

Euro, dollar or Swiss franc: which currency had the greatest impact on the Hungarian, Polish and Czech economies during the global financial crisis?

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Abstract. The article presents an analysis of the impact of foreign currency dynamics on the fundamentals (basic indices of the economic performance) of the Czech Republic, Hungary and Poland during the financial crisis of 2007/2008 and its aftermath until 2017. The subject of the analysis are three currencies: the US dollar, the euro and the Swiss franc. The assessment of their impact on the fundamentals of the three above-mentioned economies is based on the joint volatilities of bond spreads and currencies. A series of copula-GARCH models was estimated. The research demonstrates that the impact of foreign currencies was the strongest in the case of Poland and Hungary, as these two countries were more dependent on loans in foreign currencies than the Czech Republic. Another finding shows that the impact decreased significantly in Hungary after its government introduced loan conversion.

Keywords: bond spread, copula-GARCH model, debt crisis, Central Europe

JEL: C32, C51, G01, G15

1. Introduction

The importance of exchange rates to the functioning of the whole economy is unquestionable. Exchange rates link the domestic economy of a given country with the international economy. Nominal exchange rates determine real exchange rates. The real exchange rate is an important factor influencing macroeconomic stability (see: Williamson, 2009). This article aims to analyse the impact of foreign currency dynamics on the fundamentals (most basic indices of economic performance, including GDP, inflation, interest rates, government credibility, etc.) of selected Central European economies: the Czech Republic, Hungary and Poland, during the financial crisis of 2007/2008 and its aftermath until 2017. All the countries are European Union members which retained their national currencies until the end of the studied period. All of them had floating exchange rate regimes at the beginning of the studied period. In November 2013, the Czech Republic decided to change the regime of its currency into an ‘other managed arrangements’ group (International Monetary Fund [IMF], 2014).

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The condition of the fundamentals was measured through the spreads of the bond yields to the safest economy in the region, i.e. Germany. Data was taken daily and covered the period of 2008–2014. Its source was the Thomson Reuters Datastream and the Stooq.pl portal.

It is a well-known fact that the dynamics of Central European currencies is strongly affected by the EUR-USD dynamics (see e.g. Doman, M., 2009). When analysing effective interest rates, it becomes clear that the dynamics is indeed composed mainly of euro and dollar FX rates. However, as Polish and Hungarian households have been heavily indebted in the Swiss franc (CHF), we assumed that this currency could also have affected these economies. Therefore, the impact of the three currencies (USD, EUR and CHF) on the fundamentals of the three V-4 economies,¹ which retained their own currencies during the studied period, was taken into account in this study. Its aim is then to check whether the impact of the Swiss franc might have been stronger than or at least as strong as the impact of the euro and the US dollar, despite having been a marginal part of the effective rates.

The following research hypotheses were formulated:

- The influence of the euro and the US dollar should be greater than the influence of the Swiss franc, since the effective exchange rates are composed mainly of euros and dollars;
- The impact of the Swiss franc on the fundamentals of the Polish and Hungarian economies should be greater than on the Czech economy;
- The replacement of a free-floating exchange rate regime in the Czech Republic with a managed-floating regime should permanently weaken the relationship between bond spreads and foreign exchange rates;
- The reforms implemented in Hungary, especially the obligatory conversion of loans from the foreign-currency-denominated to the forint-denominated, were likely to contribute to the weakening of the relationship between the Hungarian fundamentals and the exchange rates.

The article has the following structure: the first part presents the dynamics of the sovereign spreads of Polish, Hungarian and Czech bonds to those of German bonds, and the dynamics of the respective exchange rates. It also shows descriptive statistics and the changes of the variables in the context of the economic situation of the countries. The second part contains a description of the model used to demonstrate the influence of the exchange rates on the fundamentals of the economies under study. The last section is devoted to a discussion on the findings in relation to the domestic policies of the countries.

¹ V4 denotes Visegrad economies: the Czech Republic, Hungary, Poland, Slovakia.

2. Literature review

The issue of dependence between exchange rates has been extensively described in the literature. Rebitzky (2010) analysed articles on this subject written from 1990, so over 30 years, and according to his findings, most researchers agree that momentous news has a significant influence on exchange rates. Yet, some other researchers show that there are exceptions – Engel & West (2005), for example, demonstrate that fundamentals (such as relative money supplies, outputs, inflation and interest rates) do not necessarily improve floating exchange rate forecasts, while the opposite relationships hold. Nevertheless, researchers agree that relationships between exchange rates and fundamentals indeed exist and are statistically significant. Indicators describing the fundamentals are published monthly or even less frequently, which makes it problematic to include them in the model together with the daily quoted exchange rates without any loss of information on the latter.

For this reason, researchers approximate the condition of fundamentals with either sovereign credit default swaps (sCDS) series or bond spreads, i.e. the difference between the yield of domestic government bonds to the yield of the bond considered the safest in the region. In this paper, the condition of fundamentals has been assessed through the dynamics of the spreads of 10-years' sovereign bonds yields compared to the yields of 10-years' German bonds. Numerous researchers indicate that sovereign bonds are significantly more sensitive to the domestic condition of the economy than the alternative measure of sovereign risk – the spreads of sCDS. For instance, Matei & Cheptea (2012), who analysed spreads of European bonds against the German ones, demonstrated that large fiscal deficits and public debt, as well as political risks and, to a lesser extent, liquidity, are likely to put substantial upward pressures on sovereign bond yields in many advanced European economies. Kocsis (2014) proved that in the case of sCDS, global and regional factors can be clearly derived, yet no such factors exist in the case of domestic bond markets. In his opinion, bond spreads reflect different monetary policies or an overall domestic policy, which differs across countries. The idiosyncratic factor can explain even up to 80% of the variance of bond yields (e.g. in Hungary, where in the case of sCDS this figure is only 33%). Claeys & Vašíček (2014) indicated that the movements of bond spreads anticipate changes in ratings prepared by credit rating agencies.

Considering the above, the condition of fundamentals was measured through the spreads of the bond yields against the safest economy in the region, i.e. Germany.

Our aim was to assess how the exchange rate market affected the fundamentals of the selected Central and East Europe (CEE) economies over the years 2008–2017, during which very important international events occurred. First of all, the

beginning of the period saw the outbreak of an international financial crisis which spread across Europe. Simultaneously, following an international growth risk, speculators attacked Central European currencies (2008/2009). Kliber & Kliber (2010) showed that in 2008, when the speculative attacks took place, the CEE currencies were strongly affected by the common fluctuations of the EUR-PLN and the EUR-HUF exchange rates. In 2009, investors who up to that point had used to paint the CEE currencies with a broad brush, seemed to have started noticing the differences among them (see for instance: Kliber, 2009). During the crisis, the internal situation of Hungary was declining, while the economies of Poland and the Czech Republic got affected by the crisis only to a limited extent (see e.g. Kliber & Płuciennik, 2015, 2017; Komárková et al., 2013). However, both Polish and Hungarian households were massively indebted in Swiss franc, as prior to the crisis a lot of people had taken mortgage loans in this currency. This phenomenon did not occur on such a large scale in the Czech Republic, though.²

3. The data

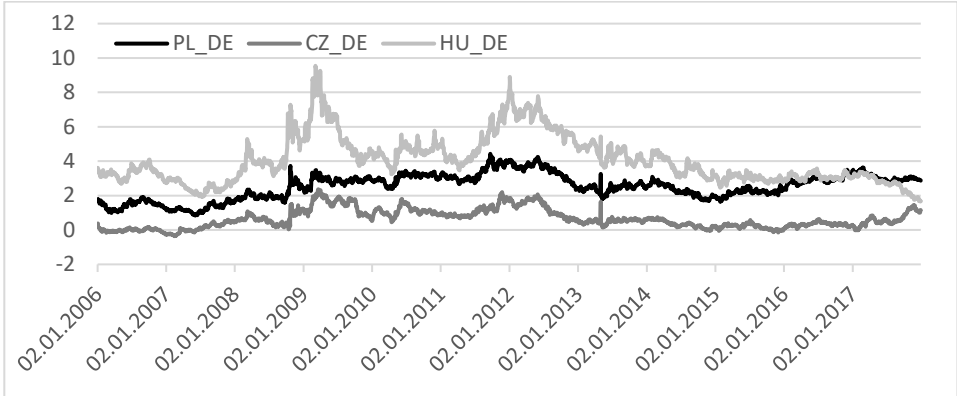
Figure 1 presents the dynamics of the CEE yields against the German yields. All the bonds were of a 10-years' maturity. Spreads are interpreted as measures of risk of a given country against the safest one in the region. The highest value of the spread was observed in Hungary. In fact, it was this country that was affected by the crisis to the largest extent of all the three analysed countries. The value of the Polish spread was lower than the Hungarian one, but higher than the Czech one. The dynamics of the Polish and Czech spreads were similar, and different from the dynamics of the Hungarian spread.

