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Euro or not? Vulnerability of Czech and Slovak economies to regional and international turmoil☆

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ABSTRACT

The paper compares vulnerability to crises of the Czech Republic and Slovakia, which had operated as Czechoslovakia prior to 1993. In 2009, Slovakia adopted the euro, while the Czech Republic retained its koruna. The main research question is if the introduction of the euro made Slovakia more vulnerable to pan-European crisis. The paper concentrates on two episodes: the Greek (pan-European) and Hungarian (regional) turmoil. The level of the country risk is measured through volatility of bond-spreads. From DCC-copula model the authors derive time-varying probability of crisis transmission and dynamic correlations. The main findings of the paper are: (i) Euro adoption did not make Slovakia more vulnerable to the pan-European problems. (ii) The country is still identified by investors as an emerging Central-European region, rather than a country of the Eurozone.

1. Introduction

The aim of our research was to verify vulnerability of the Czech and Slovak economies to the transmission of financial crises based upon the behaviour of their sovereign bond spreads. The Czech and Slovak economies are Central-European Economies. Prior to 1993 the two republics in question used to be single economic space. Later on, i.e. in 2009, Slovakia, already as an independent economy, adopted the euro as its currency. At the same time, the financial crisis started to spread from the USA to Europe, as a result of which several member states of the Eurozone experienced severe economic and fiscal breakdowns. Economic problems were no strangers to Hungary either, which is an important country in the region of Central Europe. These crises affected the way investors rated their risks in the other economies in the whole of Europe or in the sub-region. Our goal is to verify the direction and strength of transmission of these two crises to the two economies in question.

The euro is the official currency of the Eurozone. It is managed and administered by the independent European Central Bank. Any EU state that aims at adopting the euro has to comply with special financial and budget constraints. Of the Visegrad Group (hereinafter: V4) countries only Slovakia adopted the euro, following their successful implementation of structural reforms. The euro was supposed to bring stability by preventing devaluation that had been a result of self-fulfilling runs on currency. The introduction of the euro meant also that countries with sovereign debt problems could not use monetization and devaluation as a way to prevent default (see: Whelan, 2013). Together with the outbreak of the financial crisis, the economic situation of some Eurozone members began to deteriorate. The countries with a high level of debt and dependent on the inflows of private credit seemed to have found themselves in the worst situation (Spain, Ireland). Fundamentals of some other countries had been poor even before the crisis (Portugal). Eventually, in the case of Greece, not only had the fundamentals been in poor condition, but also the statistics about them had been falsified. Revealing the “true” value of the debt ratio aggravated the international evaluation of the Greek condition.

The impact of the exchange rate regime on vulnerability of the economy to the crises has already been studied thoroughly. For instance, Holtemoeller and Mallick (2013) showed that the higher flexibility of the currency regime is, the lower the misalignment of actual real effective exchange rate from its equilibrium level, and thus – the probability of a potential currency crisis. Misalignment occurs

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when the actual exchange rate does not respond adequately to changes in the economic fundamentals. Since the euro is a single currency shared by many European economies with very different fundamentals, we claim that there was a possibility of such misalignment in the case of Slovakia. Being a small Eurozone member, it was unlikely to have affected the euro exchange rate. On the contrary – the fundamentals of other distressed economies could have accomplished that. The measures taken by the European Central Bank, as well as the European Commission, imposing burdens on other countries to help Greece, could have affected not only the deficit of Slovakia but also the investors' sentiment about the country.

Many authors have drawn attention to the reaction of Western economies to the Greek problems. For instance, Gomez-Puig and Sosvilla-Rivero (2016) indicated that before the crisis of the peripheral Eurozone members, the bond spreads of the European Economic and Monetary Union (EMU) countries with respect to Germany moved in a narrow range with only slight differentiation across countries. However, they spiralled, starting from November 2009. The authors presented a correlation matrix between the yields spreads, showing that correlations with Greece ranged from 0.96 (Portugal) to 0.54 (Finland). Thus, the natural question is whether the Slovak Republic, being a young Eurozone member, followed the path of the South-Western members or remained more immune to the Mediterranean problems, as it was the case with the northern economies (Finland, Netherlands).

Therefore, our first research question is: was the influence of the Greek crisis more severe to Slovakia than to the Czech Republic?

