Central European Foreign Exchange Markets

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PREFACE

This monograph consists of three essays on new EU foreign exchange markets (FX), i.e. the Czech koruna, Polish zloty and Hungarian forint. In the first two essays, the impact of foreign macroeconomic news announcements and central banks' monetary policy settings on the value and volatility of examined exchange rates is analyzed. In the third chapter, the conditional comovements and volatility spillovers on new EU FX markets is examined. The aim of this monograph is to contribute to the existing empirical literature by providing new evidence of the examined currencies during periods, which have not been examined yet (after the Global financial crisis (GFC), during the EU debt crisis and during currency interventions in the Czech Republic).

The first essay (Chapter 2) examines the impact of Eurozone/Germany and US macroeconomic news announcements and monetary policy settings of the ECB and the Fed on the value of new EU member states' currencies. It is a complex analysis of 1-minute intraday dataset performed by event study methodology (ESM). We observe different reactions of exchange rates in pair with the US dollar on the US macroeconomic announcements and Euro-expressed FX rates on Germany macro news during the EU debt crisis and after it. We also provide evidence of leaking news, showing that FX markets react even before the news is announced.

The second essay (Chapter 3) analyses the impact of German macroeconomic news announcements and ECB meeting days on the conditional volatility of the Czech, Polish, and Hungarian foreign exchange markets over six years (2010–2015) by employing EGARCH model. The analysis shows that new EU FX rates react differently to news coming from US and Germany/Eurozone.

The third essay (Chapter 4) analyzes time-varying exchange rate comovements, hedging ratios and volatility spillovers on the new EU forex markets during 1999M1-2018M5. We find significant differences in the extent of currency comovements during various periods of market distress that are related to real economic and financial events. This implies favorable diversification benefits; the hedge-ratio calculations show all three currencies bring hedging benefits during crisis periods, but at higher costs. During calm periods, most of the volatilities are explained by own-currency volatility. During the distress periods, volatility spillovers among currencies increase substantially and the Hungarian currency takes a leading role in transmission mechanism.

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Acronyms

ARCH	Autoregressive Conditional Heteroscedasticity
APP	Asset Purchase Program
AR	Autoregression
bn.	Billion
CAR	Cumulative average residual method
CEE	Central and Eastern Europe
CMRM	Constant Mean Return Model
CNB	Czech National Bank
CZK	Czech koruna
DCC	Dynamic Conditional Correlation
DY index	Diebold and Yilmaz's spillover index
ECB	European Central Bank
EGARCH	Exponential General Autoregressive Conditional Heteroscedasticity
EU	European Union
EUR	Euro
FDI	Foreign Direct Investments
FOMC	Federal Open Market Committee
ESM	Event Study Methodology
Fed	Federal Reserve System
FGS	Funding for Growth Scheme
FX	Forex Exchange
GARCH	Generalized Autoregressive Conditional Heteroscedasticity
GFC	Global Financial Crisis
HUF	Hungarian forint
IMF	International Monetary Fund
LM	Lagrange Multiplier
MNB	Hungarian National Bank
NBP	National Bank of Poland
QE	Quantitative Easing
PLN	Polish zloty
TGARCH	Threshold Generalized Autoregressive Conditional Heteroscedasticity
US	The United States of America
USD	US dollar
VAR	Vector Autoregression
ZIRP	Zero lower bound interest rate parity

1 Introduction

The foreign exchange (FX) market is the largest and the most actively traded financial market in the world. FX spot and OTC derivatives markets averaged US$5.1 trillion per day, which exceeded the global equity trading volume by 25 times in 2016 (BIS, 2016). Comparison of FX and Nasdaq's daily trading volume shows, that FX market outpaces Nasdaq stock exchange by more than 41 times.[1] The robust FX market's liquidity allows traders to enter and exit position easily, handling even large trading volumes without significant price movements. FX market's high liquidity is also supported by flexible opening hours. This decentralized market is opened 24 hours a day, 5 days a week. Therefore, FX traders can react immediately to domestic and global economic events at the time of occurrence. Neely and Dey (2010) show that the world forex market is responsive to a vast amount of information in the form of macroeconomic and monetary news.

Developments in macroeconomic fundamentals are extensively evidenced to be quite important for exchange rate movements (Cavusoglu, 2011) and specifically macroeconomic news releases were shown to have produced about 15 percent of exchange rate variation (Laakonen, 2007). The available evidence is mostly based on developed markets, limited sets of news and the pre-2008 crisis period. Emerging markets, the post-crisis period, and other techniques are much less explored. There is evidence demonstrating that foreign macroeconomic news announcements have a greater impact on emerging financial markets than domestic news. For instance, Andritzky et al. (2007) show that domestic news has a limited impact on bond spreads in several emerging markets, whereas changes in US interest rates exert a significant influence there.

Foreign exchange (FX) market is the corner stone of international trade and global investing. Unstable and volatile currencies, which may lose their purchasing power during turbulent periods rapidly, are less attractive for risk averse investors, who prefer storing their money in value-preserving assets. Recognizing safe haven assets (currencies) is critical for financial risk management and risk reduction in terms of portfolio diversification (Nguyen and Liu, 2016). Reasonably, currencies with tendency to appreciate are preferred and experience the inflow of capital. The FX rate influences the

[1] Daily trading volume averaged close to US$122.6 billion during the May 6-10, 2019 on Nasdaq (https://www.nasdaqtrader.com/Trader.aspx?id=DailyMarketSummary)

price of exported and imported goods and services. Generally speaking, stronger currency decreases the competitiveness of domestic companies. Import tends to rise due to lower prices of imported goods and services and export has tendency to fall, because of a rise in relative prices. Fall in export and rise in import leads to decline in foreign trade and drop in GDP. Likewise, FX market plays an essential role in consumer price inflation, especially in open economies. Basically, FX rate affects the prices of imported goods, services and due to competitive pressure also prices of domestic goods and services. The Czech National Bank (CNB) monitored this relationship. In order to achieve inflation target and price stability, it set a maximum value of CZK against EUR at the level of 27.00 on November 7, 2013. The Czech National Bank kept the exchange rate commitment up to April 6, 2017.

In 3 essays, we examine the new EU FX markets (the Czech Koruna, Polish zloty, Hungarian forint), which are less explored in the literature even though, they are quite important for diversifying mutual and hedge fund portfolios that are primarily domiciled in developed markets (Jotikasthira et al., 2012). All three countries (The Czech Republic, Poland and Hungary) were part of the largest EU expansion in 2004. In that time, 10 countries from the Central and Eastern Europe joined European Union and political divisions between east and west Europe was declared and healed. Later, 6 out of 10 new member countries joined Eurozone. However, the Czech Republic, Poland and Hungary kept their own currencies. For this reason, we can analyze the impact of German, Eurozone and US macroeconomic news announcements and central banks' meeting days on the value and conditional variance of new EU FX rates. We also examine new EU FX rates comovements with the world forex market and volatility spillovers on these markets. Our analyses are performed during specific events such as the Global financial crisis (GFC), EU debt crisis and after them.

In the first essay (Chapter 2) on the Intraday Effect of News on Emerging European Forex Markets: An Event Study Analysis we examine the impact of Germany/Eurozone and US macroeconomic news announcements and changes in the ECB and Fed monetary policy settings on the value of the CZK/EUR, PLN/EUR, HUF/EUR, CZK/USD, PLN/USD, HUF/USD.

Literature analyzing the new EU markets based on an empirical exploration of intraday data is scare. Hanousek et al. (2009) study the reaction of asset prices to macroeconomic announcements in Hungary, the Czech Republic, and Poland using

intraday data. They find that the Czech stock market is impacted more by US macroeconomic announcements than by EU ones, while the opposite is true for the Hungarian and Polish stock markets. Continuing this line of research, Hanousek and Kočenda (2011) suggest that the Czech, Hungarian, and Polish stock markets have significant responses to EU macroeconomic news, but not to US macroeconomic news. Buttner et al. (2012) analyze the same set of markets during 1999–2006 and find that the impact of EU news dominates the impact of US news on all three markets. The above evidence centers on stock markets. New EU country forex markets' responsiveness to incoming information are analyzed by Égert and Kočenda (2014). They show that the Czech, Hungarian, and Polish currencies react to macroeconomic news in an intuitive manner corresponding to exchange rate-related theories. However, while before the crisis the number of macroeconomic news releases affect forex market reactions, during the crisis the relationships break down and the currencies react only to news on the key economic indicator (real GDP growth).

We employ Event Study Methodology (ESM) to analyze intraday one-minute data from January 1999 to May 2018. ESM allows us to focus on specific events isolated form other disturbances affecting the financial market during the day and helps us to identify temporary market inefficiencies on the examined currency markets. The first sample covers the period prior to the GFC (1999-2008), the second reflects the GFC itself (2008-2010) and the third covers the European debt crisis (2010-2012). The last portion of the data reflects the period during which both crises were subdued (2012-May 2018).

The aim of the essay is to bring complex and detailed analysis of foreign macroeconomic news and central banks' announcements (ECB, Fed) impact on the value of new EU FX rates. We distinguish the origin of the news (Germany/Eurozone or US), the qualitative character of the news (good, bad, neutral), the period during the GFC, EU debt crisis and non-crises periods offering complex reaction of the new EU FX rates minute by minute.

We bring the novelty to the literature by (i) exploring an under-researched segment of the emerging European forex market (ii) we examine the post-GFC period, which has not been examined yet (iii) employing ESM, which brings detailed minute by minute overview of new EU FX market reaction to large set of foreign macroeconomic news and changes in ECB and Fed monetary policy settings.

This essay shows that the values of statistically significant abnormal returns of euro-expressed exchange rates are smaller, occur less often, and last for a shorter time than for US dollar-expressed exchange rates. Examining the whole time period (1999-May2018), we can observe that new EU exchange rates react differently to good US and German/Eurozone macroeconomic news. The Czech koruna, Polish zloty and Hungarian forint appreciate against the euro after positive German/Eurozone macroeconomic news is released. On the other hand, new EU currencies depreciate after better than expected US news is announced. Going to the detail, we notice diverse dynamics for the US dollar-expressed exchange rate returns during the EU debt crisis. Concerning ECB and Fed monetary policy settings, the ECB monetary decisions matter the most for the CZK/EUR and the least for HUF/EUR. On the other hand, the Czech koruna (CZK/USD) does not show any reaction to the monetary changes provided by Fed. However, the Polish zloty and the Hungarian forint depreciate after the Fed loose monetary policy.

This essay is published in Economic Systems (Kočenda, E., Moravcová, M. (2018). Intraday effect of news on emerging European forex markets: An event study analysis. Economic Systems, 42(4), 597-615).

In the second essay (Chapter 3) titled The impact of German macroeconomic news on Emerging European market, we focus on the impact of German macroeconomic news announcements and ECB monetary policy meetings days on the conditional volatility of the Czech koruna, Polish zloty and Hungarian forint as proxied by daily returns of CZK/EUR, PLN/EUR, and HUF/EUR exchange rate returns after Global financial crises (2010–2015). In contrary to the first essay, the impact of foreign news announcement on the conditional volatility is analyzed.

The volatility of the exchange rate can either be higher or lower on the day of new information release. Ederington and Lee (1995) show higher US exchange rate volatility on the days of US macroeconomic news release. An increased volatility may be due to higher uncertainties created by news. On the other hand, Fišer and Horváth (2010) find that Czech macroeconomic data announcements have a calming effect on CZK/EUR conditional volatility. They claim that there is higher uncertainty in emerging markets before news release. New information about the economy is likely to have calming effect on the markets.

Many authors suggest that news from the largest economies has significant effects on emerging markets assets. For example, Cakan et al. (2015) show that positive US news

decreases the volatility of emerging stock markets and contributes to the stability of many emerging stock markets. Examining emerging markets, particularly the new EU markets, Égert and Kočenda (2014) analyze the impact of local macroeconomic news releases on new EU currencies. Büttner et al. (2012) investigate the effects of euro area and US macroeconomic news on new EU markets and find that after the Copenhagen Summit, the importance of EU news for the Czech, Hungarian and Polish financial markets increase. On the other hand, US news has a significant impact only on the Hungarian money market.

Germany is the biggest economy of the Eurozone and close trade partner for all examined countries. Therefore, we expect that "surprise element" related to the German news announcements will be reflected in conditional volatility of new EU exchange rates. We also examine the impact of ECB meeting days on the conditional volatility of new EU FX markets. The exponential generalized autoregressive conditional heteroscedasticity (EGARCH) model is employed.

The main contribution of this essay is that it brings recent evidence of macroeconomic news announcements on the conditional volatility of the new EU exchange rates after the GFC. Also, we bring the new insight into the research of macroeconomic news impact on the new EU FX market analyzing the period of currency interventions. The Czech National Bank (CNB) launched forex interventions on November 7, 2013 and used them until April 6, 2017. The central bank prevented the koruna from excessive appreciation below CZK 27/EUR by intervening in the forex market.

The comprehensive analysis of German macroeconomic news announcement and ECB meeting days shows the following results; (i) the Ifo index, Factory Orders increase and the PMI index from the Service sector, the labor market data decrease conditional volatility of PLN/EUR. (ii) the Ifo index and Industrial Production increase conditional volatility of HUF/EUR on the day of the announcement. (iii) data from the labor market has a calming effect on CZK/ EUR during the period of currency interventions. (iv) the Ifo index increases and the PMI index from the Manufacturing sector decreases conditional volatility of CZK/EUR before currency interventions were introduced (2010–11/2013). (v) ECB meeting days do not influence new EU FX rates' conditional volatility.

The second essay is published in Prague Economic Papers (Moravcová, M. (2018). The impact of German macroeconomic news on Emerging European market. Prague Economic Papers, 27(5), 505–521).

In the third essay (Chapter 4) titled Exchange rate comovements, hedging and volatility spillovers on new EU forex markets we again examine new EU FX markets (CZK/EUR, PLN/EUR and HUF/EUR) in terms of time-varying exchange rate comovements and volatility spillovers with the USD/EUR.

In the literature, numerous studies have examined co-movements and volatility spillovers in forex markets. However, most of them focus on developed markets. For example, Inagaki (2007) examines the connectedness between the British pound and the euro. His findings support unidirectional volatility spillover from the euro to the British pound. McMillan and Speight (2010) analyze interdependencies and volatility spillovers in the US dollar, Japanese yen and British pound. They claim that news affecting the US dollar account for as much as 30% of the movement in sterling and yen returns.

Emerging markets, and especially new EU exchange rates, are under researched. Bubák et al. (2011) analyze the dynamics of volatility transmission to, from and among the Czech, Hungarian and Polish currencies, together with the US dollar for the period of 2003- 2009. They find that each new EU currency is characterized by a different volatility transmission pattern. Pramor and Tamirisa (2006) examine volatility trends in the 5 Central and Eastern European currencies. Their results suggest that these trends are closely correlated, although to a lesser degree than the major European currencies prior to the introduction of the euro. Hanousek et al. (2009) document the positive spillover effect from Frankfurt stock exchange to Prague stock exchange. Andrieş et al. (2016) investigate exchange rates in Central and Eastern European countries via a wavelet analysis. They find a high degree of co-movements in short-term fluctuations among the exchange rates of the Czech Republic, Poland and Hungary.

In this essay we analyze the extent and evolution of interdependencies and connectedness on the new EU forex markets. Based on the Dynamic Conditional Correlation (DCC) model developed by Engle (2002), we analyze the degrees and dynamics of co-movements among currencies. We analyze volatility spillovers using a generalized version of Diebold and Yilmaz's (2012) spillover index (DY index). Our analysis is performed on daily data running from 1999 to May 2018. Our dataset is divided into four subsamples. The first sample covers the period prior to the GFC (1999-2008), the

second reflects the GFC itself (2008-2010) and the third covers the European debt crisis (2010-2012). The last portion of the data reflects the period during which both crises were subdued (2012-May 2018).

The aim of this essay is to analyze the degrees and dynamics of co-movements among currencies. The assessment of time variations in the correlations between different assets has critical inference for asset allocation and risk management because weak market linkages offer potential gains from international diversification (Singh et al., 2010). We use conditional variances and covariances estimated from the DCC model to compute hedge ratios and portfolio weights of individual currencies in an optimal portfolio. Further, we examine the extent and nature of volatility spillovers in new EU forex markets. This is performed because volatility and its spillovers across currencies may exacerbate nonsystematic risk that diminishes the gains from international portfolio diversification (Kanas, 2001).

We bring the main findings; (i) conditional correlations between new EU currencies and the USD/EUR change over time. They reach the lowest values during the distressed periods of the GFC and the EU debt crisis suggesting appropriate characteristics for international portfolio diversification. However, our analysis shows that these favorable diversification benefits come at higher costs up to 75 percent. (ii) the analysis of volatility spillovers shows that own-currency volatility spillovers dominate the market. Though, cross-currency volatility raises in turbulent periods. Hungarian forint is the dominant currency of the volatility transmission mechanism. The total volatility spillover index reaches the highest values during the GFC, EU debt crisis and after the US president Donald Trump withdrew the US from NAFTA agreement in 2017. At that time the USD/EUR became the source of volatility to new EU currencies. (iii) the Czech koruna was volatility receiver during the intervention period. Though, it became the source of volatility after the central bank terminated currency interventions in 2017. Also, the end of currency interventions led to currency appreciation and consequently, its optimal weight in currency portfolio declined.

The last essay is published in Journal of International Financial Markets, Institutions & Money (Kočenda, E., Moravcová, M. (2019). Exchange rate comovements, hedging and volatility spillovers on new EU forex markets. Journal of International Financial Markets, Institutions and Money, 58, 42-64).

Overall, this monograph provides deep insight into the new EU FX markets functioning. The monography shows the evidence that foreign macroeconomic news and foreign central banks monetary decisions influence both the value and the conditional volatility of new EU FX markets. Therefore, investors and policymakers should consider both local and developments outside small open economies in forecasting techniques and decision-making process. However, the origin of the news matters. We show that abnormal returns after US news are larger than after Germany/Eurozone news. Also, the new EU FX markets react differently to US news during and after EU debt crisis. The linkages between new EU FX markets and world forex market presented by conditional correlations are not stable in time and decay during turbulent periods. This attribute is beneficial for investors, who search for diversification opportunities. New EU FX markets are part of the world forex market therefore, they are not isolated from volatility spillovers. We assess volatility and new EU forex markets interdependencies with the world forex market via DY spillover index. In terms of volatility transmission, the own-currency volatility explains a substantial share of volatility spillovers in the examined markets. On the other hand, volatility spillovers between currencies considerably increase during the GFC.

2 Intraday Effect of News on new European Forex Markets: An Event Study Analysis

We analyze the impact of German/Eurozone and US macroeconomic news announcements and the change in the monetary policy settings of the ECB and the Fed on the new EU forex markets. We employ an event study methodology to analyze intraday data from 2011–2015. Our comprehensive analysis of the wide variety of macroeconomic information during the post-GFC period shows that: (i) macroeconomic announcements affect the value of the new EU country exchange rates, (ii) the origin of the announcement matters, (iii) the type of announcement matters, (iv) different types of news (good, bad or neutral) result in different reactions, (v) markets react not only after the news release but also before, (vi) when the US dollar is the base currency the impact of the news is larger than in the case of the euro, (vii) announcements on ECB monetary policy result in stronger effects than those of the Fed, (viii) temporary inefficiencies are present in new EU country forex markets, (ix) new EU country exchange rates react differently to positive US news during the EU debt crisis compared to the rest of the period.

2.1 Introduction and literature

The world forex market is responsive to a vast amount of information in the form of macroeconomic and monetary news as surveyed by Neely and Dey (2010). News originating in large economies is empirically shown to matter most. Faust et al. (2003), Andersen et al. (2003) and Chaboud et al. (2004) evidence the importance of US news releases. Ehrmann and Fratzscher (2005), Cakan et al. (2015) and Gilbert et al. (2016) show that both US and European news releases have significant effects on pricing on forex markets and on financial markets in general (for recent evidence on other classes of assets see for example Savor and Wilson, 2013; or Lucca and Moench, 2015).

There is also similar recent evidence on the impact of news on emerging (financial) markets (Andritzky et al., 2007; Fedorova et al., 2014) including emerging European markets (Hanousek et al., 2009; Hanousek and Kočenda, 2011; Büttner et al., 2012). That evidence centers chiefly on stock markets, though.

We analyze how the emerging European forex markets react to foreign macroeconomic news and the monetary policy settings of the major central banks. Developments in macroeconomic fundamentals are evidenced to be quite important for

exchange rate movements (Cavusoglu, 2011). Their effects on exchange rates materialize via macroeconomic news (Andersen et al., 2003), whose releases produce substantial exchange rate variation (Fratzscher, 2006; Laakonen, 2007). The available evidence comes mostly from developed markets (Neely and Dey, 2010), while emerging markets are much less explored and the evidence from emerging European forex markets is downright scarce. This is quite surprising because new European Union (EU) markets are documented to be quite important for international portfolio diversification (Jotikasthira et al., 2012; Wang and Bilson, 2017).[2] Further, while the effects of news on mature forex markets are well established, the potential reaction of the new EU currencies to foreign macro news might be less than obvious; their reaction to shocks in the US dollar varies greatly (Orlowski, 2012), but at the same time there exist positive and increasing co-movements between the euro and the new EU currencies (Orlowski, 2016).

Analyses of how macroeconomic and monetary news impact the emerging European forex markets are rare. Scalia (2008; p. 544) finds only a weak effect of public news on the Czech koruna (CZK) exchange rate but suggests to analyze "the distinct news items and their 'surprise' component". Further, Égert (2007) uses event study methodology to show that central bank interventions coupled with communications (and backed by interest rate news) have a significant effect on the exchange rate of the Czech, Hungarian and Polish currencies. A more detailed exercise is conducted by Égert and Kočenda (2014), who analyze the new EU forex markets and divide their analysis into the pre-crisis (2004–2007) and crisis (2008–2009) periods. They show that before the crisis several types of macroeconomic news impact forex markets, but during the crisis the relationships break down and the currencies react only to news on the key economic indicator (real GDP growth) and do not react to other macro announcements. Authors explain this break down in the market response by the character of the crisis, i.e., investors focus mainly on the fundamentals, which are strongly related to the economic downturn, e.g. GDP. Other macroeconomic indicators were overlooked at that time. The responsiveness of the currencies to central bank verbal interventions follows a slightly different pattern: exchange rate-related verbal communications of central banks matter

[2] According to Jotikasthira et al. (2012), new EU markets are important for the portfolio diversification of mutual and hedge funds domiciled mainly in developed markets. They show 270 active funds in the Czech Republic, 276 funds in Poland, and 295 funds in Hungary after the crisis. What is more important, these fund holdings account for 3.6% of the float-adjusted market capitalization in the Czech Republic, 8.6% in Hungary, and 4.7% in Poland; this is more than 2.6% of the average number of free-float market capitalization in 25 emerging markets examined by Jotikasthira et al. (2012). Wang and Bilson (2017) show that Eastern European emerging bond market returns exhibit low correlations with traditional fixed income investments and thus offer opportunities for portfolio diversification.

when markets experience high uncertainty (crisis), while during calmer days markets are less attentive. This is explained by the fact that central banks played a crucial role in ensuring economic and financial stability. In this respect Égert and Kočenda (2014) show that important news does not always produce significant effects on exchange rates. However, to the best of our knowledge so far there are no studies that analyze the impact of macroeconomic and monetary news on the emerging European forex markets after the 2007 crisis. Hence, it is legitimate to ask relevant questions arising with respect to the propagation of news in the new EU forex markets. Does specific news—in terms of type and quality—exhibit a markedly different impact? Is the impact dependent on the base currency? What is the duration of the impact? Are the new EU forex markets efficient when new information arrives?

We differentiate from the existing literature in that we explore an under-researched segment of the emerging European forex market during the post-crisis period. In this, we contribute to the literature in several ways. We analyze how three new EU currencies (the Czech koruna, Polish zloty and Hungarian forint) react to a large set of foreign macroeconomic news and changes in ECB and Fed monetary policy settings. Because of the underlying economic links between the new EU and old EU countries (Hayo et al., 2010) as well as with the US. We examine both Eurozone and US macroeconomic announcements and the exchange rates expressed with respect to the euro and the US dollar. Macroeconomic data are an important source of information not only for the actual state of real economies, but more importantly for their future prospects. For this reason, we examine both traditional macroeconomic announcements (GDP, Trade Balance, Industrial Production, Retail Sales, NFP, CPI, PPI and Core Durable Goods orders) and also forward-looking indicators on the economic climate and prospects (PMI, ZEW, and Ifo indices). We also assess the impact of the key monetary announcements as they are shown to be important on the forex market in general (Neely and Dey, 2010). Because the post-2008 period is not covered well, we employ intraday one-minute data and cover a relatively long post-crisis period of 2011–2015.

In terms of methodology, most of the related research employs a GARCH-type modeling approach. However, the vast amount of daily or even intraday data dwarf the relatively limited number of announcements and this disproportion makes this technique disadvantageous Rather we opt for the event study approach in order to accurately assess the “surprise component” of the qualitatively different good, bad and neutral news and

the effect of monetary policy settings on exchange rates. The technique is more suitable for our study because it enables targeting the effect of specific macro news as well as monetary announcements over a precisely defined time interval (Gürkaynak and Sack, 2005; Bredin et al., 2009; Wongswan, 2009; Rai and Suchanek, 2014).[3]

Our key results provide a comprehensive account of how new information entering the emerging EU forex markets propagate during the post-GFC period and can be summarized in the following points. We show that (i) macroeconomic announcements affect the value of the exchange rates of the new EU countries, (ii) the origin of the announcement matters, (iii) the type of the announcement matters, (iv) different types of news (good, bad or neutral) result in different reactions, (v) markets react not only after the news release, but also before, (vi) when the US dollar is a base currency, the impact of news is larger than in the case of the euro, (vii) announcements on ECB monetary policy result in stronger effects than those of the Fed, (viii) temporary inefficiencies are present on the forex markets of new EU countries, (ix) new EU country exchange rates react differently on positive US news during the EU debt crisis when compared to the rest of the period.

2.2 Data: sources, description and characteristics

We intentionally deviate from standard practice and introduce the data before outlining our methodology. The reason is that when we describe our use of event study methodology in Section 2.3 we need to refer to some specific details related to announcement releases.

2.2.1 Forex data

We analyze six exchange rates (R) of three new EU currencies the Czech koruna (CZK), Hungarian forint (HUF) and Polish zloty (PLN)) quoted with respect to the euro (EUR) and the US dollar (USD); for example, CZK/EUR denotes exchange rate between amount of Czech currency per 1 euro. The set of six independently quoted intraday one-minute exchange rates is taken from MetaQuotes corresponding to the CET time zone for the period beginning on January 3, 2011 and ending on December 31, 2015. Raw data (R_t) are transformed into a stationary series of percentage exchange rate returns (r_t):

[3] Other studies that applied the event study methodology on emerging markets are, for example, Gurgul and Wójtowicz (2014), Égert (2007), Naidu (2011), Leon and Williams (2012), and Menkhoff (2013).

$$r_t = \left(ln\frac{R_{t+1}}{R_t}\right) \times 100 \quad (1)$$

Thus, a negative change in an exchange rate means an appreciation of the quoting currency i (CZK, HUF, PLN) with respect to the reference currency j (EUR, USD); from a perspective of a forex trader appreciation means a positive return, because less units of the quoting currency is needed to buy 1 unit of the reference currency. Conversely, a positive change represents a depreciation of the quoting currency; depreciation means a negative return. Since the EUR/USD is the most heavily traded currency pair globally, we assume that price changes in EUR/USD exchange rate are directly reflected in prices of the euro-expressed and US dollar-expressed exchange rates and prevent market from arbitrage opportunities. This way the effect of the EUR/USD on new EU currencies is effectively accounted for. In this respect, we follow the approach of Cai et al. (2009) who examine the impact of the US and local news announcements on forex emerging markets or Caporale at al. (2017) who analyze the effects of news on the exchange rates vis-a-vis both the US dollar and the euro for the currencies of the BRICS.

In Figures 2.1-2.2 we present the dynamics of the exchange rates under research. All three examined CEE currencies depreciated against the US dollar during the examined time period (2011– 2015). At the same time, the Czech crown and Hungarian forint weakened relative to the euro. On the contrary, the Polish zloty has been resilient to the euro and has kept its value. All three of the examined new EU countries use a free-floating exchange rate regime with independent central banks aiming for price stability. The big spike in CZK/EUR and CZK/USD daily returns shows the start of exchange rate interventions. The Czech National Bank (CNB) decided to use the exchange rate as a monetary policy instrument and have performed foreign exchange interventions since November 7, 2013 to prevent the excessive appreciation of the koruna below CZK 27/EUR. On the weaker side of the CZK 27/EUR level, the CNB is allowing the koruna exchange rate to float. In terms of volatility, the exchange rates of the new EU country currencies with respect to the US dollar are generally more volatile than with respect to the euro.[4] This can be explained by the closer economic connection of the new EU countries to Germany or the EU in general, especially with respect to international foreign trade and

[4] With regard to market volatility, we acknowledge that the Chicago Board Options Exchange SPX Volatility Index (VIX) stayed at relatively low levels during the period under research. However, Baruník et al. (2017) show that connectedness on the forex market was high during 2008–2010, was somewhat lower during 2011–2012, and increased during 2013–2015. This evidence means that while the overall market volatility might be relatively low, there were substantial volatility spillovers among currencies on the forex market during most of the time covering the span of the current research.

foreign direct investment. Still, the most volatile currency is the Hungarian forint. The volatility of the Czech koruna is the lowest among the new EU country currencies.

2.2.2 Macroeconomic announcements

German/Eurozone macroeconomic news announcements

We gathered data on macroeconomic announcements coming from the Germany/Eurozone and the US. An extensive data set of macroeconomic announcements (news) from both regions is divided into four main categories. The Germany/Eurozone data set contains announcements on:

(i) business climate (the Markit's Purchasing Managers' Index (PMI) from the Manufacturing and Services sectors, the German Business Climate Index (Ifo) and the German ZEW Economic Sentiment Index)

(ii) the real economy indicators (Industrial Production, GDP, Retail Sales and Trade Balance)

(iii) (iii) prices (measured by Consumer Price Index (CPI) and Producer price Index (PPI))

(iv) (iv) monetary-type indicators represented by central bank (ECB) announcements of key interest rate changes and monetary policy settings

In detail we are examining the following macroeconomic indicators:

- Consumer Price Index (CPI) measures change in the price of goods and services purchased by consumers. There are two versions of the CPI index released about two weeks apart: Flash and Final. The sequence in which macroeconomic data are announced is argued to play an important role in market reaction (Andersson et al., 2009). For this reason, we prefer examining the Flash report to the Final report in our analysis. Also, we prefer aggregate CPI and PPI indices from the Eurozone to German indices, because they are the key indicators followed by the ECB monetary policy targets.
- Producer Price Index (PPI) measures change in the price of finished goods and services sold by producers.
- Retail Sales measures the change in the total value of inflation-adjusted sales at the retail level.

- Trade Balance measures the difference in value between imported and exported goods and services. Even though, Germany is the largest Eurozone economy, and German Retail Sales and Trade Balance is published a few days earlier, we prefer analyzing aggregate Eurozone data to German data. Data from the Eurozone contains complex information about 19 member countries.
- Gross Domestic Product (GDP) is the change in the inflation-adjusted value of all goods and services produced by the economy. German GDP is published three hours before the aggregate GDP from the Eurozone. For this reason, we expect the primary market reaction to German GDP and we examine it. There are also two versions of the GDP report release approximately 10 days apart: preliminary and final. The preliminary release is published first and thus we expect it to have a larger impact on the market. We examine preliminary German GDP report.
- PMI Index from the Manufacturing and Non-manufacturing sector is a leading economic indicator - businesses react quickly to market conditions, and purchasing managers hold perhaps the most relevant insight into the company's economic situation. Purchasing managers rate the relative level of business conditions including employment, production, new orders, prices, supplier deliveries, inventories. Germany's PMI indices are preferred to the Eurozone's PMI indices, because they are published 30 minutes earlier.
- ZEW German Economic Sentiment Index represents survey of about 275 German institutional investors and analysts who rate the relative 6-month economic outlook for Germany.
- German Business Climate Index (Ifo) consists of survey of about 7 000 businesses, which rate the relative level of current business conditions and expectations for the next 6 months.
- German Industrial Production measures change in the total inflation-adjusted value of output produced by manufacturers, mines, and utilities.

In total we employ six German macroeconomic indicators (Ifo, ZEW, PMI indices from the Manufacturing and Services sectors, Industrial Production and GDP) and four indicators related to the Eurozone economy (CPI, PPI, Trade Balance and Retail Sales).

US macroeconomic news announcements

The US macroeconomic indicators are also divided into four categories. These are announcements on:

(i) business climate (Purchasing Managers' Index (PMI) from the Manufacturing and Services sectors provided by ISM)

(ii) the real economy (Industrial Production, GDP, Retail Sales, Trade Balance, Core Durable Goods Orders and Non-farm Payrolls (NFP))

(iii) prices (Consumer Price Index (CPI) and Producer Price Index (PPI))

(iv) monetary-type indicators represented by central bank (Fed) announcements of key interest rate changes and monetary policy settings

In detail we are examining the following US macroeconomic indicators:

- The PMI Index from Manufacturing and Services sectors is constructed by the the Institute for Supply Management (ISM) asking about 400 purchasing managers to rate the relative level of business conditions including employment, production, new orders, prices, supplier deliveries, and inventories.
- Industrial Production is monthly change in the total inflation-adjusted value of output produced by manufacturers, mines, and utilities.
- Advance GDP is annualized change in the inflation-adjusted value of all goods and services produced by the economy. There are 3 versions of GDP released a month apart – Advance, Preliminary, and Final. We examine the Advance release, which is the earliest one and thus tends to have the most impact.
- Retail Sales show month over month change in the total value of sales at the retail level. This is the earliest and broadest look at vital consumer spending data.
- Trade Balance measures the difference in value between imported and exported goods and services during the reported month.
- Core Durable Goods Orders is monthly change in the total value of new purchase orders placed with manufacturers for durable goods, excluding transportation items. It's a leading indicator of production - rising

purchase orders signal that manufacturers will increase activity as they work to fill the orders.

- NFP (Non-Farm Payrolls) shows the change in the number of employed people during the previous month, excluding the farming industry. We prefer the NFP announcement to the unemployment rate because Andersen et al. (2007) show that Non-farm Payrolls is one of the most significant US macroeconomic announcements. Also, it is published in the beginning of the month and gives us early information about US economy.
- CPI (Consumer Price Index) measures month over month change in the price of goods and services purchased by consumers.
- PPI (Producer Price Index) measures month over month change in the price of finished goods and services sold by producers.

The macroeconomic announcements are reported by Reuters with a clearly defined calendar, the timing of news releases and the market expectations of specific news. The so-called consensus forecast of financial market analysts constitutes a proxy for market expectations. We follow Andersen et al. (2007) and define the surprise news variable (xn_{it}) as:

$$xn_{it} = (sn_{it} - E_{t-1}[sn_{it}]) / \sigma_i , \quad (2)$$

where $snit$ stands for the value or extent of the Reuters scheduled announcement i at time t. $E_{t-1}[sn_{it}]$ is the value of the announcement for time t expected by the market (market consensus) at time t-1 and σ_i is the sample standard deviation of announcement i. The standardization does not affect the properties of the coefficients' estimates as the sample standard deviation σ_i is constant for any announcement indicator i. This approach allows us to divide all releases into three clusters of surprise announcements: better than expected (good news), worse than expected (bad news) and in line with consensus (neutral news).

The reaction of exchange rates to news might not be always clear. First, while an exchange rate-based contract might be considered a single instrument, an announcement impacts the relative price of the two currencies. Second, under the prevailing economic conditions, an announcement considered good news in one country might not be the same in another country. For that reason, we refrain from forming overly specific expectations of the effects of announcements on abnormal exchange rate

returns. However, in accord with the relevant literature, we can say that in case of the PMI Manufacturing index, the PMI Services index, the German Ifo Business Climate Index, the German ZEW Economic Sentiment Index, Retail Sales, Trade Balance, Core Durable Goods Orders, GDP, NFP and Industrial Production, an announcement above the consensus (good news) is expected to have a positive impact on the quoting currency (Ramchander et al., 2008), whereas CPI or PPI above the forecast (bad news) is expected to have a negative impact on the quoting currency (Ehrman and Fratzscher, 2005). The same logic applies for the opposite surprises.

We provide a comprehensive overview of the employed news in Table 2.1; it includes the release date and time as well as the sequencing of the news. The sequence in which macroeconomic data is announced may play an important role in market reaction. Indicators published at the beginning of the month may attract more investor attention and market reaction than those published at the end of the month (Andersson et al., 2009). From this perspective, we can hypothesize that the business climate indicators might ignite the most significant reaction of the financial market. With respect to US macroeconomic news announcements, NFP and PMI are among the earliest indicators to be published each month. Retail Sales, CPI, Industrial Production and PPI are released in the middle of the month. Core Durable Goods Orders are announced at the end of the month. Trade Balance is released after the month ends and quarterly GDP is published one month after the respective quarter ends. The first information about the German economy is provided via the business climate indicators (Purchasing Managers Indices, Ifo Business Climate Index and ZEW Economic Sentiment Index). Later on, CPI, PPI, Retail Sales, Trade Balance and Industrial Production are available. The last one released is GDP.

A confounding events problem may occur if two or more macroeconomic announcements are released on the same day, within a 90-minute time span, and do not have the same hypothesized effect on the quoting currency. In the US, the problem is chiefly connected with CPI, PPI, and Industrial Production. Industrial Production is always released 45 minutes after the price indices. We consider news on CPI, PPI and Industrial Production only if they do not contain contradictory information, i.e., if all the announcements have the same effect on the quoting currency (we follow the approach suggested by Park (2004); further details are provided in Table 2.1).

2.2.3 Monetary settings

We also analyze the effects of monetary policy decisions. We now provide a brief background of the monetary policy settings in the US and Europe and describe the events we investigate.

In December 2009, with the financial crisis in full swing, the Federal Open Market Committee (FOMC) of the Fed lowered the target for the federal funds rate to nearly zero. The unfamiliar monetary environment of the zero lower bound interest rate policy (ZIRP) lasted until December 2015. Applying the ZIRP is a method of stimulating economic growth, while keeping interest rates close to zero. Under this policy, the governing central bank can no longer reduce interest rates, rendering conventional monetary policy ineffective. As a result, unconventional monetary policy such as quantitative easing is used to increase the monetary base. We analyze the impact of six events when the Fed changed the monetary policy settings during the examined time period.

The main task of the European Central Bank (ECB) is to maintain price stability in the euro area and to preserve the purchasing power of the joint currency. The ECB targets CPI at a rate close to but below two percent. ECB announcements inform investors about decisions on interest rates. Following the US financial crisis and the European debt crisis, the ECB gradually lowered all three main interest rates in the examined time period. We investigate the market reaction to the ECB rate announcements only on the days when at least one of the three main rates were changed. Furthermore, we look into two more ECB meetings. On January 22, 2015 there was no rate change, but the ECB announced the planned launch of the Quantitative Easing (QE) program at a press conference. This event took place after the rate announcement at 2:30 p.m. CET and on March 5, 2015 the ECB introduced details of the QE program.

The list, content, timing and other details of the monetary policy settings are presented in Table 2.9. Because of the varied nature of the Fed and ECB events, we quantify these events in the form of dummy variables with precise time identification. Thus, the monetary policy setting dummy reflects key information arising at the market from each central bank. Because the number of such announcements is small, we set the dummy variable to be equal to one for each event and zero otherwise. In this way, we do not distinguish the qualitative nature of central bank announcements. Rather, we aim to capture the potential effect of central bank announcements as well as the recognition of such announcements by the market.

