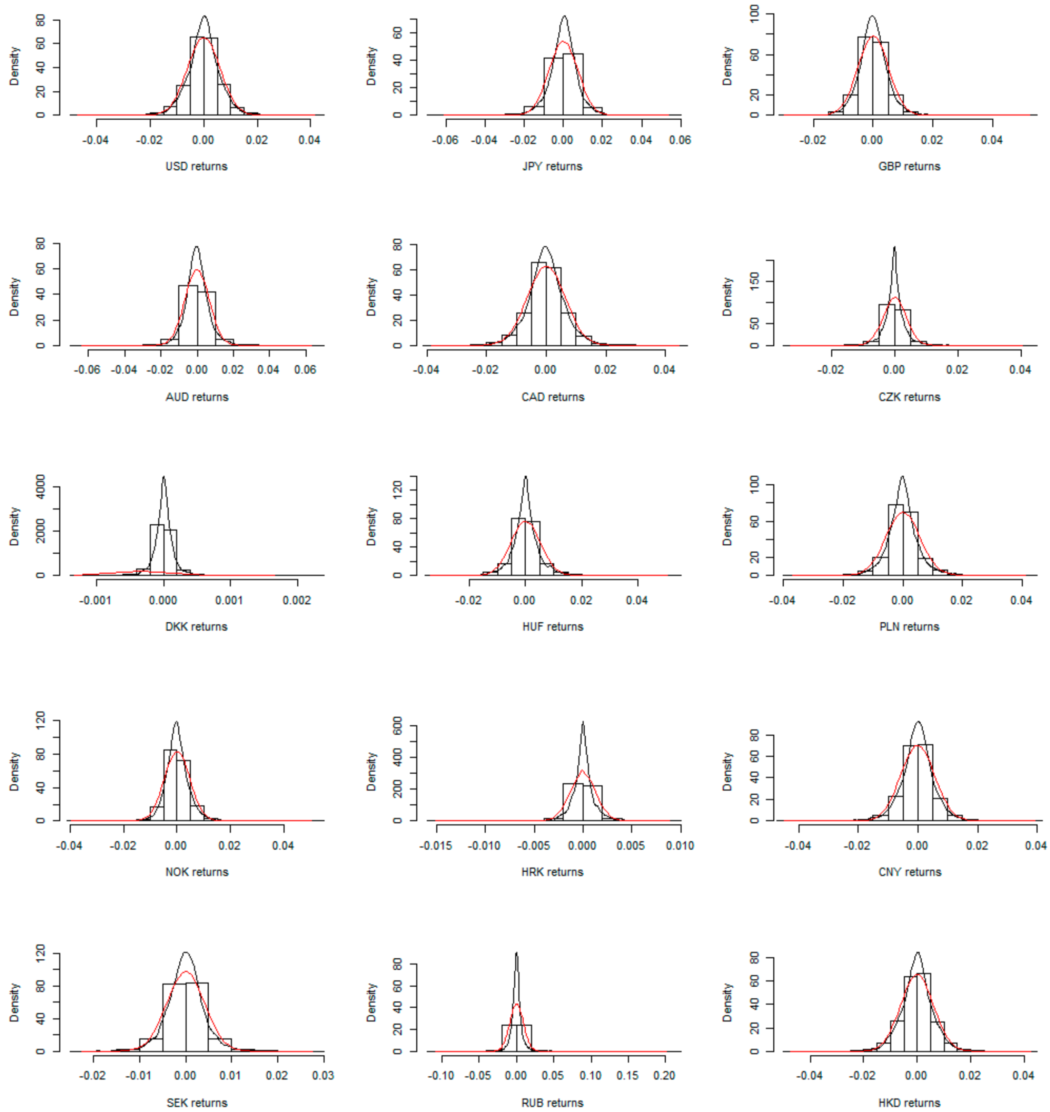
Appendix

Table A. Unit root test results

Currency pair		ADF test	PP test	KPSS test	ERS test
EUR/USD	In levels	-1.492908	-1.479215	1.835449	-1.531169
	In first differences	-74.06045	-74.06285	0.092588	-73.82070
EUR/AUD	In levels	-2.657189	-2.647104	0.763090	-2.037184
	In first differences	-72.06848	-72.05835	0.037617	-3.762704
EUR/CUD	In levels	-3.992422	-3.926264	0.434773	-1.884410
	In first differences	-73.88933	-73.96224	0.039235	-71.71690
EUR/CZK	In levels	-1.478668	-1.512645	1.905751	-1.335231
	In first differences	-73.38142	-73.38485	0.038226	-4.460989
EUR/DKK	In levels	-4.104789	-3.934646	0.172070	-3.753606
	In first differences	-70.54209	-70.53090	0.019467	-8.063880
EUR/GBP	In levels	-2.796410	-2.754517	0.804253	-1.942399
	In first differences	-71.97012	-71.99930	0.070024	-69.73873
EUR/HKD	In levels	-1.473057	-1.470299	1.820727	-1.524046
	In first differences	-74.10288	-74.10497	0.091604	-73.84312
EUR/HUF	In levels	-4.143357	-3.798491	0.961985	-3.307227
	In first differences	-73.45379	-74.00907	0.013890	-9.846900
EUR/JPY	In levels	-2.135897	-2.095066	0.745905	-2.047637
	In first differences	-74.54041	-74.56018	0.064438	-2.503096
EUR/NOK	In levels	-2.269483	-2.250473	1.237134	-1.054403
	In first differences	-73.95505	-73.97203	0.032424	-2.555699
EUR/PLN	In levels	-3.160395	-3.078826	0.323370	-3.032678
	In first differences	-53.38697	-72.45319	0.025380	-2.782901
EUR/SEK	In levels	-2.715647	-2.509558	0.623982	-2.091403
	In first differences	-73.34194	-73.69031	0.046746	-3.183294
EUR/CNY	In levels	-2.540774	-2.529852	0.694431	-2.430713