Two peaks were observed in the Hungarian data: the first one occurred in March 2009, and the second in January 2012. The first peak can be attributed to foreign currency attacks on the forint and to the new legislation introduced in Hungary which limited the role and independence of the central bank. The Hungarian currency depreciated then by 26% against the euro (see e.g. Valentinyi, 2012). By November 2011, the forint had depreciated by 56% against the Swiss franc. The country faced serious problems with foreign currency loans. As a consequence, in September 2011 the Hungarian government passed legislation that unilaterally changed the terms and conditions of all foreign currency loan contracts. The cost of

² According to Brown et al. (2009), in 2007 59% of total bank lending to households was in CHF, while the corresponding ratio for non-financial enterprises amounted to 16%. In Poland, 90% of CHF lending was taken out by households and was secured by mortgages. Loans to non-banking clients in Hungary in 2007 amounted to CHF 36.2 bn, while in Poland to CHF 30.9 bn. The amount of claims by Polish banks was thus almost as high as in Hungary, but while the share of CHF claims among the total foreign currency claims was higher in Poland (69%), their share of the total loans was lower (17%).

the transaction had to be borne entirely by banks. In mid-December 2011 the government and banks agreed to share the costs of any further arrangements. Figure 1 shows a constant and steep growth of the Hungarian spread up to the beginning of January 2011. Afterwards, the spread started to decrease.

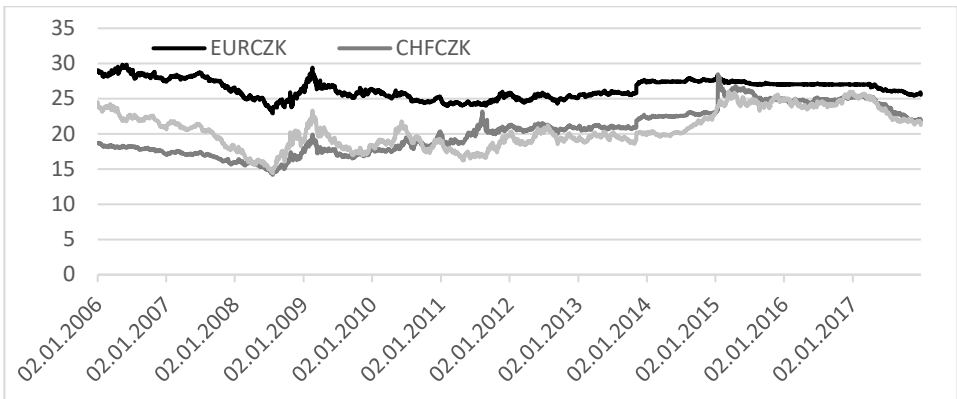
Figure 1. Dynamics of the spreads of Polish, Hungarian and Czech bond yields against the yields of German bonds



Note. PL_DE illustrates the difference between the Polish and German yields, HU_DE between the Hungarian and German yields, and CZK_DE between the Czech and German yields. Source: authors' calculations.

The two peaks were not distinctly marked in the dynamics of the spreads of the Polish and Czech bonds. The peaks in the corresponding periods are observable, but not very high. The most spectacular increases were observed in November 2008 during the speculative attacks on local currencies.

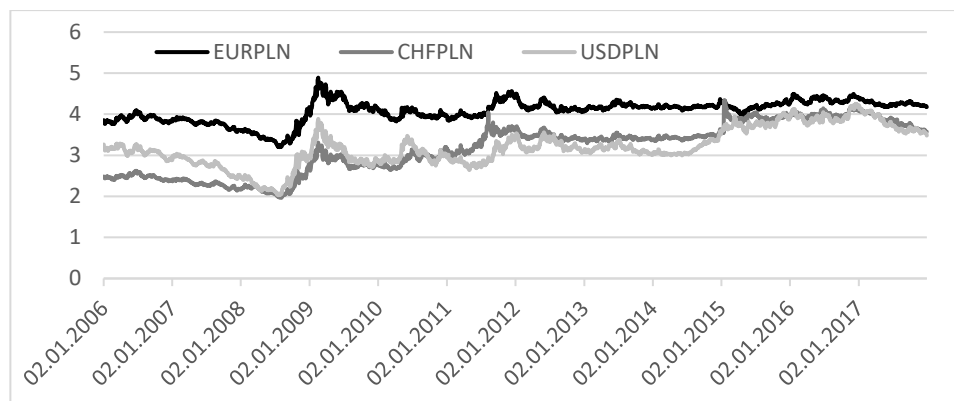
Figure 2. Dynamics of the exchange rate of the Czech koruna to Swiss franc, US dollar and the euro



Source: authors' calculations.

In Figures 3 to 5 the dynamics of the three currencies are presented: the Czech koruna, Hungarian forint and the Polish zloty, each expressed in three foreign currencies: the Swiss franc, the euro and the US dollar. At the beginning of the period, all the three countries had floating exchange rates, and additionally, Poland and the Czech Republic had free-floating rates. In November 2013, the Czech Republic decided to switch to ‘other managed arrangement’ (IMF, 2014). This IMF category includes currencies which are allowed to float independently but with discretionary management, as well as other practices which may apply to one currency only. The change took place on 7th November 2013 and was justified by problems with inflation targeting and expected continuous overshooting (IMF, 2014). The Czech National Bank announced that it would intervene in the foreign exchange market to weaken the koruna so that the exchange rate against the euro remained close to CZK 27 (but it would not intervene to strengthen the currency towards this level). This change is clearly visible in the dynamics of the Czech koruna as shown in Figure 2.

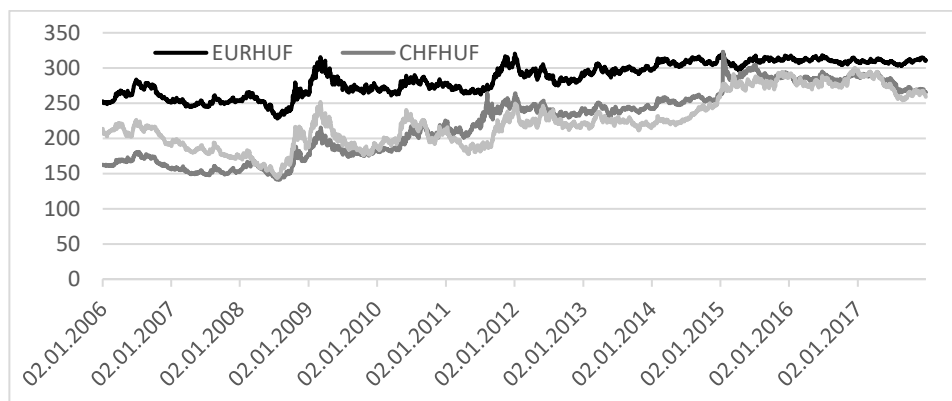
Figure 3. Dynamics of the exchange rate of the Polish zloty against the Swiss franc, US dollar and euro



Source: authors' calculations.

Figure 3 presents the dynamics of the exchange rates of the Polish zloty expressed in Swiss francs, US dollars and euros. A period of appreciation was observed until July 2008, followed by a sharp depreciation that continued until February 2009. Over the period 2010–2017, the price of the euro fluctuated around PLN 4.2, with the exception of late 2011–early 2012, when it grew to approximately 4.5 PLN. The joint dynamics of the CHF-PLN and the USD-PLN exchange rates is very interesting. Although at the beginning of 2006 the price of the Swiss franc was much lower than that of the US dollar, already in July 2008 the prices of both currencies almost equalled, and from then on, until the end of 2017, they ‘intertwined’, e.g. from January 2011 to January 2012 the US dollar was cheaper than the Swiss franc.