2.3 Event Study Methodology Approach

We analyze the effects of macroeconomic announcements and policy settings on exchange rates using event study methodology (ESM) as outlined in Ball and Brown (1968) and Fama et al. (1969). We opt for the ESM because of its precision in identifying the reaction of an asset following each event. The approach is grounded in the fact that the effect of the macroeconomic announcements is analyzed during periods, when news enters the market and avoids extended periods without announcements (Swanson, 2011). Further, in contrast with time-series methods, the ESM allows to focus on examinations of specific events that are isolated from other unwanted news disturbances (noise) that occur outside of the event window (Fatum and Hutchinson, 2003b). Thus, the ESM avoids the problem of "noise" affecting the precision of the time-series approach (Fratzscher, 2008).[5] The ESM has been widely employed to analyze forex markets in different regions (Égert, 2007; Browman et al., 2015) with various data frequencies (Poole, 2005; Menkhoff, 2010) including intraday frequency (Ranaldo and Rossi, 2010; Fuentes et al., 2014).

The initial task of conducting an event study is to define the event of interest and to identify the period over which an asset price will be examined, e.g. an event window. In this monograph, the assets are currency prices (new EU exchange rates) and the events are defined as the unexpected component of the macroeconomic news announcements and the central bank's monetary policy changes; they are described in detail in the data section. The effect of such events is hypothesized to materialize in abnormal returns that are studied with respect to pre-event and event windows.

2.3.1 Pre-event and event windows

The key element of an event study is the appropriate choice of pre-event and event windows and typically the estimation window and the event window do not overlap (MacKinlay, 1997). It is customary to define the pre-event window as larger than the event window. We define the windows in the following way. First, similar to Gurgul and Wójtowicz (2014), we set the pre-event window at 130 minutes. That is more than two hours before the event occurs. Second, we choose the event window to have a length of 26 minutes. The event window covers (i) exchange rate returns that occur five minutes before the event, (ii) returns at the time of the news announcement (labeled as the zero-

5 We acknowledge the wealth of research contained in studies examining the impact of macroeconomic news announcements and central bank monetary policy settings via in time-series approach. They employ various types of (G)ARCH models in order to examine jointly the conditional volatility and market reaction. Examples assessing the issue on emerging European financial markets include Egert and Kočenda (2007, 2011, 2014), Buttner et al. (2012), Hanousek et al. (2009), and Hanousek and Kočenda (2011).

minute period that lasts for one minute) and (iii) returns covering the 20 minutes after the macroeconomic news announcement.

When estimating pre-event period parameters, the event period is generally not included. This procedure prevents the event itself from influencing the parameters obtained from the estimation of the normal performance model. The choice of the event window's length is grounded in the following facts related to each segment of the event window. First, because investors and traders know the calendar of macroeconomic news announcements and form expectations about their values abnormal returns related to each specific event may also occur in the pre-event period. Thus, the event window starts five minutes before the news announcement. Second, we consider 20 minutes after the macroeconomic news release and central banks' monetary policy changes to be a sufficiently long time for the news to be absorbed by the financial market because Égert and Kočenda (2011) show that new information entering the Czech, Hungarian and Polish stock markets is largely absorbed by the markets within five minutes after the announcement and it is fully absorbed within 20 minutes. The pre-event window begins at t = -135 minutes and runs up to -6 minutes before the news announcement. The event window evolves from t = -5 to +20, that is from 5 minutes before the news announcement until 20 minutes after it. The time when the news is released (t_0) is assigned as 0. ESM examine only data included in the pre-event and the event windows. Data outside of the pre-event and the event windows are not examined.

2.3.2 Abnormal returns

Abnormal returns are defined as the difference between actual returns and their expected values. Hence, for the ith event and time t the abnormal return (AR_{it}) is defined formally as:

$$AR_{it} = r_{it} - E[r_{it}/x_{it}], \tag{3}$$

where r_{it} denotes the actual return and $E[r_{it}/x_{it}]$ denotes the expected return given the conditioning information x_{it} for the expected return model.

We follow the practice in the literature (MacKinlay, 1997; Kothari and Warner, 2006) and calculate expected returns from a model estimated on the basis of the returns

materializing before the event window.[6] All computations are based on one-minute log-returns computed on the close prices.

When estimating the expected returns $[r_{it}/xi_t]$, we test the currencies' returns for autocorrelation and heteroscedasticity over all 155-minute-long periods (pre-event plus event windows) associated with ith event.[7] We would like to emphasis that ESM works only with FX returns that are part of pre-event and event windows. ESM does not work with data outside the pre-event and event windows. We individually test each 155-minute time series for autocorrelation and heteroscedasticity. The results show the absence of autocorrelation and heteroscedasticity in the returns, which allow us to employ a Constant Mean Returns Model (CMRM); an autoregressive model would be an alternative in case of detected autocorrelation. Hence, the expected returns are derived based on the following CMRM regression:

$$E[r_{it}/x_{it}] = \mu_i + \varepsilon_{it} , \qquad (4)$$

where μ_i is the mean return for asset i and ε_{it} is the time period t disturbance term for event i with an expectation of zero ($E(\varepsilon_{it}) = 0$) and variance var (ε_i) = $\sigma\varepsilon_i^2$. Although the constant mean return model is perhaps the simplest model, Brown and Warner (1980) find that it often yields a result similar to those of more sophisticated models. This logic corresponds to MacKinlay (1997), who argues that the lack of sensitivity to a particular model is due to a small reduction of the variance of the abnormal returns when a more sophisticated model is employed.

2.3.3 Standardized abnormal returns

In financial markets, volatility of abnormal returns tends to increase at the time of macroeconomic news announcements, i.e. during event window. To effectively account for a change in variance in abnormal returns and to ensure that each abnormal return

[6] The same approach has recently been adopted by Shah and Arora (2014) and Gurgul and Wójtowicz (2014).

[7] In Tables 2.2-2.7we show in the parenthesis the distribution of the examined German/Eurozone and US events (457 and 494 in total, respectively). In Table 2.9 we show the number of the ECB and FED announcements on monetary policy settings (12 and 6 in total, respectively). We work with 3 new EU currencies expressed in EUR and USD; e.g. we analyze 6 exchange rates. Hence, the number of all 155-minute-long periods (pre-event plus event windows) is 2907 [= 3*(457+12) + 3*(494+6)]. Accordingly, we perform the Ljung-Box test on all 2907 series of returns and squared returns. Absence of autocorrelation is shown in 2839 cases out of 2907 tests on returns and in 2868 cases out of 2907 tests on squared returns. Thus, in general, we do not find presence of autocorrelation or heteroskedasticity in examined 155-minute-long returns. The applied ESM analysis examines only the event and the pre-event returns. Data outside of these two data boxes are not part of our calculation.

will have the same variance we proceed with their standardization. We calculate the standardized abnormal returns to be tested for statistical significance, instead of using the estimated ones (Corrado, 2011; Corrado and Truong, 2008). The standardized abnormal returns SAR_{it} are defined as the ratio of abnormal returns and standard deviation:

$$SAR_{it} = AR_{it}/S(AR_i)\,, \tag{5}$$

where $S(AR_i)$ is the standard deviation of abnormal returns from the pre-event window (t running from minus 135 to minus 6). The standard deviation is calculated in the following way:

$$S(AR_t) = \sqrt{\frac{1}{129}\sum_{t=-135}^{-6} AR_{it}^2}\ . \tag{6}$$

Further, the standardized abnormal returns are classified into two categories in order to control for the event-induced volatility change in the cross-sectional variance:

$$SAR_{it}^{`} = \begin{Bmatrix} SAR_{it} & t = -135, \dots, 0 \\ \frac{SAR_{it}}{S(SAR_t)t} & t = 1, \dots \dots, 20 \end{Bmatrix}\ , \tag{7}$$

where

$$S(SAR)_t = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(SAR_{it} - \overline{SAR}_{it})^2}\ . \tag{8}$$

$S(SAR_t)$ is the cross-sectional standard deviation of standardized abnormal returns. $\overline{SAR}_{it}$ is average standartized abnormal return calculated as $\frac{1}{N}\sum_{i=1}^{N} SAR_{it}$ and N is the number of observations in the cluster.

To test the statistical significance of mean abnormal returns in the event window, we employ the rank test of Corrado and Zivney (1992) with the correction of event-implied volatility by using SAR as described above. The two main advantages of this

nonparametric test are that it does not need any assumption about the normality of abnormal returns and compared to other tests used in event studies, it has higher power than other standardized tests (Corrado, 2011). Furthermore, the rank test of Corrado and Zivney (1992) based on the event period standardized returns has proven to be robust both against event-induced volatility (Campbell and Wasley, 1993) and to cross-correlation due to event day clustering (Kolari and Pynnönen, 2010).

The statistical significance of standardized abnormal returns is tested by the Corrado-Zivney Tcz statistics; its calculation is based on the standardized ranks as defined in Corrado (2011):

$$T_{CZ}(t_0) = \frac{1}{\sqrt{N}} \sum_{i=1}^{N} \frac{(rank(SAR_{it0}) \frac{n+1}{2})}{\sqrt{n(n+1)/12}} \quad (9)$$

where $t0$ stands for each individually examined minute in the event window, n represents the size of the pre-event window (i.e., n = 130). *Rank* (SAR_{ito}) implies the rank of SAR_{ito} within the series of the standardized abnormal returns ($SAR`_{it}$) from the pre-event window calculated by the Formula (7). With increasing number of observations (n), the distribution of T_{CZ} statistics converges quickly to the standard normal distribution.

The values of abnormal returns during pre-event and post-event windows are assessed in conjunction with their statistical significance and serve as the basis for the interpretation of our results presented in the next section.

2.3.4 Testable hypotheses

Based on our research topic we formulate the following testable hypotheses.

Hypothesis 1: The new EU FX market react on the news announcements even before the news is released. There are pre- announcement price drifts on new EU FX market. The impact of pre-announcement price drifts is tested by the statistical significance of the mean abnormal returns (ARs in percentage) calculated using equations 3-8 before the news is released ($t < 0$). (The statistical significance is tested using equation 9). Kurov et al. (2017) find evidence of substantial pre-announcement informed trading in equity index and Treasury futures markets for US macroeconomic announcements. We expect to find the same evidence as Kurov et al. (2017), i.e., new EU

FX markets react before the news is release. Our assumption is that ARs for individually examined macroeconomic news are statistically significant even before the news is announced ($t < 0$). The results are presented in Tables 2.2-2.7.

Hypothesis 2: Individually examined macroeconomic news has different impact on the value of new EU exchange rates. The impact of each macroeconomic news is calculated by the mean abnormal returns (ARs in percent) using equations 3-8. The statistical significance of ARs is tested using equation 9. Hence, for each macroeconomic news announcement and each minute we report the value of the percentage mean abnormal return (AR%) and the corresponding statistical significance (p-value) in Tables 2.2-2.7. Büttner et al. (2012) find that out of 11 examined German and Eurozone news announcements only 6 have the impact on new EU FX rates' values. They show that increase in German unemployment rate leads to CZK appreciation and positive Ifo index cause depreciation of zloty. They demonstrate that some news does not affect the value of new EU FX rates, while the others does influence the value of new EU FX rates. We expect to find similar results, i.e., different news announcements (e.g. Ifo, ZEW, PMI, GDP, …); have different impact on new EU FX rates. In the other words, we expect some news having higher impact (higher values of statistically significant ARs) on new EU FX rates after the news announcement ($t \geq 0$) than the other news. Eventually, some news may not have statistically significant ARs, i.e., does not affect the value of new EU FX rates, while the other news has statistically significant ARs and influence the value of new EU FX rates.

Hypothesis 3: The origin of news announcements is relevant with respect to its effect on the value of new EU FX rates. Büttner et al. (2012) demonstrate that US indicators exert no significant impact after 2002 on new EU FX rates. They explain that US indicators no longer matter after the Copenhagen Summit, while European and German news remain significant for new EU FX markets. Similarly, we expect to find different reaction of new EU FX markets on the German/Eurozone macroeconomic news announcements and the US news announcements. We test this hypothesis calculating cumulative mean abnormal returns (CARs) (Eq. 10). Our assumption is that cumulative mean abnormal returns after the German/Eurozone macroeconomic news announcements reach different values from CARs calculated after the US news announcements (Figure 2.3) during the whole examined period.

Hypothesis 4: Announcements about ECB or Fed monetary policy settings affect the value of new EU FX rates. The impact of announcements is characterized by the mean abnormal returns (ARs) calculated using equations 3-8. The statistical significance is tested using equation 9. Hence, for each central bank announcement and each minute we report the value of the percentage mean abnormal return (AR%) and the corresponding statistical significance (p-value). Jansen and De Haan (2005) demonstrate that statements on ECB monetary policy influence the conditional mean of the EUR/USD exchange rate. Therefore, we expect to find statistically significant abnormal returns (ARs) after the ECB and Fed monetary policy announcements ($t \geq 0$). Results are shown in Table 2.8.

2.4 Empirical Results

2.4.1 Abnormal returns: effect of the news

We assess the impact of German/Eurozone macroeconomic news announcements on exchange rates quoted with respect to the euro (CZK/EUR, PLN/EUR, HUF/EUR). Similarly, we assess the effect of US macroeconomic news announcements on exchange rates quoted with respect to the US dollar (CZK/USD, PLN/USD, HUF/USD). The news announcements are divided into three clusters: good, bad and neutral news as defined in Section 2.2.2.[8] Good news is news with a value above the market consensus, bad news is below the market consensus, and neutral news is in line with the market consensus. This logic applies to all macroeconomic announcements except for CPI and PPI, where good news is below the market consensus (i.e. lower than the expected inflation) and bad news is above the market consensus (i.e. higher than the expected inflation). There is no neutral news for PMI in the case of euro-expressed exchange rates. The results are presented in the Tables 2.2-2.7. The impact of news announcements is characterized by the mean abnormal returns (in percent) calculated using equations 3-8. The statistical significance is tested using equation 9. Hence, for each macroeconomic news announcement and each minute we report the value of the percentage mean abnormal return (AR%) and the corresponding p-value. We report the results from -5 up to +10 minutes covering the period 5 minutes before and 10 minutes

[8] As a preliminary exercise, we also analyzed the effect of the news without distinguishing among good, bad and neutral news. We have found that all of the examined macroeconomic announcements are linked to significant abnormal returns over much of the event window. Moreover, the abnormal returns are often present also before the announcements are officially released. The biggest impact, in terms of the highest abnormal return, in euro-expressed currency pairs, occurs on the PMI indices, the Ifo index, and the GDP release. With respect to the US dollar-expressed currency pairs, the highest abnormal returns are linked with the NFP and GDP releases. The exchange rates with respect to the US dollar exhibit higher abnormal returns than the euro-expressed currency pairs

after the news release; later the statistically significant impact of the announcements quickly evaporates. The number of events in each cluster is shown in parentheses close to each announcement label. For example, Table 2.2 shows that after announcement of better than expected German ZEW index the CZK/EUR reaches abnormal return 0.002% at 1% level of statistical significance three minutes after the news is announced.

Overall, from the tables 2.2-2.7 we see the immediate reaction of new EU FX rates after the release of CPI and PPI indices (non-zero statistically significant ARs' percentage returns in $t > 0$). Specifically, all examined new EU FX currencies expressed in US dollar show significant abnormal returns during the first minute ($t = 0$) after the announcement of CPI index (tables 2.5-2.7). The Czech crown shows -0.007, the Polish zloty -0.009 and the Hungarian forint -0.012 percentage ARs after the announcement of below the forecast (good) values of CPI index. The market reaction to the news on prices and their movements is intuitively correct and can also be understood based on the theory.[9] The most persistent reaction in terms of long sequence of statistically significant abnormal returns after the news release can be traced to the announcements of PMI, Retail Sales, Ifo or Industrial Production. This finding indicates that news from the real economy does have important information value for the market. It also indirectly hints that transactions on the new EU country forex markets do reflect real economic activities despite the fact that globally the majority of forex transactions are speculative in nature.[10]

Euro-expressed exchange rates (CZK/EUR, PLN/EUR, HUF/EUR)

The occurrence of statistically significant abnormal returns right at the time of a news release ($t = 0$) is considerable, albeit not dominant (Tables 2.2-2.4). Rather, the exchange rates react to abnormal returns in the following minutes. The Hungarian forint (HUF/EUR) shows the largest number of statistically significant abnormal returns. (Table 2.4). The strongest reaction of all the new EU country currencies is exhibited for the ZEW index, the PMI index, the Ifo index and GDP as the statistically significant abnormal returns are farther from zero (Tables 2.2-2.4). This finding might be related to the

[9] A movement in prices affects the real interest rate along with terms of trade, and a movement in prices also affects the prices of forex options via interest rate parity. In both cases a movement in prices potentially strongly impacts the amount of money traded on the forex market.

[10] The financial education website Investopedia states that "day-to-day corporate needs comprise only about 20% of the market volume. Fully 80% of trades in the currency market are speculative in nature" (http://www.investopedia.com/articles/forex/06/sevenfxfaqs.asp; retrieved on March 10, 2016). The data provided by the BIS (2013; p.6) do not provide a direct estimate of speculative trading but allow an indirect inference via foreign exchange market turnover by counterparty that is proportionally divided among non-financial customers (9%), reporting dealers (39%), and other financial institutions (53%). Further, in terms of instruments, "FX swaps were the most actively traded instruments in April 2013, at $2.2 trillion per day, followed by spot trading at $2.0 trillion" (BIS, 2013; p.3).

sequence of the release of macroeconomic indicators. Generally, the strongest reaction of the market is identified with neutral news. This may be explained by the fact that this cluster in most cases contains a small number of events. The fact that neutral news is often linked to quite high abnormal returns might indicate that analysts, whose expectations form the market consensus, are understandably not always successful in predicting macroeconomic indicators with a complete accuracy. This can be explained by the wide range of possible outcomes of individual macroeconomic indicators. Some indicators are subject to less outcome possibilities and, for example, it is more probable to estimate the correct prediction for CPI than for NFP.

The highest significant abnormal return appears in HUF/EUR three minutes after a good German GDP data release (Table 2.4). In the other words, after announcement of better than expected German GDP the HUF/EUR reach abnormal return -0.034% at 5% level of statistical significance. ZEW, PMI and Ifo are the first indices giving us new information about the economy. Bad news about industrial production is related to the longest sequence of statistically significant ARs for all new EU country currencies, which implies the most persistence market reaction to the news announcement. With respect to the euro-expressed exchange rates, we can observe three key patterns (Tables 2.2-2.4): (i) the values of abnormal returns are smaller, (ii) the number of statistically significant abnormal returns is lower than with US dollar-expressed exchange rates and (iii) the statistically significant abnormal returns in the case of euro-expressed exchange rates appear immediately after the news announcements. We also see that larger abnormal returns are in general linked more with good news than with bad news.

Analyzing Tables 2.2- 2.4 in detail, we detect the statistically significant abnormal returns even before the news is release ($t<0$). This phenomenon can be detected for PMI index, Retail Sales and Trade Balance for CZK/EUR and HUF/EUR. For example, the Czech crown continuously depreciate from 4 minutes before the news announcement up to the announcement time of worse than expected PMI index exhibiting statistically significant abnormal returns (AR_{t-4} = -0.002%, AR_{t-3} = -0.005%, AR_{t-2} = -0.004%, AR_{t-1}= -0.002%). Due to the fact, that abnormal returns are statistically significant before the news announcement we cannot reject Hypothesis 1. These pre-announcement price drifts are important evidence that news does leak or are even traded before their official release. This behavior is not uncommon and has been found in many other studies. For example, Lucca and Moench (2015) confirm that since 1994 international equities react

largely and with high statistical significance before official FOMC announcements are released. Further, Kurov et al. (2017) show that prices of stock indices and future prices of treasuries start to move in line with the direction of the news announcement about 30 minutes before the release time.[11]

US dollar-expressed exchange rates (CZK/EUR, PLN/EUR, HUF/EUR)

In the case of the US dollar-expressed exchange rates three key patterns emerge (Tables 2.5-2.7). First, the values of abnormal returns are larger. Second, statistically significant abnormal returns occur more often than in the case of euro-expressed exchange rates (Tables 2.2-2.4 vs. 2.5-2.7). Therefore, the results show that the segment of the new EU country forex market where currencies are traded with respect to the US dollar exhibits more temporary inefficiencies than its euro-based counterpart. These results are also consistent with the graphical representation in Figure 2.3, where US related CARs reach higher values than euro related CARs. Third, statistically significant abnormal returns occur much later usually two minutes after an announcement is released.

Some specific results further underline the above common patterns. The strongest reaction in terms of abnormal returns is related to NFP and GDP announcements. Again, NFP is one of the first news released at the beginning of each month, while GDP is a comprehensive number representing the state of the whole economy. NFP news is possibly leaked as the highest significant abnormal return emerges one minute before the (good) NFP announcement is actually released.[12] As a contrast to the above, announcements of Industrial Production and Core Durable Goods Orders exhibit the weakest reaction in terms of the low values of the associated abnormal returns.

Finally, one minute before the news announcement there is a strong statistically significant reaction of all US dollar-expressed exchange rates to the good news of the NFP, PMI Services index, Retail Sales and Core Durable Goods Orders (Tables 2.5-2.7). The US dollar-expressed exchange rates exhibit the smallest amount of statistically significant returns following the announcements of Industrial Production, CPI, PPI and Trade Balance. Non-zero statistically significant ARs in Tables 2.2-2.7 provide the ample

[11] The term "leaking news" stand for the early information available to specific group of market participants either due to self-calculation (improvements in technology and data processing lead to predictive models enhancement) or its availability to individual groups of investors before its official release.

[12] We consider only good and bad news clusters because there is a low number of observations of neutral news.

evidence that macroeconomic news announcements affect abnormal returns. In the other words, macroeconomic news has the impact on the value of new EU FX rates' returns. However, not all news has the same impact. We also provide evidence in Tables 2.2-2.7 that ARs related to individually examined macroeconomic news exhibit different statistically significant values. Therefore, some news has higher/lower impact (depend on the value of statistically significant ARs) on the new EU FX rates and some has no impact (not statistically significant ARs). For example, the Czech crown after the announcement of worse than expected IFO index reach abnormal return -0.001% and after the announcement of worse than expected PMI index the abnormal return is higher at the level of -0.019%. These results demonstrate that individually examined macroeconomic news announcement have different impact on the value of new EU FX rates and we cannot reject Hypothesis 2.

2.4.2 Size of abnormal returns

The impact of the announcements presented in Tables 2.2-2.7 indicate the presence of asymmetric reactions. We verify this feature and establish its statistical background. First, we present the Box-and- Whisker plots of the percentage mean abnormal returns (AR%) in Figure 2.6. The plots show the distribution asymmetry of mean abnormal returns related to the three clusters of macroeconomic news announcements, i.e. good, bad and neutral. The abnormal returns in the neutral cluster show the biggest dispersion. This may be explained either by the low number of observations in the cluster or by the indecisiveness of investors whether neutral news is actually positive or negative for the quoting currency. The mean abnormal returns of the new EU country exchange rates expressed in the USD reach higher absolute values than those expressed in the euro. As a result, we may say that the forex segment with new-EU-country exchange rates expressed in the U.S. dollar show more temporary inefficiency than that with new-EU- country currencies expressed in euro.

We further perform a nonparametric Kruskal-Wallis (KW) test (Table 2.10) to properly answer the question whether there are differences in the reaction of new EU country currencies to good, bad, or neutral news. Specifically, we compare the reaction of new EU foreign exchange rates after the individual news announcements classified into appropriate clusters of good, bad or neutral news during the first minute (t_0) after the news release in order to account for the cumulative market reaction. The results

show that in the case of euro- expressed exchange rates abnormal returns we detect statistically significant results of Kruskal/Wallis test in terms of good news of the ZEW index and Retail Sales; to bad news from Ifo index; and to neutral news on the CPI. Hence, in the above cases the Kruskal-Wallis hypothesis of equal distribution can be rejected. Kruskal-Wallis test provides us with some evidence on the asymmetric perception of the quality of information irrespective of its value. On the other hand, for the US dollar-expressed exchange rates the results show no asymmetry in the distribution of abnormal returns for any type of news.

2.4.3 Duration of abnormal returns

An examination of post-event returns provides us with information on market efficiency (temporary inefficiency). Systematically nonzero abnormal returns following an event are inconsistent with market efficiency and imply a profitable trading rule (ignoring trading costs). Therefore, the speed of market adjustment to the information revealed at the time of the event is an empirical question. We test how quickly the news is absorbed by the market applying the cumulative average residual method (CAR). CAR uses the sum of each minute's average abnormal returns in percent (AR%). CAR starting at time t_1 through time t_2 (event window) is defined as:

$$CAR(t_1, t_2) = \sum_{t=t1}^{t2} AR_t \qquad (10)$$

where t_1 is equal to -5 (5 minutes before the news release) and t_2 equals 20 (the last minute of the event window). The aggregation of mean abnormal returns through time provides us with information about the overall influence of the event of interest on the new EU country currency market. Moreover, CAR describes the duration and strength of each news cluster (good, bad, or neutral) on euro- or US dollar- expressed new EU country currencies in the first 20 minutes after the news announcement as well as shortly before news is actually released (Figure 2.3). The left and right portions of Figure 2.3 depict CAR for euro- and US dollar-expressed exchange rates, respectively.[13]

[13] As we defined earlier in Section 2.2.1, a negative change (growth rate) in an exchange rate means an appreciation of the quoting currency (CZK, HUF, PLN) with respect to the reference currency (EUR, USD). In terms of the monetary profit realized by a forex trader, appreciation means a positive return because less units of the quoting currency is needed to buy 1 unit of the reference currency. Same analogy is valid for a currency's depreciation. We graphically present positive (negative) cumulative abnormal returns (CAR) in a positive (negative) domain of the graph.

A visual inspection of Figure 2.3 shows a substantial effect of macroeconomic announcements on new EU country currencies. However, important asymmetries can be detected with respect to both base currencies. Good German/Eurozone macroeconomic news leads to new EU (quoting) currency appreciation with respect to the euro (base currency). This does not mean that the euro depreciates after good news is released. Rather, the CAR evidences a stronger reaction of the new EU country currencies to good news from Germany/the Eurozone. Similarly, neutral news that is in line with market consensus leads to new EU country (quoting) currency appreciation as well. In a sense, we might say that the finding resonates well with the common notion that "no news, good news". On the contrary, bad news leads towards a depreciation of the new EU country currencies with respect to the euro.

The US dollar-expressed exchange rates offer a different picture, though. Good US macroeconomic news leads to US dollar (base currency) appreciation and local new EU country (quoting) currency depreciation; the opposite pattern is linked to bad news. This discrepancy in the reaction, when compared to the euro-expressed exchange rates, can be reasonably explained, though. Earlier we stressed the importance of economic links between the new EU countries and the Eurozone and specifically Germany. Hence, there is a strong reaction of the new EU country currencies to German/Eurozone news. On the other hand, the economic links of the new EU countries with the US are less strong. Hence, when US-originated good news is released, both the US dollar and other currencies react. It is no surprise that the reaction of the US dollar should be stronger than the reaction of any new EU country currency. Therefore, a depreciation of a new EU country currency following good US news simply means that the reaction of the currency is weaker than the reaction of the US dollar itself. The reaction to neutral news is mixed. Finally, note that the reaction of US dollar-expressed exchange rates is greater than reaction of those linked to the euro. This is clearly visible from the Figure 2.3, where CARs of US dollar-expressed exchange rates reach higher values.

The CAR analysis provides an aggregate assessment and shows the pattern of the market reaction. The cumulative abnormal returns of the euro-expressed exchange rates reach lower values with a maximum of 0.2% and a minimum of -0.2% during the first 20 minutes after the news release, while those linked to the US dollar reach three times higher values with a maximum slightly above 0.9% and a minimum of -0.5%. The higher values of CARs link to US dollar mean that the overall impact of US macroeconomic news

announcements on US dollar-expressed FX rates is stronger than the impact of German/Eurozone news on Euro-expressed FX rates. These results are presented in the Figure 2.3 and do not allow us to reject null Hypothesis 3. The above results also mean that the forex market's segment with new EU country currencies expressed in the US dollar exhibit more temporary inefficiencies than that with currencies related to the euro.

The reaction of US-expressed new EU country currencies to bad news is 50 percent stronger than the reaction to good news. The CARs of US dollar-expressed new EU exchange rates reach 0.9% after bad news and -0.5% following good news. Moreover, the reaction of the market to bad news lasts longer. It takes twice as long for the CAR curve to get flat. Conversely, euro-expressed new EU country currencies show a heavier reaction to good news when it comes to CZK/EUR and PLN/EUR. This does not hold for HUF/EUR, where CAR for bad news reaches higher values than for good news, especially from the 11th minute after the news announcement.

Concerning the duration of the news announcement effect, it is obvious that mean abnormal returns appear on the market even before the news is released. Generally speaking, CARs start to move two minutes before the announcement. The strong immediate market reaction takes place two minutes after the announcement for good news and approximately five minutes after bad news announcement. The slower market reaction to bad news can be explained by the fact that investors probably do not hesitate buying in case of unexpected good news, but they hesitate selling in case of unexpected bad news needing some time for bad news impact recalculations. This does not hold for PLN/EUR, which reacts indifferently to bad news.

Examining the above results and inspecting Figures 2.3, 2.5, 2.6 we can see that new public information is relatively quickly incorporated into the currency prices, despite that some temporary inefficiencies exist. In the other words, the curve in CARs charts (Figures 2.3, 2.5, 2.6) become flat after several minutes of news announcements. This means that new EU FX markets need some time to process the new information released, which corresponds to temporary market inefficiency. According to Fama (1970) if markets are efficient, then all information is already incorporated into prices. The not flat curve of CARs shows that the new EU country forex market does exhibit temporary inefficiency.

2.4.4 ECB and Fed communication on their monetary policy settings

Lastly, we examine the reaction of new EU country currencies to changes in the Eurozone and US monetary policy settings. We analyze these reactions during the period (2011–2015) characterized by the fact that conventional monetary policy tools were unable to adequately respond to the economic situation (Swanson and Williams, 2014). Many central banks had to find new ways of using the tools at their disposal to stimulate economic activity in the face of the prolonged downturn and sluggish recovery. One way of doing so was, and for many central banks continues to be, further asset purchases on the central bank's account with the policy interest rate already at (or near) the zero bound.

We examine the forex market reaction when the ECB or the Fed announced changes in their monetary policy settings mostly related to monetary expansion (see Table 2.9 for details). The quantitative results are shown in Table 2.8. All three currencies react to steps taken by the two key central banks in a remarkably different manner.[14]

The Czech koruna reacted immediately after the ECB loosened monetary policy conditions. The CZK/EUR exchange rate exhibits the strongest reaction among the euro-expressed exchange rates as the abnormal returns are statistically significant immediately after the news release. The forceful and quick reaction of CZK/EUR is, however, complicated with alternating signs of abnormal returns. Such an undetermined direction of movement may be explained by the CNB currency interventions and its presence on the currency market as, on the stronger side of the CZK 27/EUR level, the CNB is preventing the koruna from further appreciation by intervening on the foreign exchange market. Mean abnormal returns of PLN/CZK is mostly consistent in the direction of the currency reaction, even though significant abnormal returns appear only five minutes after information release. The results show that easier monetary conditions in the Eurozone led to the depreciation of the Polish currency and euro appreciation. The reaction of HUF/EUR is the mildest one.

The impact of US monetary policy changes on the new EU country currencies is present but is less significant than that of the ECB monetary policy.[15] Both PLN/USD and

[14] In terms of consistency, we apply the same length of the event window examining the central banks communication as we used for macroeconomic news announcements.

[15] We acknowledge that the more significant impact of ECB monetary policy settings in comparison with Fed statements might be also due to the timing of when reports are published. ECB reports are published at 1:45 pm CET (7:45 am EST) followed by a press conference at 2:30 pm CET (8:30 am EST). This means that the ECB policy reports are published during the period of highest market activity, when UK and US forex trading sessions overlap. Conversely, the Fed's statements are always published at 2:00 pm EST (8:00 pm CET) followed by a press

HUF/USD depreciate after the Fed eases monetary policy. Negative abnormal returns appear in the first minute after the news release and depreciation reaches 0.024% (PLN) and 0.49% (HUF). There is no statistically significant impact on CZK/USD, though.

Based on the above findings we do not reject null Hypothesis 4 because statistically significant ARs provide evidence that ECB and Fed monetary policy changes do affect short-term changes in the value of new EU currencies.

2.4.5 Impact of the European sovereign debt crisis

The sample period considered in our empirical study covers a post-US financial crisis period but it also involves the European sovereign debt crisis period. In this section we explore the impact of the EU debt crisis on the new EU currency pairs during the interval January 1, 2011-July 26, 2012.

Draghi (2014) clearly distinguishes timing of both crises, plus shows the differences in the relationship between financial stress and unemployment during the financial crisis (from 2008) and debt crisis (from 2011). Hence, we begin the analysis of the debt crisis interval in early 2011 "because during this period, the sovereign debt crisis erupted in full force" as argued by Frutos et al. (2016; p. 17) who, in their analysis of the stress on the euro-area interbank market, also show a progressing divergence of the government bonds' yield within the euro-area. The end of the debt crisis interval coincides with the remarkable verbatim of the ECB President Mario Draghi who, at the Global Investment Conference in London on July 26, 2012, said: "Within our mandate, the ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough" (Draghi, 2012). Fiordelisi and Ricci (2016) show that the European financial markets started to rally immediately after the above statement and economic situation begun to improve as well. Eurostoxx gained 4.3% on the day of the speech (8.1% up to the end of July 2012); other important stock indices performed in a similar way: IBEX 6.1% (13.1%), MIB 5.6% (12.4%), CAC40 4.1% (7.1%), DAX 2.8% (6.0%).

We assess the issue of the European sovereign debt crisis based on the cumulative abnormal returns (CAR) shown separately for the debt crisis (Figure 2.4) and post-debt crisis (Figure 2.5) periods. The dynamics of the post-debt crisis period's CAR is remarkably similar to that reported already for the full span of our analysis (Figure 2.3). However, the dynamics of the debt-crisis CAR (Figure 2.4) differs for the CAR of the US

conference at 2:30 pm EST (8:30 pm CET), i.e., during the US trading session when many traders in Europe are no longer active in the markets. On the other hand, 24-hour trading on the forex market does allow for the policy announcements to affect exchange rates around the clock.

dollar-expressed exchange rate returns. The debt-crisis CAR patterns for the US dollar-expressed exchange rates (Figure 2.4) indicate that during the European sovereign debt crisis the new EU markets reacted quite sensitively to the positive US macro news. Such sensitivity might be strengthened by the fact that the three new EU countries were to some extent protected from the negative impact of the euro-area debt-crisis by having their own currencies. Further, during the European sovereign debt crisis the US economic situation was better compared to that in the EU (McKee et al., 2012). Hence, despite the dominating connection of the new EU countries to the EU and the euro-area, the positive US announcements were received by the new EU forex markets remarkably well. In sum, the debt-crisis CAR patterns for the US dollar-expressed exchange rates (Figure 2.4) indicate that during the European sovereign debt crisis the new EU markets reacted quite sensitively to positive macro news. In this respect, positive US macroeconomic data have been conveying the sign of restored economic growth in the US and signaled some potential of the economy recovery coming to the euro-area as well. Hence, the contrast between the positive news coming from the US and bleak economic prospects during the European sovereign debt crisis seems to be a realistic factor behind the finding.

Our interpretation can be further corroborated by the findings of Baruník et al. (2017) who, in their intraday analysis, show that negative volatility spillovers among the key world currencies during 2011-2012 were chiefly tied to the sovereign debt crisis in Europe. In addition, when comparing the CAR values during the sovereign debt crisis and post-crisis periods, we observe that the market segment with the euro-expressed exchange rates show fewer temporary inefficiencies in the post-crisis period. The situation is different in the market segment with the US dollar-expressed exchange rates that exhibit more temporary inefficiencies after the European debt crisis in terms of high CAR values.

2.5 Conclusion

We analyze the impact of specific information entering the forex market on the currencies of new EU members (Czech koruna, Hungarian forint and Polish zloty); the exchange rates are expressed in the euro and the US dollar. The information covered includes Eurozone/Germany and US macroeconomic news announcements, and communication on the monetary policy settings of the ECB and the Fed. In our analysis,

we fully exploit the wealth of intraday data and cover a relatively long period after the Global financial crisis (2011–2015). As a tool. we use event study methodology (ESM) because of its precision in identifying the reaction of an asset following each event, i.e. a macroeconomic announcement or policy setting communication. The impact of the events is characterized by the behavior of the mean abnormal returns. Hence, by using ESM we are also able to assess temporary forex market inefficiencies.

The results of our analysis can be summarized as follows. The biggest impact, in terms of the highest abnormal return, in euro-expressed currency pairs, occurs on PMI indices, the Ifo index and the GDP release. With respect to the US dollar-expressed currency pairs, the highest abnormal returns are linked with the NFP and GDP releases. The most persistent reaction in terms of significant abnormal returns after the news release can be traced to announcements of the PMI, Retail Sales, Ifo or Industrial Production. The exchange rates with respect to the US dollar exhibit higher abnormal returns than euro- expressed currency pairs.

We distinguish the surprise element in the announcements by dividing the news into three clusters—good, bad, and neutral news—which are defined by the difference between the announcement and its expectation. Larger abnormal returns after Eurozone/Germany news announcements are in general linked with good news. Conversely, in the case of US dollar-expressed exchange rates, larger abnormal returns are linked to bad news. The results also show that the values of statistically significant abnormal returns of the euro-expressed exchange rates are smaller, occur less often, and last for a shorter time than for US dollar-expressed exchange rates. Finally, the segment of the new EU forex market, where currencies are traded with respect to the euro, show fewer temporary inefficiencies than its US dollar-based counterpart. Examining the EU debt crisis separately, we noticed that the dynamics of the debt-crisis CAR differs for the US dollar-expressed exchange rate returns during the European debt crisis. Particularly, positive US announcements result in positive CAR. Sharp difference in the economic development between the US and the euro-area during the debt crisis seem to be a plausible factor behind the result.

Communications on the monetary policy settings show that ECB communication matters. The CZK/EUR exchange rate exhibits the strongest and HUF/EUR the quietest reaction among euro- expressed exchange rates. The impact of Fed monetary policy changes on the new EU country currencies is present but less significant than that of the

ECB: both PLN/USD and HUF/USD depreciate after the Fed eases monetary policy but there is no statistically significant impact on the CZK/USD exchange rate.

Our analysis is the first of its kind, providing a comprehensive analysis of the reaction of selected new EU forex markets to a wide array of macroeconomic information during the post-GFC period. We show strong and specific reactions along with temporary inefficiencies present on these forex markets.