At the same time Hungary, one of the Central-European economies, but not a Eurozone member, also experienced its own crisis. Slovakia, with the new currency, could have become more immune to Central-European problems and thus may be associated by investors with Western Europe rather than with Central Europe. On the other hand, according to specialist literature one of the crisis-transmission channels is actually region-based, i.e. crises can spread more easily in the economies in the same region (see e.g. Crescenzi et al., 2016). The reason for this could originate from international investors themselves and their withdrawals of investments from several financial markets (Fazio, 2007), especially when one of the countries in the region is on the brink of crisis. Given the scarcity of information, investors are prone to treat the seemingly similar countries as equal (e.g. Dieder et al., 2008). In view of the fact that the Czech and Slovak Republic used to be one country, we can suppose that uninformed investors could have treated them as equal and painted them with a broad brush. As they belong to the CEE region, the news of the Hungarian crisis could have made investors lose their confidence in the other CEE countries. On the other hand, if the investors had been aware of the fact that Slovenia is one of the Eurozone members, they could have already been treating it differently.

The reaction of the Czech Republic to the Hungarian crisis is also unclear. For instance, Buettner and Hayo (2010) showed that the Czech Republic can be viewed by investors as more advanced in terms of real and nominal convergence; from the perspective of the CEE markets the most integrated seem to be the Polish and Hungarian economies. Having assessed the reaction of the two economies to the Hungarian crisis we can also attempt to answer the question how international investors treat the two economies: still as risky emerging markets or rather – as similar to the more developed Western economies. Hence, we asked ourselves a question whether the reaction of investors was any different in the case of the two countries.

Therefore, our second research question is: did the Hungarian crisis spread to the Czech Republic, having left Slovakia unaffected?

In our study we have concentrated on bond spreads. Spreads of the bonds to the yield of the safest economy in the region are treated as indicators of the country's risk relative to the safest country in the region. D'Agostino and Ehrmann (2014) showed that in the case of spread of any country relative to a "safe haven" government bond (e.g. Germany), a country's fundamentals constitute a considerably more influential determinant of spread dynamics than fundamentals of the benchmark economy. Researchers confirm that the importance of fundamentals in bond spread pricing increased especially during the financial crisis (e.g. Bernoth and Erdogan, 2012 or Borgy et al., 2011). Moreover, many studies proved that bond yields are much less vulnerable to sunspots and volatility spillovers from abroad than any of the daily-priced instruments (see e.g. Kocsis, 2014,[1] Będowska-Sójka and Kliber, 2013).

We have analysed the influence of the Greek and Hungarian crises on the Czech and Slovak economies by studying common dynamics of their volatilities. To estimate the volatilities, we have used the DCC-copula model. Such an approach also allowed us to obtain the dynamics of the rank correlation coefficient, the Kendall τ, as well as the tail dependence coefficient (λ). The latter is especially important to our analysis as it has provided us with information about the possibility of transmission of extreme events from high-risk countries.

Contrary to our expectations, it has turned out that Slovakia, despite adoption of the euro, was more immune to the Greek crisis transmission than the Czech Republic. What is interesting, however, is that the two economies seemed to have been similarly exposed to the Hungarian crisis. The key points in the Hungarian policy, resulting in the growth of the Hungarian spread, were reflected in the correlation and probability of extreme events transmission. Moreover, the interdependencies between the Czech Republic and Slovakia grew in unison with the evolution of the crisis.

The structure of the article is as follows: first, the data used in the study are presented, i.e. bond spreads of the Czech Republic, Greece, Hungary, and Slovakia over the period 2009–2012, together with descriptive statistics. Next, the model used in the study is described: the DCC-copula. Finally, the results of our model are recounted and interpreted.

2. Literature review

The negative impact of the Greek crisis on other developed European markets has been studied by many researchers. For instance Samitas and Tsakalos (2013) confirmed contagion between Greece and UK, Germany, France and so-called PIIGS economies based upon the analysis of the main stock indices. Phillipas and Siriopolous (2013), using the Markov-switching and copula approach, also confirmed contagion from Greece to France and Germany. Gomez-Puig and Sosvilla-Rivero (2014) showed that causality relationships between Greece and Western European Economies (France, Austria, Finland and Belgium) grew in response to Greek crisis. The results presented by the authors linked the probability of spillovers to high exposure of these banks (e.g. French, German) to the debt of peripheral countries. As a response to Greek problems, the 1-year yield spreads of French, Austrian, Finish and Dutch bonds over the German ones grew significantly, while their ratings remained high. The authors associated the increase of the spreads with the herd behaviour of investors and the growth of risk aversion. In their later study (Gomez-Puig and Sosvilla-Rivero, 2016) they confirmed that the growth of sovereign risk premium in the euro area during the European sovereign crisis was caused not only by the deterioration of debt sustainability in member states, but also by the perceptions of market participants in contagion episodes from peripheral (among others: Greece) to central countries.