Figure 4. Dynamics of the exchange rate of the Hungarian forint to the Swiss franc, US dollar and the euro



Source: authors' calculations.

Figure 4 presents the dynamics of the prices of different currencies (Swiss francs, euros and US dollars) expressed in Hungarian forints, which was constantly depreciating over the analysed period. The end of February and beginning of March 2009 saw a sharp peak of the exchange rates of all the three analysed CEE currencies. This situation can be attributed to the deteriorating situation in Hungary and to the signing of the Supplemental Memorandum of Understanding between the European Union and Hungary on 11th March 2009.³ Since all the three currencies and the bond spreads reacted at the same time, it may be presumed that investors might have expected the Hungarian problems to spread across CEE.

Table 1 contains descriptive statistics of the changes of the spreads and exchange rate series (the changes were modelled, as the levels of the spreads are non-stationary). The stationarity of the change series is confirmed by the KPSS test (Kwiatkowski et al., 1992) and the HML test (Harris et al., 2006). The exchange rates of the forint proved the most volatile in terms of standard deviation. The exchange rates of the Polish zloty and the Czech koruna demonstrate similar, yet significantly smaller standard deviations (than those of the forint). Additionally, the Hungarian bond spread was more volatile than the Czech and Polish ones, but the difference between their standard deviations was not as great as in the case of exchange rates. The ARCH effect applies to all the studied cases. All considered series are leptokurtic, but the different values of kurtosis of the considered time series is also worth

³ The Memorandum of Understanding between the European Union and Hungary was signed in November 2008. In December 2008, Hungary received a disbursement of EUR 2 bn, while the second instalment was planned for March 2009. In February 2009, in the light of a deteriorating growth outlook for 2009, the Commission services together with the IMF staff revised the deficit target for 2009. This revision, together with a number of additional policy conditions, was laid down in the first Supplemental Memorandum of Understanding in March 2009.

noticing, for instance: 5.41 for changes of the USD-HUF exchange rate and 29.5 for the changes of the Polish bond spread.

Table 1. Descriptive statistics of the changes of bond spreads and foreign exchange rates

Variable	Obs No.	Mean	Std. Dev.	Skewness	Kurtosis	Min.	Max.
dCZ	3109	0.000251	0.065114	0.504075	85.593820	-1.2140	1.21600
dHU	3109	-0.000629	0.131711	-0.079470	15.631520	-1.2980	1.21600
dPL	3109	0.000350	0.072206	0.342191	60.561380	-1.2410	1.21600
dEUdCZK	3109	-0.001099	0.112960	0.065964	12.906930	-0.8740	1.17200
dCHF CZK	3109	0.001024	0.152034	11.880500	428.107900	-1.7340	5.14100
dUSDCZK	3109	-0.001034	0.160680	0.047913	4.241496	-1.2590	1.01100
dEUdHUF	3109	0.018729	1.723809	0.275266	4.353579	-11.8700	12.44000
dCHF HUF	3109	0.033204	2.073979	6.406754	189.420000	-20.3100	57.09000
dUSDHUF	3109	0.014577	2.102789	0.139020	3.059948	-11.2300	13.04100
dEUdPLN	3109	0.000102	0.024049	0.164908	6.841460	-0.1644	0.20150
dCHFPLN	3109	0.000340	0.028253	6.230465	183.971200	-0.2906	0.77090
dUSDPLN	3109	6.904E-05	0.029696	0.166432	4.370532	-0.1974	0.21304

Note. dCZ – changes in the Czech bonds spread, dPL – changes in the Polish bond spread, and dHU – changes in the Hungarian bonds spread.

Source: authors' calculations.

The dynamics of exchange rates reflect not only the domestic monetary policy, but also the monetary policy of the countries whose currencies are being referenced. Thus, in all the three charts a peak of exchange rates expressed in the Swiss franc can be observed in September 2011. Following the peak, the exchange rates relatively stabilised and their volatility decreased. This situation might have resulted from the Swiss National Bank's (SNB) decision announced on 6 September 2011, to no longer tolerate the EUR-CHF exchange rates below a minimum of CHF 1.20. The institution committed itself to enforcing this minimum rate and was prepared to buy foreign currencies in unlimited quantities. In addition, the SNB emphasised that, even the rate of CHF 1.20 per euro meant that the Swiss franc was too strong and was expected to continue to weaken over time (see: Chronicle of monetary events 1948-2016 on the official webpage of SNB and IMF, 2011). As a consequence, the previously free-floating exchange rate regime was reclassified to 'other managed arrangement' (IMF, 2012). From January 2012 to January 2013 the Swiss franc remained within a narrow 2% margin of the announced minimum exchange rate. Therefore, starting from January 2012, the de facto exchange rate arrangement was retrospectively reclassified from 'other managed arrangement' to 'stabilised arrangement'. For the sub-period of January – May 2013 it was again re-classified to 'managed arrangement' due to the departure of the currency from the stabilised band against the euro. However, starting from May 2013 the Swiss franc followed an appreciating trend within a 2% band against the euro. Therefore, the de facto

exchange rate was reclassified to a 'crawl-like arrangement' from 'other managed arrangement' (IMF, 2013).

When considering the dynamics of the USD exchange rate, a peak which was not observed in the dynamics of the other exchange rates could be noticed in June 2010. This peak was most likely to have resulted from the EUR-USD exchange rate. On 8th June 2010, the price of the euro in the US dollars reached its minimum (1.1942). Interestingly, the EUR-CZK, EUR-HUF and EUR-PLN exchange rates did not react strongly to this. In conclusion, the EUR-USD dynamics affects the dynamics of the domestic CEE currencies against the US dollar stronger than against the euro.

4. The model

The goal of this study was to model interdependencies among bond spreads and exchange rates within a given country. Therefore, prior to selecting the appropriate model, the data was pre-tested against various hypotheses. One of them referred to constant or time-varying correlations. In the case of all series, the test of Engle & Sheppard (2001) and Tse (2000) strongly rejected the hypothesis of a constant conditional correlation. Therefore, only models with time-varying conditional correlation were taken into account.

The initial idea was to model the data using a DCC model (e.g. the one of Engle & Sheppard, 2001 or Tse & Tsui, 2002). One of the pre-requisites for this model is that all univariate conditional error distributions should be the same. However, even a short analysis of the descriptive statistics (Table 1) suggests that the empirical distributions of the modelled data vary across samples, as, for instance, in the case of kurtosis (from 5.41 for the variable dUSD-HUF, to 29.5 when considering the Polish bond spread). In consequence, when fitting univariate GARCH models with GED distributions to the data, different values of the degrees of freedom were recorded, depending on the analysed variable, which supports the thesis that conditional distributions also vary across samples. In such cases it is recommendable to apply the conditional copula model instead of using a DCC model. In dynamic copula models the structure of the dependence and dynamics of each univariate series is modelled separately. It allowed the application of GARCH-type models with GED innovations to model conditional variance of each univariate data, and then the *t*-copula to model the structure of dependence.

Copula models allow the use of measures of dependence other than the Pearson coefficient. When the time series distribution is not normal, using Pearson's correlation coefficient to identify the dependencies between random variables may yield misleading conclusions (Lindskog, 2000), since this coefficient is very sensitive to outliers. Moreover, a correlation equal to zero implies independence only if the

variables are normally distributed. The heavier the tails, the larger the error of the estimator. Since the applied data are strongly leptokurtic (see Table 1), the option to use Pearson’s correlation was rejected and the focus shifted onto the Kendall τ .

Another advantage of using copula is the possibility to investigate the dependencies between extreme values using tail-dependence measures. Assuming that the links between exchange rates and bond spreads tend to grow in response to internal or external shocks the studied economies experience, this approach seems to be the most relevant.

To sum up, in order to assess the strength of the aforementioned links among the analysed countries, the conditional copula model was applied. This model offers no restrictions on marginal distributions, and it allows for determining measures of dependencies other than the correlation coefficient does.

We further present a dynamic estimation of the rank correlation coefficient, the Kendall τ , as well as the tail dependence coefficient (λ). The latter measure is of particular importance to the analysis. It provides information on the probability of the transmission of extreme events from the risk countries to other countries. Schmidt (2002) explains that asymptotic dependencies should not be identified with a linear correlation coefficient. It is a well-known fact that in some cases the correlation between the considered series is strong, yet no dependence exists in the tails. It should be noted that a bivariate normal distribution is asymptotically tail-independent if its correlation coefficient ρ is less than 1.