2.6 **Tables**

Table 2. 1:German/Eurozone and US macroeconomic news release calendar

Time (CET)	Germany/Eurozone
11:00 a.m.	ZEW German Economic Sentiment Index (on 2nd or 3rd Tuesday of the current month)
9:30 a.m.	PMI German Manufacturing & Non-Manufacturing Sector (3 weeks into current month)
10:00 a.m.	IFO German Business Climate Index (3 weeks into current month)
11:00 a.m.	Eurozone Flash CPI (around the end of the current month)
11:00 a.m.	Eurozone Retail Sales (around 35 days after the month
11:00 a.m.	Eurozone PPI (around 35 days after the month ends)
8:00 a.m.	German Industrial Production (about 40 days after the month ends)
11:00 a.m.	Eurozone Trade Balance (about 45 days after the month ends)
8:00 a.m.	German preliminary GDP (about 45 days after quarter ends)
	16 19 22 25 28 31 | 5 9 10 14 15 17 18 20 21 24 25 27 30 30 | 1 15 20 30
	Month X | Month X+1 | Month X+2

Time (CET)	US
4:00 p.m.	PMI Manufacturing Index (1st business day after the month ends)
2:30 p.m.	NFP (1st Friday after the month ends)
4:00 p.m.	PMI Non-manufacturing Index (3rd business day after the month ends)
2:30 p.m.	Retail Sales (about 13 days after the month ends)
2:30 p.m.	PPI (about 14 days after the month ends)
3:15 p.m.	Industrial Production about 16 days after the month ends)
2:30 p.m.	CPI (about 16 days after the month ends)
2:30 p.m.	Core Durable Good orders (about 26 days after month ends)
2:30 p.m.	Trade Balance (about 35 days after month ends)
2:30 p.m.	Advance GDP (about 30 days after quarter ends)
	25 28 31 | 2 3 5 11 12 14 15 17 18 20 21 24 25 26 30 | 1 5 10 15 20 30
	Month X | Month X+1 | Month X+2

Notes: The table shows the sequence of examined macroeconomic news announcements in Germany/Eurozone and the US.. The time difference between the European and US financial markets is accounted for by setting a homogenous CET time for all news releases so there is no time difference. We took into consideration that Daylight Savings Time starts in the US two weeks earlier than in Europe in the spring and ends one week later in the fall. All announcements are released monthly except for GDP, which is measured quarterly.
The announcements are abbreviated as follows: NFP – Nonfarm Payrolls, PMI – Purchasing Managers' Indices from Manufacturing and Non-Manufacturing (Serv. – Service) sectors, GDP – Gross Domestic Product, Ind. Prod. – Industrial Production, Core DGO – Core Durable Goods Orders, Trade. Bal. – Trade Balance, CPI – Consumer Price Index, PPI – Producer Price Index, ZEW – German Economic Sentiment Index, Ifo – German Business Climate Index, Ret. Sales – Retail Sales.
A confounding events problem may occur if two or more macroeconomic announcements are released on the same day within a 90-minute time span and do not have the same hypothesized effect on the quoting currency. In the US, the problem is chiefly connected with CPI, PPI and Industrial Production. Industrial Production is always released 45 minutes after the price indices. We consider news on CPI, PPI and Industrial Production only if they do not contain contradictory information, i.e., if all the announcements have the same effect on the quoting currency. Altogether, there are only 39 of 60 price announcements examined (CPI and PPI). Regarding German PMI indices, we analyze 32 out of 60 events, because PMI indices from the manufacturing and non-manufacturing sectors are usually released on the same date and hour.

Table 2. 2: Minute by minute effect of macroeconomic news on Abnormal Returns of CZK/EUR

A: Good News

Time	ZEW (24)		PMI (13)		IFO (31)		Industrial Production		GDP (9)		Retail Sales (23)		Trade Balance (23)		CPI (21)		PPI (24)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	-0,002	a	0,009	c	0,002		-0,003		0,001		-0,001	c	0,000		0,000	b	0,001	
-4	0,001		-0,007	a	0,002		-0,001	a	0,000		0,004	b	0,002		0,002		0,002	c
-3	0,002		0,005		0,001	b	0,004		0,001		-0,001	c	-0,003	a	0,000		0,000	c
-2	0,001		0,005		-0,004	a	0,007		-0,005	b	-0,004		-0,001	c	-0,001	c	0,003	b
-1	0,011		0,007		0,008		0,001		0,000		0,001	c	-0,003	c	0,000	b	-0,001	c
0	0,000	b	0,000		0,004	b	0,002		0,002		0,004		-0,002	b	0,000	b	0,000	b
1	0,001		0,012		0,011		0,000		-0,004	a	0,004		-0,005	a	-0,002	a	0,004	
2	-0,001		0,015		0,002		0,003	a	0,007		-0,002	b	-0,002		0,001		0,000	
3	0,002	a	-0,002	b	0,001	a	-0,001	c	0,001	b	0,000		0,001		0,001		-0,005	a
4	-0,002		0,000	c	0,008		-0,003	a	-0,003	a	0,006		0,001	b	-0,005	a	0,000	
5	0,001	a	0,004	a	-0,005	a	0,003		0,001		-0,003	a	0,002	b	0,004		-0,001	
6	0,000		-0,006	b	-0,001	a	0,002	b	0,001		-0,001		0,001	a	0,000	b	0,001	
7	-0,003	a	0,003	b	0,000	a	0,001	c	-0,001	c	0,001	c	0,002		0,001	a	0,005	
8	-0,003		0,000		0,008		-0,004	b	-0,002	a	0,002		-0,006	a	0,001		0,001	a
9	0,004		0,000		0,003		0,002		-0,001	b	0,002	a	0,008		0,000		0,002	c
10	-0,001	c	0,005		0,005	b	0,000	a	-0,006		0,001	b	0,000		0,001		0,001	

B: Bad News

Time	ZEW (32)		PMI (19)		IFO (26)		Industrial Production (33)		GDP (7)		Retail Sales (29)		Trade Balance (30)		CPI (21)		PPI (24)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	0,002		0,001	b	0,003		-0,002	c	0,003		-0,001		-0,001		0,000	b	0,001	
-4	0,003		-0,002	c	0,000	a	-0,002	a	-0,007	a	0,000	c	0,004	b	0,002		0,002	c
-3	-0,004	a	-0,005	b	-0,003	a	0,002		0,001		0,003		-0,001	b	0,000		0,000	c
-2	0,001		-0,004	a	0,001		-0,001	b	0,006		-0,003	a	0,001	b	-0,001	c	0,003	b
-1	-0,007	a	-0,002	b	-0,002	c	-0,004	a	-0,015	a	-0,002	a	-0,002	b	0,000	b	-0,001	c
0	-0,001		-0,019	a	-0,001	a	-0,002	c	-0,006	c	0,001		0,002	c	0,000	b	0,000	b
1	0,002		0,004		0,000	c	-0,002	a	-0,005	b	0,000	a	-0,005	c	-0,002	a	0,004	
2	0,000		-0,006	a	0,000	c	-0,001	a	0,002	b	0,003		-0,005		0,001		0,000	
3	-0,004	a	-0,005	a	0,006		-0,002	a	-0,006		0,004		-0,002	b	0,001		-0,005	a
4	-0,001		-0,003	b	-0,001	b	0,000	a	-0,004		0,002		-0,001	a	-0,005	a	0,000	
5	0,001	a	-0,003	a	0,000	a	0,000		0,004		-0,004	a	0,002	a	0,004		-0,001	
6	0,003		-0,001		0,001	b	-0,007	a	0,001		0,000		0,000	a	0,000	b	0,001	
7	0,004		0,000	c	0,001	a	0,001	a	-0,002		-0,002	a	0,001	a	0,001	a	0,005	
8	0,002		-0,002		0,002		0,004		0,002		0,005		-0,001	a	0,001		0,001	a
9	0,001		-0,002	b	0,003		0,000		-0,004	a	-0,001	a	-0,002		0,000		0,002	c
10	0,003		-0,004	b	-0,002	a	-0,003	a	0,006		-0,002	a	0,002		0,001		0,001	

C: Neutral News

Time	ZEW (1)		IFO (1)		Industrial Production (3)		GDP (4)		Retail Sales (7)		Trade Balance (2)		CPI (19)		PPI (14)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	0,007		0,008		0,011		-0,007	a	-0,003		0,000		0,000		-0,002	c
-4	-0,015	b	-0,010		-0,012	a	0,007		0,002		0,000		-0,003	b	0,000	b
-3	-0,037	b	0,000		0,009		0,002		-0,003	b	-0,008		0,000		0,002	
-2	-0,007		0,008		0,004		0,005		0,007		0,000		0,014		-0,007	
-1	0,026		-0,014	c	0,010		-0,005	b	0,006		0,004		-0,008		-0,002	c
0	0,007		-0,007		0,001		0,001		0,000		-0,002		-0,001	a	-0,003	a
1	-0,004		-0,007		-0,001		0,016		0,004		0,002		-0,003	a	0,002	b
2	-0,011	c	0,015		0,002		-0,001	b	0,012		0,000		-0,001		-0,001	
3	-0,007	c	0,004		0,000	b	0,007		0,004		-0,002		0,001		-0,014	a
4	0,004		-0,018	b	0,000		0,002		0,002		0,000	c	0,005		0,002	
5	0,015		0,047		0,011		-0,004	b	0,003		0,000	c	-0,003	b	-0,001	
6	-0,007		0,000		0,003		0,002		-0,001		0,004		-0,005	b	-0,001	
7	0,004		0,000		-0,009	a	0,005		0,006		0,002		-0,003	a	0,002	c
8	0,018		0,000		0,001		-0,005	b	0,006		0,002		-0,002	a	0,000	a
9	-0,007		-0,010		0,000		-0,003		-0,001	a	0,002		-0,001		0,001	b
10	0,000		-0,021	b	0,001		0,002		-0,002		0,002		0,000		0,001	

Note: Table contains values of mean abnormal percentage returns (AR%) on a currency pair as an effect of the macroeconomic announcements in the event window running from -5 to 10 minutes; announcement occurs at 0 minute. We report statistical significance (denoted by a symbol) at the 1 (a), 5 (b), and 10% (c) levels based on the Corrado-Zivney Tcz statistics with the corresponding critical values of 2,58 (1%), 1,96 (5%), and 1,65 (10%). The sample runs from January 3, 2011 to December 31, 2015. The announcements are abbreviated as follows:,ZEW – German Economic Sentiment Index, PMI – Purchasing Managers' Indices from Manufacturing and Services sectors, IFO – German Business Climate Index, GDP – Gross Domestic Product, CPI – Consumer Price Index, PPI – Producer Price Index. Number of observations (examined events) is indicated in the parentheses.

Table 2. 3: Minute by minute effect of macroeconomic news on Abnormal Returns of PLN/EUR

A: Good News

Time	ZEW (24)		PMI (13)		IFO (31)		Industrial Production (24)		GDP (9)		Retail Sales (23)		Trade Balance (23)		CPI (21)		PPI (24)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	-0,003	c	0,012		-0,001	c	0,001		0,002		0,000		-0,001	c	-0,001	a	-0,003	a
-4	0,001		-0,001		-0,002	a	-0,001	b	-0,002		-0,002	b	-0,005	a	0,006		-0,002	a
-3	0,004		0,015		-0,008	a	-0,004	a	-0,006		-0,006	a	-0,003	b	0,002	b	0,002	
-2	0,004		0,004		0,004		-0,001	a	-0,004		0,001		-0,002	b	0,004		0,007	
-1	0,020		0,009		0,017		0,007		0,013		0,006		0,007		-0,005	b	0,001	a
0	0,003		-0,002	a	0,005	a	0,007		-0,005	a	0,006		0,002		-0,003	a	0,004	
1	0,003		0,005		0,004		-0,006	a	0,005		-0,001	b	0,004		0,008		0,002	b
2	0,002		-0,013	a	-0,003	b	-0,002	b	-0,006	a	0,002		-0,007	a	0,005		0,001	
3	0,002	a	-0,005	b	0,002	c	0,003		0,003	b	0,003		0,001		0,000		0,000	c
4	0,000		0,008		-0,004	b	-0,002	a	0,001	b	0,001	c	-0,003	a	-0,001	b	-0,003	b
5	0,000	c	-0,007	a	-0,001	c	0,002	b	-0,001		0,005		0,003		-0,002	a	-0,001	
6	-0,005	a	0,003		-0,001	a	0,002	b	0,002		-0,002	b	0,002		0,004		-0,003	a
7	0,000		-0,004		-0,011	a	-0,003	a	0,016		-0,002	b	0,001		-0,001	b	0,003	
8	0,004	a	-0,002	b	0,002		0,004	a	0,009		-0,002	a	-0,004	a	0,002		0,000	
9	-0,006	b	0,005		0,001	b	-0,005	a	0,003		-0,006	a	0,000	b	0,001		0,000	b
10	0,002		-0,008	a	-0,006	a	-0,003	a	-0,002	b	-0,001	b	-0,005	a	0,001		-0,002	

B: Bad News

Time	ZEW (32)		PMI (19)		IFO (26)		Industrial Production (33)		GDP (7)		Retail Sales (29)		Trade Balance (30)		CPI (18)		PPI (20)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	-0,003	a	-0,002	c	0,001		0,000	b	0,002		-0,003	a	-0,011	a	0,005		-0,009	a
-4	0,005		-0,007	a	0,004		0,000	a	0,001		-0,003	a	0,001		0,002		-0,002	b
-3	-0,002	a	-0,022	a	-0,001	a	-0,002	b	-0,005	a	0,004	c	0,001	a	-0,004	b	0,001	
-2	0,002		-0,004	b	-0,005	a	0,001		-0,002		-0,003	b	0,009		-0,001		0,005	
-1	-0,007	a	-0,019	a	-0,003	b	-0,001	a	0,004		0,000		0,005		-0,002		0,008	
0	0,000	b	-0,004	b	0,012		-0,002	a	-0,004		0,000	c	-0,004	a	0,004		0,007	
1	0,000	b	0,007		0,000	a	-0,001	b	0,012		-0,001	b	-0,001		0,001		0,002	
2	0,009		-0,009	a	0,008		-0,002	a	-0,007	b	0,000	a	0,000		0,005		-0,003	b
3	0,000		0,005		0,001		0,002	a	-0,003	c	0,003		0,006		0,001		0,002	
4	0,004		-0,003		-0,006	a	0,002	c	-0,012	a	-0,002	b	-0,003	b	0,002		-0,002	c
5	0,006		0,011		0,002		0,000	b	-0,004	b	-0,003	a	-0,001	b	-0,007	a	-0,006	b
6	0,001		-0,010	a	0,000		-0,002	a	-0,008	a	0,003		0,000	c	-0,004	b	0,001	
7	-0,002	c	-0,006	a	0,004		0,002	a	-0,001	b	-0,002	a	0,000	c	-0,005	b	0,001	
8	0,000	a	-0,007	a	0,003		-0,001	a	-0,003		-0,001	a	0,000		0,002		0,002	c
9	0,001		0,000		-0,002	a	0,000	a	-0,003	b	-0,003	a	-0,004	b	0,004		0,003	
10	0,001		0,004		-0,006	a	0,002	b	0,000		-0,002	b	-0,002		-0,002		0,001	c

C: Neutral News

Time	ZEW (1)		IFO (1)		Industrial Production (3)		GDP (4)		Retail Sales (7)		Trade Balance (2)		CPI (19)		PPI (20)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	-0,002		-0,014		0,003		-0,005	a	-0,003		0,004		-0,002	b	-0,005	a
-4	0,000		0,000		0,008		0,000		-0,009	a	-0,011		-0,002	a	0,005	
-3	-0,002		0,000		0,003		0,002		0,000		-0,026	a	-0,011	a	0,007	
-2	-0,004		0,031		-0,010	b	-0,002		-0,003	c	-0,006		0,000		0,003	
-1	0,027		-0,021	c	0,005		0,000		0,012		0,005		0,002		0,000	b
0	0,000		-0,002		0,002		-0,005	b	0,006		-0,002		-0,003	b	0,001	
1	0,012		0,010		0,010		0,025		0,004		0,013		0,005		-0,004	
2	0,015		0,017		-0,003	b	0,011		0,010		0,007		-0,006	a	-0,004	
3	-0,009	b	0,000		-0,004	b	-0,006	c	0,005		0,016		0,001		0,007	
4	-0,004	c	0,000		0,004		-0,010	a	-0,006		0,000		-0,007	a	0,000	b
5	0,000		-0,007		-0,002		0,003		0,008		0,000		-0,001		-0,003	
6	0,000		-0,049	b	0,000		0,001		-0,003	a	0,013		-0,003	a	-0,002	
7	0,000		-0,021		0,002		-0,013		0,007		-0,007	c	0,001		0,001	
8	-0,004		0,015		0,015		0,000	c	-0,004	b	-0,008	b	-0,006	a	0,002	
9	0,000		0,003		-0,001	b	0,000		-0,006	b	0,003		-0,004		0,001	
10	0,000		-0,004		-0,004	b	0,000		-0,002	b	0,004		0,005		-0,005	

Note: Table contains values of mean abnormal percentage returns (AR%) on a currency pair as an effect of the macroeconomic announcements in the event window running from -5 to 10 minutes; announcement occurs at 0 minute. We report statistical significance (denoted by a symbol) at the 1 (a), 5 (b), and 10% (c) levels based on the Corrado-Zivney Tcz statistics with the corresponding critical values of 2,58 (1%), 1,96 (5%), and 1,65 (10%). The sample runs from January 3, 2011 to December 31, 2015. The announcements are abbreviated as follows: ZEW – German Economic Sentiment Index, PMI – Purchasing Managers' Indices from Manufacturing and Services sectors, IFO – German Business Climate Index, GDP – Gross Domestic Product, CPI – Consumer Price Index, PPI – Producer Price Index. Number of observations (examined events) is indicated in the parentheses.

Table 2. 4: Minute by minute effect of macroeconomic news on Abnormal Returns of HUF/EUR

A: Good News

Time	ZEW (1)		PMI (13)		IFO (31)		Industrial Production (24)		GDP (9)		Retail Sales (23)		Trade Balance (23)		CPI (21)		PPI (24)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	0,005		0,006		-0,002	a	0,003		0,001		0,000		0,000		0,005		-0,003	c
-4	-0,002		0,008		-0,001		0,002		0,000		0,012		0,004	c	0,005		-0,003	c
-3	0,001	b	0,012		-0,004	a	0,006		-0,002		-0,004	b	-0,004	b	0,008		-0,004	a
-2	0,004		0,002	b	-0,002	a	-0,002	b	0,000		-0,005	a	-0,007	a	-0,004	b	-0,011	a
-1	0,018		0,020		0,024		0,016		0,008		0,011		0,006		0,009		0,006	
0	0,011		-0,002	a	0,013		0,005		0,000		-0,002	a	0,003	b	0,000	c	-0,001	
1	0,004		0,003		-0,003	a	0,000	a	-0,002	c	-0,002	b	-0,004	b	0,003		0,001	
2	-0,005	a	-0,004	c	0,005		0,000	b	0,000		0,002		-0,005	b	0,005		0,000	
3	0,001	a	-0,001	b	0,002	b	0,008		-0,034	b	-0,004	a	0,006	b	0,002		0,001	
4	0,008		-0,010	a	-0,005	a	0,003	b	0,017		-0,011	a	0,008		0,003		0,002	c
5	-0,005	a	0,002		-0,001	a	-0,001	a	0,010		0,004		0,002		-0,008	a	-0,003	a
6	-0,008	a	0,002		-0,007	a	-0,006	a	0,002		-0,001	a	0,000	a	0,008		-0,008	a
7	0,004		-0,003		-0,001	a	0,002		-0,002		0,001	c	0,011		0,004		0,000	a
8	-0,002	a	-0,006	c	-0,004	a	-0,006	a	0,010		-0,002	b	0,000		0,002		0,005	
9	-0,005	a	-0,007	a	0,003		0,000		0,011		-0,001	b	0,008		0,000		0,003	
10	-0,003	a	0,004	b	-0,003	a	-0,004	a	-0,003	c	-0,001	a	-0,011	a	-0,003	b	-0,004	c

B: Bad News

Time	ZEW (32)		PMI (19)		IFO (26)		Industrial Production (33)		GDP (7)		Retail Sales (29)		Trade Balance (30)		CPI (18)		PPI (20)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	-0,001	b	-0,004	b	0,001	c	-0,006	a	-0,002	c	0,002		-0,004		0,007		-0,003	b
-4	0,007		0,002		-0,004	a	0,000	a	-0,001		-0,004	a	0,013		-0,004	b	-0,001	
-3	0,004		-0,020	a	-0,005	b	0,000		0,000		-0,003	a	0,007		0,005		0,003	b
-2	0,003	b	0,000		-0,003	b	0,000	a	-0,005	b	-0,001	c	0,008	b	0,005		0,000	c
-1	-0,011	a	-0,009	b	-0,006	a	-0,016	a	-0,023		0,001		0,000	a	0,003		0,002	
0	-0,009	a	-0,003	b	-0,005	b	0,001	a	0,004		-0,002		0,001		0,011		0,005	
1	0,001	c	-0,002	b	-0,004	a	-0,001	b	0,003		0,001		-0,001	b	-0,001		0,001	c
2	0,005		0,002		0,004		0,003	b	-0,012	b	-0,011	a	-0,012		0,003	a	0,000	c
3	0,004		-0,002		0,002		0,002	c	-0,002	b	0,006		0,003		0,006		0,004	
4	0,001		-0,004	b	0,000	b	0,000	a	-0,009	a	-0,001	a	-0,010	a	-0,002		-0,003	
5	0,004		0,000	c	0,004		0,007		-0,007	b	0,005		-0,010	a	-0,002	b	-0,003	a
6	0,000		-0,003		0,000	a	-0,001	a	0,001		0,003		0,003		0,000		-0,001	b
7	0,003		0,002	b	0,000	b	-0,001	c	0,006		-0,003	a	0,003		0,000		0,003	
8	-0,002	c	-0,005	c	-0,002	a	0,005		-0,007	b	-0,005	a	-0,002	a	0,000		-0,003	a
9	0,001	b	-0,004	a	-0,002	a	-0,004	b	-0,006	b	0,005		0,003		-0,008	a	0,002	
10	-0,001	b	-0,003	c	0,006		0,001	a	-0,006	a	-0,001	c	0,008		-0,006		-0,006	a

C: Neutral News

Time	ZEW (1)		IFO (1)		Industrial Production (3)		GDP (4)		Retail Sales (7)		Trade Balance (2)		CPI (18)		PPI (14)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	0,003		0,000		0,002		-0,024	c	0,014		-0,017		0,007		-0,002	b
-4	0,017		-0,003		-0,007	b	-0,014		-0,003	c	-0,004		-0,004	b	-0,001	c
-3	-0,007		0,003		0,001		0,003		0,005		0,002		0,005		0,016	
-2	0,000		-0,003		0,025		-0,003		-0,001	b	-0,003		0,005		0,008	
-1	0,000		0,019		-0,029	a	-0,002		0,004		0,025		0,003		-0,001	b
0	-0,003		-0,009	c	0,008		-0,003		0,008		-0,004	c	0,011		-0,011	
1	0,003		0,010		-0,006	b	0,003		0,013		0,012		-0,001		-0,004	
2	0,003		0,003		-0,004		0,000		-0,011	a	0,004		0,003	a	-0,001	
3	-0,003		-0,003		0,000		-0,003	c	-0,007		0,010		0,006		0,004	
4	0,007		0,000		0,004		0,003		0,016		-0,014	b	-0,002		-0,004	c
5	-0,010	c	0,013		0,003		0,007		0,005		-0,001		-0,002	b	-0,001	b
6	0,003		0,026		0,004		0,013		0,005		0,006		0,000		0,002	
7	0,000		0,007		-0,005	b	-0,017		0,011		0,002		0,000		-0,005	b
8	-0,007		0,019		0,011		-0,004		-0,008		0,014		0,000		0,002	
9	-0,007	c	0,007		0,006		0,014		-0,005	a	-0,009		-0,008	a	-0,001	b
10	-0,007		-0,032	b	-0,002		0,003		-0,007	a	0,003		-0,006		-0,006	b

Note: Table contains values of mean abnormal percentage returns (AR%) on a currency pair as an effect of the macroeconomic announcements in the event window running from -5 to 10 minutes; announcement occurs at 0 minute. We report statistical significance (denoted by a symbol) at the 1 (a), 5 (b), and 10% (c) levels based on the Corrado-Zivney Tcz statistics with the corresponding critical values of 2,58 (1%), 1,96 (5%), and 1,65 (10%). The sample runs from January 3, 2011 to December 31, 2015. The announcements are abbreviated as follows: , ZEW – German Economic Sentiment Index, PMI – Purchasing Managers' Indices from Manufacturing and Services sectors, IFO – German Business Climate Index, Ind. Prod. – Industrial Production, GDP – Gross Domestic Product, CPI – Consumer Price Index, PPI – Producer Price Index. Number of observations (examined events) is indicated in the parentheses.

Table 2. 5: Minute by minute effect of macroeconomic news on Abnormal Returns of CZK/USD

A: Good News

Time	NFP (30)		PMI Man (31)		PMI Services (30)		Retail Sales (18)		GDP (7)		Industrial Production (23)		Core DGO (20)		Trade Balance (24)		CPI (16)		PPI (16)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	0,007		0,002		0,001	c	-0,002	b	0,017		-0,005	b	0,005		-0,007	a	0,001	c	0,003	
-4	0,013		0,002		-0,002	b	0,001		0,009		0,005		-0,005	a	-0,006	a	-0,011	a	-0,009	a
-3	0,017		-0,001	b	0,004	c	0,005		0,000		-0,005	a	-0,004	c	0,001	b	-0,001		0,009	
-2	-0,005	c	0,002		0,008		0,000		-0,014	a	-0,012	a	-0,003	a	-0,002	c	0,017		-0,002	
-1	-0,204	a	-0,008	a	-0,041	a	-0,063	a	-0,081		0,013		-0,043	a	-0,025	a	0,029		0,036	
0	-0,029		-0,011	a	-0,002	a	0,000		-0,005		0,007		0,000		0,013		-0,007	c	-0,010	
1	-0,004	a	-0,004	b	-0,011	a	0,005		-0,019	b	0,002		0,021		-0,002	c	0,005		0,005	
2	-0,016	b	-0,001		-0,003	a	0,004		0,039		0,004		-0,005	a	-0,019	a	-0,007	b	0,012	
3	0,002		0,007	c	0,004		-0,009	b	-0,027	b	0,004		0,004		0,003		-0,001		0,011	
4	-0,019	a	-0,013	a	0,000	c	-0,002	c	0,000		0,002	c	-0,016	a	-0,003		0,001		-0,003	
5	-0,019	a	0,000	a	-0,005	a	0,000	b	0,003		-0,001	b	-0,005	b	-0,014	a	-0,005		-0,005	b
6	-0,005	c	0,000	a	-0,001	b	0,016		0,002		-0,003	a	0,002	c	-0,009	a	0,009		-0,005	
7	0,002		0,012		0,002		0,003		0,016		-0,004	a	0,001	c	0,003		0,000	c	-0,005	b
8	-0,006	a	0,000	b	0,011		0,013		0,036		0,005		-0,002	b	0,004		-0,012	a	0,011	
9	-0,014	a	-0,003	a	0,004		0,016		-0,002		0,001		0,002		-0,005	a	-0,007	c	0,021	
10	-0,014	a	0,002		-0,006	a	-0,003	b	0,012		-0,004	a	0,000	b	-0,004	b	0,000		0,005	

B: Bad News

Time	NFP (29)		PMI Man. (28)		PMI Services (26)		Retail Sales (24)		GDP (11)		Industrial Production (31)		Core DGO (38)		Trade Balance (26)		CPI (5)		PPI (17)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	0,002		-0,006	a	0,000	c	0,005		0,002		-0,004	a	0,004		0,009		0,008		-0,001	
-4	-0,005	a	0,001	b	0,008		-0,010	a	0,019		-0,001	c	0,000	b	-0,004	a	0,007		0,000	
-3	0,004	c	0,002		0,002		0,009		0,010		-0,002		0,003		-0,002		0,002		0,007	
-2	0,000	b	0,012		0,009		0,014		-0,016	a	-0,012	a	0,001	b	-0,012	a	-0,001		0,008	
-1	0,128		0,022		0,042		0,080		0,026		-0,001		0,015		0,023		-0,071	a	-0,016	a
0	-0,014	a	0,002		-0,004	a	0,014		0,037		0,005		0,003		-0,012	a	-0,010	c	0,005	
1	0,014		-0,017	a	-0,005	a	-0,015	a	-0,010	a	0,003		0,009		0,008		0,031		0,000	b
2	-0,001	a	-0,008	b	0,011		0,021		0,008		0,004		0,004	c	0,021		-0,016	b	-0,005	b
3	0,012	b	0,004		-0,005	a	0,005		0,004	c	0,002		0,007		0,017		0,022		0,012	
4	0,000	a	0,014		-0,001	b	0,013		-0,012	a	-0,003	a	-0,003	b	0,010		0,017		0,011	
5	-0,006	b	0,000	b	-0,017	a	0,006		0,004		0,001	b	-0,005	a	-0,010	a	0,000		0,007	
6	0,003		-0,003	a	0,014		-0,013	a	0,009		0,003	a	0,004	c	-0,008	a	-0,005		-0,005	b
7	-0,005		-0,008	a	0,022		0,010		0,040		-0,008	a	0,008		0,013		0,019		0,002	c
8	0,004	c	-0,007	a	0,000		-0,004	a	0,002		0,005		-0,008	a	-0,004	a	-0,014	a	0,009	
9	0,010		0,005		-0,004	a	0,009		0,010		0,008		0,005		0,011		-0,006	b	0,001	b
10	-0,002	a	-0,001	a	-0,005	b	0,001		0,000		0,004		-0,013	a	-0,004	b	0,005		-0,004	a

C: Neutral News

Time	NFP (1)		PMI Man (1)		PMI Services (4)		Retail Sales (5)		GDP (2)		Industrial Production (5)		Core DGO (1)		Trade Balance (1)		CPI (18)		PPI (6)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	0,032		0,000		0,003		0,008		-0,005		0,010		0,023		-0,026		0,000		-0,001	
-4	-0,092	b	0,010		0,025		0,005		0,012		0,006	c	0,014		-0,010		0,004		-0,008	b
-3	-0,032	c	-0,020		0,003		0,009		-0,012	b	0,021		-0,009		-0,063	b	0,006		-0,014	a
-2	0,005		0,000		0,007		0,005		0,049		-0,022	a	0,028		0,016		0,002		-0,001	
-1	0,037		0,000		0,011		0,006		-0,073	a	-0,003		0,009		0,000		-0,077	a	0,026	
0	-0,032	c	0,000		0,010		-0,007		0,022		-0,011		-0,005		0,016		-0,001		0,020	
1	0,000		0,000		0,002		0,015		-0,037	b	0,012		0,032		-0,073	b	-0,021	b	0,011	
2	-0,134	b	-0,010		0,031		-0,003		0,063		-0,001		0,028		-0,052		0,008		0,001	c
3	0,011		0,124		0,018		0,006		-0,051	a	0,007		-0,005		-0,005		0,001		-0,016	c
4	-0,065	b	0,000		0,024		0,014		-0,012		-0,014		-0,028	c	-0,026		0,000		0,007	
5	-0,059	b	0,005		0,010		-0,007		-0,012		0,009		0,000		0,026		0,010		0,006	
6	-0,155	b	-0,020		-0,025	b	0,003		-0,063		0,008		-0,005		-0,042		0,001		-0,011	c
7	-0,032	c	-0,010		0,022		-0,004		-0,053		-0,002		0,000		0,026		0,002		0,005	
8	0,037		-0,020		-0,011		0,015		0,066		0,000		0,005		0,031		-0,005	b	0,015	
9	0,075		0,035		0,004		-0,022	b	-0,017		-0,004		0,014		0,016		-0,003	b	-0,003	
10	-0,086	b	-0,035	c	0,010		0,006		0,037		0,006		-0,005		-0,052		-0,016	a	0,013	

Note: Table contains values of mean abnormal percentage returns (AR) on a currency pair as an effect of the macroeconomic announcements in the event window running from -5 to 10 minutes; announcement occurs at 0 minute. We report statistical significance (denoted by a symbol) at the 1 (a), 5 (b), and 10% (c) levels based on the Corrado-Zivney Tcz statistics with the corresponding critical values of 2,58 (1%), 1,96 (5%), and 1,65 (10%). The sample runs from January 3, 2011 to December 31, 2015. The announcements are abbreviated as follows: NFP – Nonfarm Payrolls, PMI – Purchasing Managers' Indices from Manufacturing and Services sectors, GDP – Gross Domestic Product, Core DGO – Core Durable Goods Orders, CPI – Consumer Price Index, PPI – Producer Price Index. Number of observations (examined events) is indicated in the parentheses.

Table 2. 6: Minute by minute effect of macroeconomic news on Abnormal Returns of PLN/USD

A: Good News

Time	NFP (30)		PMI Man (31)		PMI Services (30)		Retail Sales (18)		GDP (7)		Industrial Production (23)		Core DGO (20)		Trade Balance (24)		CPI (16)		PPI (16)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	0,001		0,005	c	-0,005	a	-0,002	a	0,020		0,001	c	-0,001	a	-0,006	a	-0,003	b	0,003	
-4	0,009		0,004		-0,005	b	0,000		0,013		-0,001		-0,012	a	-0,005	a	-0,016	a	-0,008	a
-3	0,016		-0,005	a	0,007		0,004		-0,003		-0,002	b	-0,009	a	0,003		-0,006	a	0,009	
-2	0,006		-0,003	a	0,001		0,005		-0,011	b	0,001	c	-0,001		-0,002	c	-0,006	b	0,007	
-1	-0,194	a	-0,001	a	-0,033	a	-0,058	a	-0,103	b	0,008		-0,027	a	-0,026	a	0,058		0,043	
0	-0,037		-0,006	a	0,006	c	-0,010	b	-0,007		0,004		-0,007	b	0,013		-0,009	b	-0,014	c
1	0,000	b	0,005		-0,012	a	0,029		0,003		0,007		0,024		0,005		0,004		0,004	
2	0,008		0,003		0,000	a	0,003		0,016		0,011		-0,004	b	-0,024	a	-0,007	b	0,015	
3	-0,013	b	0,003		-0,001		-0,014	b	0,012		-0,001		0,003		0,000		-0,001		0,007	
4	0,000	b	-0,019	a	-0,002	c	0,008		-0,003		0,004		-0,026	a	-0,005		-0,004		-0,001	c
5	-0,016	a	0,008		-0,003		-0,002	b	0,009		0,009		-0,004		-0,013	b	-0,014	c	-0,003	c
6	0,002		0,000	a	-0,003	b	0,022		0,002		-0,008	a	0,005		-0,008	a	0,003		-0,002	
7	0,002		0,018		-0,016	a	0,005		0,023		0,003	c	0,010		-0,002		0,002		0,000	c
8	0,003	c	0,007		0,011		0,013		0,001		-0,004		-0,003	c	-0,005	b	-0,013	a	0,005	
9	-0,015	a	-0,011	a	0,001	b	0,011		0,006		0,000	a	-0,002		-0,005	b	0,003		0,027	
10	-0,018	a	0,003	c	-0,005	a	-0,006	a	0,021		-0,009	a	-0,007	a	-0,002		0,003		0,000	c

B: Bad News

Time	NFP (29)		PMI Man (28)		PMI Services (26)		Retail Sales (24)		GDP (11)		Industrial Production (31)		Core DGO (38)		Trade Balance (26)		CPI (5)		PPI (17)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	0,000		-0,006	a	-0,004	b	0,001	b	0,008		-0,003	b	0,001	c	0,007		0,007		-0,008	a
-4	-0,014	a	-0,006	a	0,003		-0,002		0,009		-0,007	a	0,003		-0,007	a	0,006		0,000	
-3	0,003	a	0,001		0,010		0,009		0,004		-0,006	a	0,005		-0,007	a	0,001		-0,010	a
-2	0,008		0,005		0,010		0,000	b	-0,008	c	-0,009	a	0,004		-0,008	a	0,004		0,002	
-1	0,172		0,025		0,044		0,091		0,023		-0,002		0,018		0,016		-0,086	a	-0,020	a
0	-0,020	a	0,005		-0,005	a	0,013		0,025		0,007		0,009		-0,006	a	-0,013	b	-0,003	c
1	0,033		-0,016	a	-0,013	a	-0,012	a	-0,010	b	0,007		0,007		0,015		0,029		-0,006	b
2	0,015		-0,006	c	0,003		0,028		0,000		0,003	c	0,004		0,017		-0,023	c	-0,002	c
3	0,004	c	0,007		-0,005	a	0,015		0,006		0,005		0,005	c	0,013		0,025		0,026	
4	-0,020	a	0,013		-0,009	a	0,012		-0,023	a	0,000	c	-0,008	a	0,005		0,026		0,007	
5	-0,017	a	0,003		-0,014	a	-0,002	a	0,006		0,005		-0,006	a	-0,004	a	0,010		0,007	
6	0,002	c	-0,004	b	0,014		-0,019	a	0,008		0,000	b	0,002	b	-0,002	b	-0,015	b	-0,011	a
7	0,000		-0,008	c	0,031		0,021		0,042		-0,001	c	0,002	c	0,012		0,007		0,003	
8	0,011		-0,003	b	0,002		0,001		-0,005		0,004		-0,010	a	0,002	c	-0,002		0,012	
9	0,016		0,002		-0,007	a	0,008		0,006		0,011		0,005		0,009		-0,005	c	-0,001	
10	0,000	a	-0,006	a	0,005		-0,008	a	-0,006	b	0,000		-0,009	a	-0,003		0,006		-0,004	b

C: Neutral News

Time	NFP (1)		PMI Man (1)		PMI Services (4)		Retail Sales (5)		GDP (2)		Industrial Production (5)		Core DGO (1)		Trade Balance (1)		CPI (18)		PPI (6)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	0,051	c	0,003		-0,008		0,008		-0,011		0,014		0,058	b	-0,018		-0,001		-0,005	
-4	0,000		0,030	c	0,021		0,004		0,007		0,004		0,009		-0,033		-0,001		-0,016	
-3	-0,127		0,000		0,023		0,015		0,008		0,013	b	0,024	c	-0,125		0,007		-0,011	
-2	0,036		-0,036		0,024		0,012		0,028	c	-0,010		-0,006		0,012		0,003		0,011	
-1	0,115	c	-0,010		-0,004		0,014		-0,084		0,000		-0,025		-0,042		-0,071		-0,019	
0	-0,049		0,017		0,009		-0,003		0,018		0,007		-0,009		0,015		0,000		0,015	
1	0,042		0,007		0,007		0,020		-0,046		0,005		0,052	c	-0,077		-0,026		0,021	
2	-0,155		0,000		0,060	c	-0,006		0,077	b	0,006		0,055	c	0,017		0,013		0,018	
3	-0,034		0,036		0,009		0,028		-0,053		0,016		0,027	c	-0,071		0,003		-0,021	
4	-0,037		0,062	c	0,017		0,003		-0,007		-0,013		0,024	c	0,012		-0,001		0,017	
5	-0,061		-0,003		0,037	b	0,001		-0,026		0,013		-0,025		-0,071		0,009		-0,005	
6	-0,027		0,000		-0,031		-0,007		-0,053		0,015	c	0,021		-0,045		0,006		-0,019	
7	-0,033		-0,010		0,015		-0,008		-0,035		0,004		0,000		0,038		0,004		0,000	
8	0,003		-0,020		0,007		0,037	b	0,051	c	-0,007		-0,025		0,062	c	-0,007		0,015	
9	-0,121		0,033		-0,006		-0,010		-0,032		-0,009		-0,009		0,003		-0,006		0,007	
10	0,012		-0,016		0,055	b	-0,009		0,033		0,013		-0,009		-0,048		-0,007		0,011	

Note: Table contains values of mean abnormal percentage returns (AR) on a currency pair as an effect of the macroeconomic announcements in the event window running from -5 to 10 minutes; announcement occurs at 0 minute. We report statistical significance (denoted by a symbol) at the 1 (a), 5 (b), and 10% (c) levels based on the Corrado-Zivney Tcz statistics with the corresponding critical values of 2,58 (1%), 1,96 (5%), and 1,65 (10%). The sample runs from January 3, 2011 to December 31, 2015. The announcements are abbreviated as follows: NFP – Nonfarm Payrolls, PMI – Purchasing Managers' Indices from Manufacturing and Services *sector*s, GDP – Gross Domestic Product, Core DGO – Core Durable Goods Orders, CPI – Consumer Price Index, PPI – Producer Price Index. Number of *observations (*examined events*)* is indicated in the parentheses.