On the other hand, Pragidis et al. (2015) found no contagion between Greece and the aforementioned economies based upon the analysis of bond spreads of 10-years maturity. According to Kalbaska and Gątkowski (2012), up to 2010 the Greek sovereign credit default

[1] According to this study, in the case of Hungary the idiosyncratic factor can explain up to 80% of the variance of bond yields, while in the case of sovereign CDS this figure is only 33%.

swaps (sCDS) had lower impact on French, German and other PIIGS contracts than the Spanish and Irish ones. Mink and de Haan (2013) analyzed the way the stock prices of 48 European banks (including Poland and Hungary in their sample) reacted to the news about Greece and its bailouts. The authors found that - with the exception of the Greek banks, the news about Greece did not lead to any abnormal returns. Then again, the news about the bailout did, even in the case of banks without any exposure to Greece (or other highly indebted euro countries).

The differences in the conclusions can be linked not only to the methodology applied, but also to different definitions of contagion. The fact is, however, that the spreads of the bonds of developed European economies grew significantly the moment the Greek crisis commenced.

Significantly fewer articles have been written which analyze the impact of the Hungarian crisis on the European economies. Most researchers concentrate on finding the roots of the crisis and on describing its impact on the Hungarian economy (see e.g. Monostori, 2013). It is understandable that the effect of the Hungarian crisis should be visible within the region. Again, most researchers who included the CEE economies in their datasets, concentrated on the impact the overall turmoil exerted on the countries. Claeys and Vasicek (2014) analyzed bond spreads of the European countries, including Central European economies. The authors found that the CEE countries were linked by bilateral relationships (unlike the UK, Denmark and Sweden, which seemed to be quite isolated from other EU countries). They also confirmed that a deterioration of the neighbouring markets affects the economy more than their own deterioration. Nickel et al. (2009) investigated the CEE-countries together with Turkey in their study of the impact of expected fiscal deficit on bond spreads over the period 1997–2007. Dumicic and Ridzak (2011) analysed spreads of emerging European markets over the years 2000–2010 to find out that before the crisis spreads were determined mainly by market sentiment and macroeconomic fundamentals, while together with the outbreak of crisis external imbalances gained importance as well. Some CEE markets were included in the study of Csonto and Ivaschenko (2013), who also confirmed that in the periods of severe market stress (e.g. intensive phase of the Eurozone debt crisis) global factors tend to drive changes in spreads, and that the countries with stronger fundamentals are more immune to changes in global factors. The issue of reaction of the Central European economies to the Hungarian and Greek crises was already described by Kliber (2013). The author, however, concentrated on Poland, Czech Republic, and Hungary and investigated sCDS premiums, which are more vulnerable to international events and sunspots than bond yields. The author proved, inter alia, that the co-movement between CEE sovereign markets increased as a result of the increase of market volatility in the crisis period. The results confirm the findings presented by Komarkova et al. (2013) obtained for the Czech Republic.

To summarize – the review of the specialist literature on the CEE economies reveals that the strength of the country's reaction to external turmoil may depend on the strength of its fundamentals. Further, it is possible that both – the crisis in the neighbouring country (Hungary) and the Eurozone crisis (due to Greek problems) – may affect any CEE economy. In our further study we have tried to make a distinction between the impacts of the two crises and investigate their strength in relation to the analysed CEE economy.

3. The data

Our data consisted of four time series of spreads of Czech, Greek, Hungarian and Slovak bonds to the German ones; see Fig. 1. Czech, Hungarian and Slovak spreads have been presented on the left axis, while the Greek ones on the right axis. At first, we can observe that the values of the Czech and Slovak spreads were small, i.e. in the range of 0–4 points, while the Hungarian spread took up to 10 points in the moments of speculative attacks against the forint (2009) and upon the