Conditional copulas were introduced by Patton (2002, 2006). The author derived the properties of conditional joint distributions and the conditional copula from the properties of unconditional distributions and the copula. Conditional copulas have been applied and developed by numerous scientists, including Cifter & Ozun (2007), Doman, R. (2009, 2010), Hafner & Manner (2012), and Jondeau & Rockinger (2002, 2006).

Let the multivariate time series be denoted by $x_t = x_{1,t}, \dots, x_{d,t}$. The general copula model can be described by the following formulas:

$$\begin{aligned}
 &x_{i,t}|\Omega_{t-1} \sim F_{i,t}(\cdot | \Omega_{t-1}) \text{ for } i = 1, \dots, d, \\
 &x_t|\Omega_{t-1} \sim F_t(\cdot | \Omega_{t-1}), \\
 &F_t(x_t|\Omega_{t-1}) = C_t(F_{1,t}(x_{1,t}|\Omega_{t-1}), \dots, F_{d,t}(x_{d,t}|\Omega_{t-1})|\Omega_{t-1}),
 \end{aligned}$$

where Ω_{t-1} is the information set up to the moment $t - 1$ inclusively. The existence and uniqueness of the C_t copula is guaranteed by the Sklar theorem for conditional copulas, introduced by Patton (2002). Let us consider the following model:

$$F_t(x_t, \alpha_1, \dots, \alpha_d, \theta|\Omega_{t-1}) = C_t(F_{1,t}(x_{1,t}|\Omega_{t-1}, \alpha_1), \dots, F_{d,t}(x_{d,t}|\Omega_{t-1}, \alpha_d)|\Omega_{t-1}, \theta),$$

where α_i is the parameter vector of the marginal conditional distribution $F_{i,t}$, and θ is the parameter vector of the conditional copula C_t . This model is estimated through the maximisation of the likelihood function in the following form:

$$L(\alpha_1, \dots, \alpha_d, \theta) = \sum_{t=1}^T \ln c_t(x_{1,t} | \Omega_{t-1}, \alpha_1), \dots, F_{d,t}(x_{d,t} | \Omega_{t-1}, \alpha_d) | \Omega_{t-1}, \theta) + \\ + \sum_{t=1}^T \sum_{j=1}^d \ln f_{j,t}(x_{j,t} | \Omega_{t-1}, \alpha_j),$$

where $f_{j,t}$ denotes the conditional marginal density function and c_t – the density function of the copula C_t .

The research herein is based on the DCC- t -copula model. The model was applied in two steps using the maximum likelihood method. In the first step, each univariate series $x_{i,t}$ is fitted; and the $u_t = u_{1,t}, \dots, u_{d,t}$ is the multivariate time series, with each $u_{i,t}$ having been determined as the value of the cumulative distribution function for $\varepsilon_{i,t}$, to one of the univariate GARCH-type models with the t Student or GED innovation distribution.

$$\begin{aligned} x_{i,t} &= \mu_{i,t} + y_{i,t}, \\ y_{i,t} &= \sigma_{i,t} \varepsilon_{i,t}, \\ \varepsilon_{i,t} &\sim \text{iid}(0,1), \\ u_{i,t} &= F_i(\varepsilon_{i,t}), \end{aligned} \tag{1}$$

where $\varepsilon_{i,t}$ stands for the standardised residual series and F_i is the cumulative distribution function of the innovation distribution from the model fitted to $x_{i,t}$. The conditional mean $\mu_{i,t}$ was modelled as an ARMA-type model of the following form:

$$x_{i,t} = a_0 + \sum_{i=1}^p a_i x_{t-i} + \sum_{j=1}^q b_j y_{t-j}.$$

The authors apply standard GARCH models (Bollerslev, 1986), GJR-GARCH (Glosten et al., 1993), the IGARCH (Engle & Bollerslev, 1986) with t Student or GED innovation distribution with κ degrees of freedom to describe the dynamics of $\sigma_{i,t}^2$. In specific models, the conditional variance equations show the following specifications:

- GARCH(p,q) – $\sigma_t^2 = \omega + \sum_{i=1}^p \alpha_i y_{t-i}^2 + \sum_{j=1}^q \beta_j \sigma_{t-j}^2$, where y_t is the residual series;

- GJR-GARCH(p, q) - $\sigma_t^2 = \omega + \sum_{i=1}^p \alpha_i y_{t-i}^2 + \gamma_i S_{t-i}^- y_{t-i}^2 + \sum_{j=1}^q \beta_j \sigma_{t-j}^2$, where S_t^- is a dummy variable that takes the value of 1 when γ_i is negative and 0 when it is positive;
- IGARCH(1,1) - $\sigma_t^2 = \alpha y_{t-1}^2 + \beta \sigma_{t-1}^2$, where $\alpha + \beta = 1$.

In the second step, the conditional t copula is fitted to the u_t series, where the rank correlation matrix R_t is driven by the DCC model of Engle (2002).

$$C_{v,R_t}^t(u_t) = \int_{-\infty}^{t_v^{-1}(u_{1,t})} \dots \int_{-\infty}^{t_v^{-1}(u_{d,t})} \frac{\Gamma\left(\frac{v+d}{2}\right)}{\Gamma\left(\frac{v}{2}\right)\sqrt{(\pi v)^d |R_t|}} \left(1 + \frac{x'R_t^{-1}x}{v}\right)^{-\frac{v+d}{2}} d^d x, \quad (2)$$

where $u_t = (u_{1,t}, \dots, u_{d,t})'$, $x = (x_1, \dots, x_d)'$, $\Gamma(\cdot)$ is the gamma function,

$$R_t = \text{diag}(Q_t)^{-1/2} Q_t \text{diag}(Q_t)^{-1/2},$$

where the positive-definite matrix Q_t is described by the following formula:

$$Q_t = (1 - \sum_{m=1}^M \alpha_m - \sum_{n=1}^N \beta_n) \bar{Q} + \sum_{m=1}^M \alpha_m \tilde{u}_{t-m} \tilde{u}'_{t-m} + \sum_{n=1}^N \beta_n Q_{t-n}, \quad (3)$$

where $\tilde{u}_t = [t_v^{-1}(u_{1,t}), \dots, t_v^{-1}(u_{d,t})]$, where t_v^{-1} is the inverse of the univariate, standardised t Student distribution, with v denoting degrees of freedom. The log-likelihood function is provided by the following formula:

$$\begin{aligned} L_{St}(R_t, v, \theta, \tilde{u}_t) = & -T \ln \frac{\Gamma\left(\frac{d+v}{2}\right)}{\Gamma\left(\frac{v}{2}\right)} - pT \ln \frac{\Gamma\left(\frac{v+1}{2}\right)}{\Gamma\left(\frac{v}{2}\right)} - \\ & - \frac{d+v}{2} \sum_{t=1}^T \ln \left(1 + \frac{\tilde{u}'_t R_t^{-1} \tilde{u}_t}{v}\right) \\ & - \sum_{t=1}^T \ln |R_t(\theta)| + \frac{v+1}{2} \sum_{t=1}^T \sum_{i=1}^p \left(1 + \frac{\tilde{u}_{i,t}^2}{v}\right), \end{aligned} \quad (4)$$

where θ is the DCC parameter vector. More details about conditional copulas can be found in Doman & Doman (2013), Patton (2002) and Patton (2006).

The Kendall τ is applied as a measure of dependence. This is a measure of the ‘concordance’. Let $(x_1, y_1), (x_2, y_2), (x_n, y_n)$ be a set of observation pairs generated from random variables X and Y . Observation pairs (x_i, y_i) and (x_j, y_j) are concordant if their ranks are consistent (i.e. if $x_i > x_j$ and $y_i > y_j$ or $x_i < x_j$ and $y_i < y_j$).

Similarly, observation pairs (x_i, y_i) and (x_j, y_j) are disconcordant if their ranges are not consistent (i.e. if $x_i < x_j$ and $y_i > y_j$ or $x_i > x_j$ and $y_i < y_j$). If $x_i = x_j$ or $y_i = y_j$, then observation pairs are neither concordant nor disconcordant. The Kendall τ coefficient is the difference between the probability of concordance of observation pairs (x_i, y_i) and (x_j, y_j) , and the probability of their disconcordance. Thus,

$$\tau(X, Y) = P[(x_i - x_j)(y_i - y_j) > 0] - P[(x_i - x_j)(y_i - y_j) < 0]. \tag{5}$$

In the case of the conditional t copula, the Kendall τ coefficient is given by the formula:

$$\tau(X, Y) = \frac{2}{\pi} \arcsin(\rho),$$

where $\rho = R_{12,t}$ is the correlation coefficient between X and Y .