Table 2. 7: Minute by minute effect of macroeconomic news on Abnormal Returns of HUF/USD

A: Good News

Time	NFP (30)		PMI Man (31)		PMI Services (30)		Retail Sales (18)		GDP (7)		Industrial Production (23)		Core DGO (20)		Trade Balance (24)		CPI (16)		PPI (16)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	-0,001		-0,002	a	0,002		-0,003	b	0,022		0,001	c	-0,004	a	0,000	c	-0,008	a	-0,011	a
-4	0,012		0,005		-0,004	b	0,001		0,016		0,003		-0,008	a	-0,001	b	-0,023	a	-0,003	b
-3	0,015		0,001	b	0,004		0,007		-0,014	c	-0,005	b	-0,008	a	0,007		-0,006	b	0,011	
-2	-0,016	a	-0,006	a	-0,002	b	0,007		-0,019	a	0,005		-0,006	a	0,002		0,008		-0,002	
-1	-0,186	a	0,000	b	-0,030	a	-0,058	a	-0,062		0,000		-0,039	a	-0,022	a	0,038		0,050	
0	-0,044	a	-0,005	a	-0,009	a	0,003	b	-0,046	b	-0,001	b	0,000		0,018		-0,012	b	0,000	
1	0,000	a	0,004		-0,017	a	0,004		0,002		0,005		0,030		0,000		-0,010	c	0,000	
2	-0,001	b	0,014		-0,015	a	0,009		0,015		0,009		-0,006	a	-0,017	a	0,012		0,006	
3	-0,004	c	0,000		0,003		-0,011	b	-0,011	c	0,011		0,005		-0,006	b	0,002	c	0,008	
4	-0,013	a	-0,006	a	0,001		-0,001		0,009		0,000	c	-0,017	a	-0,005		0,007		-0,003	
5	-0,014	a	0,002	b	-0,003		0,001		-0,005		0,002		-0,008	b	-0,020	a	-0,008	c	0,004	
6	-0,008	b	-0,001	a	-0,005	b	0,015		0,004		0,008		0,003		-0,014	a	0,011		-0,002	
7	0,010		0,012		0,001	c	0,002		0,025		0,007		0,003		0,003		-0,006	c	-0,004	b
8	-0,008	b	0,008		0,008		0,019		0,007		0,004		-0,001	b	0,001		-0,008	b	0,016	
9	-0,023	a	-0,009	a	0,004	c	-0,006	c	-0,005	c	-0,003	a	-0,004	b	-0,009	b	0,005		0,011	
10	-0,005	b	0,005	c	-0,003	b	-0,004	c	0,036		-0,009	a	-0,003	c	0,008		-0,004	c	0,008	

B: Bad News

Time	NFP (29)		PMI Man (28)		PMI Services (26)		Retail Sales (24)		GDP (11)		Industrial Production (31)		Core DGO (38)		Trade Balance (26)		CPI (5)		PPI (17)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	0,004		-0,001	b	-0,008	b	0,000		-0,002	c	-0,002	a	0,001	b	0,005		-0,001		-0,006	a
-4	-0,013	a	0,003		0,012		-0,008	a	-0,001		0,000	b	0,001	b	-0,007	a	0,008		0,007	
-3	0,006	b	0,008		0,002	b	0,012		0,000		-0,007	a	-0,002	b	-0,004	a	0,002		-0,003	
-2	0,002		0,005	b	0,016		-0,006	a	-0,005	b	-0,013	a	0,008		-0,014	a	-0,005		-0,011	b
-1	0,133		0,029		0,047		0,079		-0,023		-0,001		0,025		0,020		-0,077	a	-0,023	a
0	0,000	a	0,004		-0,009	a	0,013		0,004		0,005		0,010		-0,004	a	-0,012	c	0,003	
1	0,044		-0,008	a	0,004		-0,010	a	0,003		0,002	b	0,002		0,019		0,020		0,004	
2	0,020		-0,007	b	0,004		0,031		-0,012	b	0,006	c	0,000		0,011	c	-0,009		0,006	
3	0,010	b	-0,001		-0,005	b	0,005		-0,002	b	0,007		0,001	b	0,019		0,028		0,013	
4	-0,034	a	0,012		0,006		0,015		-0,009	a	0,007		-0,004	c	0,007		0,031		0,015	
5	-0,013	a	0,020		-0,023	a	0,013		-0,007	b	0,000		-0,008	a	-0,014	a	0,002		0,002	
6	0,008		-0,001	b	0,010		-0,016	a	0,001		0,007		0,002	b	-0,003	a	0,012		-0,009	a
7	0,008		0,000	b	0,031		0,014		0,006		-0,006	a	0,001		0,008		0,013		0,008	
8	0,002	c	-0,001	b	0,010		-0,002	a	-0,007	b	0,004		-0,007	a	0,013		-0,013	b	0,003	
9	0,023		0,009		-0,007	a	0,011		-0,006	b	0,013		0,005		0,009		-0,005		0,009	c
10	-0,004	a	-0,005	a	0,001		-0,004	c	-0,006	a	0,002	b	-0,010	a	-0,002	c	0,012		-0,005	a

C: Neutral News

Time	NFP (1)		PMI Man (1)		PMI Services (4)		Retail Sales (5)		GDP (2)		Industrial Production (5)		Core DGO (1)		Trade Balance (1)		CPI (18)		PPI (6)	
	AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %		AR %	
-5	0,040		0,001		-0,030	b	0,006		-0,047	b	0,008		-0,012		-0,022		-0,006	a	-0,011	b
-4	-0,063	b	0,037		0,038		0,015		-0,021	b	-0,007	c	0,029		-0,026		0,006		-0,014	b
-3	-0,009		-0,009		-0,002		0,000		0,020		0,027		0,110		-0,088	b	-0,001	c	-0,011	a
-2	-0,018		-0,027	c	0,007		0,006		0,040		0,004		0,000		0,035		-0,003		-0,014	
-1	0,364		-0,036	b	0,013		0,002	b	-0,106	a	-0,007	c	0,000		-0,048	b	-0,053	a	0,020	
0	-0,095	b	0,028		0,024		-0,010		0,033		0,007		0,000		0,061		-0,016		0,018	
1	-0,018		0,023		-0,005		0,049		-0,058	b	0,001		0,000		-0,105	b	-0,026	a	0,018	
2	-0,171		0,005		0,031		-0,006		0,077		-0,002		0,000		-0,074		0,008		0,003	b
3	-0,041		0,046		0,037		0,028		-0,039	c	-0,004	b	0,008		-0,004		-0,001	c	-0,014	b
4	-0,095		0,037		0,026		0,001		0,018		0,002		0,004		-0,013		-0,002		0,004	
5	-0,005		0,001		0,023		-0,008		0,007		0,006		-0,004		0,013		0,012		0,010	
6	-0,014		-0,036	c	-0,022	b	0,018		-0,062		0,028		0,000		-0,039		0,008		-0,011	c
7	-0,041		0,005		0,024		0,019		0,003		-0,008	b	0,045		0,013		0,002		-0,015	a
8	0,008		0,010		-0,010		0,005		0,053		0,006		0,012		0,035		-0,011	a	0,010	
9	-0,104		0,019		-0,002		-0,019		0,007		-0,014	c	-0,008		-0,013		0,002	b	0,005	
10	-0,005		-0,027		0,015		0,005		0,095		0,017		0,020		-0,048		-0,010	b	0,006	

Note: Table contains values of mean abnormal percentage returns (AR) on a currency pair as an effect of the macroeconomic announcements in the event window running from -5 to 10 minutes; announcement occurs at 0 minute. We report statistical significance (denoted by a symbol) at the 1 (a), 5 (b), and 10% (c) levels based on the Corrado-Zivney Tcz statistics with the corresponding critical values of 2,58 (1%), 1,96 (5%), and 1,65 (10%). The sample runs from January 3, 2011 to December 31, 2015. The announcements are abbreviated as follows: NFP – Nonfarm Payrolls, PMI – Purchasing Managers' Indices from Manufacturing and Services sectors, GDP – Gross Domestic Product, Core DGO – Core Durable Goods Orders, CPI – Consumer Price Index, PPI – Producer Price Index. Number of observations (examined events) is indicated in the parentheses.

Table 2. 8: Minute by minute effect of Monetary Policy announcements on new EU FX Abnormal Returns (AR%)

Panel A: Effect of the examined ECB Monetary changes on Euro-expressed FX rates

Percentage Abnormal Returns (AR%) and their statistical significance

Time	CZK/EUR (12)			PLN/EUR (12)			HUF/EUR (12)		
	AR %		Tcz Q	AR %		Tcz Q	AR %		Tcz Q
-5	0,000	c	1,69	0,020		-0,56	0,003	a	3,49
-4	0,003	a	3,56	-0,002	b	2,05	0,001		1,09
-3	0,006		0,64	0,005		0,18	0,003		0,20
-2	-0,002		0,56	-0,016	a	3,18	-0,005		1,39
-1	-0,005	c	1,89	0,013		0,37	0,005	c	1,91
0	0,021		-0,57	0,007		-0,20	0,016		-1,46
1	0,000	a	2,77	0,042		-1,00	0,007		0,47
2	0,007	b	2,30	0,025		-3,00	0,005		-0,21
3	-0,018	a	2,66	0,027		-0,13	0,024		-1,76
4	-0,001	b	2,08	-0,009		1,53	0,000		-0,08
5	0,005		0,95	-0,012	a	3,54	0,018		0,80
6	0,001	a	2,77	0,005		0,17	0,001		0,61
7	0,011		0,38	-0,003	c	1,65	-0,008		1,34
8	0,019		-0,02	-0,004	b	2,51	0,000		0,86
9	0,011		1,40	0,002		0,90	0,024		-0,71
10	0,011	b	2,15	0,024		-1,77	0,004		0,91
11	-0,003	c	1,66	-0,007	b	2,44	0,004		-0,46
12	0,021		0,37	-0,006		1,09	0,027		-0,51
13	-0,005		1,43	0,025		-0,45	0,005		0,20
14	0,008		1,33	-0,007		1,44	-0,010	a	3,33
15	-0,007	a	2,74	-0,008	a	2,71	0,004		-0,14

Note: Symbols a, b, and c denote statistical significance at the 1, 5 and 10% levels based on the Corrado-Zivney T_{CZ} statistics. The examined ECB monetary policy events are presented in Table 2.9. Number of observations (examined events) is indicated in the parentheses.

Panel B: Effect of the examined Fed Monetary Policy changes on USD-expressed FX rates

Abnormal Returns (AR%) and their statistical significance

Time	CZK/USD (6)			PLN/USD (6)			HUF/USD (6)		
	AR %		Tcz Q	AR %		Tcz Q	AR %		Tcz Q
-5	0,002		1,11	-0,001		0,08	-0,015	a	2,94
-4	0,002		0,86	0,009		-0,83	0,001		0,18
-3	-0,010		1,54	0,002		0,55	0,009		0,03
-2	-0,032		1,47	-0,019		1,19	-0,002		1,15
-1	-0,002		1,21	-0,064		1,58	-0,076	a	3,16
0	-0,013		0,51	-0,024	c	1,70	-0,049	b	2,19
1	-0,045		1,61	0,010		-0,15	0,015		-0,12
2	0,018		-0,36	0,002		0,76	0,020		0,12
3	0,004		0,54	0,000		0,98	0,020		-0,82
4	0,010		-0,29	0,027		-0,85	-0,007	c	1,67
5	-0,021		0,86	0,000		-0,03	0,024		0,08
6	0,002		0,88	0,031		0,05	0,005		0,52
7	0,004		0,88	0,027		-0,30	-0,005		-0,03
8	0,073		0,02	0,020		0,03	0,013		0,38
9	0,015		-0,12	-0,039	a	2,64	0,017		0,22
10	0,008		0,31	0,027		0,59	-0,008		1,32
11	0,039		-0,04	0,046		-0,36	0,040		-0,25
12	0,001		1,15	-0,005	c	1,71	0,023		-0,88
13	-0,014		1,31	0,001		0,69	-0,019	b	2,36
14	-0,018		0,98	0,005		0,26	-0,008		0,61

Note: Symbols a, b, and c denote statistical significance at the 1, 5 and 10% levels based on the Corrado-Zivney T_{CZ} statistics. The examined Fed monetary policy events are presented in Table 2.9. Number of observations (examined events) is indicated in the parentheses.

Table 2. 9: The list of examined monetary policy events

Panel A: ECB meetings

Day of the ECB meeting	Time of the announcement	Deposit Interest Rate	Main Refinancing Operations	Marginal Lending Facility
7.4.2011	1:45 p.m. CET	0,50	1,25	2,00
7.7.2011	1:45 p.m. CET	0,75	1,50	2,25
3.11.2011	1:45 p.m. CET	0,50	1,25	2,00
8.12.2011	1:45 p.m. CET	0,25	1,00	1,75
5.7.2012	1:45 p.m. CET	0,00	0,75	1,50
2.5.2013	1:45 p.m. CET	0,00	0,50	1,00
7.11.2013	1:45 p.m. CET	0,00	0,25	0,75
5.6.2014	1:45 p.m. CET	−0,10	0,15	0,40
4.9.2014	1:45 p.m. CET	−0,20	0,05	0,30
22.1.2015	2:30 p.m. CET	QE announcement		
5.3.2015	2:30 p.m. CET	QE details announcement		
3.12.2015	1:45 p.m. CET	−0,30	0,05	0,30

Panel B: FOMC meetings

Date of the FOMC meeting	Time of the announcement	Unconventional monetary policy settings
21.9.2011	8:00 p.m. CET	FOMC meeting with the announcement of operation Twist planning to purchase 400 billion dollars of bonds with maturities of 6 to 30 years and to sell the bond within less than 3 years, thereby extending the average maturity of the Fed's own portfolio.
20.6.2012	8:00 p.m. CET	FOMC announced an extension to the Twist program by adding 267 billion dollars.
13.9.2012	8:00 p.m. CET	FOMC announced the 3rd round of the Quantitative Easing program (QE3) with monthly purchases worth 40 billion dollars of mortgage-backed securities.
12.12.2012	8:00 p.m. CET	FOMC voted to expand its QE program with an additional monthly 45 billion USD of longer-term Treasury securities.
18.12.2013	8:00 p.m. CET	FOMC announced tapering back QE3 purchases at a rate of 10 billion USD each month.
16.12.2015	8:00 p.m. CET	FOMC announced its key interest rate (the Fed Fund rate) increase for the first time after June 2006. The hike was from the range (0%–0.25%) to the range (0.25%–0.5%).

Table 2. 10 Response of currencies to qualitatively different news: Comparison based on the Kruskal-Wallis test

Panel A: Exchange rates of local currencies expressed in Euro, first minute after the news announcement

	Good news		Bad news		Neutral news	
	KW	**P value**	**KW**	**P value**	**KW**	**P value**
ZEW	4.934551	0.0848[c]	4.073051	0.1305	2.000000	0.3679
PMI	2.758580	0.2518	0.258286	0.8788	-	-
IFO	2.852702	0.2402	4.638005	0.0984[c]	2.000000	0.3679
Ind. Prod	1.731355	0.4208	0.485510	0.7845	1.155556	0.5611
GDP	1.675485	0.4327	1.476809	0.4779	1.038462	0.5950
Retail Sales	5.504078	0.0638[c]	0.418441	0.8112	1.098330	0.5774
Trade Bal.	1.561545	0.4581	3.420464	0.1808	0.857143	0.6514
CPI	0.796202	0.6716	3.434792	0.1795	7.311447	0.0258[b]
PPI	3.494863	0.1742	3.818689	0.1482	2.076887	0.3540
ALL	29.71996	0.0745	29.55768	0.1625	13.05349	0.7326

Note: Symbols a, b, and c denote statistical significance at the 1, 5 and 10% levels. The announcements are abbreviated as follows: ZEW – German Economic Sentiment Index, PMI – Purchasing Managers' Indices from Manufacturing and Services sectors, IFO – German Business Climate Index, GDP – Gross Domestic Product, CPI – Consumer Price Index, PPI – Producer Price Index.

Panel B: Exchange rates of local currencies expressed in US, first minute after the news announcement

	Good news		Bad news		Neutral news	
	KW	**P value**	**KW**	**P value**	**KW**	**P value**
NFP	0.352821	0.8383	0.278024	0.8702	2.000000	0.3679
PMI Man	0.412336	0.8137	0.139376	0.9327	2.000000	0.3679
PMI Non-Man	0.921709	0.6307	0.090930	0.9556	0.346154	0.8411
Retail Sales	0.153984	0.9259	0.065676	0.9677	0.320000	0.8521
GDP	0.230056	0.8913	3.151276	0.2069	0.857143	0.6514
Ind. Prod.	2.726222	0.2559	1.399960	0.4966	0.260000	0.8781
Core DGO	0.481311	0.7861	0.605612	0.7387	2.000000	0.3679
Trade Bal.	0.180365	0.9138	0.241031	0.8865	2.000000	0.3679
CPI	0.004464	0.9978	0.060000	0.9704	0.490685	0.7824
PPI	0.438776	0.8030	0.878893	0.6444	0.327485	0.8490
ALL	14.22008	0.9204	27.90317	0.2195	12.47131	0.9625

Note: Symbols a, b, and c denote statistical significance at the 1, 5 and 10% levels. The announcements are abbreviated as follows: NFP – Nonfarm Payrolls, PMI – Purchasing Managers' Indices from Manufacturing and Services sectors, GDP – Gross Domestic Product, Core DGO – Core Durable Goods Orders, CPI – Consumer Price Index, PPI – Producer Price Index.

2.7 Figures

Figure 2. 1: One-minute spot exchange rates of local currencies expressed in Euro and their percentage returns (*January* 3, 2011 - *December* 31, 2015)

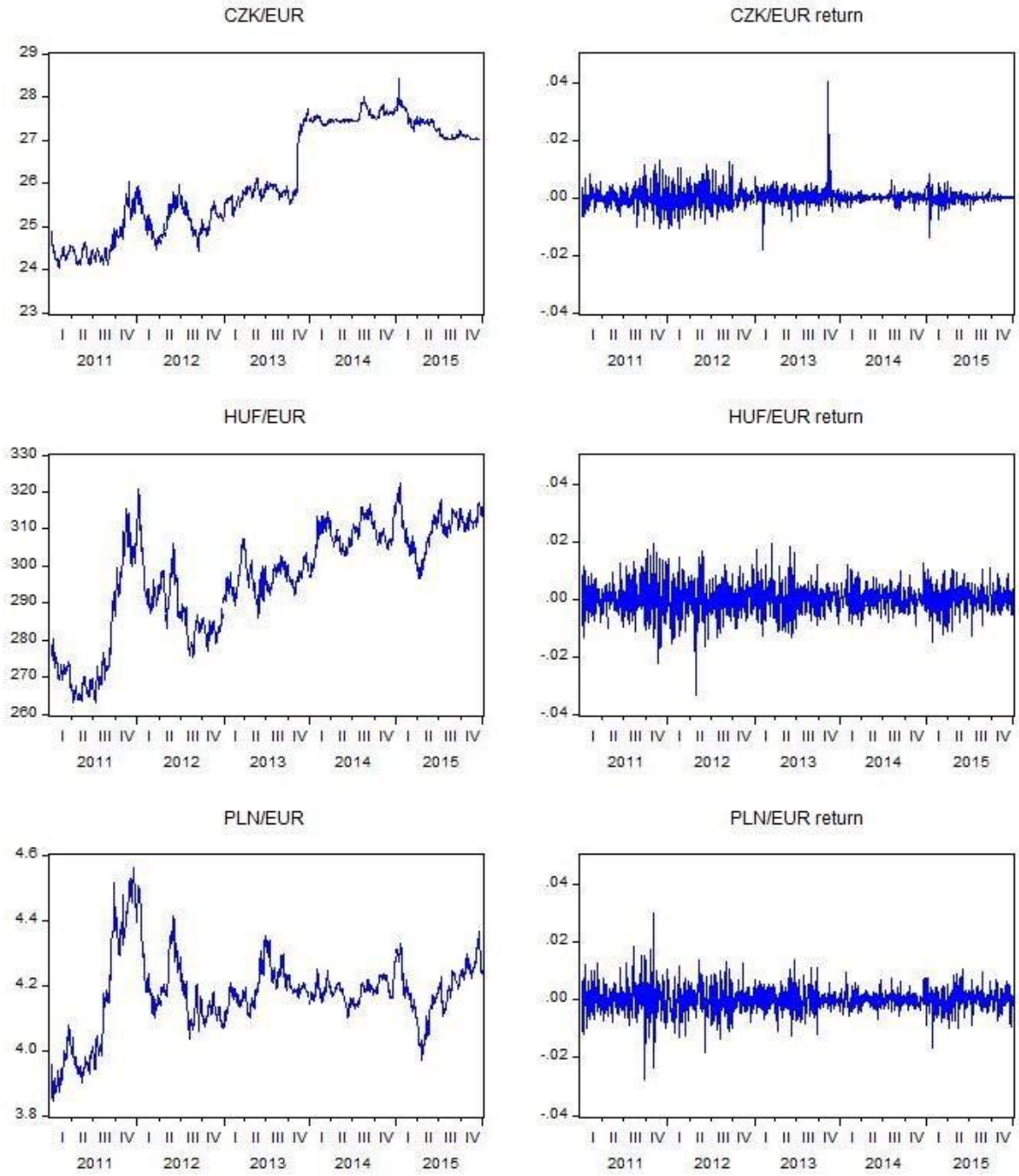


Figure 2. 2: One-minute spot exchange rates of local currencies expressed in US dollar and their percentage returns. (*January* 3, 2011 - *December* 31, 2015)

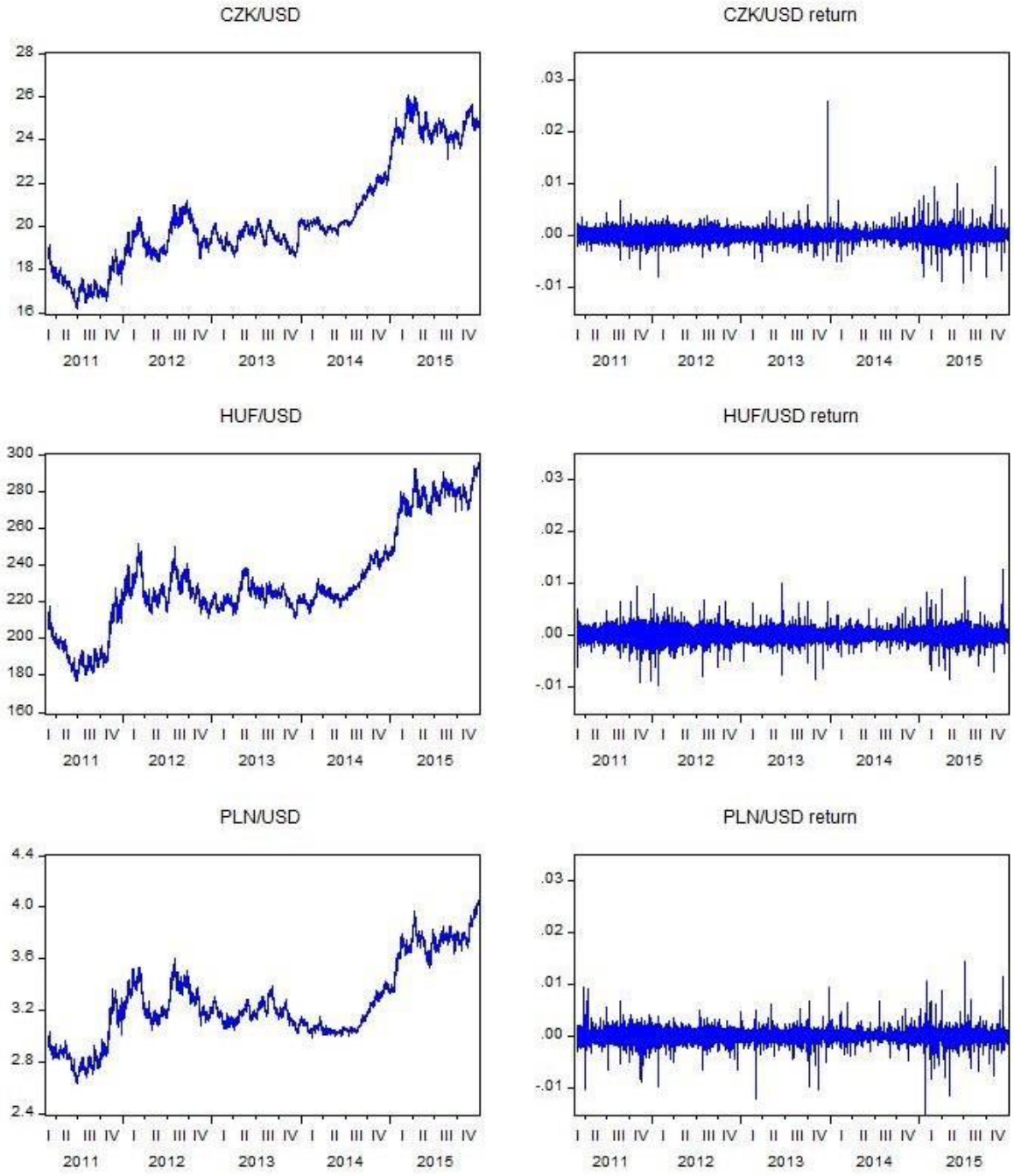


Figure 2. 3: Cumulative mean abnormal returns (CAR in %) on the currency pairs linked to good, bad, and neutral news

Total examined period (2011-2015)

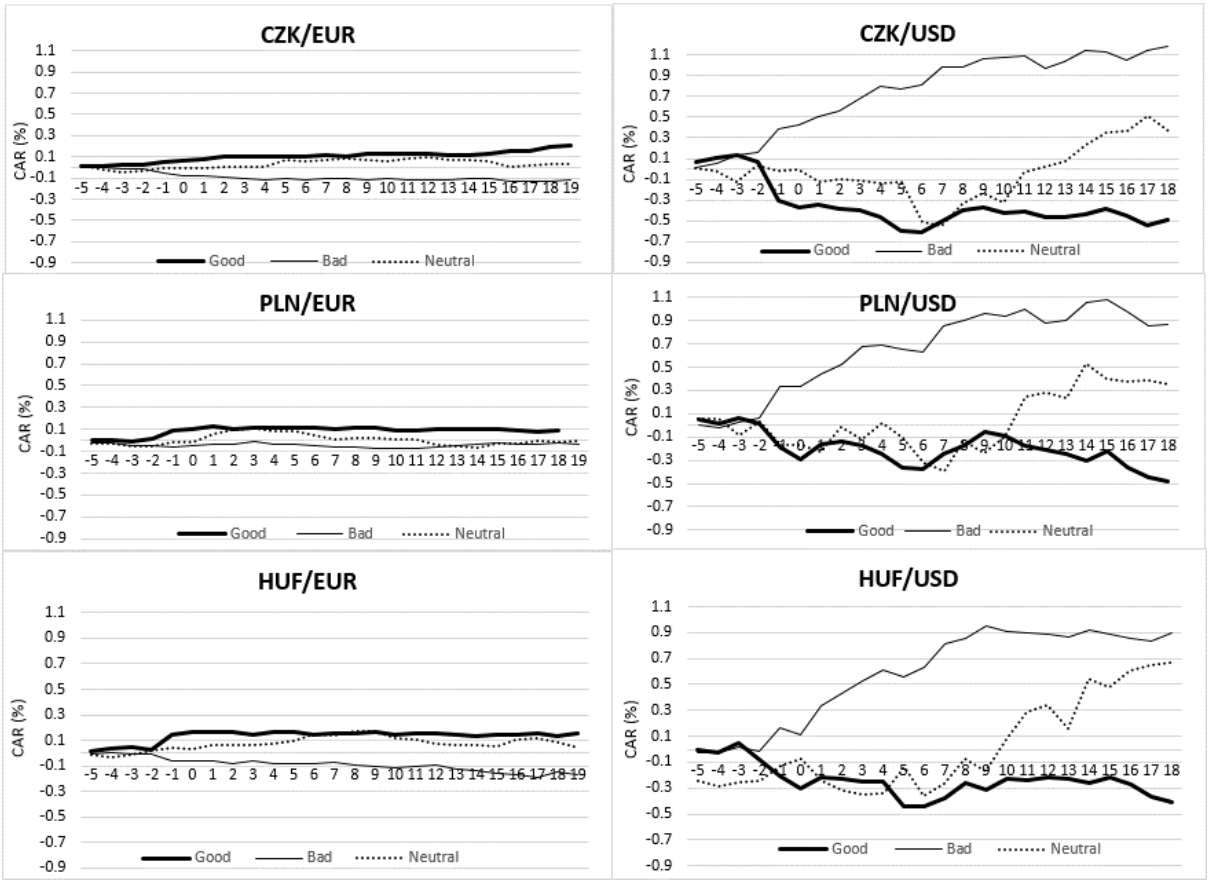


Figure 2. 4: Cumulative mean abnormal returns (CAR in %) on the currency pairs linked to good, bad, and neutral news. EU debt crisis (3.1.2011– 26.7.2012)

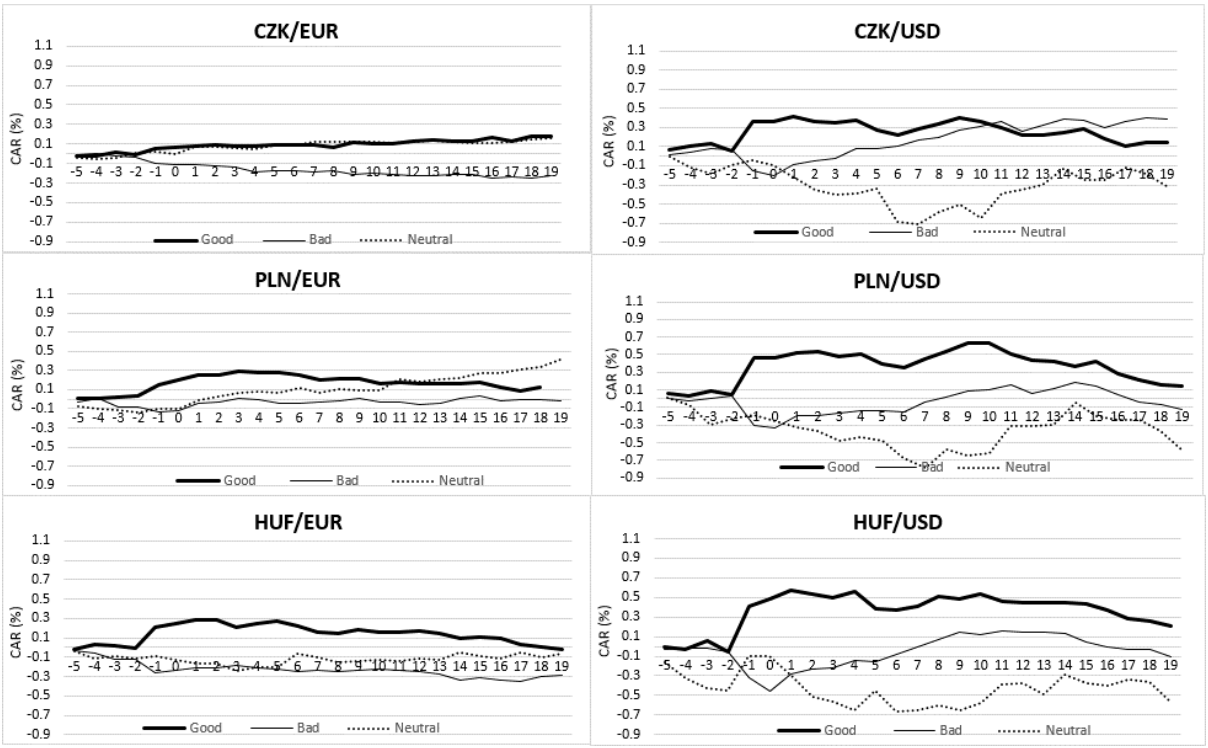


Figure 2. 5: Cumulative mean abnormal returns (CAR in %) on the currency pairs linked to good, bad, and neutral news. Post-EU debt crisis (27.7.2012 – 31.12.2015)

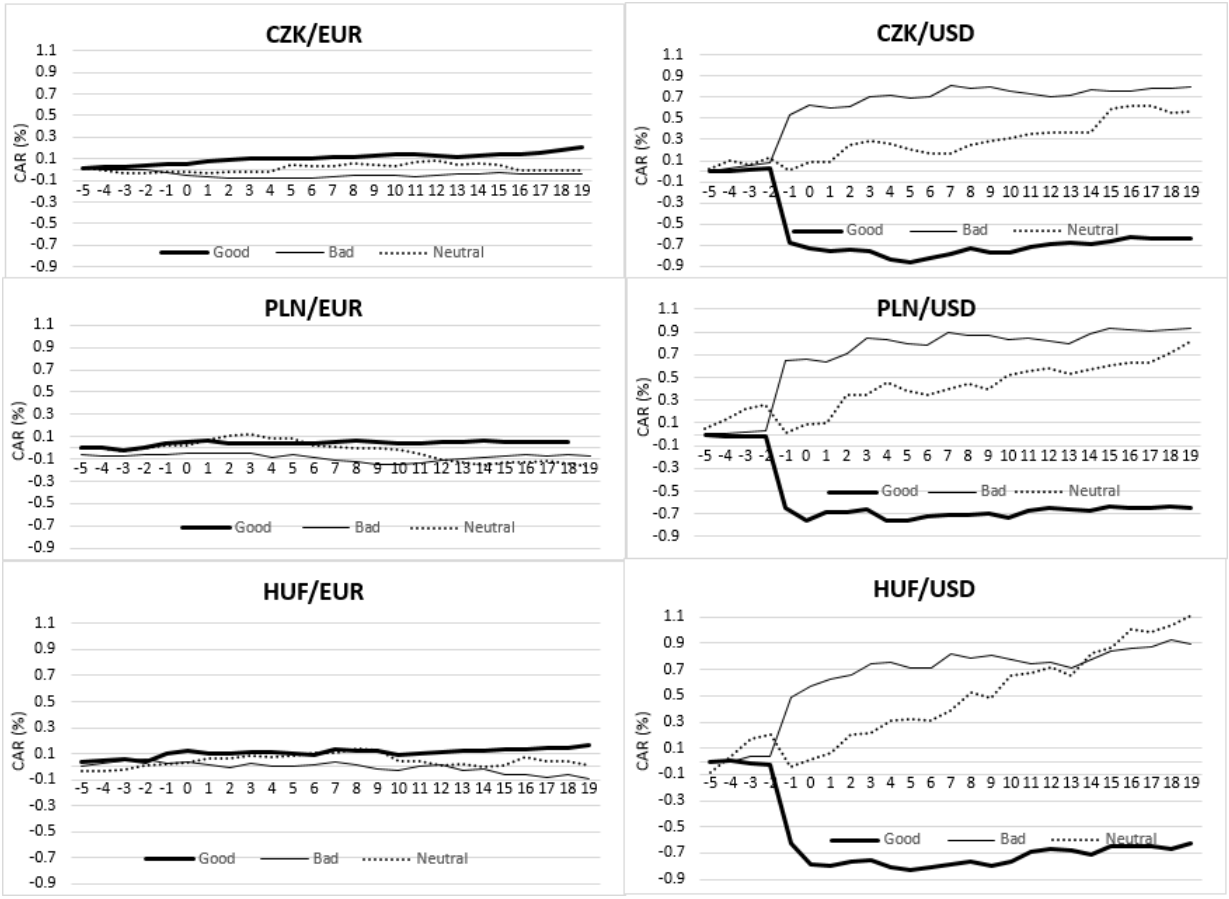
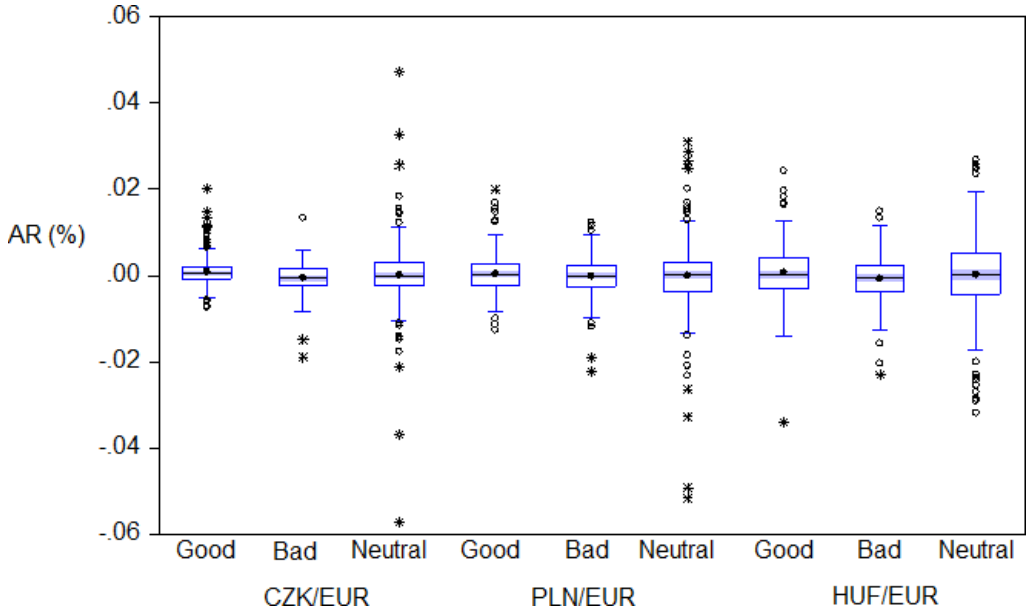
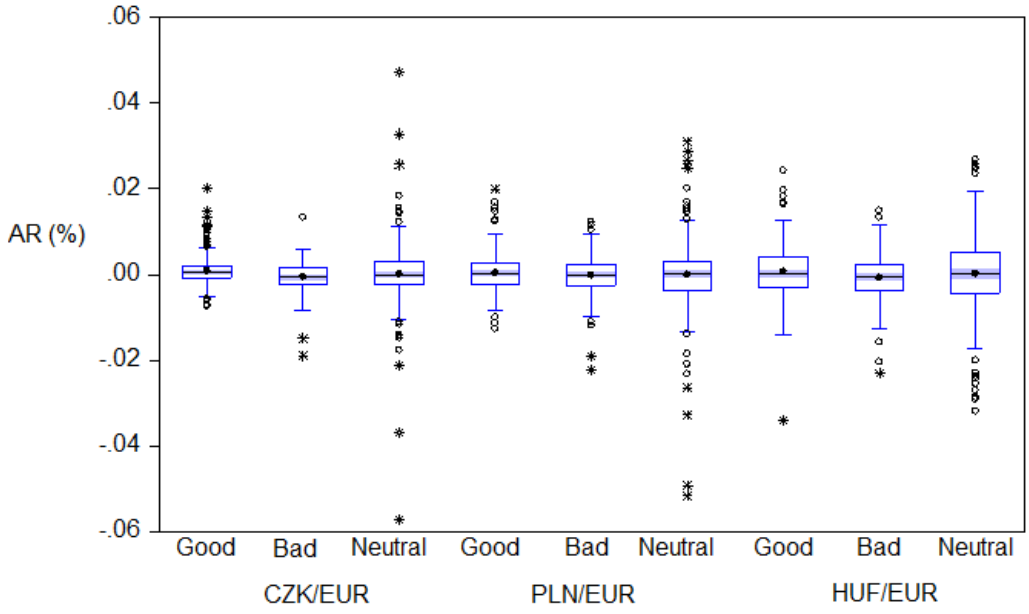


Figure 2. 6: Box-and-whisker plots of percentage abnormal returns (AR%) linked to clusters of good, bad, and neutral news

Panel A: Exchange rates of local currencies expressed in Euro



Panel B: Exchange rates of local currencies expressed in US dollar



3 The Impact of German Macroeconomic News on Emerging European Forex Markets

This essay analyses the impact of German macroeconomic news announcements and ECB meeting days on the conditional volatility of the Czech, Polish, and Hungarian Foreign Exchange markets as proxied by CZK/EUR, PLN/EUR, and HUF/EUR exchange rate returns over six years (2010–2015). A currency intervention period (11/2013–2015) in the Czech Republic is examined separately. EGARCH-type models with normal and Student's *t*-distributions are employed. The comprehensive analysis shows the following results. (i) The IFO index, Factory Orders increase and the PMI index from the Service sector, the labor market data decrease conditional volatility of PLN/EUR. (ii) The IFO index and Industrial Production increase conditional volatility of HUF/EUR on the day of the announcement. (iii) Data from the labor market have a calming effect on CZK/EUR after the central bank launched currency interventions. (iv) IFO index increases and the PMI index from the Manufacturing sector decreases conditional volatility of CZK/EUR before currency interventions were introduced (2010–11/2013).