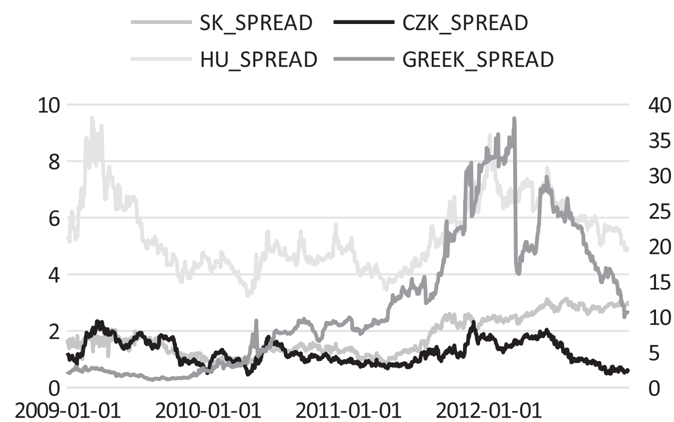

Fig. 1. Spreads of Czech, Slovak, Hungarian and Greek bonds to German one: 2009–2012. Note: Czech, Slovak and Hungarian spreads: left axis, Greek spread: right axis. Source: Own calculations.

Hungarian crisis in 2012. Greek spread values are much higher than the Hungarian ones. In March 2012, we observed a sharp decrease in the spread; this was the moment of the restructuring of the Greek sovereign bonds.

In Table 1 we present the descriptive statistics of the changes of the spreads. We have modelled the changes as the levels of the spreads are non-stationary. We decided not to logarithm the data for the sake of interpretation. We have observed that the most volatile (in terms of standard deviation) was Greece. The Hungarian spread was– unsurprisingly – less volatile than the Greek one – but more than the Czech and Slovak ones. The least volatile was the spread of the Czech bonds. In all of the cases the ARCH effect was observed.

3.1. Slovakia

Slovakia, unlike other states of the V4, had adopted the euro. The consequences of this decision were twofold. At the beginning, Slovakia enjoyed the benefits of having a stable currency. Introduction of the euro eliminated transaction costs, exchange rate volatility, and the possibility of speculative attacks against the currency (Gal, 2013). Slovakia managed also to avoid large indebtedness in foreign currencies. However, with the outbreak of the crisis, having the euro as a currency became tricky. First of all, the stable currency contributed to the decline of competitiveness of the Slovak economy (the sharp decrease in foreign demand – being one of the results of the crisis – led to the crash in the production sector and to a deep recession (see: Sobjak, 2013). Secondly, participation in rescue funds (European Financial Stability Facility, European Stability Mechanism) imposed a heavy short-term burden on public finances and presents an additional risk in the case of default of any of the Eurozone members (see also: Gal, 2013).

Despite the difficulties, Slovakia was the first of the V4 members to have overcome the recession, mainly due to the strong growth of productivity. In 2009, the GDP grew to 4.4%. Still, three years later, in 2012 the Slovak economy slowed down moderately. The growth of GDP was brought about only by the expansion of the export-oriented automotive industry, while the domestic demand was on the wane, mainly due to the high unemployment rate. The gradual growth of the bond spread, observed in Fig. 1, can be the consequence of the domestic predicaments in Slovakia.

3.2. The Czech Republic

At the onset of the crisis, the fundamentals of the Czech Republic were relatively strong. The Czech Republic had been the least indebted state in the region (45.5% of GDP in 2011). The banking sector of the Czech Republic had remained healthy, mainly due to the conservative

Table 1
Descriptive statistics of the bond spreads changes.
Source: Own calculations.

Variable	Obs no	Mean	Std. Dev.	Minimum	Maximum	skewness	kurtosis
dSK	1042	0.001	0.093	−0.685	0.670	0.116	14.846
dCZ	1042	−0.001	0.065	−0.280	0.328	0.319	5.633
dGR	1042	0.008	0.837	−19.641	4.218	-13. 061	302.802
dHU	1042	0.000	0.165	−0.974	0.942	0.002	8.716

Note: dSK – changes of Slovak bonds spread, dCZ – changes of the Czech bonds spread, dGR – changes of the Greek bonds spread and dHU – changes of the Hungarian bonds spread.

approach the Czech banks had adopted in the pre-crisis period (Slosarcik, 2011). Moreover, the vast majority of the Czech household debts had been denominated in the Czech crowns, and hence, did not suffer from the currency fluctuations (as it was the case in Hungary or Poland).

The post-crisis recovery in the Czech Republic was, however, driven by export growth, not by the domestic demand. At the same time the Czech government restructured expenditures, through cutting wages in public sector and limiting social benefits. The tax, health care, and pension systems were reformed. All the factors contributed to the very slow return to the pre-crisis GDP level. However, in 2012 the Czech economy was back in recession (Sobjak, 2013). Yet, as observed in Fig. 1, the Czech bonds spread was the lowest from all of the analysed levels, starting from the second half of 2011. One of the reasons for this could be the "upgrade" of the rating of the Czech Republic in August 2011 by S & P (from A to AA-).