In this research, it is particularly important to check how the occurrence of extreme values of one series influences the probability of the occurrence of extreme values of the other series. The tail dependence coefficients λ^L and λ^U provide asymptotic measures of the dependence in the left and right tail, respectively. If F_1 and F_2 are cumulative distributions of vector (X, Y) , then the tail dependence coefficients are given by the following formulas:

$$\lambda^L(X, Y) = \lim_{\alpha \rightarrow 0^+} P(Y \leq F_2^{-1}(\alpha) | X \leq F_1^{-1}(\alpha)), \tag{6}$$

$$\lambda^U(X, Y) = \lim_{\alpha \rightarrow 1^-} P(Y > F_2^{-1}(\alpha) | X > F_1^{-1}(\alpha)), \tag{7}$$

if the limits exist. In the case of the t copula, they are given by the formula:

$$\lambda(X, Y) = \lambda^U(X, Y) = \lambda^L(X, Y) = 2t_{v+1} \left(- \sqrt{\frac{(v+1)(1-\rho)}{1+\rho}} \right).$$

5. The results

The first step involves fitting a GARCH-type model to each considered series. Since a long sample is used, in some cases it was necessary to use a complicated GARCH-type model specification to explain the autocorrelation in squared residuals. The

results of the estimations of the models are presented in Table 1. The details of the Box-Pierce test for standardised residuals and squared standardised residuals show that the models indeed explain the linear and non-linear dependencies. Following the estimation of the univariate models, standardised residuals were collected, and 4-dimensional t-copulas with a conditional covariance matrix explained by the DCC(1,1) model were fitted to the $u_{i,t}$ series. Taking into account the purpose of the study, the copulas were fitted to three exchange rates and the bond spread for each country separately. The estimation results are presented in Table 3.

Table 2. Results of the estimations of univariate GARCH models

dCHF CZK		dEUR CZK		dUSD CZK		dCZ	
par.	estimate	par.	estimate	par.	estimate	par.	estimate
a_1	-0.055700***	a_1	-0.105700***	$\ln(\xi)$	0.046570***	a_1	-0.0817***
v	4.241659	a_2	-0.051900***	v	7.055000***	a_2	-0.0321***
α_1	0.198700***	v	4.726103	ω	0.000100	a_3	0.0083***
β_1	0.801200***	α_1	0.098200***	α_1	0.049667***	v	1.0732***
		β_1	0.901800***	β_1	0.948515***	ω	0.4240
						α_1	0.0557***
						β_1	0.9325***
dCHF HUF		dEUR HUF		dUSD HUF		dHU	
par.	estimate	par.	estimate	par.	estimate	par.	estimate
v	5.33840	v	1.3445	v	0.890000	v	1.0266
$\ln(\xi)$	0.06856***	$\ln(\xi)$	0.1075***	b_1	-0.165100***	ω	0.0001
ω	0.05900	ω	0.0140	ω	0.027660	α_1	0.1320***
α_1	0.13470***	α_1	0.1126***	α_1	0.075700***	γ_1	-0.0923***
β_1	0.85520***	γ_1	-0.0881***	γ_1	-0.060000***	β_1	0.9085***
		β_1	0.9263***	β_1	0.947287***		
dCHF PLN		dEUR PLN		dUSD PLN		dPL	
par.	estimate	par.	estimate	par.	estimate	par.	estimate
v	1.423200	v	1.422732	$\ln(\xi)$	0.083279***	a_1	0.02700***
ω	0.077207	ω	0.05460 (-)	v	8.976840***	a_2	-0.04470***
α_1	0.177400***	α_1	0.125400***	ω	0.037000	v	8.67900
γ_1	-0.097600***	γ_1	-0.084700***	α_1	0.089780***	ω	1.15000
β_1	0.875100***	β_1	0.905500***	γ_1	-0.050640***	α_1	0.09206***
				β_1	0.910220***	β_1	0.89259***

Note. The following models were applied for the respective series:

dCHF CZK – GARCH(1,1) (t Student), dEUR CZK – AR(2)-IGARCH(1,1) (t Student), dUSD CZK – GARCH(1,1) (skewed t Student), dCZ – AR(4)-GARCH(1,1) (GED) with restriction $a_3 = 0$.

dCHF HUF – GARCH(1,1) (skewed t Student), dEUR HUF – GJR-GARCH(1,1) (skewed t Student), dUSD HUF – GJR-GARCH(1,1) (GED), dHU – GJR-GARCH(1,1) (GED).

dCHF PLN – GJR-GARCH(1,1) (GED), dEUR PLN – GJR-GARCH(1,1) (GED), dUSD PLN – GJR-GARCH(1,1) (t Student), dPL – AR(2)-GARCH(1,1) (t Student).

Source: authors' calculations.

Table 3. Estimation results of 4-dimensional DCC-t-copulas with a conditional matrix R_t explained by the DCC(1,1) model – the Czech Republic, Hungary, Poland

Country	Parameter	Estimate	Std. error	t-stats	p-value
The Czech Republic	ν	10.8744	1.577	6.8935	<0.0001
	α_1	0.0299	0.002	12.3636	<0.0001
	β_1	0.9672	0.003	361.0533	<0.0001
Hungary	ν	10.0158	0.779	12.8511	<0.0001
	α_1	0.0251	0.003	9.4857	<0.0001
	β_1	0.9747	0.003	350.9480	<0.0001
Poland	ν	13.9115	1.234	11.2704	<0.0001
	α_1	0.0390	0.003	15.0528	<0.0001
	β_1	0.9600	0.003	345.9441	<0.0001

Source: authors' calculations.

The results of the estimations are presented in Figures 5 to 13. As the data suggest, the dynamics of the interrelations are partially similar for the studied countries, which is assumed to be related to selected international events of that period. Thus, the international events which were likely to have impacted the interrelationships (and the risk of volatility transmission) are described below, followed by an account of any domestic events which might have affected the dynamics as well.

First of all, when analysing the relationship of bond spreads with the euro, an 'echo' of the Greek crisis is visible in all the investigated cases (May 2010 saw the beginning of the Greek crisis, while the summer of 2011 a cut of the nominal value of Greek bonds). As regards the relationship of the exchange rates of domestic currencies to the Swiss franc, a global peak was observed in August 2011, followed by a period of a diminishing relationship between the spreads and exchange rates. This situation may have resulted from the previously-mentioned decision of the Swiss National Bank to control the EUR-CHF exchange rate.

A very sudden and steep decline of relationships in all the analysed cases was recorded in the second half of 2012, which may be explained by the situation on international markets. A fall in risk aversion was observed on the global financial market, mainly due to central banks' policies. The European Central Bank (ECB), for instance, took measures to improve the liquidity of the banking sector in the Eurozone and to reduce the tensions on the governmental bond markets of the selected Eurozone countries (Narodowy Bank Polski [NBP], 2012). The result of the election in Greece in June 2012 added to the fall in risk aversion. In July of the same year the ECB lowered interest rates (the main refinancing operations (MRO) rate to 0.75% and the interest rate on deposit facility to 0%) and in September it launched the outright monetary transactions (OMT) purchases programme for sovereign bonds in the Eurozone secondary markets. As a result, the risk perceived by the

market participants decreased (as illustrated by the dynamics of sovereign CDS spreads), and the euro appreciated against the US dollar. The fall in global risk has evidently translated into a decline of the volatility transmission measured by parameter λ .