3.1 Introduction and motivation

Exchange rates are an important part of international trade and quite responsive to developments in the real economy. The Czech Republic, Hungary, and Poland are open economies. Exports and imports are at high levels relative to GDP. Exports of goods and services in the Czech Republic made up 83.0% of GDP, in Hungary 90.7% of GDP, and in Poland 49.6% of GDP in 2015. Not only the exports, but also the imports represented significant part of GDP. Particularly, imports of goods and services spoke for 76.8% of GDP in the Czech Republic, 81.8% of GDP in Hungary and 46.5% of GDP in Poland. All in all, net exports produced 3.47% of GDP in the Czech Republic, 5.32% of GDP in Hungary and 1.01% in Poland.[16]

The analysis of Škubna et al. (2011) confirms the high interdependence between the value of exports and the value of gross domestic product. Moreover, they say that EU member states contribute to the turnover of the foreign exchange trade of the Visegrad Four (V4) countries by about 70%. Germany is Central Europe's most important economic partner in terms of foreign trade and investments.[17] According to Paplowski (2016) the

[16] Data come from OECD database (https://data.oecd.org/trade/trade-in-goods-and-services.htm)
[17] The Visegrad Four group consist of the Czech Republic, Poland, Hungary and Slovakia. Slovak currency is not involved in our research, because the country adopted the euro in 2009.

value of Germany investments in the V4 countries doubled, from €36 billion to €77 billion in the period 2004–2012.

Exchange rate movements are also an important determinant of inflation and thus achieving the inflation target. This was demonstrated by the Czech National Bank's (CNB) decision to launch currency interventions on November 7, 2013. The bank set a minimum CZK/EUR value at a level of 27 to achieve an inflation target of 2%, as measured by the annual increase in the consumer price index (CPI).

Cavusoglu (2011) provides extensive evidence that macroeconomic fundamentals influence exchange rate movements. In other words, the exchange rate is quite responsive to developments in the real economy. There is a fair amount of evidence demonstrating that foreign macroeconomic news announcements have a greater impact on emerging financial markets than domestic news. For instance, Andritzky et al. (2007) show that domestic news has a limited impact on bond spreads in several emerging markets, whereas changes in US interest rates exert a significant influence. I follow this idea and examine the impact of German macroeconomic news announcements and ECB meeting days on the conditional volatility of new EU markets due to their mutual economic linkages.

Specifically, we try to address the following questions. (i) Do German macroeconomic news announcements influence the conditional exchange rate volatility of new EU countries? If so, does the news increase or decrease the volatility? (ii) Do the European Central Bank's meetings affect the volatility of the exchange rates of new EU members? (iii) Do the Czech National Bank's interventions change the CZK/EUR exchange rate characteristics?

The Generalized autoregressive conditional heteroscedastic (GARCH) model developed independently by Bollerslev (1986) and Taylor (1986) is applied to estimate exchange rate volatility. The main contribution of this essay is to fill a gap in the literature by bringing recent evidence of German macroeconomic news announcements on the conditional volatility of CZK/EUR, PLN/EUR, and HUF/EUR. Exchange rates are examined from January 1, 2010 to December 31, 2015, which corresponds to the period after the financial crisis. This period has not been examined yet. The impact of news announcements is measured as the deviation of the actual news value from the expected value.

The main contribution of this essay is that it brings recent evidence of the impact of German macroeconomic news announcements on the conditional volatility of new EU FX markets. The essay examines the period after the Global financial crisis, which has not been examined in the literature yet. From a broader perspective, this essay also focuses on the impact of the European Central Bank's meeting days on the new EU FX rates conditional volatilities similar to Jansen and de Haan (2005). Moreover, the essay develops novel insights into the impact of foreign macroeconomic news releases on Czech currency market during the period of currency interventions.

This essay brings these main findings: (i) the Ifo index increases the conditional volatility of all three examined exchange rates (CZK/EUR, PLN/EUR, HUF/EUR) on the day of announcement, (ii) the PMI index from Service sector and Labor data decrease conditional volatility of PLN/CZK; the PMI index from Manufacturing sector decreases the conditional volatility of CZK/EUR on the day of announcement. (iii) the ECB meeting days do not have significant impact on the conditional volatility of examined exchange rates, (iv) currency interventions on the Czech FX market downgraded the impact of German macroeconomic data on the Czech currency market.

3.2 Review of the related literature

The significance of the effect of macroeconomic news releases on financial markets has been intensively analyzed previously in the literature. One strand of the literature focuses on the impact of macroeconomic data announcements on the stock market. For example, Jones et al. (2005), Erenburg et al. (2006), and Rigobon and Sack (2008). Jones et al. (2005) examine the impact of UK macroeconomic news announcements on the volatility of UK financial market using GARCH model. They demonstrate the impact of PPI index and Industrial Production on the volatility of FTESE 100 index. These findings correspond to our results showing that the release of German Industrial Production data increase the conditional volatility of HUF/EUR on the day of announcement. The other strand examines how macroeconomic news announcements influence foreign exchange markets. Andersen et al. (2003) find that surprise announcements (that is, divergences between expectations and the realization of news) produce conditional mean jumps and that high-frequency exchange rate dynamics are thus linked to fundamentals. Evans and Lyons (2008) also produce empirical evidence of the effects of macroeconomic news announcements on exchange rates. Fratzscher

(2006) shows that macroeconomic news releases accounted for approximately 15% of the variations in exchange rates.

However, most of the recent research focuses on developed markets. New EU financial markets are under-researched. The impact of macroeconomic news announcements on these markets is examined in two areas. The first analyzes the impact of domestic news and the second focuses on the impact of foreign news announcements on the new EU markets. Regarding the first one, Fišer and Horváth (2010) find that Czech macroeconomic data announcements have a calming effect on CZK/EUR conditional volatility. Büttner and Hayo (2012) show no evidence that Czech macroeconomic news affects the value of the CZK/EUR exchange rate. Égert and Kočenda (2014) show that during the pre-crisis period PPI index and unemployment rate affect the value of the CZK/EUR exchange rate, whereas during the crisis period, only GDP announcements have an impact on the mean CZK/EUR rate.

Concerning impact of foreign news on new EU markets, Hayo et al. (2010) show a deepening euro area influence on new EU countries over time and a corresponding reduction in the relative importance of US shocks. Similarly, Büttner et al. (2012) suggest the growing importance of EU news after the Copenhagen Deal for European Union Enlargement in comparison to US news. Moreover, Hanousek et al. (2009) show that there are substantial positive spillover effects from the German stock market to the Czech stock market.

3.3 Data

Section 3.3 starts with exchange rates, then macroeconomic news and central bank announcements are quantified. The description of the model follows in Section 3.4.

3.3.1 Foreign exchange rates

The daily exchange rates of CZK/EUR, PLN/EUR, HUF/EUR are taken from MetaQuotes Software corresponding to the CET time zone for the period beginning on January 1, 2010 and ending on December 31, 2015. Under direct quoting, the spot exchange rate S_i ($x_i/1_j$) is expressed as the amount x of a currency i (quoting currency) that one needs in order to buy one unit of currency j (base or reference currency). In this case the Czech koruna, Polish zloty, and Hungarian forint are the quoting currencies and the euro is the base currency.

Daily data are transformed into percentage returns:

$$r_t = \ln\left(\frac{R_{t+1}}{R_t}\right) * 100, \quad (11)$$

where r_t is the daily percentage return to the exchange rate, R_t and R_{t+1} denote the exchange rates on the current day t and following day $t+1$, respectively. Daily exchange rates returns are stationary.

Thus, a negative change in an exchange rate means that the amount of the quoting currency i needed to buy one unit of currency j becomes smaller, which means an appreciation of the quoting currency i with respect to the reference currency j. Similarly, a positive change represents a depreciation of the quoting currency.

The dynamics of the exchange rates under research are presented in Figure 3.1. The Czech koruna and Hungarian forint weakened relative to the euro during the examined time period. However, part of the Czech koruna weakness was caused by the Czech National Bank currency interventions. The CNB commenced foreign exchange interventions on November 7, 2013 and used it until April 6, 2017. The CNB prevented the koruna from excessive appreciation below CZK 27/EUR by intervening on the foreign exchange market. On the weaker side of the CZK 27/EUR level, the CNB is allowing the koruna exchange rate to float. The big spike in CZK/EUR daily returns in Figure 3.1 shows the start of exchange rate interventions. Regarding Polish zloty, it has been resilient to the euro and has kept its value, fluctuating around 4.2.[18]

Descriptive statistics for the continuously compounded returns of CZK/EUR, HUF/EUR, and PLN/EUR are presented in Table 3.1. The sample contains 1603 observations for each currency pair. The highest standard deviation of exchange rate returns produces the Hungarian forint (0.54%). The Czech market demonstrates the lowest standard deviation (0.35%) among the examined markets. Following the p-value of Jarque-Bera test, the null hypothesis can be rejected. In a normally distributed series, skewness is 0 and kurtosis is 3. Likewise, values of the skewness and excess kurtosis for all three exchange rates indicate that the time series do not correspond to a normal

[18] In the case of the National Bank of Poland (NBP), no unconventional monetary instruments are used during the examined time period. The Hungarian National Bank (MNB) introduced the Funding for Growth Scheme (FGS) in September 2013. MNB provided approximately 700 billion HUF liquidity at zero cost to banks for lending to SMEs at a maximum rate of 2.5%.

distribution. On the top of that, the largest kurtosis is present in CZK/EUR returns due to the act of launching interventions. Neglecting the day of the intervention's announcement, the kurtosis and skewness decreased. In summary, the central bank's interventions changed the attributes of the exchange rate returns. Firstly, it shifted the skewness from negative to positive values and enlarged kurtosis. Secondly, the missing ARCH effect in the residuals suggests there is no volatility clustering or persistence after CNB took control over the CZK/EUR exchange rate.

For testing heteroskedasticity in the residuals, the Lagrange Multiplier (LM) test for autoregressive conditional heteroscedasticity (ARCH) is implemented. All examined exchange rates exhibit patterns of volatility persistence and clustering, The presence of ARCH effect (conditional heteroscedasticity) is observed, which allows us using the class of GARCH-type models (please see the results in Table 3.1).

3.3.2 Macroeconomic news

The scheduled German macroeconomic news announcements were obtained from Reuters. The examined dataset contains announcements on:

i. *business climate (Markit's Flash Purchasing Managers' Index (PMI) from the Manufacturing and Non-manufacturing sectors, the German Business Climate Index (Ifo) and the German ZEW Economic Sentiment Index)*

   - PMI index from the Manufacturing and Non-manufacturing sectors is a leading indicator of economic health. Businesses react quickly to market conditions, and their purchasing managers hold probably the most current and relevant insight into the company's view of the economy. It consists of survey of about 500 purchasing managers, who are asked to rate the relative level of business conditions including employment, production, new orders, prices, supplier deliveries, and inventories. The level above 50.0 indicates industry expansion, below indicates contraction.
   - IFO index is also a leading indicator of economic health. Businesses react quickly to market conditions, and changes in their sentiment can be an early signal of future economic activity such as spending, hiring, and investment. It consists of survey of large sample size about 7 000 businesses (manufacturers, builders, wholesalers, services, retailers), who are asked to rate the relative level of current business conditions and expectations for the next 6 months.

- ZEW index is a leading indicator of economic health. About 300 German institutional investors and analysts are asked to rate the relative 6-month economic outlook for Germany. Institutional investors and analysts are highly informed by virtue of their job, and changes in their sentiment can be an early signal of future economic activity.

ii. *the real economy (Industrial Production, GDP, Factory Orders, Change in the Number of Unemployed People)*

- Industrial Production measures the change in the total inflation-adjusted value of monthly output produced by manufacturers, mines, and utilities.
- GDP measures the change in the inflation-adjusted value of all goods and services produced by the economy. We use preliminary inflation adjusted quarterly percentage change of GDP.
- Factory Orders are monthly percentage change in total value of new orders placed with manufactures.
- Change in the Number of Unemployed People during the previous month.
- Retail Sales are monthly percentage change in inflation-adjusted excluding automobiles and gas stations.

iii. prices (CPI).

- CPI index is the German preliminary price index measuring monthly percentage change in consumer price inflation, i.e., change in the price of goods and services purchased by consumers.

Altogether 9 German macroeconomic indicators are examined.

All announcements are made monthly except for GDP, which is measured quarterly. Reuters provides investors with a macrocalendar that contains a clearly defined date and timing of news releases. Furthermore, the macrocalendar specifies the previous, expected, and actual value of the indicator.[19] This monograph follows Egert and Kočenda (2014) and examines the impact of news announcements on the exchange rate as the deviation of the news' actual value from the previously expected value. It is reasonable to hypothesize that a deviation or excess impact may then affect exchange

[19] Market expectations are constructed using a survey of the world's best-rated institutional analysts and economists approximately one week before the information is released. This number represents the market consensus and its value is taken from Reuters terminal. It is not the news itself that matters but the difference between the actual and expected value.

rates. Formally, the excess impact news variable, or "surprise" as Andersen et al. (2007) call it, is labeled yn_{it} and defined as:

$$yn_{it} = \frac{(an_{it} - E_{t-1}[an_{it}])}{\sigma_i}, \tag{12}$$

where an_{it} stands for the value of a scheduled announcement i at time t; i ranges from 1 to 9; $E_{t-1}[an_{it}]$ is the value of the announcement for time t expected by the market at time t -1; yn_{it} is the excess impact news variable or surprise effect. Time t-1 means the time before the news announcement during which the estimations were collected. As news are reported in different units they are standardized to empower for comparison. σ_i is the sample standard deviation of the surprise component (an_{it} – $E_{t-1}[an_{it}]$). The standardization does not affect the properties of the coefficients' estimates as the sample standard deviation σ_i is constant for any announcement i. Hence, the macroeconomic variables enter into the model with a value of yn_{it} (non-zero) on an announcement day and a value of zero on non-announcement days.

3.3.3 Central Bank Announcements

The impact of the European Central Bank's meeting days is investigated using the date of the ECB meetings as a dummy variable. The variable takes the value of unity on days when the ECB meeting takes place, not distinguishing if the central bank took any rate decision or not.

3.4 Methodology

The dependent variables are the daily percentage returns of the CZK/EUR, PLN/EUR, and HUF/EUR exchange rates computed following equation 11. The volatility of the exchange rates can be either higher or lower on the day of the macroeconomic news announcement than the average exchange rate volatility. Kim (1998) claims that the conditional volatility changes when market participants are caught by surprise and must adjust their positions, thus leading to market price adjustment. However, reduced volatility should be the result of reduced uncertainty due to reductions of speculative trading based on incorrect information.

The models for individual time series were chosen following these criteria: (i) eliminating the ARCH effect from the residuals, (ii) eliminating serial correlations in the

residuals, (iii) considering the best AIC and SIC criterion (Javed and Mantalos, 2013). Examining the impact of German macroeconomic news announcements on the conditional volatility of the exchange rate, the following EGARCH (1,1,1) model is used:

Mean Equation:

$$r_t = \mu + \varepsilon_t \tag{13}$$

Variance Equation:

$$\ln(\sigma_t^2) = \gamma_1 + \gamma_2 \left(\frac{|\varepsilon_{t-1}|}{|\sigma_{t-1}|} - \sqrt{\frac{2}{\pi}} \right) + \gamma_3 \frac{\varepsilon_{t-1}}{\sigma_{t-1}} + \gamma_4 \ln(\sigma_{t-1}^2) + \theta_i \sum_{i=1}^{9} NEWS_{it} + \rho_1 ECB_t, \tag{14}$$

where r_t stands for the log of daily change of examined exchange rate returns, the error term ε_t in mean equation (13) is assumed to have conditional variance σ^2 specified in equation (14), μ denotes average returns. The variance equation (14) includes the constant γ_1, ARCH term ε_{t-1}^2, GARCH term σ_{t-1}^2 . The symbol $NEWS_{it}$ captures the news announcement effect and represents nine German macroeconomic news variables transformed into daily variables by assigning the value of zero for days without the particular news announcement and the magnitude of the news (equation 12) for announcement days. Dummy variable ECB_t captures the effect of European Central Bank meetings.

The key benefit of the EGARCH (1,1,1) model is in capturing the asymmetry (leverage) effect. This model captures asymmetric responses of the time-varying variance to shocks and ensures that the variance is always positive. This model is asymmetric due to the $\frac{\varepsilon_{t-1}}{\sigma_{t-1}}$ component in variance equation (14). If the coefficient γ_3 is negative, positive shocks generate less volatility than negative return shocks, assuming other factors remain unchanged. The magnitude of the shock is represented by the ARCH term $\left(\frac{|\varepsilon_{t-1}|}{|\sigma_{t-1}|} - \sqrt{\frac{2}{\pi}} \right)$, and the significance of the conditional variance is represented by the GARCH term $ln(\sigma_{t-1}^2)$.

Note that GARCH models with higher lags were also estimated, but they were not able to eliminate serial correlation from the residuals. Also, threshold autoregressive conditional heteroscedasticity (TARCH) models with different lags were applied, but they failed to improve on the results obtained from the EGARCH models.

3.4.1 Testable Hypothesis

Based on the researched topic and given the GARCH methodology outlined above, the following testable hypotheses are formulated.

Hypothesis 1: Individually examined German macroeconomic news influence conditional volatility of new EU exchange rates on the day of announcement. This hypothesis is tested by parameter θ_i in equation 14. The positive sign of statistically significant parameter indicates that German macroeconomic news increases conditional volatility and negative sign implies the decrease in conditional volatility on the day of announcement. Omrane and Hafner (2011) find that US news surprises have the significant effect on the British Pound volatility; and UK and European scheduled news trigger significant boost on the three currency volatilities. Therefore, we expect to find significant parameter θ_i in equation 14. This would imply, that individually examined German macroeconomic news announcements have the impact on the conditional volatility of new EU FX rates (positive sign increases and negative sign decreases conditional volatility).

Hypothesis 2: ECB meeting days influence the conditional volatility of new EU exchange rates. This hypothesis is tested by parameter ρ_1 in equation 14. The positive sign of statistically significant parameter indicates that ECB meeting days increase conditional volatility and negative sign implies decrease in conditional volatility on the day of announcement. Fišer and Horváth (2010) find that CNB communication has a calming effect on CZK/EUR volatility. We expect to find statistically significant parameter ρ_1 in equation 14, confirming our expectations that ECB meeting days either increase or decrease conditional volatility of examined exchange rates.

3.5 Empirical Results

All the results are presented in Table 3.2. Firstly, we discuss the impact of German macroeconomic news and ECB meeting days on PLN/EUR exchange rate conditional volatility. Secondly, HUF/EUR and thirdly, CZK/EUR are analyzed.[20]

3.5.1 PLN/EUR

The best model from the GARCH family is selected according to the rules mentioned in Section 3.4 (Methodology). The results of the EGARCH (1,1,1) model with 1

[20] The estimations were conducted using the Student version of EVIEWS software with the default settings.

asymmetry term and normal error distribution in Table 3.2 show that the asymmetric term (γ_3) is significant and has a positive sign. The positive sign of the parameter means that there in not asymmetry in PLN/EUR volatility, meaning that downward price movements are not associated with higher volatility. The statistical significance of the ARCH (γ_2) and GARCH (γ_4) terms provides evidence of volatility clustering and persistence.

With reference to the examined variables in EGARCH (1,1,1) model calculated using equations (13 and 14), the business climate index (Ifo) ($\boldsymbol{\theta_2}$) and the real economy indicator (Factory Orders) ($\boldsymbol{\theta_6}$) increase the conditional volatility on the day of the announcement. More specifically, one standard deviation in unanticipated change in Factory Orders increases the conditional volatility of PLN/EUR by 11.90%. One may be surprised that one standard deviation in unanticipated change in the Ifo index increases conditional volatility by 55.46%. The average daily return is 0.0021%, so a rise of 55.46% would lead to a return of 0.0033%. Following the above results, we cannot reject Hypothesis 1.

On the other hand, one standard deviation in the business climate index (the PMI index from Service sector) (θ_5) and the real economy indicator (labor market data) (θ_9) decrease PLN/EUR conditional volatility by 20.51% and 9.32%, respectively. Said differently, the above news has a calming effect on the Polish exchange rate. According to Fišer and Horváth (2010), the calming effect of news on the financial market may reflect that there is in general higher uncertainty in emerging markets and news is likely to diminish this uncertainty and calm down market participants. Hence, it can be said that 4 German macroeconomic news referring to business climate and real economy (Factory Orders, the Ifo index, the PMI index from Service sector, and Labor market data) influence the conditional volatility of PLN/EUR on the day of announcement. The insignificance of parameter ρ_1 in table 3.2 indicates that ECB meeting days have no significant impact on the volatility of Polish exchange rate market and Hypothesis 2 can be rejected.

3.5.2 HUF/EUR

Referring to the Hungarian exchange rate market, the same econometrical model as for PLN/EUR is applied. Examining the model's parameters, all are significant. The positive sign of the asymmetric term (γ_3), shows no asymmetry in the exchange rate's

volatility. Significance of ARCH (γ_2) and GARCH (γ_4) terms in the equation is the evidence of volatility clustering and persistence.[21]

Business climate index and real economy indicator (Ifo index ($\boldsymbol{\theta_2}$) and Industrial Production (θ_7)) increase conditional volatility of HUF/EUR on the day of announcement (please see the results in table 3.2). One standard deviation in unanticipated change in the Ifo index increases the conditional volatility of HUF/EUR by 55.46%. Notably, the impact of the Ifo index on the HUF/EUR exchange rate conditional volatility is similar to PLN/EUR. Considering the number of significant macroeconomic news variables for conditional exchange rate volatility, German macroeconomic news plays a more important role in the Polish than in the Hungarian exchange rate market. The above results confirm that the Ifo index and Industrial Production have the impact on conditional volatility of HUF/EUR leading to not rejecting Hypothesis 1. The parameter (ρ_1) in table 3.2 is not statistically significant meaning that ECB announcements do not affect the HUF/EUR conditional volatility, leading to rejecting Hypothesis 2.

3.5.3 CZK/EUR

We first report the results for the period before the Czech National Bank (CNB) launched currency interventions (January 1, 2010–November 6, 2013). Second, the period after introducing currency interventions is examined (November 8, 2013 – December 31, 2015). Third, these two periods are put together and examined without the day of the intervention announcement.

CZK/EUR before currency interventions (January 1, 2010 – November 6, 2013)

The time period before the introduction of currency interventions is characterized by higher exchange rate volatility compared to the time period after the CNB started to prevent the Czech koruna from appreciating below 27 crowns for 1 euro.

The same process as before is applied and the best model for estimating the impact of German macroeconomic data on CZK/EUR conditional volatility is set. The EGARCH (1,0,1) model with no asymmetry parameter is selected.[22] The results of EGARCH (1,0,1) model specified in Table 3.2 show no presence of leverage effect (γ_3). Furthermore,

[21] Please, see the results in Table 3.2.

[22] A simple GARCH model with different lags was not able to eliminate serial correlation from residuals. The asymmetry term in the variance equation $\frac{\varepsilon_{t-1}}{\sigma_{t-1}}$ was not significant and excluding it did not worsen the model parameters.

the significance of the ARCH (γ_2) and GARCH (γ_4) terms show the volatility persistence and clustering.

As for macroeconomic news announcements, the Business climate indices (Ifo) represented by the statistically significant parameter ($\boldsymbol{\theta}_2$) in Table 3.2, increases CZK/EUR conditional volatility and statistically significant PMI index from Manufacturing sector represented by the parameter ($\boldsymbol{\theta}_4$) decreases volatility on the day of announcement. Peculiarly, one standard deviation in unanticipated change in the Ifo index increases the conditional volatility of CZK/EUR by 39.26%. One could see the same impact of the Ifo index on the PLN/EUR and HUF/EUR exchange rates. Moreover, one standard deviation in unanticipated change in the PMI index from Manufacturing sector decreases conditional volatility of CZK/EUR by 47.99%. The statistical significance of the Ifo index and the PMI index from Manufacturing sector in Table 3.2 demonstrate the impact of selected German macroeconomic news on the conditional volatility of CZK/EUR leading to not rejecting Hypothesis 1. Hypothesis 2 can be rejected, ECB meeting days do not impact the conditional volatility of CZK/EUR, because parameter (ρ_1) in table 3.2 is not statistically significant.

CZK/EUR Currency Intervention Period (November 8, 2013 –December 31, 2015)

The period of currency interventions is analyzed separately in order to investigate if the decision of the CNB to start intervening on the foreign exchange market, changed the characteristics of the Czech currency market and its reaction to German macroeconomic news announcements.

CNB decreased CZK/EUR volatility by setting the floor for CZK appreciation at 27.00 level on November 7, 2013. From this time on, CZK/EUR fluctuated around 27.00 level most of the time and returns approached values close to zero. We can reject the null hypothesis about the absence of ARCH effect only at 10 percent probability level (Table 3.1). The lower volatility on the Czech FX market after CNB took control over CZK/EUR exchange rate, diminished the presence of ARCH effect and deteriorate the possibility of applying GARCH-type models. For this reason, the basic EGARCH (1,1,1) model was not suitable for the examined time series and we had to increase p, q parameters. The EGARCH (2,1,3) model with 1 asymmetry term and Student's t-error distribution shows the best results in terms of AIC, BIC, residual tests and explanatory

power.[23] The asymmetry component (γ_3) is significant with a negative sign, showing the asymmetry in the exchange rate's volatility. This means that negative news causes higher variance than positive news. The significance of both ARCH and three GARCH terms confirm the presence of volatility clustering and persistence.

Higher values of p, q did not show any additional explanatory power. However, neither EGARCH (2,1,3) nor any of the TGARCH or GARCH models with normal, Student's t, or GED distributions of different lags were able to eliminate serial correlation in the residuals.

Regarding macroeconomic variables, the announcement from the real economy - labor market data ($\boldsymbol{\theta}_9$) have a calming effect on the CZK/EUR conditional volatility leading to not rejecting Hypothesis 1. The same impact can be seen in the Polish exchange rate market. Hypothesis 2 is rejected due to the insignificance of parameter (ρ_1). This means that ECB meeting days do not influence CZK/EUR conditional volatility (all the parameters are reported in table 3.2).

CZK/EUR 2010 – 2015

The EGARCH (1,1,1) model with 1 asymmetry term and Student's t-distribution was employed. A significant positive asymmetry component (γ_3) shows no asymmetry in exchange rate's volatility. Further, CZK/EUR exchange rate shows volatility persistence and clustering during the years 2010-2015.

Regarding macroeconomic variables, no German macroeconomic data affect the conditional variance of CZK/EUR volatility. This may be explained by different patterns of CZK/EUR volatility before and after currency interventions. Putting together different characteristics of the CZK/EUR exchange rate may result in no significance of German macroeconomic data. Consequently, Hypothesis 1 is not rejected. As for ECB meeting days represented by the parameter (ρ_1), they are insignificant, too. Hypothesis 2 can be rejected, meaning that ECB meeting days do not impact the conditional volatility of CZK/EUR during 2010-2015. All the results are presented in Table 3.2 and are in line with Egert and Kočenda (2014), who showed that the effects of news announcements on the new EU FX rates change over time and differ with the specific type of macroeconomic news. Similar results are in Galati and Ho (2003) and Ehrmann and Fratzscher (2007).

[23] Hsieh (1989) shows that GARCH models with a standardized t distribution for the residuals are useful for modeling the time- varying nature of daily exchange rate returns.

3.6 Conclusion

Essay studies the effect of German macroeconomic news and European Central Bank meeting days on the conditional variance CZK/EUR, PLN/EUR, HUF/EUR. Empirical results provide evidence that German macroeconomic data announcements influence the conditional volatility of the new EU exchange rates: (i) The Ifo index and Factory Orders increase the conditional volatility of PLN/CZK. On the other hand, the PMI index from Service sector and data from the labor market decrease the conditional volatility of the PLN/EUR exchange rate. (ii) When it comes to the Hungarian foreign exchange market, the Ifo index and Industrial Production increase the conditional volatility of HUF/EUR. (iii) Regarding the Czech market, the Ifo index increases and the PMI index from Manufacturing sector decreases CZK/EUR conditional variance on the announcement day before the Czech National Bank launched currency interventions. (iv) CNB currency interventions changed CZK/EUR returns' attributes. Furthermore, currency interventions have downgraded the impact of German macroeconomic data on the Czech currency market. Finally, the empirical results show that there is no leverage effect in the all examined financial time series.

The above results of three new EU currencies are consistent with Kočenda and Moravcová (2018) who find, that the most persistent reaction in terms of significant abnormal returns after the German/Eurozone news release can be traced to the announcements of the PMI indices, Retail Sales, the Ifo index and Industrial Production. The data show that ECB meeting days do not influence new EU exchange rates' volatility during 2010–2015.

Identifying the impact of German macroeconomic news announcements on new EU FX markets may improve the forecasting techniques of policy makers. The exchange rate is an important part of international trade and therefore forecasting is relevant for policymakers and local central banks. Understanding the relationship between German macroeconomic data and new EU currency markets can be beneficial for diversification and hedging strategies. International investors may benefit from diversification by allocating part of their portfolios to new EU market assets. According to Jotikasthira et al. (2012), mutual and hedge fund holdings domiciled in developed countries account for about 13– 19% of the free-float adjusted market capitalization in new EU countries (16.6% in the Czech, 17% in the Hungarian, and 13.3% in the Polish equity markets).

3.7 Tables

Table 3. 1: Descriptive statistics of the examined new EU exchange rates: CZK/EUR, PLN/EUR, HUF/EUR

	CZK/EUR	CZK/EUR returns	CZK/EUR returns	HUF/EUR	HUF/EUR returns	PLN/EUR	PLN/EUR returns
			no intervention day				
Mean	25,969	0,000	0,000	293,309	0,000	4,139	0,000
Median	25,715	0,000	0,000	296,000	0,000	4,157	0,000
Max.	28,255	0,046	0,015	322,680	0,027	4,566	0,035
Min.	23,946	-0,022	-0,022	261,200	-0,022	3,828	-0,032
Std. Dev.	1,175	0,004	0,003	15,536	0,005	0,132	0,005
Skewness	0,117	1,364	-0,040	-0,336	0,448	0,073	0,301
Kurtosis	1,581	23,294	5,815	1,892	5,443	3,215	8,177
Jarque-Bera	138,130	28004,760	529,800	128,680	518,210	5,280	2122,240
Probab.	0,000	0,000	0,000	0,000	0,000	0,070	0,000
ARCH LM test (heterosc.)		0,064	0,000		0,000		0,000
Observations	1603	1603	1602	1603	1603	1603	1603

Note: Values in the column named "CZK/EUR returns no intervention day" do not include data of November 7, 2013 (the day of intervention announcement). The daily return on that day was 4.717%. Dropping off this one day from data sample shows different values in 2nd (intervention announcement day included) and 3rd column (intervention announcement day excluded).

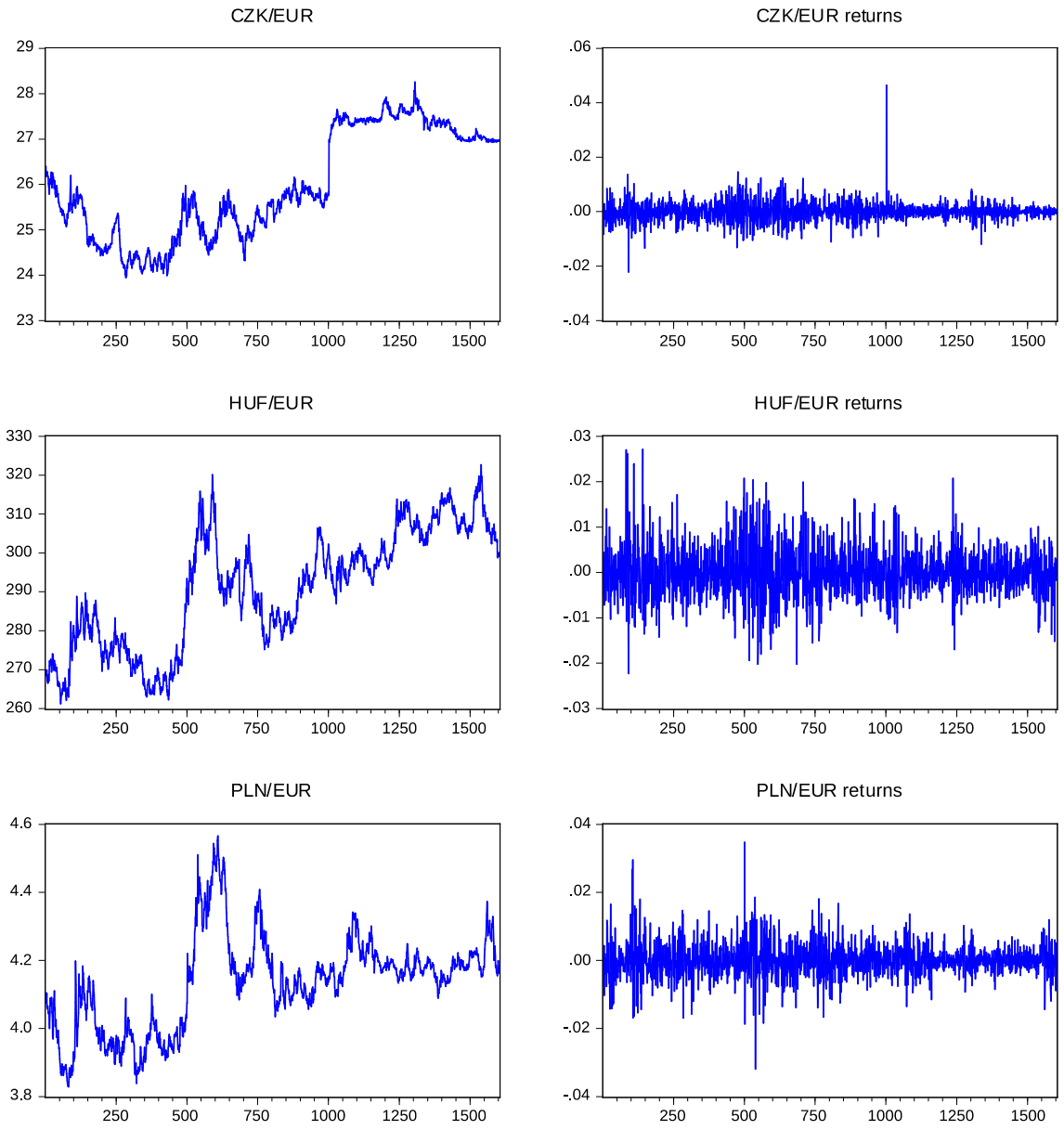
Table 3. 2: Effect of German Macroeconomic Announcements on the conditional volatility of PLN/EUR, HUF/EUR, CZK/EUR

		PLN/EUR		**HUF/EUR**		**CZK/EUR (**Jan. 1, 2010– Nov. 6, 2013)		**CZK/EUR (**Nov. 8, 2013 – Dec. 31, 2015)		**CZK/EUR** (Jan. 1, 2010 – Dec. 31, 2015)	
Model applied		EGARCH (1,1,1))		EGARCH (1,1,1)		EGARCH (1,0,1)		EGARCH (2,1,3)		EGARCH (1,1,1)	
Error distribution		Normal Distribu.		Normal Distribu.		Normal Distribu.		Student's t distrib.		Student's t distrib.	
Mean Eq.											
Variable		**Coeff.**	**Prob.**	**Coeff.**	**Prob.**	**Coeff.**	**Prob.**	**Coeff.**	**Prob.**	**Coeff.**	**Prob.**
C	μ	0,000	0,255	0,000	0,287	0,000	0,777	0,000	0,684	0,000	0,73
Variance Eq.											
C	γ_1	-0,280	0,000 ***	-0,217	0,000 ***	-0,470	0,001 ***	-2,225	0,011 **	-0,168	0,001 ***
ARCH term	γ_2	0,139	0,000 ***	0,089	0,000 ***	0,132	0,000 ***	0,411	0,000 ***	0,151	0,000 ***
ASYMMETRIC term	γ_3	0,984	0,000 ***	0,986	0,000 ***			-0,069	0,020 **	0,995	0,000 ***
GARCH	γ_4	0,079	0,000 ***	0,048	0,000 ***	0,967	0,000 ***	-0,551	0,000 **	0,037	0,047 **
ZEW	θ_1	0,078	0,713	0,199	0,223	-0,064	0,831	-1,207	0,161	-0,085	0,745
IFO	$\boldsymbol{\theta_2}$	0,600	**0,002 *** **	0,555	**0,000 *** **	0,393	**0,087 ***	-0,555	0,574	0,877	0,173
CPI	θ_3	-0,073	0,567	0,002	0,99	-0,344	0,142	0,615	0,254	0,201	0,325
PMI MANUFACTURING	θ_4	-0,013	0,943	-0,204	0,153	-0,480	**0,075 ***	0,836	0,391	0,008	0,975
PMI SERVICES	$\boldsymbol{\theta_5}$	-0,205	**0,036 ****	-0,106	0,287	0,098	0,473	-0,227	0,654	-0,125	0,374
FACTORY ORDERS	$\boldsymbol{\theta_6}$	0,119	**0,058 ***	0,038	0,5552	0,045	0,683	-0,395	**0,099 ***	-0,066	0,494
INDUSTRIALPRODUCTION	θ_7	0,033	0,626	0,188	**0,005 *** **	0,143	0,119	-0,355	0,182	0,073	0,467
GDP	θ_8	0,046	0,836	-0,126	0,461	-0,456	0,145	-1,007	0,156	-0,113	0,670
CHANGE IN UNEMPLOYED PEOPLE	$\boldsymbol{\theta_9}$	-0,093	**0,042 ****	-0,071	0,165	-0,104	0,159	-0,758	**0,004 *** **	-0,021	0,783
ECB	ρ_1	-0,022	0,809	0,006	0,947	-0,038	0,771	-0,137	0,412	-0,073	0,582
ARCH (2)								0,37	0,000***		
GARCH (2)								0,626	0,000 ***		
GARCH (3)								0,795	0,000 ***		
AIC		-8,082		-7,751		-8,328		-9,796		-8,883	
BIC		-8,037		-7,706		-8,259		-9,657		-8,829	

Note: The symbols ***, **, and * denote statistical significance at the 1, 5, and 10% levels, respectively. AIC stands for Akaike Information Criterion, BIC stands for Bayesian Information Criterion.

3.8 Figures

Figure 3. 1: Daily Spot Rates (left) and Daily Percentage Returns (right) for the Case of CZK/EUR (first row), HUF/EUR (second row), and PLN/EUR (third row) exchange rates



Note: The sample runs from January 1, 2010 to December 31, 2015

4 Exchange rate comovements, hedging and volatility spillovers on new EU forex markets

We analyze time-varying exchange rate co-movements, hedging ratios, and volatility spillovers on the new EU forex markets during 1999M1-2018M5. We document significant differences in the extent of currency comovements during various periods of market distress that are related to real economic and financial events. These imply favorable diversification benefits: the hedge-ratio calculations show all three currencies bring hedging benefits during crisis periods, but at different costs. During calm periods, most of the volatilities are due to each currency's own history. During the distress periods, volatility spillovers among currencies increase substantially and the Hungarian forint assumes a leading role.

4.1 Introduction and motivation

The evidence from mature forex markets shows that interdependencies and volatility spillovers relate to decisions of central bank interventions (Menkhoff, 2013), impact international trade (Rose, 2000), influence the stock prices of multinationals (Baum et al., 2001), and directly affect risk management and portfolio diversification (Kanas, 2001; Garcia and Tsafack, 2011; Fengler and Gisler, 2015). The analysis of such interdependencies and volatility spillovers facilitates to deepen our understanding of post-crisis financial integration (Antonakakis, 2012). Naturally, questions arise regarding how interdependencies and spillovers evolve on the emerging forex markets that are much less researched but attract substantial capital inflows in foreign currencies (Ahmed and Zlate, 2014).