3.3. Greece

The dynamics of the Greek and Hungarian spreads reflected domestic turbulences. Already in 2010, stability and credibility of Greece was being questioned. In April 2010, the Greek government requested for activation of the first EU/IMF bailout package, as a result of which rating of the Greek sovereign debt was lowered. The package was activated in May and the Greek rating was subsequently lowered by international rating agencies. This event was reflected in the first spread peak (Fig. 1). The domestic situation was going from bad to worse. Attempts to implement the budget cuts and austerity measures were received with strikes and social disapproval. Again, in June 2011, the Greek sovereign bonds were downgraded to CCC. In June 2011, the European Financial Stability Facility was created to provide another aid package for Greece. In July 2011, private investors and government institutions accepted a cut of the nominal value of Greek bonds. Subsequently, in February 2012, the second bailout package was finalized, and private investors had to accept the 53.3% cut of the Greek bonds face value. This restructuring eventually made ISDA trigger a credit event with respect to the Greek sCDS (see also: Nelson et al., 2011, Traynor 2011, Kliber, 2013, 2014).

3.4. Hungary

The Hungarian crisis was less severe. Although in June 2010 the vice-chairman of the ruling Fidesz party warned that Hungary was close to follow the Greek scenario (after: FTMDaily, 2010), the country managed to overcome the crisis. However, confidence in the market was so low that the statement itself led to a sharp growth of the Hungarian sovereign CDS (see: Kliber, 2013). Consequently, rating agencies performed a series of downgrades of Hungarian sovereign bonds. By March 2009 the forint depreciated by 26% against the euro and by November 2011 – by 56% against the Swiss franc (see: Valentinyi, 2012; EEAG, 2012). To that end, the country came up against a huge problem with foreign-currency loans. In September 2011, the government passed a legislation that unilaterally changed the terms and conditions of all foreign currency loans contracts, the cost of which had to be born entirely by banks. In mid-December 2011, the government and banks agreed to share the costs of further arrangements. Following this decision, rating agencies lowered the ranking of the Hungarian debt once again on 25 November and 22 December. As a result, the Hungarian spread went up as indicated in Fig. 1. However, the sharpest increase was observed throughout the year 2012, which may have stemmed from the fact that in January the new Hungarian constitution, heavily criticized by the EU, came into force.

4. The model

Our aim was to measure time-varying interdependences among the aforementioned economies, based on the behaviour of their bond-spreads series. Therefore, we had to choose an appropriate model. An obvious choice was the multivariate GARCH model, namely the DCC-GARCH. However, if we wanted to obtain reliable estimates from such model, we had to be sure that the univariate conditional error distributions of all the series are the same. In our case empirical distributions vary across samples: estimates of degrees of freedom in univariate GARCH models are different for every sample, as well as empirical kurtosis (302.8 in the case of the changes of Greek bond spread versus 5.6. in the case of the Czech one).

The second problem was choosing an appropriate measure of dependencies. Again, the first and obvious choice would be the Pearson's correlation coefficient. However, when time series distribution is not normal, using the Pearson's correlation coefficient to identify the dependencies between random variables may lead to misleading conclusions (Lindskog, 2000). This is because it is very sensitive to outliers. Zero correlation implies independence only if the variables are normally distributed. The heavier the tails, the greater the error of the estimator could be.

Therefore, in order to verify the strength of linkages among the analysed countries we used the conditional copula model. In this model, there are no restrictions on marginal distributions and it allows for determining measures of dependences other than the correlation coefficient. With copula models we can use measures of dependence other than the Pearson coefficient, i.e., Kendall τ.

Thus, we have presented the dynamic estimation of the rank correlation coefficient, the Kendall τ, as well as tail dependence coefficient (λ). The latter is especially important for our analysis. It provides us with information on the possibility of the transmission of extreme events from the risk countries. Since we suppose that the linkages between exchange rates and bond spreads could grow as a response to internal or external shocks to the economies in question, this approach would seem to be the best one. Schmidt (2002) explained that asymptotic dependencies should not be identified with linear correlation coefficient. It is well known that in some cases correlation between the considered series is strong, but no dependence exists in tails. Bear in mind that bivariate normal distribution is asymptotically tail independent if its correlation coefficient ρ is less than 1.