With respect to the dynamics of dependencies between the bond spreads and foreign exchange rates against the US dollar, the relationships in all the cases declined dramatically and reached negative levels at the end of 2013. The beginning of 2013 marked a sudden growth of government bond yields of mature markets due to the increase in global risk caused by the expected reduction of the scale of quantitative easing programmes in the US and the possible increase of interest rates by the US Federal Reserve (FED) at the end of 2013 (NBP, 2013). As a result, global markets' volatility increased, as well as the yields of government bonds in developed markets, and a sharp decrease in prices in global stock markets was observed. The second period, witnessing a significant rise in the risk aversion, occurred at the turn of August and September 2013, when the prices on global financial markets were negatively affected by the uncertainty regarding the time and scope of the shift in the FED's monetary policy and the possible military intervention in Syria. In September 2013, the markets were taken by surprise by the US macroeconomic data and the FED's decision to keep the level of the asset purchase programme unchanged, at the same time postponing the expected tightening of the monetary policy. This led to a decline in the yields on the Treasury debt securities on developed markets. At the same time, together with the ongoing political crisis in the US, the US dollar weakened against the euro. As the USD-PLN exchange rate was mainly affected by the EUR-USD exchange rate, the exchange rate of the zloty against the US dollar declined to its lowest level in over two years (NBP, 2013). The situation changed at the end of 2013, when the FED started tapering its asset purchase programme, and the Federal Open Market Committee (FOMC) reduced the quantitative easing programme following the committee's meeting in December 2013. At the same time, the ECB undertook measures to stimulate economic growth in the Eurozone and counteract the inflation rate persisting below the inflation target (NBP, 2014). These actions might have contributed to the drop of the τ coefficient, describing the relationships between the domestic bond spreads and exchange rates against the US dollar, below zero.

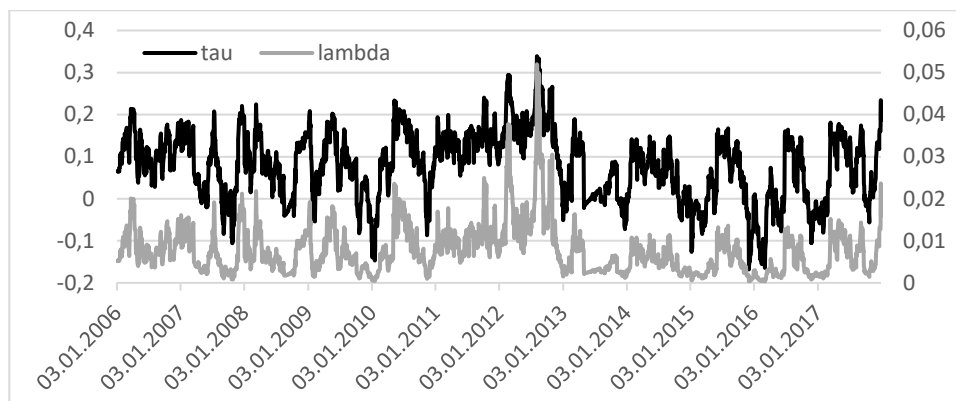
5.1. The Czech Republic

Figures 5–7 present the results of the estimations of the interdependencies between the Czech bond spread and the exchange rate of the Czech koruna, measured by the Kendall τ and λ (to make the picture clear, the value of the Spearman ρ was omitted,

but its dynamics was similar to the dynamics of the τ coefficients, albeit its values were higher). As we can see, Kendall's τ was the highest in the case of the relationships between the bond spread and the EUR-CZK exchange rate. It fluctuated around 0.3, while the remaining exchange rates around 0.2.

The value of coefficient λ was very low throughout the whole period, within which three instances of growth occurred as a consequence of international events. The first one appeared in late 2008 and early 2009, and resulted from the transmission of the crisis to Europe. The second peak was observed in spring 2010. It was most probably caused by the beginning of the Greek problems. The third one took place in the second half of 2012 and its source is likely to have been the early elections in Greece. However, the value of λ decreased shortly afterwards and as early as in November 2012 it returned to nearly 0, which might have been the effect of the policy adopted by the Czech National Bank (CNB). In late 2012, the interest rates in the Czech Republic reached 0% and the CNB announced that it would intervene in the foreign exchange market to weaken the koruna if necessary (such verbal interventions took place in 2013). Moreover, from November 2012, the CNB suspended the sales of foreign exchange reserve revenues (which were aimed at preventing a continuous rise in the reserve level), and began to publish monthly foreign exchange transaction data on its website, with a two-month lag. Moreover, May 2013 saw a sudden drop in the Kendall τ . This possibly was the consequence of the aforementioned policies and of the FED's decision to give green light to the gradual withdrawal of monetary stimulus (which influenced the EUR-USD exchange rate – see below).

Figure 5. Estimates of copula-GARCH parameters τ and λ : the Czech spread and CHF-CZK

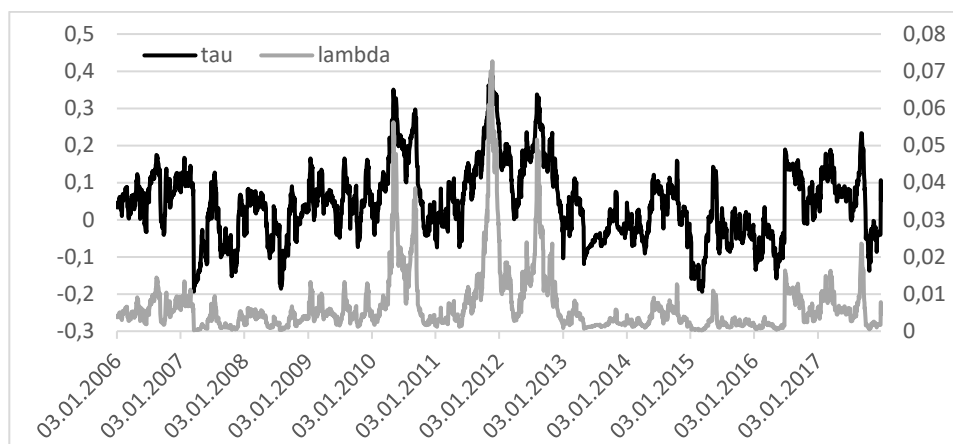


Note. Black line – τ coefficient, grey line – λ .

Source: authors' calculations.

Figure 6 presents the dynamics of the relationships between the Czech bonds spread and the EUR-CZK exchange rate. As mentioned before, it reflects to a great extent the dynamically changing situation on the pan-European market (for instance, the peak in May 2010 can be attributed to the Greek crisis). Starting from 2013, a change of relationships between the two magnitudes may be observed. It was the time when the CNB decided to stabilise the Czech koruna around the euro. This change is also visible in the remaining exchange rates, but in their case it is not as drastic.

Figure 6. Estimates of copula-GARCH parameters τ and λ : the Czech spread and EUR-CZK

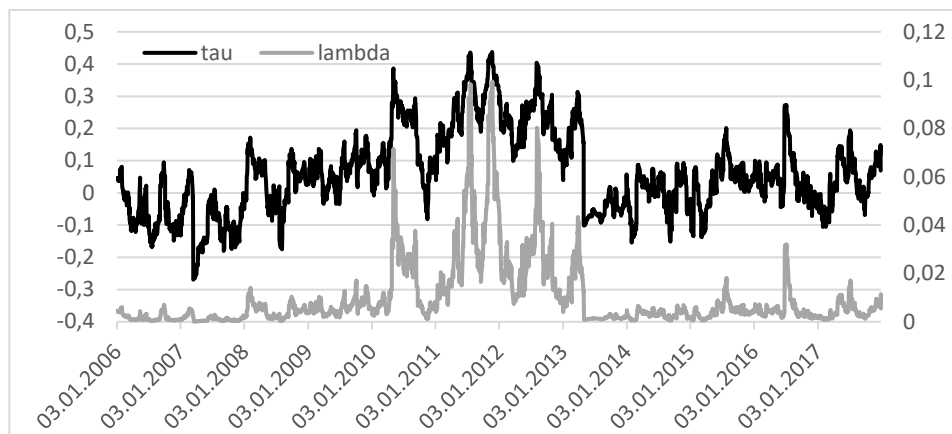


Note. Black line – τ coefficient, grey line – λ .

Source: authors' calculations.

A very interesting pattern emerges relating to the interactions between the Czech bond spread and the USD-CZK exchange rate (Figure 7). A spike of λ occurred also in November 2011, which might have resulted from the worsening economic situation in the US. In October 2011, the US President announced a USD 447 bn plan to stimulate the economy. The plan did not have the expected effect on market uncertainty, so the FED representatives announced further monetary policy easing through the purchase of securities (NBP, 2011).