Based on theoretically and empirically grounded patterns found in developed forex markets, we analyze the complex dynamics of several emerging European Union (EU) forex markets within themselves as well as with respect to the rest of the world. Surprisingly, the new EU forex market remains outside the research mainstream, even though the currencies of three advanced new EU member states (the Czech Republic, Hungary, and Poland) score highly in terms of their attractiveness to risk-capital investors (Groh and von Liechtenstein, 2009). In addition, these currencies have gained particular importance as the three countries have become more integrated into the EU economy following their 2004 accession (Hanousek and Kočenda, 2011), especially via their trade and banking sector links (Gray, 2014). Further, the three currencies are also

quite important for diversifying mutual and hedge fund portfolios that are primarily domiciled in developed markets (Jotikasthira et al., 2012).[24]

Hence, we augment the field in the literature with analyzing the extent and evolution of interdependencies and connectedness on the new EU forex markets. Specifically, we (i) analyze time- varying co-movements among the three currencies, (ii) compute their hedge ratios and portfolio weights, and (iii) study how volatility spillovers propagate among them. We calculate volatility co-movements and spillovers between new EU forex markets and the rest of the world by employing the dollar/euro exchange rate as the world forex benchmark. We also estimate mutual spillovers between new EU currencies to provide assessment whether the investors should consider new EU forex market as a single unit or whether it makes a difference to recognize volatilities of the individual currencies along with their directions and magnitudes.

Both mature and emerging forex markets experienced another important change: on September 15, 2008, the collapse of US investment bank Lehman Brothers brought volatility and distress to the financial markets, followed by a credit crunch. Financial contagion spread from the US and was soon followed by the European debt crisis. Both the Global financial crisis (GFC) and the sovereign debt crisis in Europe (EU debt crisis) renewed interest in the nature and extension of contagion effects among financial markets (Aloui et al., 2011). The effect of the GFC and the EU debt crisis spread from the source countries to the rest of the world. The financial contagion and turbulence were transmitted from developed to emerging markets (Gray, 2014).

In addition to being motivated by the lack of quantitative research, our interest in the dynamics of the new EU forex markets is motivated by the aim to assess various theoretically and empirically grounded patterns found in developed forex markets that are related to the three types of assessments we perform. Our three main findings and literature contributions are following:

(i) Investors tend to mimic other investors' behavior, described as herding behavior, which has been observed in a number of activities, including investments on the forex market (Tsuchiya, 2015) and the stock market (Bohl et al., 2017). This time-varying herding behavior can be indirectly observed from correlations between

[24] According to Jotikasthira et al. (2012), new EU markets are important for the portfolio diversification of mutual and hedge funds domiciled mainly in developed markets. They find 270 active funds in the Czech Republic, 276 funds in Poland, and 295 funds in Hungary following the crisis. More importantly, these fund holdings account for 3.6% of the float-adjusted market capitalization in the Czech Republic, 8.6% in Hungary and 4.7% in Poland; this represents more than 2.6% the average value of free-float market capitalization found in 25 emerging markets examined by Jotikasthira et al. (2012).

exchange rates that we compute. Specifically, investors tend to follow the crowd when times are uncertain; they begin to doubt their own judgment and run in herds (Lin et al., 2013). This behavior can be observed in the US financial market through rising correlations between financial assets. Further, the assessment of time variations in the correlations between different assets has critical implications for asset allocation and risk management because weak market linkages offer potential gains from international diversification (Singh et al., 2010).[25] Hence, we analyze the degrees and dynamics of comovements among currencies based on the Dynamic Conditional Correlation (DCC) model developed by Engle (2002).

(ii) In his optimal portfolio theory, Markowitz (1991) describes how risk-averse investors can construct portfolios to optimize or maximize expected return based on a given level of market risk. We assess this idea by using the conditional variances and covariances estimated from the DCC model to compute hedge ratios and portfolio weights for the three individual currencies in an optimal portfolio. We also account for different periods of distress in the market. Our results may help foreign investors recognize whether new EU countries should be treated as a whole or whether it is preferential to select assets individually from each country to improve portfolio diversification.

(iii) Hau (2002) argues that more open economies exhibit less volatile real exchange rates. The three countries under study are small open economies (Halka, 2015). We indirectly assess the volatility of their currencies by showing the nature and extent of volatility spillovers among the currencies. Further, analysis of the extent and nature of volatility spillovers in new EU forex markets is performed because volatility and its spillovers across currencies affect decisions about hedging open forex positions and may exacerbate the nonsystematic risk that diminishes the gains from international portfolio diversification (Kanas, 2001). In this respect, Menkhoff et al. (2012) accentuate the role of innovations in global forex volatility on a liquidity risk. Further, volatility represents a systematic risk that is considered to underline carry-trades.[26] We analyze volatility spillovers using a generalized version of Diebold and Yilmaz's (2012) spillover index (DY index).

[25] Correlations between markets increase during volatile periods (Ang and Chen, 2002) and decrease in bull markets (Longin and Solnik, 2001). Such asymmetry is explained via the leverage effect (Black, 1976) and the volatility feedback effect (Wu, 2001).

[26] Carry trade represents investment in high-interest currency based on the opportunity that emerges due to the failure of uncovered interest rate parity.

Our analysis is also relevant from the perspective of the European forex market and its recent financial turmoil. The EU forex market underwent a fundamental change when the euro became a joint currency for euro-area members in 1999. The euro's introduction also altered the relative importance and nature of interdependencies among major world currencies on the global forex market (Antonakakis, 2012), as the euro became the second most–traded currency in the world (BIS, 2016). Emerging European forex markets became part of the global forex landscape once the currencies of these emerging economies gradually became freely tradable during the 1990s, and for the countries that joined the EU in 2004 and later, euro adoption became a goal.

Our analysis is performed on daily data from 1999 to May 2018. The span of our dataset begins with the introduction of the euro and covers periods of relatively calm development as well as periods of distress. For this reason, the data are divided into four subsamples. The first sample covers the period prior to the GFC (1999-2008), the second reflects the GFC itself (2008-2010) and the third covers the European debt crisis (2010-2012). The last portion of the data reflects the period when both previous crises subsided (2012-May 2018). The Dynamic Conditional Correlation (DCC) model to examine dynamic conditional correlations and the Diebold and Yilmaz (2012) spillover index to analyze volatility spillovers between the exchange rates are applied. We show that comovements between the US dollar and new EU forex market changes over time depending on the main economic events. The main findings show that investing in the new EU forex market brings portfolio diversification benefits in turbulent periods. In terms of volatility spillovers, own-currency volatility spillovers explain a substantial share of the total volatility especially in the calm periods. During the turbulent periods, volatility spillovers among currencies increase substantially and the Hungarian currency assumes a leading role.

To the best of our knowledge, our analysis represents the first comprehensive assessment of interdependencies and risk spillovers on new EU forex markets. We find that conditional correlations between new EU exchange rates and the US dollar tend to decrease prior to the GFC and the EU debt crises. Once economic and financial disturbances subside, the correlations begin to rise to pre-crisis levels. Our results show that international investors may enhance diversification benefits from allocating part of their portfolio funds to new EU exchange market. We confirm the importance of the new EU currencies for international investors in terms of diversification benefits by moving

part of their portfolio to those currencies. However, investors pay a price: our results indicate that hedging during the GFC and the EU debt crisis costs more than before or after the crisis. We assess volatility and interdependencies on the new EU forex markets via spillovers. Most of the time, own-currency volatilities explain a substantial share of exchange rate movements. On the other hand, volatility spillovers between currencies considerably increase during the GFC, and this also leads to an increase in the total volatility spillover index. Among the three currencies, the Hungarian forint is dominant in the volatility transmission in each examined period.

4.2 Literature review

Volatility in exchange rates has important economic implications. For example, it influences import and export price uncertainty and thus affects international trade flows (Rose, 2000). Chowdhury and Wheeler (2008) demonstrate that shocks to exchange rate volatility have an effect on FDI. Baum et al. (2001) analyze the impact of exchange rate volatility on multinational companies' profitability and consequently on the stock prices of these companies. Aghion et al. (2009) indicate that exchange rate volatility can influence productivity growth. Exchange rate volatility has also adverse impact on industrial production and employment (Belke and Gros, 2002).

Volatility has become the subject of broad research since Bollerslev (1986) and Taylor (1986) introduced their generalized autoregressive conditional heteroscedastic (GARCH) model. Later, Bollerslev's Constant Conditional Correlations (CCC) model was expanded by Engle (2002), who introduced the Dynamic Conditional Correlation (DCC) model. The DCC model allows modeling dynamic time-varying correlations between time series. In applications, Adrian and Brunnermeier (2016) demonstrate that multivariate GARCH models can help capture the dynamic of systematic risk. DeMiguel et al. (2009) state that time-varying movements can increase the performance of optimal asset allocation.

Diebold and Yilmaz (2009, 2012) advanced volatility research by introducing the spillover index (DY index). This index is based on forecast error variance decomposition from vector autoregressions (VARs) and measures the degree and direction of volatility transmission between financial markets. Recognition of volatility comovements and spillovers in the financial markets is fundamental for systemic risk identification (Mensi

et al., 2017). Such recognition is also relevant in the context of the shock transmission mechanism linking financial markets and the real economy.

Increasing integration of financial markets supported by globalization requires examining volatility co-movements and spillovers between developed and emerging markets. A substantial part of the literature has primarily focused on developed forex markets (McMillan and Speight, 2010; Boero et al., 2011). Emerging markets are less examined with little attention paid to new EU markets. Pramor and Tamirisa (2006) examine volatility trends in the Central and Eastern European currencies. They demonstrate that these trends are closely correlated, although to a lesser degree than the major European currencies prior to the introduction of the euro. Andrieş et al. (2016) investigate exchange rates in Central and Eastern European countries via a wavelet analysis. They present a high degree of comovements in short-term fluctuations among the exchange rates of the Czech Republic, Poland and Hungary. Bubák et al. (2011) analyze the dynamics of volatility transmission to, from and among the Czech, Hungarian and Polish currencies, together with the US dollar for the period 2003-2009. They find that during the pre- 2008 period, the volatilities of the Czech and Polish currencies are affected chiefly by their own histories but each of the three new EU currencies is characterized by a different volatility transmission pattern.

4.3 Data, methodology and hypotheses

4.3.1 Dataset and analyzed periods

Our dataset contains daily exchange rates of the currencies of three new EU member states against the euro: the Czech koruna (CZK/EUR), the Polish zloty (PLN/EUR), and the Hungarian forint (HUF/EUR). We also use exchange rate series of the US dollar against the euro (USD/EUR).[27] The time span runs from the euro's introduction on January 1, 1999 to May 31, 2018, and contains 4 970 observations. Data are quoted at 2:15 p.m. (C.E.T). Time series were downloaded from the ECB online database. The exchange rates are expressed in terms of direct quotes as the amount x of a quoting currency i that one needs to buy one unit of euro (base or reference currency).

[27] In the other words, we examine conditional correlations between new EU currencies and the US dollar. The US dollar has been the dominant international currency since World War II. It is the world's dominant vehicle currency, representing 88% of all trade in 2016 (BIS, 2016). Our analysis of new EU forex rates comovements and spillovers with the US dollar eliminates the effect of euro fluctuations. Therefore, the results regarding diversification strategies and hedging costs could be beneficial for international investors whose portfolios are expressed in the US dollar.

For example, when we refer to the (exchange rate of the) Czech koruna, we refer to its value defined as the number of korunas required to buy one euro.

Further, daily exchange rates are transformed into daily percentage log returns (r_t) defined as:

$r_t = ln(s_t/s_{t-1}) * 100$, where s_t is the daily exchange rate at time t. Via the Augmented Dickey-Fuller (ADF) GLS test, the returns are shown to be stationary (see Table 4.1). A negative change in an exchange rate means that the amount of quoting currency i needed to buy one unit of the euro decreases, denoting an appreciation of a quoting currency i with respect to the euro. Similarly, a positive change denotes a depreciation of the quoting currency.

Our intention is to analyze the data during different periods of distress, such as the GFC and the European sovereign debt crisis. For this purpose, we divide the data into four subsamples. The two major financial and economic events are also mirrored in structural breaks present in the data.[28] The coincidence aligns with the empirical evidence that structural changes in financial series can be due to various economic events (Andreou and Ghysels, 2009) or shifts in economic policy (Pesaran et al., 2006). Hence, the first sub-sample covers the period prior to the GFC (January 1, 1999-September 14, 2008), the second period represents the GFC's key phase (September 15, 2008-April 30, 2010) and the third period covers the EU debt crisis (May 3, 2010-July 26, 2012). The fourth subsample captures the period following the EU debt crisis until the end of our sample span (July 27, 2012-May 31, 2018).[29]

The GFC's beginning is associated with the Lehman Brothers' bankruptcy on September 15, 2008, which is in accord with the test as well as practice in the literature (Frankel and Saravelos, 2012). The starting point of the EU debt financial crisis corresponds to May 3, 2010, when the IMF, the ECB and the European Commission announced a 110 billion euros three-year aid package designed to rescue Greece (Hanousek et al., 2014). The period following May 2010 is characterized by a rise in the

[28] We applied the Bai-Perron (1998, 2003) test to detect structural breaks in conditional variances (of the exchange rates returns) derived via the DCC-GARCH described in the Section 4.3.2. The test shows the dominant structural break in 2008 consistent with the beginning of the GFC. Regarding the EU debt crisis, the test suggests different break points for individual new EU exchange rates. The differences in the date break estimates are not uncommon: Bai and Perron (1998) show that in the presence of multiple breaks the least squares estimator converges to a global minimum that coincides with the dominating break. For the sake of consistency, we use the common dates to limit boundaries of distress/no-distress intervals that are grounded in the well-established economic events described in the text.

[29] As a complement to the previous test, we performed the Chow (1960) breakpoint test. The test evidences structural breaks in conditional correlations of the neighboring four sub-periods defined with respect to the GFC and European debt crisis (Appendix Table A2). We also perform complementary robustness check of structural breaks and calculate DCC model for the whole examined period with dummies representing the GFC and the EU debt crisis placed in the variance equation of GARCH model. The results are presented in the Appendix Table A1.

bond yields of heavily indebted Eurozone countries in anticipation of the emergence of problems similar to those in Greece. Moreover, an increase in global risk aversion during this period resulted in a fall in equity returns in advanced countries, particularly in the financial sector (Stracca, 2015). The end of the EU debt crisis coincides with a remarkable statement by the ECB President Mario Draghi (2012) at the Global Investment Conference in London on July 26, 2012: "Within our mandate, the ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough". Fiordelisi and Ricci (2016) show that the European financial markets started to rally immediately after this statement and that the economic situation began to improve. Eurostoxx index gained 4.3% on the day of the speech (8.1% up to the end of July 2012); other important stock indices performed in a similar manner: IBEX 6.1% (13.1%), MIB 5.6% (12.4%), CAC40 4.1% (7.1%), and DAX 2.8% (6.0%). The rest of the data cover the post-EU debt crisis period.

After the EU debt crisis, significant events have occurred, especially in 2017, which increase volatility on financial markets (Figure 4.3). Donald Trump was inaugurated as the US president and withdrew the US from the Trans-Pacific Partnership. During 2017 as well as in 2018, he continued working on policies leading to diminishing the US trade deficit with foreign partners. However, his steps towards the US trade protectionism became major concern for politicians, international institutions, investors and multinational companies. Further, Jawadi and Fitti (2017) suggest that US fiscal stimuli planned by the Trump administration may lead to faster rise in the US interest rates. This could increase the rates in other countries through a contagion effect and induce more volatility on financial markets. The inflation acceleration in the US resulted in the series of interest rate hikes in 2017. Fed increased interest rates three times during 2017. This was the first time for the Fed to apply more than one interest rate increase within one year since the end of the GFC. The ECB also signaled its plans to tighten monetary policy for the first time since the EU debt crisis. It decreased the monthly amount of the asset purchase program (APP) from 80 to 60 billion euros and indicated its plans to end the quantitative easing program (QE) before the end of 2018. The Czech National Bank (CNB) decided to end its forex intervention program in 2017 and increased interest rates two times in that year. All these important events pose capacity to impact financial markets and increase the volatility on financial markets.

4.3.2 Dynamic Conditional Correlation GARCH (DCC-GARCH)

We use the DCC model of Engle (2002) to assess the evolution of comovements between new EU countries' exchange rates and the USD/EUR. Using this model, we determine whether the dynamic correlation between exchange rates increases, decreases or is stable over the time studied. The DCC model offers several advantages relative to simple correlation analysis. First, it is parsimonious compared to many multivariate GARCH models.[30] Second, the DCC model is flexible because it enables the estimation of time-varying volatilities, covariances and correlations of various assets over time.[31]

The DCC model is estimated in two stages. In the first stage, univariate GARCH models are estimated for each residual series. In the second stage, residuals transformed by their standard deviation from the first stage are used to construct a conditional correlation matrix.

Under the absence of serial correlation in the exchange rate return (r_t) in the mean equation follows a random walk and the composition of the conditional covariance matrix is:

$$H_t = D_t R_t D_t, \tag{15}$$

$$D_t = diag\,(h_{iit}^{\frac{1}{2}}, \dots, h_{NNt}^{\frac{1}{2}})' \tag{16}$$

$$R_t = diag\left(q_{ii,t}^{-\frac{1}{2}}, \dots, q_{NN,t}^{-\frac{1}{2}}\right) Q_t\, diag\left(q_{ii,t}^{-\frac{1}{2}}, \dots, q_{NN,t}^{-\frac{1}{2}}\right) or\ \rho_{ij,t} = \frac{q_{ij,t}}{\sqrt{q_{ii,t}\, q_{jj,t}}}, \tag{17}$$

where h_{iit} can be defined as any univariate GARCH model.[32]

In (17), $Q_t = (q_{ij,t})$ is the (N × N) symmetric positive definite matrix given by

$$Q_t = (1 - \alpha - \beta)\bar{Q} + \alpha u_{t-1} u'_{t-1} + \beta Q_{t-1}, \tag{18}$$

[30] The number of parameters to be estimated in the correlation process is independent of the number of series to be correlated. Thus, potentially large correlation matrices can be estimated. Of course, this comes at the cost of flexibility, as it assumes that all correlations are influenced by the same coefficients.

[31] Intentionally, we do not use an asymmetric DCC model. According to Baumöhl and Lyócsa (2014) asymmetry is not a common phenomenon in emerging markets. Baruník et al. (2017) show that different event types are characterized by different types of volatility spillovers on forex markets. For example, the GFC period is characterized by positive volatility spillovers, but during the EU debt crisis, negative spillovers dominate the forex market. Since we examine separately periods related to the key financial contagions (the GFC and the EU debt crisis), we do not expect heavy asymmetries to occur in individually examined periods.

[32] The AR(1)-GARCH (1,1) model is employed if serial correlation is presented in the residuals of the GARCH (1,1) model.

where $u_t = (u_{1t}, u_{2t}, ..., u_{Nt})'$ is the N * 1 vector of standardized residuals; $\bar{Q}$ is N * N of the unconditional variance of u_t; and α and β are non-negative scalar parameters satisfying condition $\alpha + \beta < 1$. The DCC model is estimated using a log likelihood function under a heavy-tailed multivariate generalized error distribution (GED).[33]

Based on the characteristics of the DCC model, we formulate Hypothesis 1:

Hypothesis 1: The dynamic conditional correlations between new EU currencies and the US dollar change magnitude across four examined periods. To test this hypothesis, we calculate conditional correlations for each time period separately employing DCC model's equations 15-18. The values of conditional correlations are presented in Table 4.2 row "ρ (corr)". To test the difference in correlations' magnitude, we apply the Z-transformation introduced by Fisher (1915) (equation 29). We expect the correlations to differ in magnitude during individually examined four time periods. $\rho_0 \neq \rho_1$. The hypothesis that conditional correlations are equal in magnitude can be rejected if p-values (Table 4.3) are lower than 10 percent of statistical significance. Similarly, Naoui, (2010) demonstrates unstable conditional correlations between US stock market and other developed and emerging stock markets. Specifically, he points an increase in dynamic conditional correlations between US and other developed markets following the start of subprime crisis. On the other hand, conditional correlations between US stock market and selected emerging markets decrease during the crisis period.

4.3.3 Hedge ratios and portfolio weights

We use time-varying conditional correlations from the second stage of the DCC model estimation (reported in Table 4.2) to calculate the optimal diversification of the international currency portfolio. Kroner and Sultan (1993) employ conditional variance and covariance to calculate hedge ratios. Kroner and Ng (1998) then use conditional variance and covariance to design optimal portfolio weights. The hedge ratio is calculated as:

$$\beta_{ij,t} = h_{ij,t}/h_{jj,t}, \qquad (19)$$

[33] A multivariate Student's *t* error distribution was also employed, but it did not improve our results.

where hij,t is the conditional covariance between the exchange rates of currencies i and j and hjj,t is the conditional variance of currency j at time t. This formula implies that a long-term position in one currency (e.g., i) can be hedged by a short-term position in another currency (e.g., j).

In a portfolio of two currencies optimal portfolio weights between currencies i and j at time t are calculated based on the following formula:

$$w_{ij,t} = \frac{h_{jj,t} - h_{ij,t}}{h_{ii,t} - 2h_{ij,t} + h_{jj,t}}. \tag{20}$$

In (20), $w_{ij,t}$ is the weight of currency i, and (1 - $w_{ij,t}$) is the weight of currency j. Weights implying the portfolio composition follow the conditions shown below:

$$w_{ij,t} = \begin{cases} 0, & if\ w_{ij,t} < 0 \\ w_{ij,t}, & if\ 0 \le w_{ij,t} \le 1. \\ 1, & if\ w_{ij,t} > 1 \end{cases} \tag{21}$$

With respect to the above definitions, we formulate a hedge ratio hypothesis:

Hypothesis 2: Hedge ratios are not stable over all four periods examined. We test this hypothesis using formula 19. We expect that hedge ratios ($\beta_{ij,t}$) reach different values in individually examined time periods. Antonakakis (2012) also shows that currency portfolio weights are not stable in time and reach different values in pre-euro and post-euro periods.

4.3.4 Diebold Yilmaz spillover index

To study volatility spillovers between the four examined exchange rates, the Diebold and Yilmaz (2012) spillover index based on the generalized vector autoregressive (VAR) variance decomposition is used. We first employ the following p-order, N-variable VAR model:

$$y_t = \sum_{i=1}^{p} \Theta_i\, y_{t-1} + \varphi_t, \tag{22}$$

where φ is a vector of independently and identically distributed errors, $y_t = (y_{1t}, y_{2t}, y_{3t}, y_{4t})$ is a vector of four examined endogenous variables, and Θ is 4 x 4 parameter matrix.

The key to the dynamics of the system is the moving-average representation of model (22), which is given by:

$$y_t = \sum_{i=0}^{\infty} A_i \, \varphi_{t-1}, \tag{23}$$

where 4 × 4 coefficient matrices A_i are estimated from the recursion

$A_i = \Theta_1 A_{i-1} + \Theta_2 A_{i-2} + \ldots + \Theta_p A_{i-p}$, with A_0 being the 4 × 4 identity matrix and

$A_i = 0$ for $i < 0$.

Diebold and Yilmaz (2012) use the generalized VAR framework developed by Koop et al. (1996) and Pesaran and Shin (1998), in which variance decompositions are invariant in terms of the variable ordering. In this case, the H-step-ahead forecast error variance decomposition is defined as follows:

$$\theta_{ij}^{g}(H) = \frac{\sigma_{ii}^{-1} \sum_{h=0}^{H-1} (e_i' \, A_h \sum e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \sum A_h' e_j)}, \tag{24}$$

where Σ is the variance matrix for the error vector φ, σii is the standard deviation of the error term for the ith equation, and ei is the selection vector, with a value of one for the ith element and zero otherwise. In the generalized VAR framework, shocks to each variable are not orthogonalized; therefore, the sum of each row of the variance decomposition matrix is not unity ($\sum_{j=1}^{N} \theta_{ij}^{g}(H) \neq 1$). In this case, each element of the decomposition matrix is normalized by dividing it by the row sum:

$$\widetilde{\theta_{ij}^{g}}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)}, \tag{25}$$

where by construction, $\sum_{j=1}^{N} \widetilde{\theta_{ij}^{g}}(H) = 1$ and $\sum_{i,j=1}^{N} \widetilde{\theta_{ij}^{g}}(H) = N$.

Using normalized elements of the decomposition matrix of equation (25), we construct the total volatility spillover index:

$$S^{g}(H) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \widetilde{\theta_{ij}^{g}}(H)}{\sum_{i,j=1}^{N} \theta_{ij}^{g}(H)} * 100 = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \widetilde{\theta_{ij}^{g}}(H)}{N} * 100. \tag{26}$$

This index captures cross-country spillover values by measuring the contributions of volatility spillovers across all countries to the total forecast error variance.

Based on the specification of the total volatility spillover index, we formulate the following hypothesis:

Hypothesis 3: The value of the total volatility spillover index is not stable during the four examined time periods. We test this hypothesis by calculating total volatility spillover index for four individually examined time periods using equations 22-26. Antonakakis and Vergos (2013) show that large variability in the total volatility spillover index of the Eurozone bond yield spreads during March 3, 2007–June 18, 2012 is present, and the index is responsive to economic events and news announcements. We expect the total volatility spillover index to reach different values in individually examined time periods (before the GFC, the GFC, the EU debt crisis, after the EU debt crisis).

To examine spillover effects from and to a specific currency, we use directional volatility spillovers. Specifically, the directional volatility spillovers received by currency *i* from all other currencies *j* are defined as follows:

$$S_{i\leftarrow j}^{q}(H) = \frac{\sum_{j=1}^{N} \widetilde{\theta_{ij}^{g}(H)}}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)} * 100. \qquad (27)$$

In a similar fashion, directional volatility spillovers are transmitted by currency *i* to all other currencies *j*.

The net directional volatility spillover provides information about whether a currency is a receiver or transmitter of volatility in net terms and it is given as follows:

$$S_{i}^{g}(H) = S_{i\rightarrow j}^{g}(H) - S_{i\leftarrow j}^{g}(H). \qquad (28)$$

Hypothesis 4: One of the examined new EU exchange rates is the source of volatility propagation and takes a leading role in volatility transmission mechanism in all four examined time periods. We test this hypothesis by calculating directional volatility spillovers for all new EU FX rates and USD/EUR using equation 27. Antonakakis (2012)

examines developed FX markets and show that euro is the dominant currency in volatility transmission in both pre-euro and post-euro periods. Similarly, we expect to find one new EU currency to reach the highest value of all examined new EU currencies in the row "contribution to others" in table 4.5.

4.4 Empirical results

4.4.1 Initial assessment

The dynamics of the studied exchange rates are presented in Figure 4.1. During the examined time period from January 1999 to May 2018, the Czech koruna appreciated by 30 percent and the Hungarian forint depreciated by 20 percent against the euro. The Polish zloty fluctuated around a value of 4.0. The USD/EUR exhibited various patterns. First, the US dollar appreciated against the euro from 1999 to 2002 and reached the value of 0.85. Later, the euro appreciated against the US dollar and reached the value of 1.58 at the GFC's start in fall 2008. After the GFC, the euro was continuously losing its value until reaching the minimum against the US dollar at the level of 1.04 in the beginning of 2017. Since then euro has been slowly appreciating and came back to 1.20 level against the US dollar in 2018.

Descriptive statistics of the examined exchange rates are presented in the Table 4.1. An analysis of percentage returns shows that all examined forex markets exhibit the largest volatility in 2008 when the GFC began (see the values of standard deviation in Table 4.1 and depiction of returns in Figure 4.1). Otherwise, the standard deviations of the four exchange rates decrease after the EU debt crisis, which demonstrates lower levels of contagion and financial distress. The only notable exception is a single sizable spike in the CZK/EUR daily returns observed in 2013 (Figure 4.1). The volatility spike is endogenous in nature and is associated with the introduction of the "exchange rate commitment" and ensuing currency interventions by the Czech National Bank.[34]

In addition, the average daily returns are similar across all four examined exchange rates and close to zero. When examining each period separately, the largest standard deviation in Table 4.1 (and the highest volatility) is associated with the Polish zloty (PLN) during the GFC. On the other hand, Czech currency exhibits the lowest

[34] The CNB practiced an "exchange rate commitment" (constraining exchange rate regime) from November 7, 2013 to April 6, 2017. The CNB prevented the koruna from undergoing excessive appreciation to below CZK 27/EUR by intervening in the forex market. On the weaker side of the CZK 27/EUR level, the CNB allowed the koruna exchange rate to float. The measure was similar to the "capping" practiced by the Swiss National Bank.

standard deviation in each individually analyzed period. In other words, the Czech koruna (CZK) is the least volatile currency of the three new EU currencies examined. Hau (2002) shows that more open economies have less volatile real exchange rates. We confirm this finding. Out of the three examined new EU countries, Poland has the least open economy in terms of the net export to GDP ratio and the most volatile currency during the GFC.

Further, the skewness and excess kurtosis indicate a non-normal distribution of examined time series; this is also confirmed by the *p*-value of the Jarque-Bera test, which suggests that the null hypothesis may be rejected at the 1% significance level. Exchange rates are mostly skewed to the right, implying the existence of several small and few large returns. The HUF/EUR and the USD/EUR returns exhibit the largest kurtosis and skewness values, which aligns with their highest values of standard deviation from all examined exchange rates. The CZK/EUR skewness and kurtosis values temporarily increased after the Czech central bank launched currency interventions in 2013.

Finally, the Ljung-Box test Q and Q^2 statistical results are presented. The serial correlation in squared returns is confirmed for almost all the time series and implies the presence of non-linear dependencies. Moreover, according to Engle's ARCH-LM statistics, an ARCH effect exists in the data at the 1% significance level. Overall, the exchange rates exhibit patterns of volatility persistence and clustering, in addition to non-linear dependency. These results support the application of GARCH- type models.[35]

4.4.2 Exchange rate comovements

The results of the time-varying exchange rate comovements based on the DCC-GARCH model described in Section 4.3.2 are presented in Table 4.2.

The GARCH models for individual time periods were chosen following these criteria: (i) eliminating the ARCH effect from the residuals, (ii) eliminating serial correlations in the residuals, and (iii) considering the best AIC and SIC criterion. Because the standard GARCH (1,1) model fulfilled the criteria, we consider this model sufficient for the calculations of the DCC model. The AR(1)-GARCH (1,1) model is employed if the serial correlation in the residuals of GARCH(1,1) model is presented. The main advantage of our model is its parsimonious specification, which simplifies interpretation and allows even

[35] Both the HUF/EUR and USD/EUR values for during the EU debt crisis and the CZK/EUR values for after the EU debt crisis reject the null hypothesis of an absence of ARCH effects. This can be attributed to the fewer observations included in the samples. The absence of ARCH effects found in the CZK/EUR after the EU debt crisis can be explained by central bank currency interventions and by the oscillation of the CZK/EUR at around 27.00 from November 7, 2013 to the end of intervention period on April 6, 2017.

large asset portfolios to be estimated. GARCH models with higher lags, asymmetric GARCH-type models (EGARCH, TARCH), and Student's (t) error distribution were also estimated, but they were not able to deliver improved results in terms of the AIC and SIC.[36]

Adams et al. (2017) discuss several aspects of DCC model extension. They demonstrate that the typical correlation dynamics that can be observed in the data are a direct consequence of correlation breaks that occur in response to financial and economic shocks. The presence of breaks affects the correlation news parameter α and the decay parameter β. They argue that correlations are constant over time, but that financial shocks lead to breaks that shift the level of correlations. Following Adams et al. (2017) our data sample is divided into 4 individual time frames determined by key economic events and examined separately. Asymmetry is not an issue in our case, which is qualitatively similar result as that found by Baumöhl and Lyócsa (2014) who show that asymmetry is not common phenomenon in emerging markets. Also, Gjika and Horváth (2013) examine Central Europe stock markets and argue that correlations are constant over time.

As a common pattern, the new EU exchange rates behave homogenously in individually examined time periods and exhibit common behaviors in terms of comovements with USD/EUR. The magnitude of correlations between new EU exchange rates and the US dollar is highest prior to the GFC and lowest during the EU debt crisis. Specifically, Figures 4.2 A-C show correlations ranging from 0.8 (forint – US dollar) prior to the GFC to negative 0.5 during the EU debt crisis (forint – US dollar and zloty – US dollar).[37] These results suggest that new EU currencies behave mutually similarly, but differently from the world-leading forex flow represented by USD/EUR during crisis period. New EU currencies and USD/EUR demonstrate weaker conditional correlations than the currencies of developed countries. For example, Antonakakis (2012) shows that the conditional correlations between the exchange rates of major currencies are entirely positive and range from 0.32 (JPY/GBP) to 0.87 (CHF/EUR).

[36] The results are not materially different if BIC is applied. The advantage of our approach is the we have parsimonious model.

[37] I would like to thank Eduard Baumöhl for pointing out the estimation problems with DCC model. For example, to consider the downward bias estimation problem related to the DCC model. Hafner and Reznikova (2012) suggest that the bias is considerable for a small number of observations and vanishes when the number of observations increases. Therefore, we performed robustness check by calculating the DCC model for the whole period of 18.5 years (January 1999-May 2018). In this model, the individual periods such as the GFC and the EU debt crisis are reflected by the dummy variables. As a result, the graphs of pair-wise conditional correlations representing the whole period of 18.5 years show the same behavior as conditional correlations calculated and representing partial time periods.

Based on our reasoning in Section 4.3.1, we calculate conditional correlations for each time period separately and report them in Table 4.2. Further, we assess whether the difference in the time-varying magnitude of two conditional correlations (ρ) is statistically significant. In our approach we build on Corsetti et al. (2005) and Antonakakis (2012) who employ the Z-transformation introduced by Fisher (1915)[38]. The null hypothesis of Z-transformation states that conditional correlations of two samples are equal.

In the Fisher Z-Transformation the correlation coefficients are converted to normally distributed Z variables (Z_0, Z_1) by this formula:

$$Z_0 = \frac{1}{2}\ln\left[\frac{1+\rho_0}{1-\rho_0}\right] \text{ and } Z_1 = \frac{1}{2}\ln\left[\frac{1+\rho_1}{1-\rho_1}\right], \quad (29)$$

where ρ_0 and ρ_1 are correlation coefficients in individually examined time periods. Consequently, the values for the Fisher Z-Test are calculated by formula $T = \frac{Z_0 - Z_1}{\sqrt{\frac{1}{N_0-3}+\frac{1}{N_1-3}}}$, where N_0 and N_1 denote the number of observations in individually examined time periods. Positive z-values indicate that ρ_0 is larger than ρ_1; negative z-values demonstrate that ρ_0 is smaller than ρ_1. The critical values for the Fisher Z-test with 1, 5 and 10% statistical significance are 1.28, 1.65 and 1.96, respectively.

We compare conditional correlations in pairs of neighboring samples (neighboring time periods) and report the results in Table 4.3. Based on the results of the test, we reject the null hypothesis for all period-pairs and all new EU currencies. The results in Table 4.3 provide evidence that dynamic conditional correlations change their magnitudes among the four examined time periods. The above results enable us to reject Hypothesis 1.

We also provide a robustness check of the breaks in correlation as in Chiang et al. (2007) and Dimitriou and Kenourgios (2013).We use three mutually exclusive dummy variables taking value of 1 during three sub-samples: the GFC ($DM_{1,t}$), the EU debt crisis ($DM_{2,t}$) and after the EU debt crisis ($DM_{3,t}$) to construct the regression model:

$$\rho_{ij,t} = \sum_{p=1}^{P} \phi_p \, \rho_{ij,t-p} + \sum_{k=1}^{3} \alpha_k \, DM_{k,t} + e_{ij,t}. \quad (30)$$

[38] The results of Z-transformation introduced by Fisher (1915 provide similar results as of Engle and Sheppard (2001)

In (30), $\rho_{ij,t}$ is the conditional correlation of new EU exchange rates and USD/EUR from the DCC model; the lag length is calculated for each pair-correlation individually based on the AIC criterion, and $DM_{k,t}$ represents the above dummy variables. Based on the coefficients reported in Table A3 the dummy variable for the GFC and European debt crisis is statistically significant for all correlations. The ARCH effects are absent in residuals (see row ARCH (5) in Table A3). The similar approach was applied by Forbes and Rigobon (2002) and Kenourgios (2014) who examine financial contagion during crisis periods.

The previous robustness check is a less direct approach than the former application of the Fisher Z-transformation. However, the outcomes of the Fisher Z-transformation are corroborated by this robustness check and imply that conditional correlations are not stable over the time. The results further support our empirical strategy to examine conditional correlations separately for several distress and no-distress periods—the specific results are shown presently.

Prior to the Global financial crisis (GFC)

In Figures 4.2 A-C, we present time-varying correlations between USD/EUR and the new EU exchange rates. Differing patterns of comovements in the forex market are revealed. Strongly increasing correlations between USD/EUR and three new EU currencies from 1999 to 2002 correspond to the time during which the euro was used as an electronic/accounting currency in 11 of the 15 EU member states. Conditional correlations between the forint and the US dollar and between the zloty and the US dollar reach values of nearly 0.8 during this time. In 2002, euro notes and coins became legal tender in the 12 Eurozone countries (Greece was the 12th member). From this point on, dynamic conditional correlations of the USD/EUR and the new EU currencies decrease. Koruna – US dollar correlations reach the lowest value of negative 0.2, zloty – US dollar correlations decrease to negative 0.4, and forint – US dollar correlations reach negative 0.5 just prior to the GFC. The estimated parameters of the DCC model (α and β) in Table 4.2 are statistically significant at the 1% level, indicating that the model is well specified and confirming that the second moments of exchange returns are indeed time varying (α). Moreover, high values found for parameter β and especially for the koruna – US dollar relation suggest the presence of a strong correlation structure. The zloty – US dollar relation exhibits the highest conditional correlation (0.26). In contrast, the koruna – US

dollar relation reaches a slightly negative correlation, with a value of negative 0.02, for this point in time.

The Global financial crisis (GFC)

Dynamic conditional correlations between the new EU exchange rates and USD/EUR continue to decrease during the GFC. Nevertheless, this decline is gentle, and the correlations usually fluctuate at approximately negative 0.2 (koruna – US dollar), negative 0.3 (forint – US dollar) and negative 0.4 (zloty – US dollar), as indicated in Table 4.2 and Figures 4.2 A (koruna), B (zloty), and C (forint). The absence of a time-varying correlation structure for koruna – US dollar returns is suggested by the insignificant parameter α in the DCC equation. Further, lower levels of parameter β in the DCC equation in Table 4.2 imply lower levels of correlation memory.

The EU debt crisis

The dynamic correlations exhibit patterns of behavior for the EU debt crisis that are similar to those observed for the GFC period. Again, the correlations decrease slightly and reach the lowest values of those observed in the four periods examined. The conditional correlations decrease to negative 0.3 (koruna – US dollar) and negative 0.5 (zloty – US dollar; forint – US dollar), as indicated in Table 4.2 and Figures 4.2 A (koruna), 4.2 B (zloty) and 4.2 C (forint). The dynamic conditional correlations record lower values during the EU debt crisis than during the GFC. The absence or low statistical significance of parameter α denotes an absence of time-varying correlation structures. The fact that this parameter reaches lower values during the EU debt crisis compared to the GFC period indicates more stable and less volatile conditional correlations during the EU debt crisis. The statistical insignificance of coefficient β found for the forint - US dollar relation implies an absence of correlation memory. The results of Kasch and Caporin (2013), who apply the extended DCC model, indicate that turbulent periods are associated with an increase in correlations among developed stock markets. A similar argument is put forth by Ang and Chen (2002). However, for cross-correlations between the new EU currencies, and for the Hungarian and Czech currency markets in particular, this pattern is far less pronounced. Negative values of correlations demonstrate an absence of positive comovements in new EU forex markets during both recent crises. Negative values of correlation coefficients indicate the absence of herding behavior on the

currency market during the GFC. In the other words, investing in new EU currencies provides investors with good diversifying opportunity against the US dollar. The findings are in line with the results of Miyajima et al. (2015), who show that (i) benefits from diversification in emerging market local currency bonds have increased since 2008, and (ii) emerging market government bonds (including those of Hungary and Poland) have been resilient to global risk shocks. Gilmore and McManus (2002) also confirm that US investors can obtain benefits from international diversification into Central European equity markets. Assets' liquidity is also an important factor in evaluating investment strategy. Should the lower traded volume prevent investors from considering the diversification benefits of new EU exchange market? Menkhoff et al. (2012) show that liquidity risk matters less than volatility risk for pricing returns.