Conditional copulas were introduced by Patton (2006). The author derived the properties of conditional joint distributions and the conditional copula from the properties of unconditional distributions and copula. Let us denote the multivariate time series by

$x_t = (x_{1,t}, ..., x_{d,t})'$. The general copula model can be described with the following formulas:

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

where Ω_{t-1} is the information set up to the moment $t-1$ inclusive. The existence and uniqueness of the C_t copula is guaranteed by the Sklar theorem for conditional copulas, introduced by Patton (2006). 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 marginal conditional distribution $F_{i,t}$ and θ is the parameter vector of the conditional copula C_t. This model is estimated through maximizing likelihood function of the following form

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

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

Our research is based on the DCC-*t*-copula model. The choice of dynamic structure of conditional correlation is determined by the results of Tse (2000) and Engle and Sheppard (2001). It strongly rejected the H_0 hypothesis of constant conditional correlation. The model was applied in two steps using the maximum likelihood method. In the first step, we have fitted each univariate series $x_{i,t}$, and the $u_t = (u_{1,t}, ..., u_{d,t})'$ is the multivariate time series, with each $u_{i,t}$ having been determined as the value of cumulative distribution function for $\tilde{\varepsilon}_{i,t}$, to one of the univariate GARCH-type models with *t* Student or GED innovation distribution.

$$x_{i,t} = \mu_{i,t} + y_{i,t}$$
$$y_{i,t} = \sigma_{i,t}\varepsilon_{i,t},$$
$$\varepsilon_{i,t} \sim iid(0, 1),$$
$$u_{i,t} = F_i(\tilde{\varepsilon}_{i,t}), \tag{1}$$

where $\tilde{\varepsilon}_{i,t}$ stands for standardized residual series and F_i is the cumulative distribution function of innovation distribution from the model fitted to $x_{i,t}$. Conditional mean $\mu_{i,t}$ was modelled as an ARMA-type model of the form:

$$x_{i,t} = a_0 + \sum_{i=1}^{p} a_i x_{t-i} + \sum_{j=0}^{q} b_j y_{t-j.}$$

We have considered standard GARCH models (Bollerslev, 1986), GJR-GARCH (Glosten et al., 1993), EGARCH (Nelson, 1991), the Spline-GARCH (Engle and Rangel, 2008) and the IGARCH (Engle and Bollerslev, 1986) with *t* Student or GED innovation distribution with υ degrees of freedom. In specific models, the conditional variance equations have 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 y_t is negative and 0 when it is positive,
- Spline-GARCH(*p*,*q*) with *k* knots – $\sigma_t^2 = \tau_k\left(\omega + \sum_{i=1}^{p}\alpha_i y_{t-i}^2 + \sum_{j=1}^{q}\beta_j\sigma_{t-j}^2\right)$, where $\tau_k = \exp(\sum_{i=0}^{k-1}\delta_i(t-t_i)^2)$ is the exponential of a quadratic Spline with k knots $t_0, \dots, t_{k+1}$.
- IGARCH(1,1) – $\sigma_t^2 = \alpha y_{t-1}^2 + \beta\sigma_{t-1}^2$, where $\alpha + \beta = 1$.

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

$$C_{\upsilon,R_t}^t(u_1, \dots, u_d) = \int_{-\infty}^{t^{-1}(u_1)} \cdots \int_{-\infty}^{t^{-1}(u_d)} \frac{\Gamma\left(\frac{\upsilon+d}{2}\right)}{\Gamma\left(\frac{\upsilon}{2}\right)\sqrt{(\pi\upsilon)^d|R_t|}} \left(1 + \frac{\begin{pmatrix} x_1 \\ \vdots \\ x_d \end{pmatrix}^T R_t^{-1} \begin{pmatrix} x_1 \\ \vdots \\ x_d \end{pmatrix}}{\upsilon}\right)^{-\frac{\upsilon+d}{2}} d x_1 \cdots dx_d, \tag{2}$$

where $\Gamma(x) = \int_0^\infty x^{t-1}e^{-x}dx$ is the gamma function, $R_t = diag(Q_t)^{-1/2}Q_t diag(Q_t)^{-1/2}$, where the positive-definite matrix Q_t is described by the following formula:

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

where $\tilde{u}_t = (\tilde{u}_{1,t}, \dots, \tilde{u}_{d,t})$, and $\overline{Q}$ is the empirical correlation matrix of $\tilde{u}_t$, where $\tilde{u}_{i,t} = t_\upsilon^{-1}(u_{i,t})$ for each i and is the $t_\upsilon(\cdot)$ is the t Student cumulative distribution function with υ degrees of freedom. The log-likelihood function is given by the following formula:

$$L_{St}(R_t, \upsilon, \theta) = -T\ln\frac{\Gamma\left(\frac{d+\upsilon}{2}\right)}{\Gamma\left(\frac{\upsilon}{2}\right)} - dT\ln\frac{\Gamma\left(\frac{\upsilon+1}{2}\right)}{\Gamma\left(\frac{\upsilon}{2}\right)} - \frac{d+\upsilon}{2}\sum_{t=1}^{T}\ln\left(1 + \frac{\tilde{u}'_t R_t^{-1}(\theta)\tilde{u}_t}{\upsilon}\right) - \frac{1}{2}\sum_{t=1}^{T}\ln|R_t(\theta)| + \frac{\upsilon+1}{2}\sum_{t=1}^{T}\sum_{i=1}^{d}\left(1 + \frac{\tilde{u}_{i,t}^2}{\upsilon}\right), \tag{4}$$

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

We have used Kendall τ as a measure of dependence. This is a measure of the so-called "concordance". Let $(x_1, y_1), (x_2, y_2), (x_n, y_n)$ be a set of observation pairs generated form 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 discordant 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 discordant. Kendall τ coefficient is the difference between the probability of concordance of observation pairs (x_i, y_i) and (x_j, y_j) and probability of their discordance. 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 *t* copula the Kendall τ coefficient is given by the formula

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

where ρ is the correlation coefficient between X and Y.

For the purpose of our research, it is very important to check how the occurrence of extreme values of one series influences the probability of 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:

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

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

if the limits exist. In the case of the *t* copula they are given by the

Table 2
Results of the estimation of univariate GARCH models – Slovakia, the Czech Republic, Hungary and Greece.
Source: Own calculations.

	Estimate	Std.Error	t-value	p-value
SLOVAKIA: ARMA(1,1)-Spline-GARCH (*t* Student)				
υ	5.066	0.851	5.954	0.000
a_1	0.228	0.117	1.943	0.052
b_1	−0.435	0.101	−4.307	0.000
ω	0.052	0.032	–	–
δ_0	−13.282	3.802	−3.493	0.001
δ_1	16.915	5.115	3.307	0.001
δ_2	−27.124	8.296	−3.270	0.001
α_1	0.163	0.055	2.953	0.003
β_1	0.723	0.113	6.396	0.000
The CZECH REPUBLIC: GARCH(1,1) (*t* Student)				
υ	6.472	1.232	5.252	0.000
ω	1.285	0.737	–	–
α_1	0.074	0.027	2.766	0.006
β_1	0.895	0.039	23.070	0.000
HUNGARY: AR(1)-IGARCH(1,1) (GED)				
υ	0.981	0.0626	–	–
a_0	−0.00228	0.00114	−1.992	0.047
a_1	0.0611	0.000645	94.72	0.000
ω	0.000682	0.000452	–	–
α_1	0.162	0.069	2.317	0.021
β_1	0.838	–	–	–
GREECE: AR(1)-IGARCH(1,1) (GED)				
υ	0.807	0.0455		
a_0	−0.00158	0.000596	−2.647	0.008
gr1 (M)	−19.545	0.000653	2993	0.0000
gr2 (M)	−2.223	0.000444	−5006	0.0000
a_1	0.1055	0.00025	422.7	0.0000
ω	0.000649	0.000452	–	–
α_1	0.191	0.0637	3.004	0.003
β_1	0.809			

formula

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

5. Results

In Table 2 we have presented the results of the estimation of univariate GARCH-type models. With respect to Slovakia and the Czech Republic we have assumed that the distribution of errors follows the Student distribution, while in the case of Hungary and Greece - the GED distribution. We have selected the best models based on their abilities to explain all linear and non-linear dependencies in the data, stability of parameters, and information criteria. As for Slovakia, the Spline-GARCH with three knot-points and deterministic trend have proven to be the best model, while for the Czech Republic the best model was the GARCH(1,1). As regards Hungary it was again the GARCH(1,1) model that performed best, while in the case of Greece it was the IGARCH(1,1) with two explanatory variables in mean equation: dummies indicating jumps in the data. The details of the Box-Pierce test (Box and Pierce, 1970; Ljung and Box, 1978) for standardised residuals and squared standardised residuals are provided in the Appendix A (tables A.1 - A.4) We have observed that the linear and non-linear dependencies were indeed explained by the models (we have noticed some unexplained dependencies only at the 50-th lag in the case of Slovakia and Hungary – see Table A.1 and A.4). Table A.5 contains the results of the Nyblom test of stability of each individual parameter. We observe that the parameters of ARMA model in the case of Slovakia are insignificant which suggests that the linear dependencies may have been changing in the analysed period and maybe could be better explained by the switching-parameters or the structural-break models. However, the GARCH parameters are stable. In the case of Slovakia and Greece the degrees of freedom parameter was not stable, which also suggests that the relationships were not constant over time. Eventually, the constant in the GARCH equation was not stable in the case of Greece.