The Kendall τ took negative values between November 2013 and January 2014. As explained before, the situation was most likely the result of the FED's announcement of a possible gradual withdrawal of monetary stimulus and the simultaneous introduction of a quantitative easing policy by the ECB. The fall in the relationship was most likely reinforced by the decision of the Czech National Bank, which, starting November 2013, began using the exchange rate as an additional monetary policy instrument.

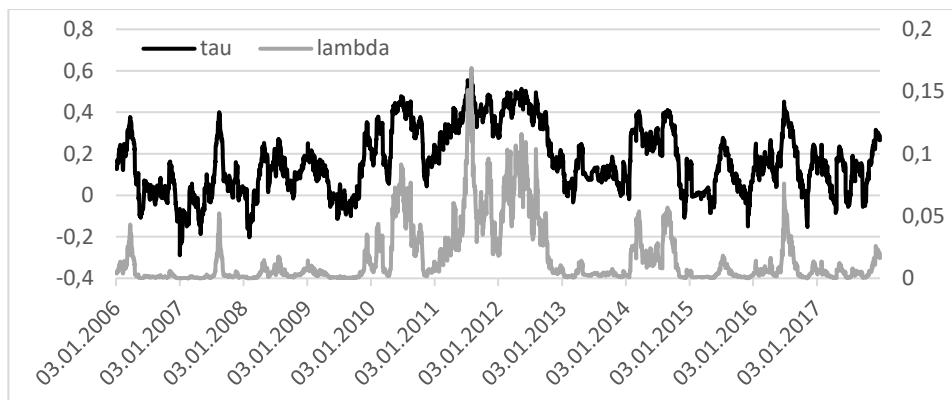
Figure 7. Estimates of copula-GARCH parameters τ and λ : Czech spread and USD-CZK

Note. Black line – τ coefficient, grey line – λ .

Source: authors' calculations.

5.2. Poland

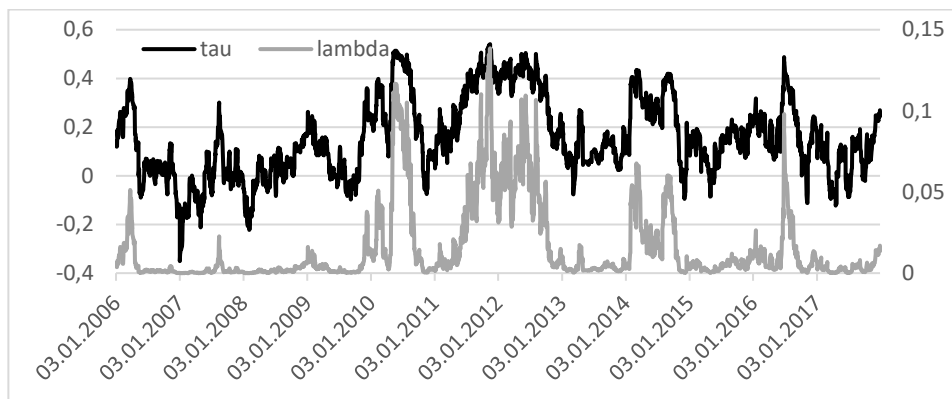
Among all the analysed currencies, the strongest relationships were obtained for bond spreads and the CHF-PLN exchange rate. The years 2011–2012 saw a growth in these relationships, with the highest peak coinciding with the beginning of the stabilisation of the Swiss franc (Figure 8). Over this period, the correlation was quite stable and the probability of extreme events transmission diminished. This change was probably caused by foreign exchange (FX) interventions. On 21st April 2011, the Polish Ministry of Finance announced it would regularly sell some foreign currency received by Poland in the framework of EU funds directly on the domestic market. On 6th July 2011, the president of the National Bank of Poland (NBP) announced the possibility of its intervention in the FX market in order to prevent the excess volatility of the price of the Polish zloty. Subsequent interventions took place in 2011 in September (a common intervention of the NBP and the State Development Bank of Poland – BGK), October, November and December 2011 (Blox, n.d.). The last one, which was performed on 29th December 2011, was also a joint intervention of the NBP and the BGK, aimed at preventing the further depreciation of the Polish zloty and recalculating the value of Poland's foreign debt. During the period of interventions, the risk of volatility spillover from the foreign exchange market onto the domestic market was gradually decreasing.

Figure 8. Estimates of copula-GARCH parameters τ and λ : Polish spread and CHF-PLN

Note. Black line – τ coefficient, grey line – λ .

Source: authors' calculations.

The relationships with the euro were rather stable over the whole period, although some peaks did occur during the most hectic moments of the European debt crisis. The highest one was observed in August 2012 (Figure 9).

Figure 9. Estimates of the copula-GARCH parameters τ and λ : Polish spread and EUR-PLN

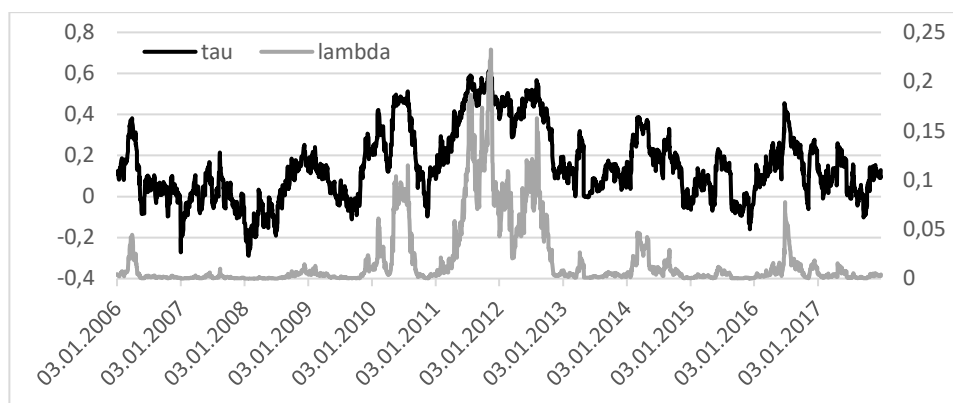
Note. Black line – τ coefficient, grey line – λ .

Source: authors' calculations.

Interestingly, the USD-PLN relationships (see Figure 10) were quite stable until the end of the first half of 2012. After that period, the τ (correlation) and λ (probability of extreme events transmission from the FX market) spiked, followed by a deep and long-lasting fall in these two kinds of relationships. It should be noted that apart

from the above-mentioned international events that could have caused this fall, some legislative changes were also introduced concerning the method of determining the ratio of public debt to GDP. This decision contributed to the decrease of the exchange rates' volatility (see: Bank Gospodarstwa Krajowego [BGK], 2013), and additionally were likely to have influenced the risk of the volatility transmission between foreign exchange and bond markets. Moreover, in 2012, Poland introduced a regulatory framework for foreign currency lending, requiring banks to offer mortgages only in the currency of the mortgagor's income, and additionally to impose stricter creditworthiness standards to foreign exchange credit exposure (IMF, 2014). This is likely to have contributed to the reduction of households' exposure to the currency risk and to the decline of relationships between the bond spreads and exchange rates. Three interventions performed in 2012 (one in February and two in May) did not seem to affect the relationships between the exchange rates and bond spreads.

Figure 10. Estimates of copula-GARCH parameters τ and λ : Polish spread and USD-PLN



Note. Black line – τ coefficient, grey line – λ .

Source: authors' calculations.

5.3. Hungary

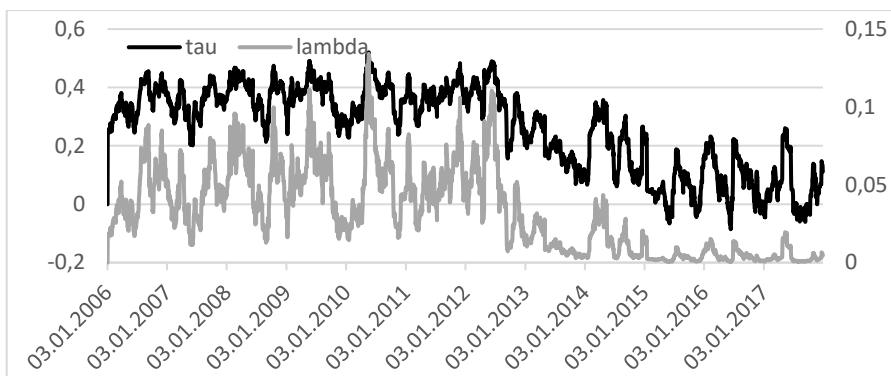
This subchapter focuses on the estimates of interrelations between the Hungarian bond spread and the exchange rates (Figures 11–13). The difference between their dynamics in Hungary and the dynamics of the relationships on the Polish and Czech markets is striking. The Hungarian market seems to have been the most affected by its domestic situation, presumably resulting from the Hungarian government's policy.