After the EU debt crisis

Following the EU debt crisis, the conditional correlations between new EU currencies and USD/EUR increase to 0.2 at the beginning of 2015, as we indicate in Figures 4.2 A (koruna), 4.2 B (zloty), and 4.2 C (forint). The reversion of the correlations' values approaching pre-crisis levels may be related to the improving conditions in the financial market following the end of the GFC and the EU debt crisis. At the beginning of 2015, ECB announced the implementation of a quantitative easing (QE) program by buying each month bonds at a value of 80 bn. euros from commercial banks. The correlations of all new EU exchange rates begun instantly falling towards the negative territory close to levels observed during the EU debt crisis. The correlations slowly return to pre-crisis levels again in the second half of 2016. However, they did not stay there for a long time and felt back to the negative territory in early 2017, when several events increased global uncertainty. First, the US president Donald Trump applied steps heading to US trade protectionism, including the country's withdrawal from the NAFTA agreement. Second, the Fed started to tighten monetary conditions with three interest rates hikes within one year. Third, the ECB terminated the period of unconventional expansionary monetary policy by approaching the cut of monetary stimulus for the first time since the EU debt crisis.

The Czech National Bank (CNB) launched forex interventions on November 7, 2013 and used them until April 6, 2017. The central bank prevented the koruna from excessive appreciation below CZK 27/EUR by intervening in the forex market. On the weaker side

of CZK 27/EUR, the CNB allowed the koruna exchange rate to float. We use the dummy variable in the GARCH equation to capture the effect of currency interventions. A dummy variable may not always sufficient reflect low returns on koruna during the period of constraining exchange rate regime. For this purpose, we also report time- varying conditional correlations for the koruna – US dollar relation separately during the period not affected by currency interventions from January 1, 1999 until November 6, 2013; see Appendix Figure A1 for details.

4.4.3 Hedge ratios and portfolio weights

The comprehensive portfolio weights and hedge ratios are presented in Table 4.4. Overall, the portfolio weights are found to be stable across all examined periods and reach the value close to 50 percent; the exceptions are CZK/PLN and CZK/HUF after the EU debt crisis. For example, the average weight for the CZK/HUF prior to the GFC is 0.5349, indicating that on average, in a 1-euro portfolio, 0.5349 euros should be invested in the CZK, and 0.4651 euros should be invested in HUF. After the EU debt crisis, the portfolio weights for the CZK decrease to 0.3972. Hence, in 1-euro portfolio, on average, 0.3972 euros should be invested in the CZK, and 0.6028 euros should be invested in the HUF. Lower share of the Czech koruna in the portfolio can be explained by the CZK appreciation after the CNB terminated currency interventions on the FX market. A regular recalculation of portfolio weights is important for investors who want to reach the maximum expected return at a certain level of risk. Attaining the optimal portfolio weights for the CZK/HUF prior to the GFC and after the EU debt crisis means decreasing the weight of the CZK by 25.7 percent and increasing the weight of the HUF by 29.6 percent.

Excessive volatility in the financial markets renders the hedge more expensive. For example, a 1-euro long position in the CZK should be hedged by a 0.32 PLN short position prior to the EU debt crisis. During the GFC, we need to open a short position in the PLN of 0.56 to hedge 1-euro long position in the CZK. This means that during the GFC, we need 75 percent more PLN to hedge our 1-euro long position in the CZK. Overall, the hedging costs increase by 75 percent due to market distress, uncertainty and increased volatility. The unfavorable conditions in the examined forex market during the GFC are also represented by the high level of standard deviation indicated in Table 4.1.

During the EU debt crisis, the average costs of hedging slowly decrease. A 1-euro long position in the CZK can be hedged with a 0.43 short position in the PLN. After the EU debt crisis, we need to open only the short position in the PLN of 0.32 to hedge 1-euro long position in the CZK. We posit that the non-standard monetary policy measures taken by the ECB in response to the crisis eased market distress. Overall, we cannot reject Hypothesis 2.

Further, the results presented in Table 4.4 indicate that the cheapest hedge is a long position in the Czech koruna and a short position in the Hungarian forint in all examined periods except during the GFC. On the other hand, the most expensive hedge is a long position in the Polish zloty and a short position in the Hungarian forint. Finally, none of the hedge ratios are in excess of unity in all periods examined. These results resonate with those of Antonakakis (2012), who show that after establishment of the euro, the developed currencies' hedge ratios stay below unity.

4.4.4 Volatility spillovers

The results of volatility spillovers based on the Diebold and Yilmaz (2012) generalized spillover index are presented in Table 4.5 and Figures 4.3-4.6. Here, we present the directions and degrees of volatility spillovers within and across all four exchange rates.[39] This way we provide two outcomes. First, we examine spillovers in a broader context of how spillovers come from the rest of the world to the new EU markets and vice versa. In our analysis the dollar/euro exchange rate represents the world forex market – this aggregate proxy is the most traded currency pair in the world representing the two world largest economies. Second, we examine forex spillovers among new EU countries that share historically strong trade relations and belong to the Visegrad Four (V4) group with economically important role in the Central and Eastern Europe (CEE). The Visegrad Four group consist of the Czech Republic, Poland, Hungary and Slovakia. Slovak currency is not involved in our research, because the country adopted the euro in 2009. Detecting and quantifying volatility spillovers between the V4 nations can help central bank policy makers to coordinate their approach if one of the currencies suffers from increased volatility. Stable currency environment (i) is crucial to achieve economic stability encompassing both stable prices and real growth immune to wide swings, and

[39] The daily variance ($\tilde{\sigma}_{it}^2$) is estimated for currency *i* and day *t* using the formula suggested by Diebold and Yilmaz (2012): $\tilde{\sigma}_{it}^2 = 0.361\left[ln(P_{i,t+1}^{close}) - \ln(P_{i,t}^{close})\right]^2$, where $P_{i,t+1}^{close}$ is the closing price of currency *i* on day *t + 1* and $P_{i,t}^{close}$ is the closing price of currency *i* at time *t*.

also (ii) brings benefits for international investors who consider new EU countries highly attractive in terms of number of funds they allocate there (Jotikasthira et al., 2012).

The diagonal values ($i = j$) of the total spillover index presented in Table 4.4 are higher than off-diagonal values ($i \neq j$). The results indicate that own-currency volatility explains a substantial share of volatility spillovers. These results are in line with those of Bubák et al. (2011), who find that during the pre-2008 period, the volatilities of both the EUR/CZK and the EUR/PLN exchange rates are affected chiefly by their own histories in terms of both the short-term and long-term volatility patterns. When examining each time period separately, the largest off-diagonal volatility spillovers are (i) bidirectional spillovers between zloty-koruna, forint-koruna and forint-zloty during the GFC and (ii) bidirectional spillovers between the zloty-forint during the EU debt crisis. These findings are consistent with those of Antonakakis (2012), who find that forex market volatility exhibits bidirectional volatility spillovers rather than unidirectional volatility spillovers between the euro and set of developed market currencies. However, other markets might exhibit entirely different behavior. For example, Rodríguez et al. (2015) show that shocks across countries explain major part in the total volatility spillover index on European sovereign bond markets.

In Figure 4.3 we present the results of the estimated time-varying total volatility spillover index based on 200-day rolling samples. We observe considerable levels of variability in the index immediately following the introduction of the euro (1999-2000). The index value peaks at above 20 percent in 2006 and again in early 2008, in 2009, and in 2017. The two peaks in 2008 and 2009 correspond to the GFC period; a similar pattern is observed by Bubák et al. (2011), who also show increase in volatility spillovers among the new EU forex markets during periods of market uncertainty. The last peak represents the period of US president Donald Trump and tightening monetary policy of Fed and ECB.

Overall, the highest value of the index is observed during the GFC reaching the value of 21.6 percent (see Table 4.5); second highest value is reached in the beginning of 2017. Further, the GFC is characterized by higher levels of volatility, as the values of the own-currency (diagonal) volatility decrease and cross-currency (off-diagonal) volatility increase.[40] These results imply that during the GFC, higher levels of volatility spill over

[40] To estimate the total volatility spillover index, we apply the VAR(4) and VAR(5) models according to the Akaike Information Criterion (AIC). Variance decompositions are based on 10-step-ahead forecasts and 200-day rolling windows for all the time periods examined.

to individual currencies from their forex counterparts. The highest off-diagonal spillover values can be observed between the forint and the zloty and between the forint and the koruna. As the GFC resolved, off-diagonal volatility decreases but remains relatively high during the EU debt crisis, with a total volatility spillover index reaching the level of 8.96 percent. The largest cross-currency spillovers occurred from the zloty to the forint. Both the GFC and the EU debt crisis stand in contrast to the calmest period prior to the GFC, when, on average 4.13 percent of the volatility forecast error variance for all four currencies can be attributed to volatility spillovers. Consequently, we cannot reject null Hypothesis 3. In a similar way, Gray (2014) recognizes greater turbulence on the new EU forex market during the GFC than in tranquil periods and finds that propagation of currency turbulences is not linear.

Further, the total volatility spillover index (in aggregated or dynamic form) does not provide on information about the direction of the spillovers. For this reason, we construct Figures 4.4 and 4.5 based on formula (27) and using 200-day rolling samples. Figure 4.4 presents directional volatility spillovers FROM each of the four currencies to others. Figure 4.5 presents directional volatility spillovers from other currencies TO each individual currency for all three periods examined.[41] These figures depict the development of volatility patterns over the research period. According to Figures 4.4 and 4.5, the Hungarian forint retains its leading role in volatility transmission, as directional volatility spillovers reach high values in all four examined periods. Further, the koruna and the zloty receive the highest volatility during the GFC, whereas the euro faces the highest volatility from outside during the EU debt crisis.

The leading role of Hungarian forint in volatility transmission for each individually examined time period is also confirmed according to the "Contributions to others" row of Table 4.5. Of the three examined new EU countries, the Hungarian economy suffered most during the GFC and EU debt crisis. One of the main problems Hungary faced was its depreciating currency. The Hungarian forint declined against the Swiss franc by 60 percent from 2008 and 2012, which enormously increased the household debt burden of mortgages expressed in Swiss francs. Moreover, the worsening economic situation in the country further increased selling pressure on the forint. The results showing diffusion of the contagion from Hungary to surrounding countries via currency spillovers may

[41] Figures 4.4 and 4.5 represent dynamic versions of the "Contributions to others" row and the "Contributions from others" column in Table 4.5, respectively.

serve as useful information for policy makers. Contrary to the Hungarian forint, the Czech koruna transmits the lowest proportion of volatility prior to the GFC and during the EU debt crisis. From another perspective, the Polish zloty assumes a leading role as volatility spillovers receiver prior to the GFC and during the EU debt crisis. Such spillovers are mainly received by the Czech koruna during the GFC.[42] These findings lead to not rejecting hypothesis 4.

Finally, Figure 4.6 shows net volatility spillovers from/to each of the four examined exchange rates computed using equation (28) based on 200-day rolling windows. USD/EUR is a net receiver of volatility from 2004-2006 and during the GFC. However, USD/EUR becomes source of volatility transmissions to the new EU currencies with the start of the EU debt crisis, as well as in 2017 when the US president Donald Trump begun to take steps for protecting the US companies. The Hungarian forint is the most vulnerable currency during the GFC and the EU debt crisis, as it is a net volatility receiver during much of the 2008-2012 period. The Hungarian forint also suffered from higher volatility coming from outside of the market in 2016 and 2017. Finally, the Czech koruna became the source of volatility in 2017, when the Czech National Bank concluded its currency interventions and led the koruna trade freely. On the other hand, during the large part (2014-2016) of the interventions' period the Czech koruna was mainly volatility receiver.

4.5 Conclusion

We analyze time-varying exchange rate comovements and volatility spillovers in the new EU forex market from 1999-2018. Specifically, we examine conditional correlations and volatility spillovers between the Czech, Hungarian, and Polish currencies with respect to the euro, and the dollar/euro exchange rate as a proxy for the world forex market. We show how the new EU forex market correlates with the US dollar by employing the DCC model and the Diebold-Yilmaz spillover index as our key analytical tools. Our results document the evolution of currency interdependencies and volatility spillovers during calm and distressed periods (the GFC and EU debt crisis).

We show that conditional correlations change over time and may be evaluated from the perspective of major economic events. During the first three years of the euro's existence (1999-2001), all three new EU currencies exhibit their strongest correlations

[42] These findings may not correspond with net spillover values (last row) in Table 4.5 due to the presence of bidirectional volatility spillovers.

with the US dollar. Since 2002, the correlations have decreased towards negative values. The conditional correlations reach the lowest values during the GFC and the EU debt crisis. After the EU debt crisis, the correlations strengthen and return to pre-crisis levels. However, after the US withdrew from the NAFTA agreement and the Fed started to tighten monetary conditions, the fear from global trade war increased and the correlations moved into the negative territory again. Also, we use the data from the DCC model in a simulated portfolio management exercise. We use time-varying magnitude of the correlations from the second stage of DCC model estimation to calculate portfolio weights and hedge ratios.

Our outcomes conflict with the general understanding that correlations between financial assets increase during turbulent periods. On the contrary, we ask whether new EU currencies help investors diversify their portfolios during crisis periods. If yes, how much would that process cost? The results imply low correlations on the new EU forex markets during periods of distress that offer valuable diversification opportunities. These potential portfolio benefits come at a price, though. We demonstrate that hedging during the GFC is 75 percent more expensive than before the GFC. Generally, on the new EU forex market, hedging is most costly during the GFC, and the cheapest hedging is observed in the period before the GFC. We show that portfolio diversification benefits offered by the new EU currencies may have been exploited by investors during the turbulent periods of the GFC and the EU debt crisis as witnessed by the increased volumes of cross-trades at those times.

In terms of volatility spillovers, we examine mutual volatility spillovers between new EU currencies together with spillovers between new EU currencies and the world forex market. The highest levels of cross-currency volatility are found during the GFC. Further, we find that own-currency volatility spillovers explain a substantial share of the total volatility. Volatility spillovers between individual currencies can be characterized as bidirectional. In this respect, the Hungarian forint is the dominant currency of the volatility transmission mechanism in that it transmits most spillovers from other currencies in each time period examined.

The results we present carry important implications for both forex market regulators and its actors in the EU. We document significant differences in the extent of currency comovements during various periods related to market distress. The extent of distress is further related to real economic and financial events. Moreover, low

correlations reflect different patterns of behavior in the world forex market and in new EU currencies during crisis periods. These results imply favorable diversification benefits for the investors investing in the new EU currencies. Despite that comovements between new EU currencies and USD/EUR are similar in individually examined time periods, the hedge-ratio calculations show that it is worth to treat new EU currencies individually and not a as group. We show that all three currencies bring hedging benefits during crisis periods, but at different costs.

4.6 Tables

Table 4. 1: Descriptive statistics of the examined exchange returns (CZK/EUR, PLN/EUR, HUF/EUR)

	Before GFC (1.1.1999 - 14.9.2008)				GFC (15.9.2008-30.4.2010)				EU debt crisis (3.5.2010-26.7.2012)				After EU debt crisis (27.7.2012-31.05.2018)			
	CZK/EUR	*PLN/EUR*	*HUF/EUR*	*USD/EUR*	*CZK/EUR*	*PLN/EUR*	*HUF/EUR*	*USD/EUR*	*CZK/EUR*	*PLN/EUR*	*HUF/EUR*	*USD/EUR*	*CZK/EUR*	*PLN/EUR*	*HUF/EUR*	*USD/EUR*
Observations	2484	2484	2484	2484	415	415	415	415	577	577	577	577	1494	1494	1494	1494
Mean	-0.0001	-0.0001	0.0000	0.0001	0.0001	0.0004	0.0003	-0.0001	0.0000	0.0001	0.0001	-0.0002	0.0000	0.0000	0.0001	0.0000
St. Dev.	0.0035	0.0060	0.0045	0.0062	0.0065	0.0103	0.0099	0.0089	0.0039	0.0062	0.0072	0.0069	0.0022	0.0035	0.0039	0.0052
Skewness	0.4921	0.6023	1.4005	0.1933	-0.0192	0.1840	0.3610	0.0251	-0.0214	0.2594	0.3742	-0.2779	3.8633	0.1989	0.1826	-0.2534
Kurtosis	9.87	7.45	16.12	4.54	5.66	5.04	6.00	6.41	4.09	6.72	7.49	3.19	85.57	5.44	4.92	6.77
ADF	-49.86***	-36.87***	-49.17***	-50.03***	-19.32***	-18.19***	-19.78***	-20.14***	-23.74***	-24.35***	-24.25***	-23.65***	-38.73***	-38.61***	-39.58***	-39.70***
JB	4984.14***	2201.64***	18633***	261.19***	122.52***	74.24***	164.89***	201.33***	28.55***	340.01***	497.89***	8.31**	427884***	381.18***	236.72***	898.18***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Q(10)	7.15	22.72**	18.43**	8.63	10.21	20.71**	10.76	17.33	17.89	16.80	10.68	4.98	8.54	2.66	20.605**	8.17
	[0.711]	[0.012]	[0.048]	[0.567]	[0.423]	[0.023]	[0.377]	[0.067]	[0.057]	[0.079]	[0.383]	[0.893]	[0.576]	[0.988]	[0.024]	[0.613]
Q2(10)	89.704***	753.92***	65.31***	67.482***	214.23***	142.29***	134.65***	97.686***	119.81***	83.979***	8.013	14.997	6.057	176.89***	272.22***	13.987
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.628]	[0.132]	[0.810]	[0.000]	[0.000]	[0.174]
ARCH(5)	11.47***	90.61***	8.48***	7.00***	19.39***	13.41***	8.42***	12.30***	7.32***	6.72***	0.95	1.14	0.26	13.85***	22.94***	2.07*
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.444]	[0.335]	[0.933]	[0.000]	[0.000]	[0.067]

Notes: *p*-values are provided in brackets. JB denotes the Jarque-Bera test for normality. Q (10) and Q2 (10) are Ljung-Box statistics for serial correlations in exchange rate and squared returns, respectively. ADF 5% and 1% critical values are -2.88 and -3.47, respectively. *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively.

Table 4. 2: Estimation results of the DCC model

	Before GFC (1.1.1999-14.9.2008)			**GFC crisis (15.9.2008 - 30.4.2010)**			**EU Debt crisis (3.5.2010-26.7.2012)**			**After EU debt crisis (27.7.2012-31.5.2018)**		
1st step univariate GARCH model and diagnostic tests												
Mean Eq.	**CZK/EUR**	**PLN/EUR**	**HUF/EUR**	**CZK/EUR**	**PLN/EUR**	**HUF/EUR**	**CZK/EUR**	**PLN/EUR**	**HUF/EUR**	**CZK/EUR**	**PLN/EUR**	**HUF/EUR**
Constant	-0.0002**	-0.0003**	0.0000	-0.0001	-0.0001	-0.0002	0.0000	-0.0001	-0.0000	-0.0000*	-0.0001	-0.0000
	(0.0022)	(0.0003)	(0.6092)	(0.6167)	(0.7167)	(0.5626)	(0.8984)	(0.5321)	(0.7445)	(0.0353)	(0.1440)	(0.5860)
Variance Eg.												
Constant	0.0000**	0.0000**	0.0000**	0.0000	0.0000	0.0000	0.0000	0.0000*	0.0000*		0.0000**	0.0000
	(0.0002)	(0.0002)	(0.0000)	(0.4352)	(0.3641)	(0.1719)	(0.1556)	(0.0292)	(0.0331)		(0.0029)	(0.1163)
α	0.0699**	0.0885**	0.0488**	0.0883**	0.0736**	0.1167**	0.0680**	0.0412*	0.0312*	0.1677**	0.1276**	0.0317**
	(0.0000)	(0.0000)	(0.0000)	(0.0013)	(0.0016)	(0.0002)	(0.0071)	(0.0345)	(0.0213)	(0.0000)	(0.0000)	(0.0001)
β	0.9029**	0.8945**	0.9486**	0.9042**	0.9185**	0.8762**	0.9174**	0.9189**	0.9515**	0.7901**	0.8373**	0.9637**
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
GED param.	1.2184**	1.4001**	1.5000**	1.5488**	1.5233**	1.4561**	1.3821**	1.4235	1.5344**	1.1257**	1.4022**	1.5304**
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Q(30)	13.1960	39.1860	16.0630	38.1710	25.6370	19.5450	23.2320	28.4040	26.2310	22.2180	25.2990	23.6220
	(0.9970)	(0.1220)	(0.9820)	(0.1450)	(0.6940)	(0.9280)	(0.8060)	(0.5490)	(0.6630)	(0.8460)	(0.7100)	(0.7890)
$Q^2(30)$	15.1510	29.0830	0.7264	20.7560	22.2590	17.6920	22.9460	36.8240	14.2490	3.6778	18.8010	33.437
	(0.9890)	(0.5130)	(1.0000)	(0.8950)	(0.8440)	(0.9630)	(0.8170)	(0.1820)	(0.9930)	(1.0000)	(0.9440)	(0.3040)
2nd step DCC model. correlations												
ρ (corr)	-0.0221	0.2631	0.0560	-0.1694	-0.3273	-0.3730	-0.2963	-0.4819	-0.4927	-0.0721	-0.0601	-0.1107
α	0.0076**	0.0287**	0.0413**	0.0307	0.1091**	0.0714*	0.0206*	0.0331*	0.0132	0.0099**	0.0186**	0.0188**
	(0.0010)	(0.0000)	(0.0000)	(0.3861)	(0.0015)	(0.0414)	(0.0172)	(0.0301)	(0.6084)	(0.0026)	(0.0000)	(0.0001)
β	0.9905**	0.9651**	0.9552**	0.7300	0.7110**	0.8087**	0.9657**	0.8962**	0.7864	0.9784	0.9703	0.9704
	(0.0000)	(0.0000)	(0.0000)	(0.0592)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.2308)	(0.0000)	(0.0000)	(0.0000)
Log-Lik	25.8242	232.4878	96.39579	6.8990	37.4631	36.4078	31.6512	80.5613	80.3013	9.6228	18.7375	22.5271

Notes: Q(30) and Q2(30) are Ljung-Box portmanteau test statistics for serial correlations of the univariate standardized and squared standardized residuals, respectively; *p*-values are presented in parentheses. Following Antonakakis (2012) the number of lags was set to 30 to reflect potential one-month seasonality in the data; * denotes 5% significance; ** denotes 1% significance.
The AR(1)-GARCH (1,1) model is employed if the serial correlation in the residuals of GARCH(1,1) model is presented. The AR(1)-class model successfully eliminated serial correlation from the residuals. For this reason, we did not employ AR(1)MA(X)-class models. To keep the consistence of data reporting we do not report AR(1) term in the table. GARCH models with higher lags, asymmetric GARCH-type models (EGARCH, TARCH), and Student's (t) error distribution were also examined, but they were not able to deliver improved results in terms of IAC and SIC.

Table 4. 3: Z-transformation (Fisher, 1915)

	Before GFC & GFC	
	Z-test statis	**p-value**
CZK/EUR & USD/EUR	2.8000	0.0079
PLN/EUR & USD/EUR	-11.4518	0.0000
HUF/EUR & USD/EUR	-8.4203	0.0000
	GFC & EU debt crisis	
	Z-test statis	**p-value**
CZK/EUR & USD/EUR	-2.0816	0.0457
PLN/EUR & USD/EUR	-2.8752	0.0064
HUF/EUR & USD/EUR	-2.2877	0.0291
	EU debt crisis & After EU debt crisis	
	Z-test statis	**p-value**
CZK/EUR & USD/EUR	4.7487	0.0000
PLN/EUR & USD/EUR	9.4709	0.0000
HUF/EUR & USD/EUR	8.6962	0.0000

Note: Table reports Z-statistics and p-values for the Z-transformation.

Table 4. 4: Hedge ratio and portfolio weight summary statistics

Before GFC period (1.1.1999 - 14.9.2008)					**GFC period (15.9.2008 - 30.4.2010)**				
Hedge ratio (long/short)					***Hedge ratio (long/short)***				
	Mean	Std. dev.	Min	Max		Mean	Std. dev.	Min	Max
CZK/PLN	0.3151	0.1953	-0.2840	0.8418	CZK/PLN	0.5610	0.0818	0.2702	0.8342
CZK/HUF	0.2325	0.1618	-0.2863	0.6677	CZK/HUF	0.5809	0.0399	0.4565	0.6741
PLN/HUF	0.4370	0.1733	-0.0229	0.8656	PLN/HUF	0.7158	0.0644	0.5288	0.8593
Portfolio weights (currency i/currency j)					***Portfolio weights (currency i/currency j)***				
CZK/PLN	0.5055	0.1524	0.0612	1.0866	CZK/PLN	0.5002	0.0906	0.1681	0.7800
CZK/HUF	0.5349	0.1981	0.1524	0.9842	CZK/HUF	0.4962	0.0529	0.3743	0.6897
PLN/HUF	0.5673	0.1981	0.1291	1.1216	PLN/HUF	0.4914	0.0868	0.2478	0.7425
EU debt crisis (3.5.2010 - 26.7.2012)					**After EU debt crisis (27.7.2012 - 31.05.2018)**				
Hedge ratio (long/short)					***Hedge ratio (long/short)***				
	Mean	Std. dev.	Min	Max		Mean	Std. dev.	Min	Max
CZK/PLN	0.4298	0.1009	0.2254	0.6513	CZK/PLN	0.3175	0.1533	-0.0088	0.8333
CZK/HUF	0.4188	0.0531	0.3065	0.5125	CZK/HUF	0.1932	0.1241	-0.1514	0.5884
PLN/HUF	0.6355	0.0780	0.3724	0.8731	PLN/HUF	0.4967	0.1434	0.1266	0.8306
Portfolio weights (currency i/currency j)					***Portfolio weights (currency i/currency j)***				
CZK/PLN	0.5001	0.0461	0.3944	0.6526	CZK/PLN	0.3897	0.1324	0.1084	0.8102
CZK/HUF	0.5010	0.0263	0.4474	0.5997	CZK/HUF	0.3972	0.1089	0.1641	0.7718
PLN/HUF	0.4968	0.1066	0.1026	1.0434	PLN/HUF	0.5243	0.0995	0.2449	0.7844

Notes: The input data (conditional covariance, conditional variance) for hedge ratios and portfolio weights calculations come from DCC model. For all reported hedge ratios and portfolio weights (CZK/PLN, CZK/HUF, PLN/HUF), the euro is the common denominator.

Table 4. 5 Volatility spillovers

Before GFC	*From j*				
To i	**CZK/EUR**	**PLN/EUR**	**HUF/EUR**	**USD/EUR**	**Contribution from others**
CZK/EUR	96.90	0.96	1.20	0.94	3.1
PLN/EUR	1.01	94.16	2.45	2.39	5.8
HUF/EUR	0.68	2.10	96.30	0.92	3.7
USD/EUR	0.69	1.66	1.61	96.03	3.9
Contribution to others	2.4	4.7	5.3	4.3	**Index:**
Contribution including own	99.3	98.9	101.6	100.3	4.13%
Net Spillover	-0.7	-1.1	1.6	0.4	

GFC period	*From j*				
To i	**CZK/EUR**	**PLN/EUR**	**HUF/EUR**	**USD/EUR**	**Contribution from others**
CZK/EUR	76.28	8.27	10.39	5.06	23.7
PLN/EUR	8.68	77.70	9.33	4.29	22.3
HUF/EUR	8.86	9.79	76.67	4.68	23.3
USD/EUR	6.20	5.00	5.97	82.83	17.2
Contribution to others	23.7	23.1	25.7	14.0	**Index:**
Contribution including own	100.0	100.7	102.4	96.9	21.60%
Net Spillover	0.00	0.8	2.4	-3.2	

EU debt crisis	*From j*				
To i	**CZK/EUR**	**PLN/EUR**	**HUF/EUR**	**USD/EUR**	**Contribution from others**
CZK/EUR	95.81	1.11	1.39	1.69	4.19
PLN/EUR	1.53	86.77	7.94	3.76	13.23
HUF/EUR	1.43	8.82	87.18	2.57	12.82
USD/EUR	2.10	1.34	2.19	94.38	5.63
Contribution to others	5.06	11.27	11.52	8.02	**Index:**
Contribution including own	100.87	98.04	98.70	102.40	8.96%
Net Spillover	0.87	-1.96	-1.30	2.39	

After EU debt crisis	*From j*				
To i	**CZK/EUR**	**PLN/EUR**	**HUF/EUR**	**USD/EUR**	**Contribution from others**
CZK/EUR	95.94	1.70	1.61	0.75	4.10
PLN/EUR	0.99	94.01	3.97	1.04	6.00
HUF/EUR	2.36	3.75	93.42	0.47	6.60
USD/EUR	1.08	0.71	0.72	97.50	2.50
Contribution to others	4.40	6.20	6.30	2.30	**Index:**
Contribution including own	100.40	100.20	99.70	99.80	4.80%
Net Spillover	0.40	0.20	-0.30	-0.20	

Notes: Values reported are variance decompositions for the estimated VAR models on conditional volatility. Variance decompositions are based on 10-step-ahead forecasts and 200-day rolling windows for all examined periods; VAR lag lengths of the order of 4 or 5 were selected via the AIC.

4.7 Figures

Figure 4. 1: Plots of daily spot rates and percentage returns for CZK/EUR, PLN/EUR, HUF/EUR, and USD/EUR exchange rates

The sample covers the period from January 1, 1999 to May 31, 2018

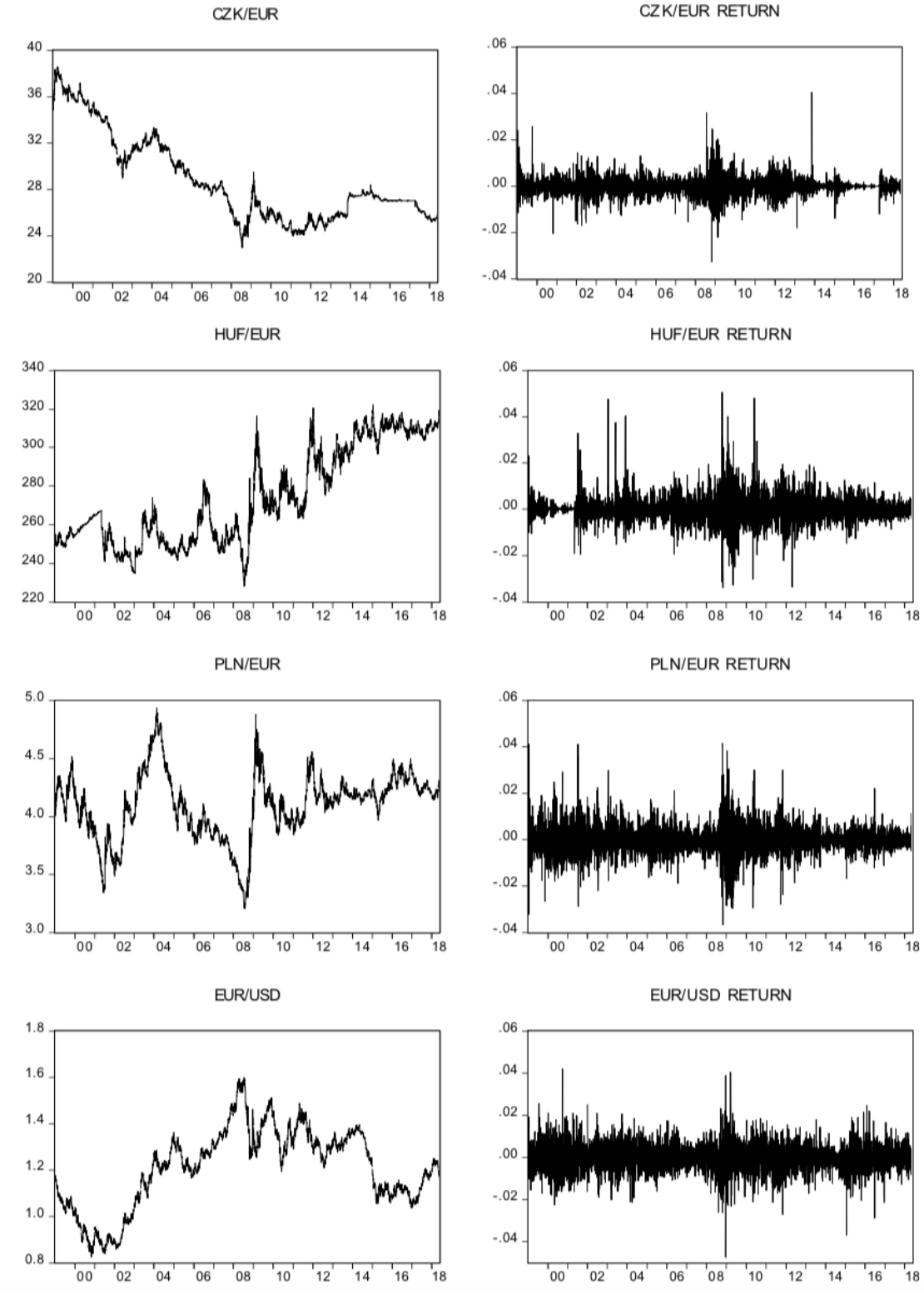
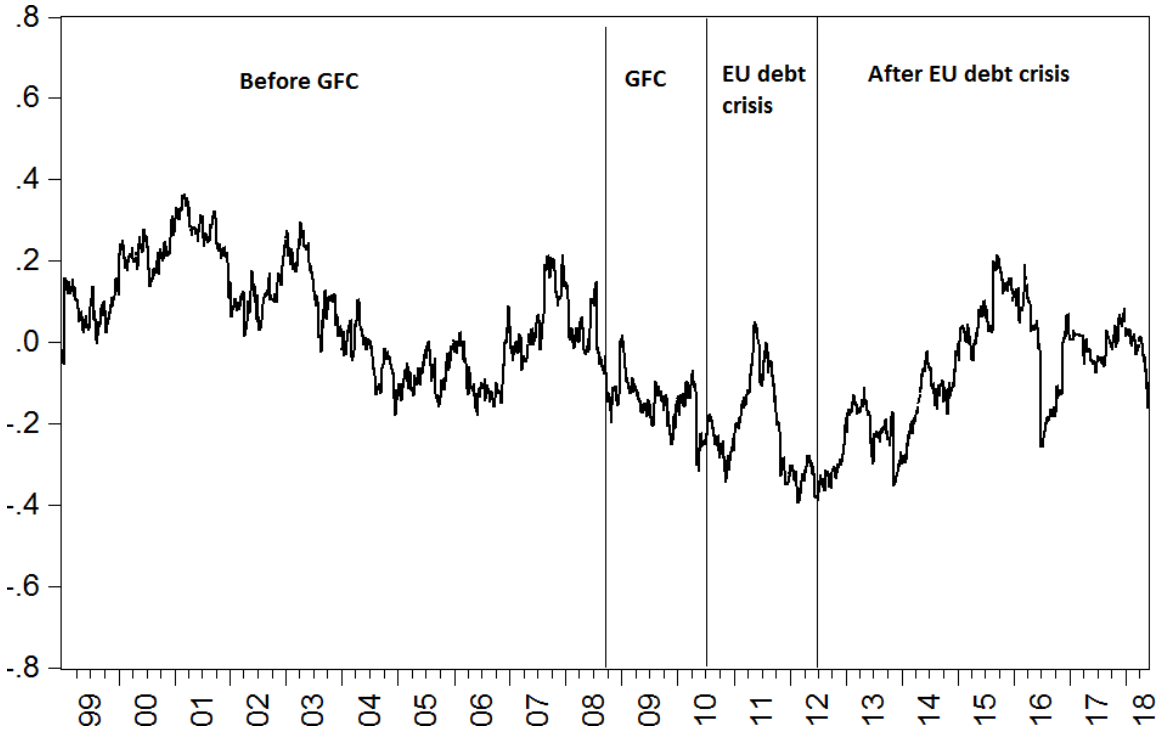
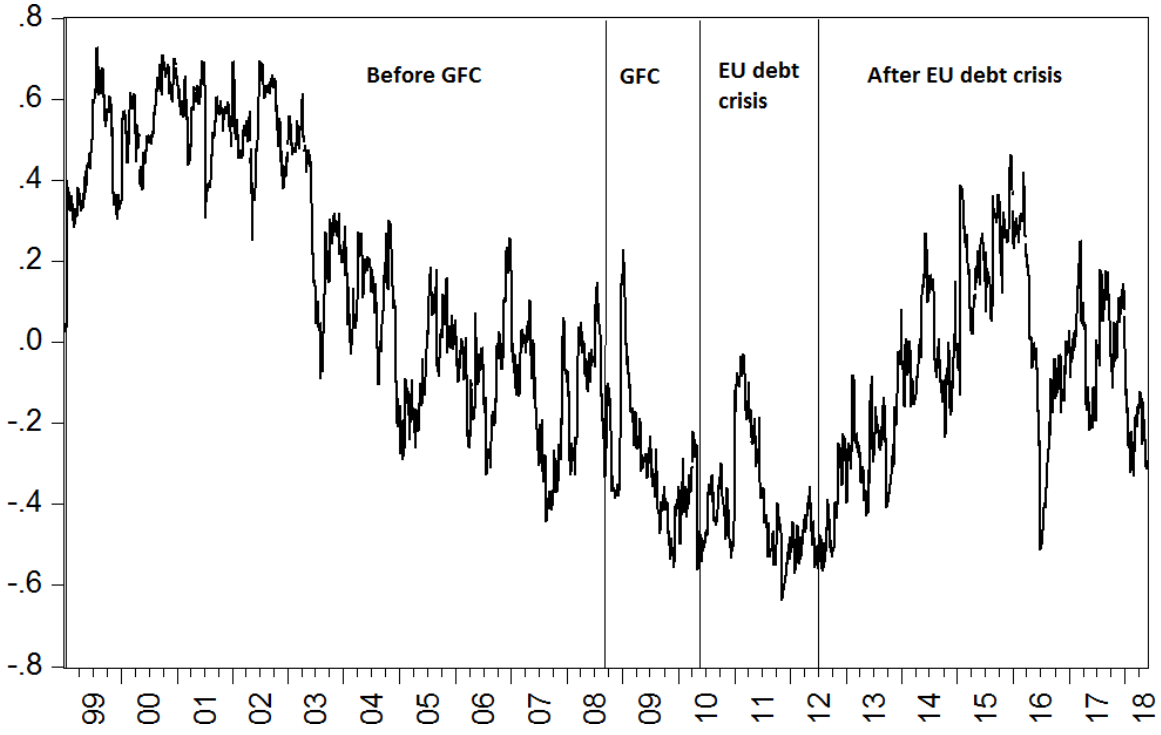