	In first differences	-62.96893	-62.96882	0.031843	-6.704023
EUR/HRK	In levels	-2.951178	-2.789143	0.961775	-2.560812
	In first differences	-32.83798	-63.76806	0.046523	-29.41636
EUR/RUB	In levels	-2.484858	-2.645928	0.661083	-1.757228
	In first differences	-33.84804	-56.88094	0.045820	-6.316480

Source: Own estimates

Figure 1. Empirical density function for exchange rate returns



Source: Own estimates

Tržna učinkovitost deviznih tečajev evra in trgovalne strategije

Izvleček

Ta članek preverja hipotezo o tržni učinkovitosti na donose evra v primerjavi s petnajstimi valutamami z domnevo o predvidljivosti donosov, odvisnih od predznaka in jakosti endogenih šokov. Upoštevajoč značilnosti donosov deviznega tečaja smo v empirični analizi izbrali avtoregresijski pristop s kvantili. Na osnovi vzorca raziskovalnih podatkov, sestavljenega iz dnevnih deviznih tečajev v obdobju od 1. januarja 1999 do 30. aprila 2020, članek nakazuje dobičkonosne trgovalne strategije v odvisnosti od para valut. V primeru šestih izmed petnajstih parov valut so se donosi na devizne tečaje izkazali kot nepredvidljivi ali skoraj nepredvidljivi. V primeru devetih upoštevanih parov valut je obstajala znatna povezava med aktualnimi in preteklimi donosi na devizne tečaje, za katero smo ugotovili odvisnost od predznaka in jakosti endogenih šokov v donosih na devizni tečaj. Ob koncu članek obravnava možne dejavnike neučinkovitosti in predlaga nadaljnje raziskave obravnavane teme.

Ključne besede: avtoregresija s kvantili, tržna učinkovitost, devizni tečaj, evro