In Poland, prior to the crisis, hundreds of thousands of households took out mortgage loans denominated in foreign currency, most often in the Swiss franc or the euro. The advantage of foreign currency loans over those in the domestic currency was that in that period, the former offered substantially lower instalments than mortgages in the Polish zloty (Gereben et al., 2011). However, the financial crisis caused the real estate values to plunge and domestic currencies to weaken. This made foreign – currency-denominated loans more difficult to pay off. In May 2011, the Hungarian government adopted repayment schemes, allowing foreign currency mortgage loans to be repaid in lump sum at artificially weak exchange rates before maturity. Some customers benefited from the scheme and in result the total amount of outstanding foreign currency-denominated mortgages dropped by over 19%. However, the cost which the Hungarian banks had to face was high – it was assessed at approximately USD 1.2 bn (Agabekian, 2013).

On 15th December 2011, the Orban administration and the Hungarian Bank Association concluded an agreement that enabled mortgagors to repay the entire sum of their Swiss franc- and euro-denominated loans at the above-mentioned fixed rates by March 1, 2012. Banks, in turn, were permitted to deduct one-third of the exchange rate losses resulting from this arrangement from their payment of the government-imposed financial-sector tax in 2012 (Lambert, n.d.).

On February 27, 2012 the Hungarian central bank (Magyar Nemzeti Bank, further the MNB) terminated the foreign currency sales tender programme. Prior to that, the MNB operated a programme of tenders of foreign exchange sales to provide banks with foreign currency to close their open positions arising from the early repayment of foreign currency-denominated mortgages (IMF, 2013).

Figure 11. Estimates of copula-GARCH parameters τ and λ : Hungarian spread and CHF-HUF

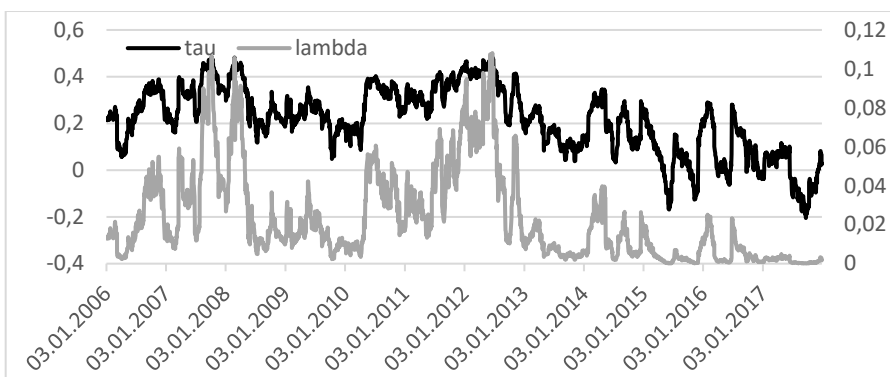


Note. Black line – τ coefficient, grey line – λ .

Source: authors' calculations.

Figures 11–13 indicate the moment in which in all the studied cases the relationships between the bond spreads and the exchange rates dropped sharply. This fall in the case of the CHF-HUF exchange rate is especially striking. The drop occurred in slightly different moments for each currency. Nevertheless, the fact that it was most significant in the case of Hungary seems to have evidently resulted from the Hungarian government's policy. Thus, out of the three analysed economies, Hungary is the one where domestic factors influenced the relationships between the bond spread and exchange rates to the largest extent. This conclusion should not be surprising, considering the fact that according to numerous authors (e.g. Baldacci & Kumar, 2010; Jaramillo & Weber, 2013), domestic factors play a prominent role when an economy is in crisis, influencing other variables. In this context we can say that Hungary – unlike Poland and the Czech Republic – underwent a crisis of its own.

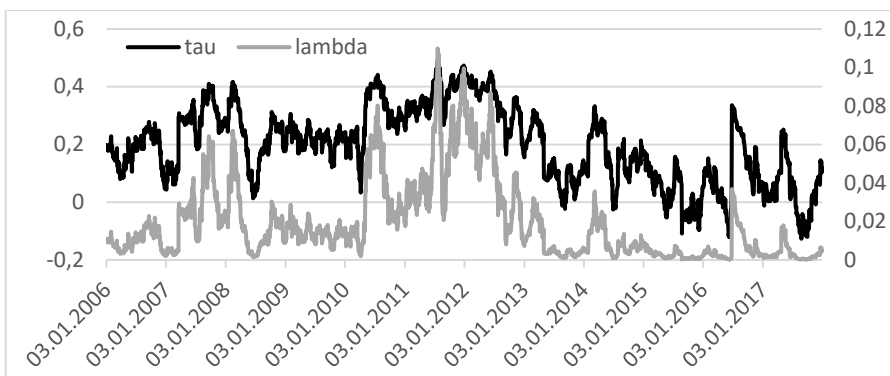
Figure 12. Estimates of copula-GARCH parameters τ and λ : Hungarian spread and EUR-HUF



Note. Black line – τ coefficient, grey line – λ .

Source: authors' calculations.

Figure 13. Estimates of copula-GARCH parameters τ and λ : Hungarian spread and USDHUF



Note. Black line – τ coefficient, grey line – λ .

Source: authors' calculations.

6. Conclusions

The aim of the article was to verify the impact of foreign currencies on the fundamentals of three CEE economies: the Czech Republic, Hungary and Poland. The condition of the fundamentals was measured through the dynamics of the spreads of 10-years' sovereign bonds against a 10-years' yield of German bonds. Two of the countries – Poland and the Czech Republic – performed relatively well during the financial crisis, while Hungary struggled with internal problems.

We estimated a 4-dimensional copula-GARCH model, on the basis of which we obtained a time-varying estimate of the Kendall τ and tail dependence coefficient λ , illustrating the probability of volatility spillovers between the sovereign market and the FX one. Three most important reference currencies were considered: the US dollar, the euro and the Swiss franc. The impact of the first two on the investigated economies is indisputable (see e.g. Doman M., 2009), while the importance of the Swiss franc stems from a huge exposure of households to mortgages denominated in this currency. This exposure was especially great in Poland and Hungary.

The question formulated in the title of this paper concerns the degree to which the currencies affect the fundamentals of the CEE economies. The analysis of the values of the Kendall τ – the measure of concordance, and the values of coefficient λ – the probability of extreme events transmission, shows that at the beginning of the period covered by the study the highest values were obtained for interrelations with the Swiss franc in Poland and Hungary. These results can be explained by the fact that Polish and Hungarian households had been heavily indebted in the Swiss franc, while this phenomenon was not that strong in the Czech Republic. Still, even in the case of the Czech Republic, the highest values of τ were also obtained in relation to the Swiss franc, which might be the result of various interactions among the CEE currencies (see for instance Orlowski, 2016) or the important role of the Swiss franc in the whole of Europe. Moreover, the Swiss central bank actually stabilised the franc around the euro, so the high dependence between the Czech koruna and the Swiss franc could also be the consequence of the strong relationship between the franc and the euro.

On the basis of the analysis presented in this paper, it can be additionally concluded that in the case of the Czech Republic and Poland, the dependencies between the FX and the sovereign market grew in the periods of international turmoil. Domestic events, such as currency interventions, seemed to have a weak influence on the interrelations and the probability of volatility spillover between the markets. The change of the floating regime of the koruna had merely a short-term effect on the relationships between the exchange rates and the fundamentals – after a short period of the relationships' weakening, their strengthening occurred again.

Hungary was in a different situation, as the domestic credit policy of the Hungarian government seemed to have a significant influence on the dependencies between the sovereign market and FX market. The probability of spillovers diminished visibly following the implementation of the obligatory conversion of foreign currency-denominated loans to forint-denominated ones. From this point of view, the controversial policy of the Hungarian government should be considered effective. The obtained results also support a thesis, quite frequently cited, that when the market is distressed, domestic factors influence the sovereign market to the largest extent, more so than international circumstances.

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