Figure 4. 2: Dynamic conditional correlations

A: CZK/EUR and USD/EUR in the period of 1999-May 2018



B: PLN/EUR and USD/EUR in the period of 1999-May 2018



C: HUF/EUR and USD/EUR in the period of 1999-May 2018

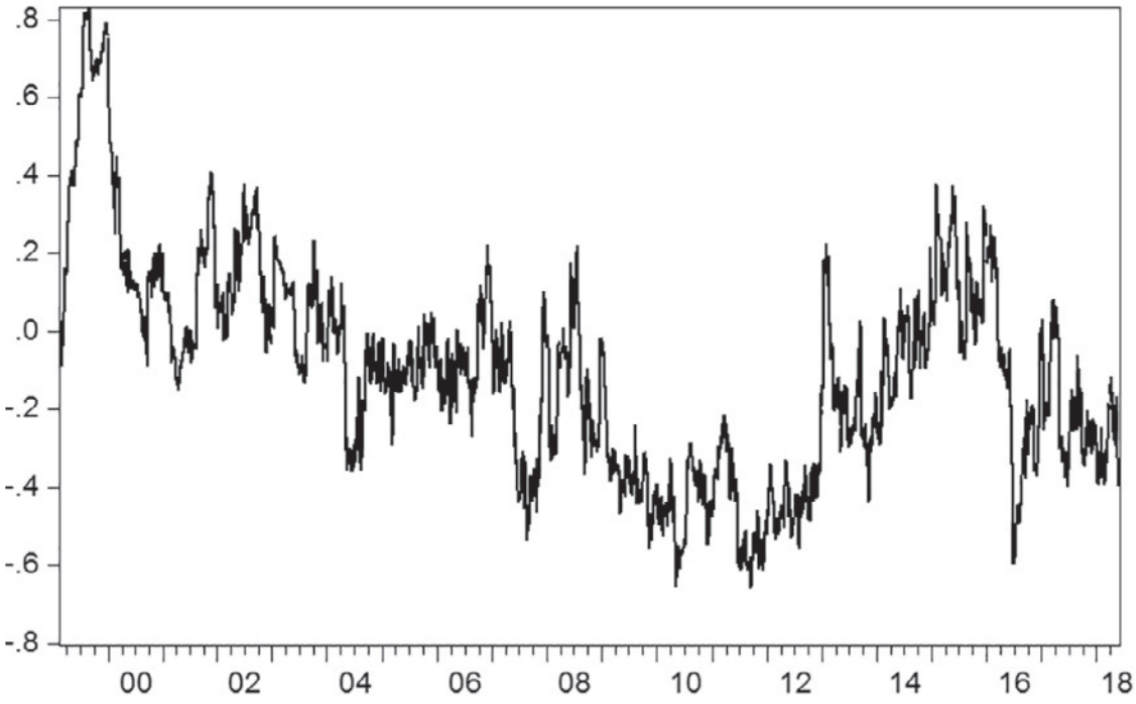


Figure 4. 3: Total volatility spillovers in the period of 1999-May 2018

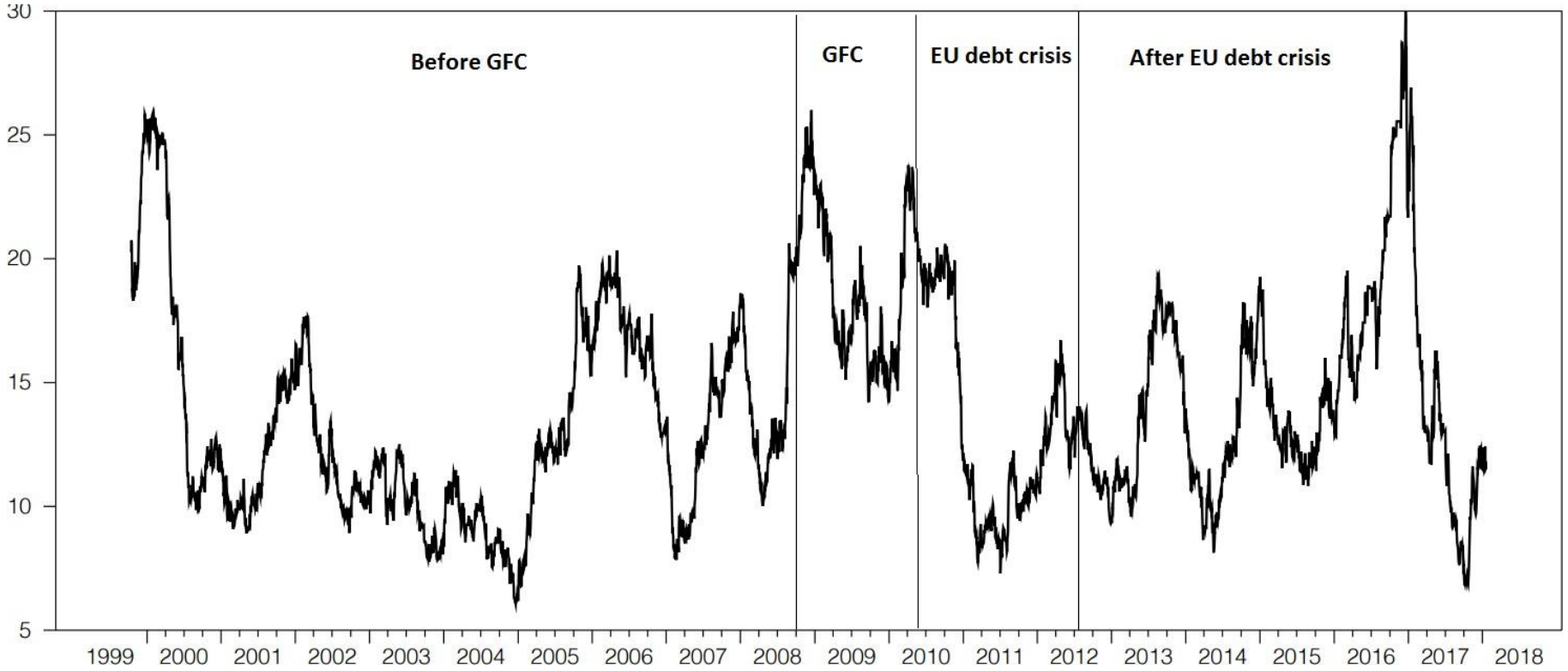
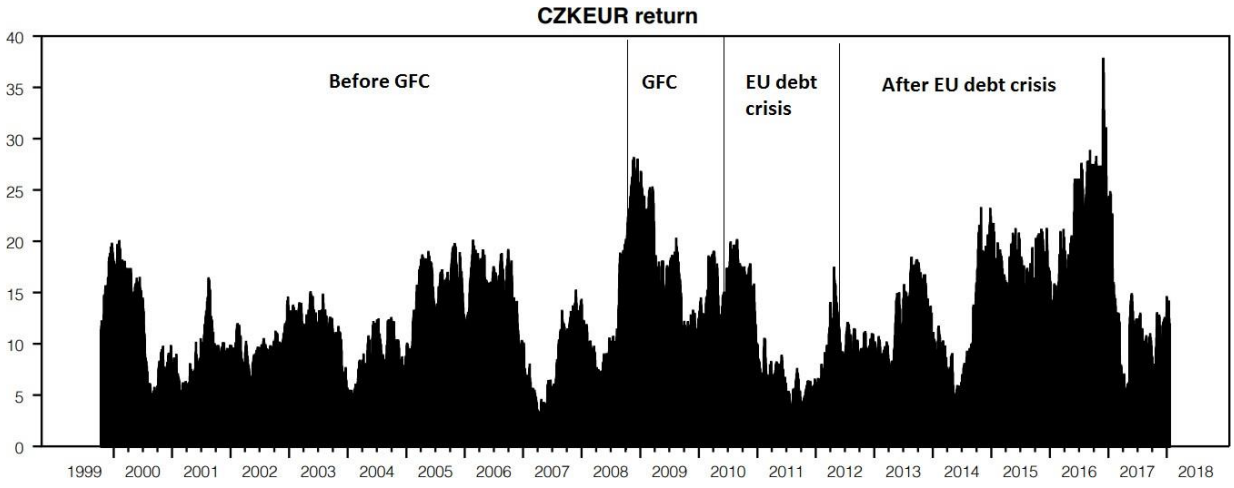
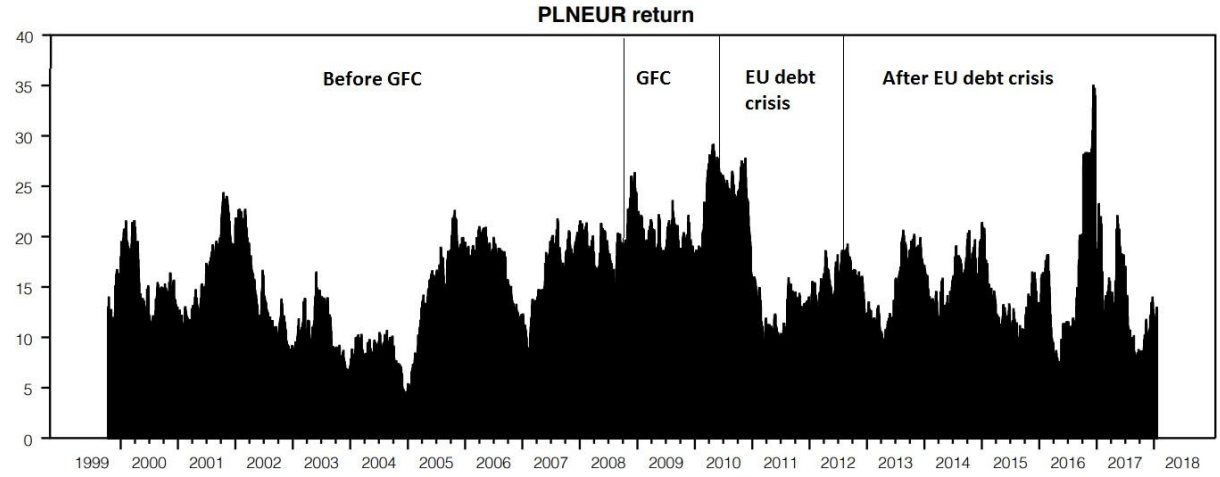


Figure 4. 4: Directional volatility spillovers FROM 4 markets; 200-day rolling windows

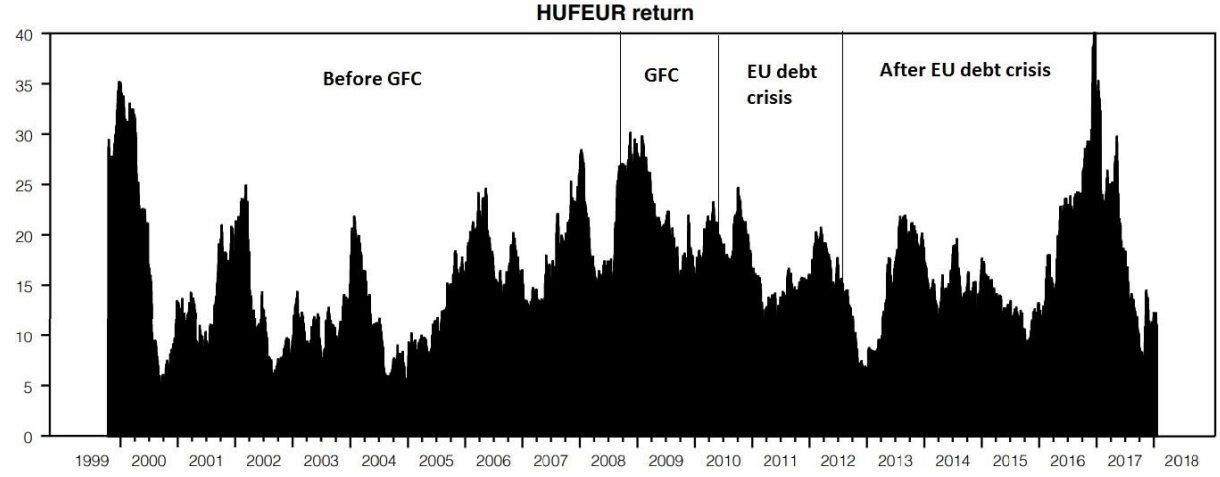
A: CZK/EUR



B: PLN/EUR



C: HUF/EUR



D: USD/EUR

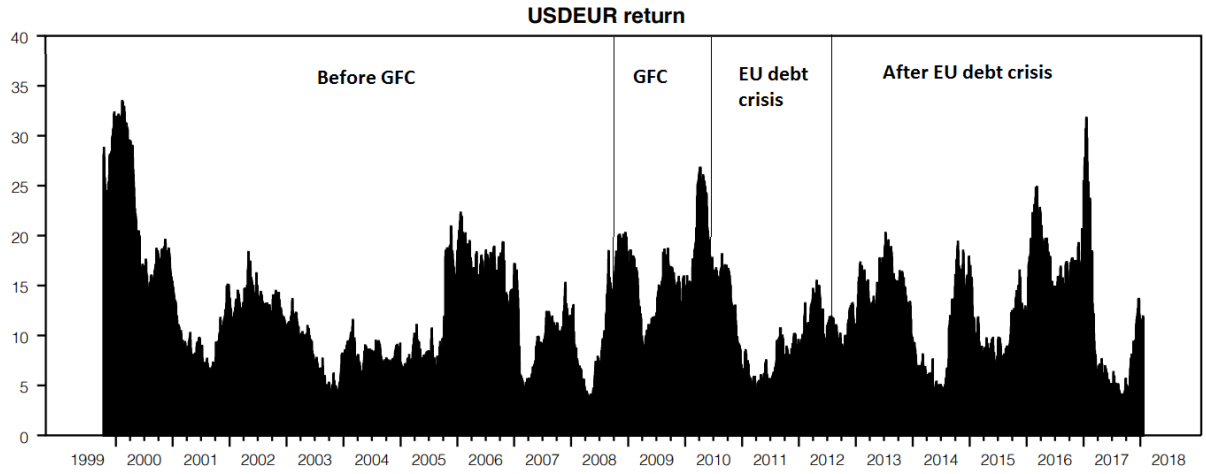
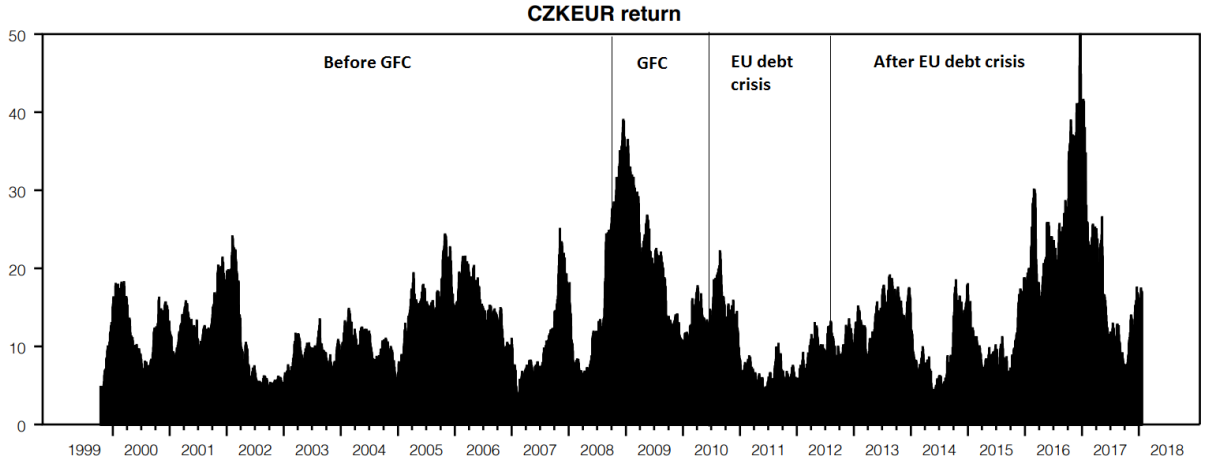
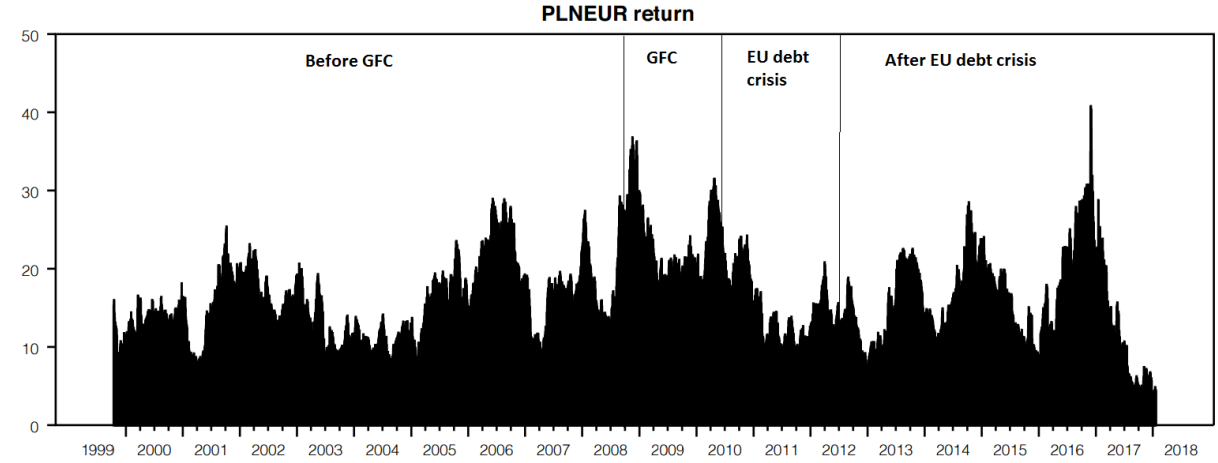


Figure 4. 5: Directional volatility spillovers TO 4 markets; 200-day rolling windows

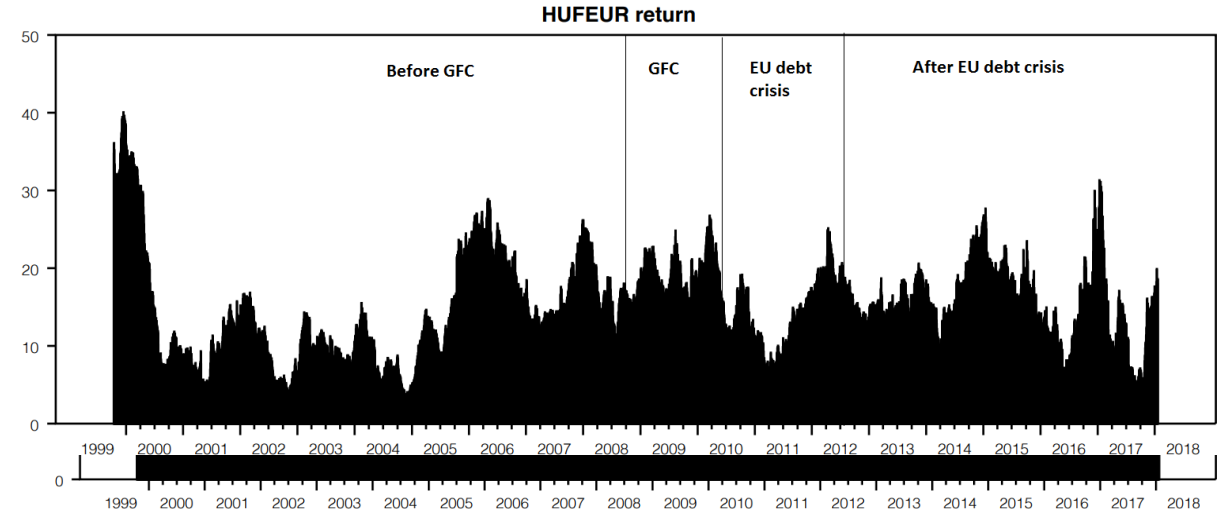
A: CZK/EUR



B: PLN/EUR



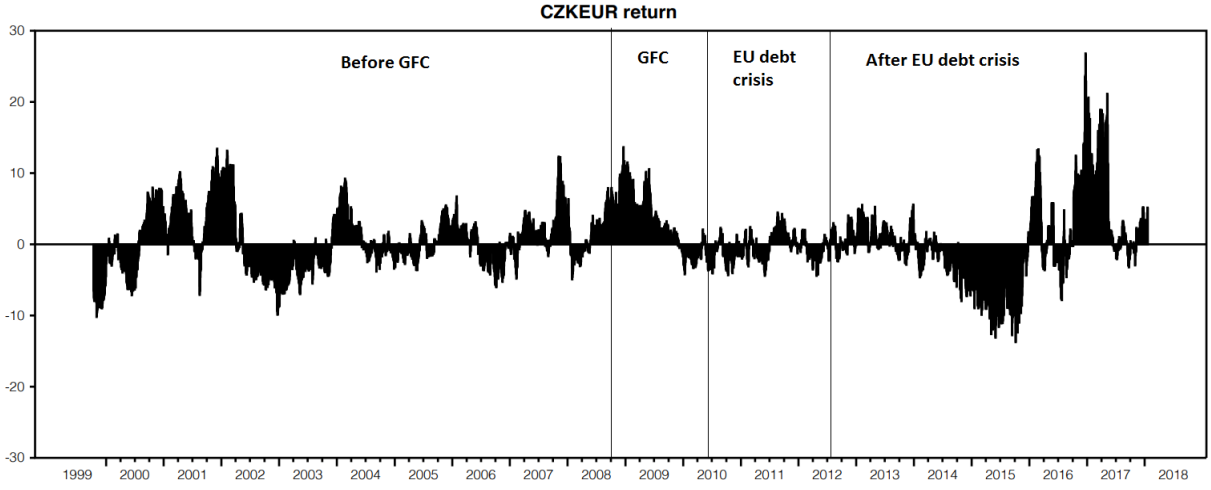
C: HUF/EUR



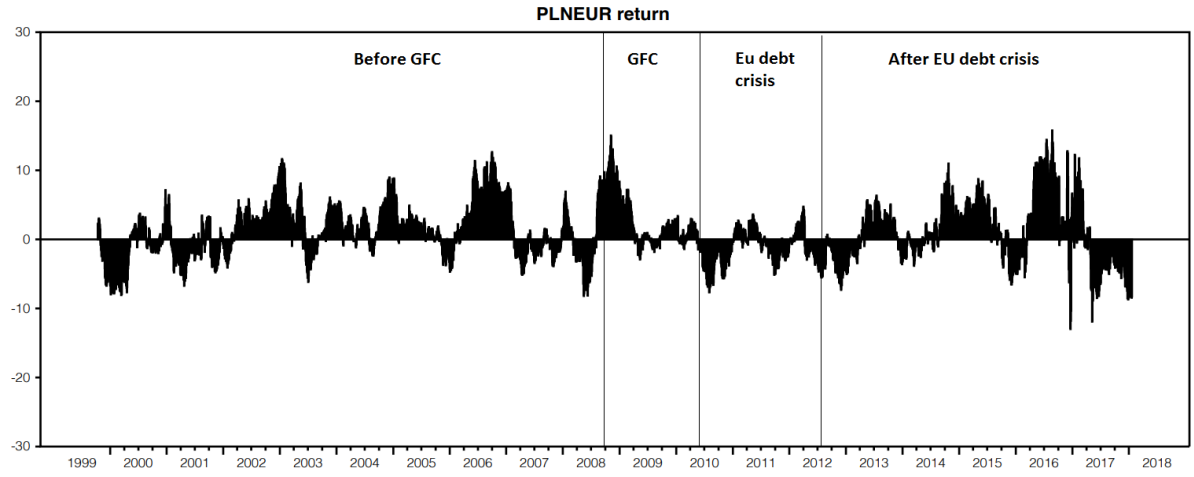
D: USD/EUR

Figure 4. 6: Net volatility spillovers; 4 markets; 200-day rolling windows

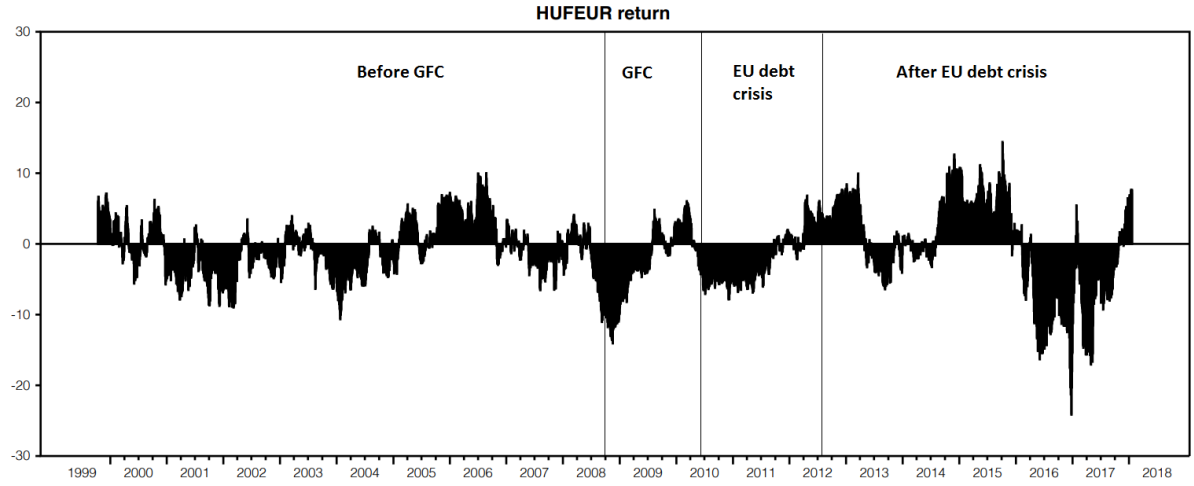
A: CZK/EUR



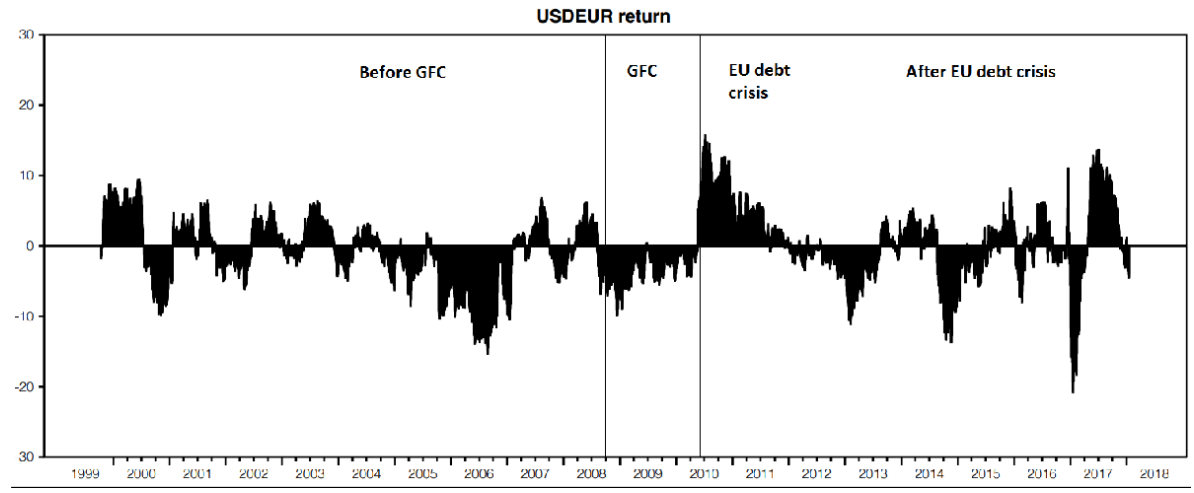
B: PLN/EUR



C: HUF/EUR



D: USD/EUR



5 Conclusion

Rising globalization trend has tendency to increase the impact of economic and political developments in large economies on small open economies. We show in the monograph that effect of globalization is presented on new EU FX markets via news announcements and central banks' monetary decisions. We demonstrate that various types of news transmit through markets quickly causing swings in the value and volatility of new EU FX markets. Specifically, we examine how macroeconomic events coming from Germany/Eurozone and US influence the value and conditional volatility of CZK/EUR, PLN/EUR, HUF/EUR during the period after the Global financial crisis (GFC). Moreover, the process of globalization has an important implication for the exchange rates' interactions. We present the link between new EU FX rates and world forex market via conditional correlations and volatility spillovers. We show that new EU FX rates are not isolated from the world forex market as long as volatility spillovers come from the rest of the world to the new EU markets and vice versa.

The essay 2 (Intraday Effect of News on Emerging European Forex Markets: An Event Study Analysis) presents detailed analysis of the impact of German/Eurozone macroeconomic news announcements and ECB monetary settings on the value of Euro-expressed FX rates (CZK/EUR, PLN/EUR, HUF/EUR) and US macroeconomic news announcements and Fed monetary policy settings on the value of US dollar-expressed FX rates (CZK/USD, PLN/USD,HUF/EUR) during the period of EU sovereign debt crisis (2011-2012) and after it (2012-2015) on intraday 1-minute data. We apply Event Study Methodology (ESM).

The results show that euro-expressed exchange rates reaction to German/Eurozone macroeconomic news announcement is smaller, occurs less often, and lasts for a shorter time comparing to reaction of US dollar-expressed exchange rates to US macroeconomic news announcements. The strongest reaction in terms of abnormal returns is related to PMI indices, Ifo index and German GDP data in terms of Euro-expressed FX rates and NFP and GDP announcements in terms of US dollar-expressed exchange rates.

We can distinguish different impact of two central banks (ECB, Fed) on three new EU FX rates (the Czech koruna, Polish zloty, Hungarian forint). The Czech koruna shows the strongest reaction to ECB loosening monetary conditions as the abnormal returns

are statistically significant immediately after the news release. The impact of US monetary policy changes on new EU currencies is less significant.

We separately assess the issue of the European sovereign debt crisis. We identify that new EU markets react quite sensitively to positive US macro news. New EU FX rates expressed in US dollar depreciate after good US macroeconomic announcements in total examined period and after the European debt crisis. However, during the crisis, the new EU FX rates appreciate after the announcement of good US macroeconomic news.

This essay offers the complex and detailed minute by minute analysis of new EU FX rates' reaction on large data set of macroeconomic news and two central banks` monetary policy changes. Results show strong and specific reactions along with temporary inefficiencies present on the new EU forex markets.

The essay 3 (The Impact of German Macroeconomic News on Emerging European Forex Markets) examines the impact of German macroeconomic news announcements and ECB meeting days on the conditional volatility of CZK/EUR, PLN/EUR, HUF/EUR after the period of Global financial crisis (2010-2015) applying the GARCH-class models.

The findings show that German macroeconomic news has the impact on the conditional variance of new EU FX rates. The Ifo index increase the conditional volatility of all three examined new EU FX rates on the day of announcement. On the other hand, results show no evidence of ECB meeting days impact on new EU FX rates volatility during the examined period.

The Czech national bank launch currency interventions during the examined period (2013-2017). We recognize that currency interventions, which prevent the koruna from excessive appreciation below CZK 27/EUR, diminish the CZK/EUR volatility and downgrade the impact of German macroeconomic data on the Czech currency conditional volatility.

Essay 4 (Exchange rate comovements, hedging and volatility spillovers on new EU forex markets) brings the evidence of conditional correlations between new EU FX rates (CZK/EUR, PLN/EUR, HUF/EUR) and world forex market represented by the USD/EUR during the 18.5-year period (1999-May 2018) using DCC model. The dataset is divided into 4 time series (i) before the Global financial crisis (1999-2008), Global financial crisis (2008-2010), the European debt crisis (2010-2012), after the European debt crisis (2012-May 2018). The correlation coefficients from the DCC model are applied for hedge ratios and portfolio weights calculations.

The findings show that conditional correlations between new EU exchange rates and the US dollar change over time. They tend to decrease prior to the GFC and the EU debt crises. They reach the lowest values during the turbulent periods (GFC, EU debt crisis, US abandoned NAFTA, Fed tightening monetary policy) and rise again in calm periods. The results confirm the importance of the new EU currencies for international investors in terms of diversification benefits by moving part of the portfolio to these currencies. However, at higher costs. Investors pay more for hedging during the GFC and the EU debt crisis than before or after the crisis.

We also examine the volatility spillovers on new EU FX markets applying Diebold Yilmaz spillover index. We show that own-currency volatilities dominate the market. However, during the turbulent periods, volatility spillovers between currencies tend to increase considerably. The Hungarian forint is dominant in the volatility transmission in each examined period. To the best of our knowledge, our analysis represents the first comprehensive assessment of interdependencies and risk spillovers on new EU forex markets.

Overall, our results demonstrate how globalized the financial markets are. We show that macroeconomic developments and monetary policy changes in developed countries like Germany and US influence the value and conditional volatility of small open economies' currencies. The effect of globalization is transmitted through FX rates to overall economic developments of individual countries. There is a direct effect on the prices of imported and exported goods and services. There is an indirect effect on economic activity and inflation as changes in the relative prices of goods and services produced domestically and overseas influence decisions about production and consumption. Together these effects also have implications for the balance of payments.

Understanding the impact of globalization on small open economies can be beneficial for forex market regulators and policy makers. Our findings can help central bankers and policy makers in their decision-making process and improve their forecasting techniques. Investors can also benefit from the results of DCC model, which shows decreasing conditional correlations between new EU FX rates and USD/EUR during turbulent periods. Therefore, new EU FX rates offer valuable diversification opportunity during distress periods in the globalized environment.

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Appendix

Table A 1: Estimation results of the DCC model
(Total examined period with dummies representing the GFC, the EU debt crisis and currency intervention period in the Czech Republic)

	Total examined period (1.1.1999-31.5.2018)		
1st step univariate GARCH model and diagnostic tests			
Mean Eq.	**CZK/EUR**	**PLN/EUR**	**HUF/EUR**
Constant	0.0000	-0.0002***	0.0001*
	(0.9998)	(0.0017)	(0.0759)
Variance Eg.			
Constant	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)
α	0.1924***	0.0899***	0.0525***
	(0.0000)	(0.0000)	(0.0000)
β	0.7888***	0.9023***	0.9344***
	(0.0000)	(0.0000)	(0.0000)
dummy1	0.0000*	0.0000*	0.0000***
	(0.0640)	(0.0854)	(0.0024)
dummy 2	0.0000	0.0000*	0.0000***
	(0.7142)	(0.0746)	(0.0000)
dummy 3	0.0000***		
	(0.0000)		
GED parameter.	1.0804***	1.3968***	
	(0.0000)	(0.0000)	
Q(30)	27.2490	23.0900	22.0110
	(0.6100)	(0.8120)	(0.8540)
$Q^2(30)$	8.5403	38.5250	2.3407
	(1.000)	(0.1370)	(1.0000)
2nd step DCC model. correlations			
ρ (corr)	-0.0224	0.0360	-0.0923
α	0.0118***	0.0269***	0.0272***
	(0.0000)	(0.0000)	(0.0000)
β	0.9856***	0.9695***	0.9707***
	(0.0000)	(0.0000)	(0.0000)
Log-Lik	67.80292	357.2143	222.5526

Notes: Q(30) and Q2(30) are Ljung-Box portmanteau test statistics for serial correlations of the univariate standardized and squared standardized residuals, respectively; *p*-values are presented in parentheses. Following Antonakakis (2012) the number of lags was set to 30 to reflect potential one-month seasonality in the data; * denotes 5% significance; ** denotes 1% significance. GARCH models with higher lags, asymmetric GARCH-type models (EGARCH, TARCH), and Student's (t) error distribution were also examined, but they were not able to deliver improved results in terms of IAC and SIC. Dummy 1 represents the GFC, dummy 2 represents the EU debt crisis and dummy 3 represents CNB interventions. GED is not applied for HUF/EUR.

Table A. 1: Structural breaks: Estimated results for the Chow test with single structural change

	Chow test								
	Break date	**F-statistics**	**Prob. F**	**Break date**	**F-statistics**	**Prob. F**	**Break date**	**F-statistics**	**Prob. F**
USD/EUR	**15.9.2008**	77.46	0.00***	**2.5. 2010**	117.36	0.00***	**26.7.2012**	311.67	0.00***
CZK/EUR	**15.9.2008**	26.57	0.00***	**2.5. 2010**	192.98	0.00***	**26.7.2012**	280.45	0.00***
PLN/EUR	**15.9.2008**	2.74	0.10*	**2.5. 2010**	292.26	0.00***	**26.7.2012**	390.37	0.00***
HUF/EUR	**15.9.2008**	457.43	0.00***	**2.5. 2010**	0.87	0.35	**26.7.2012**	146.28	0.00***

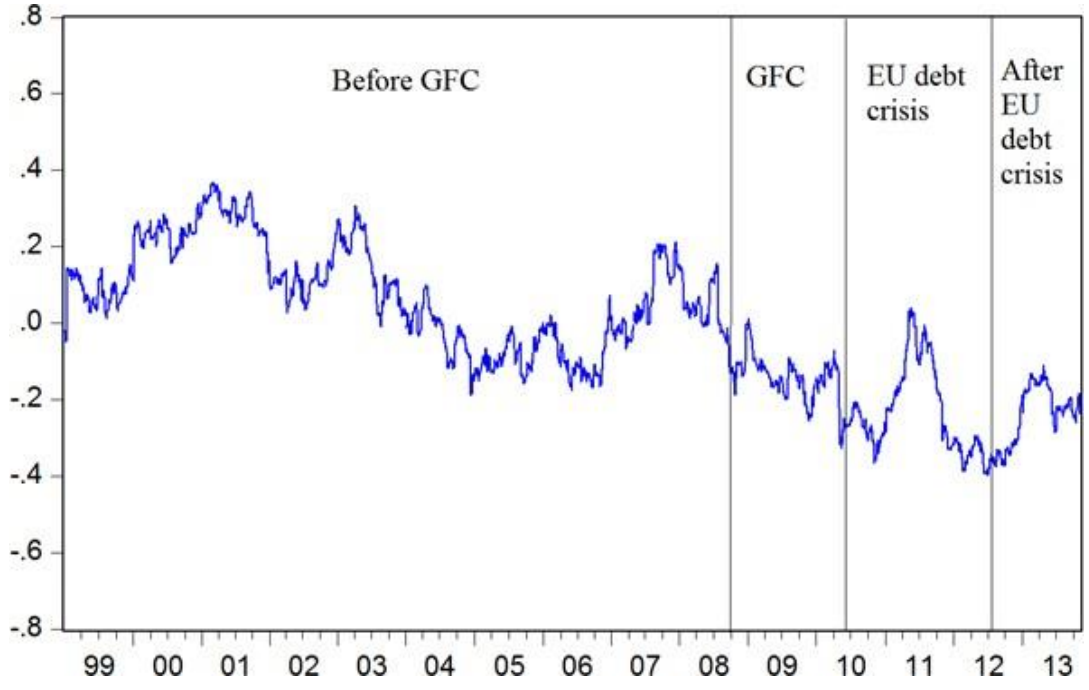
Notes: *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively.

Table A. 2: Test of changes in dynamic correlations among the new EU exchanges rates and USD/EUR during the examined time period (1.1.1999 – 31.05.2018)

	CZK/EUR - USD/EUR		**PLN/EUR - USD/EUR**		**HUF/EUR - USD/EUR**	
P_{t-1}	1.019	0.00***	1.014	0.00***	0.986	0.00***
P_{t-2}	-0.027	0.06*	-0.023	0.10*		
$DM_{1,t}$	-0.002	0.06*	-0.004	0.05**	-0.005	0.02**
$DM_{2,t}$	-0.003	0.00***	-0.006	0.00***	-0.007	0.00***
$DM_{3,t}$	-0.001	0.07*	0.002	0.08*	-0.002	0.13
Q(5)	5.570		0.920		3.810	
ARCH(5)	0.990		0.990		0.990	

Notes: $DM_{1,t}$ stands for the GFC (15.9.2008 – 30.4.2010). $DM_{2,t}$ is the dummy variable for the EU debt crisis (3.5.2010 – 26.7.2012), dummy $DM_{3,t}$ represents the period after the EU debt crisis (27.7.2012 – 31.05.2018). The lag length is chosen by AIC criterion. Serial correlation in the residuals is tested by the Ljung-Box Q-statistics up to five lags Q(5), heteroscedasticity in the residuals is tested by the ARCH LM test up to five lags ARCH(5). *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively

Figure A 1: CZK/EUR and USD/EUR in the period of 1999-2013 (without the period involving CNB currency interventions)



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