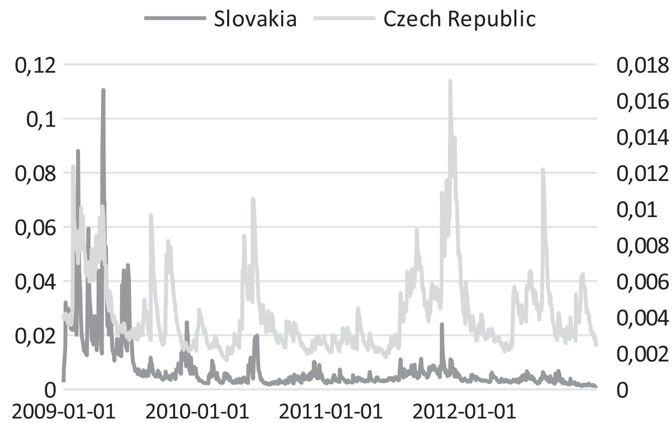

Fig. 2. Conditional variance of the Slovak (left axis) and Czech (right axis) bond spreads.

In Fig. 2 we have presented the estimates of conditional variances of the Slovak and Czech bond spreads. We can see that the values taken by volatility of the Czech series are much lower than the Slovak ones. In both cases volatility grew at the beginning of 2009. As for Slovakia volatility declined gradually, while in the case of the Czech Republic several high peaks were observed. However, the volatility values of the Czech bonds were lower than the Slovak values over the period of analysis, although the relative reaction of volatility to international events was stronger.

In Fig. 3 we have plotted the conditional variances of the Hungarian and Greek bond spreads. Again, the values taken by volatility of the Hungarian bonds were much slower than the values taken by the Greek volatility. In 2009, the dynamics of volatility of the Hungarian bonds was similar to one of other members of the V4 group. In May 2010, the peaks of Hungarian and Greek volatilities overlapped. What is interesting, we can see that the reaction of the Czech volatility to this event is stronger than that of Slovakia. The peaks overlapped also in September and November 2011. The last peak is also reflected in the Slovak spread, but not in the Czech one. A quick and cursory analysis of the charts has shown that the reaction of the Czech volatility to the Hungarian and Greek events might have been relatively stronger and more dynamic than the reaction of the Slovak volatility.

Having estimated the univariate models, we have collected stan-

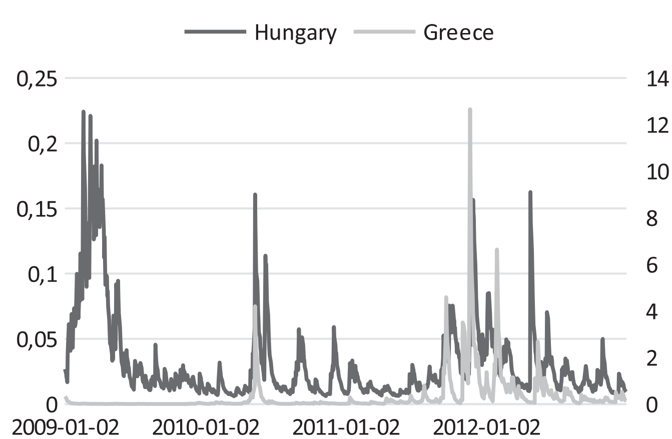

Fig. 3. Conditional variance of the Hungarian (left axis) and Greek (right axis) bond spreads.

Table 3
Estimation results of 4-dimensional copula with conditional matrix R_t explained by DCC(1,1) model – Slovakia, the Czech Republic, Hungary and Greece.
Source: Own calculations

	Estimate	Std. Error	*t*-value	*p*-value
υ	16.183	3,385	–	–
α_1	0.0196	0.004	5.234	0,0000
β_1	0.975	0.005	203.224	0,0000

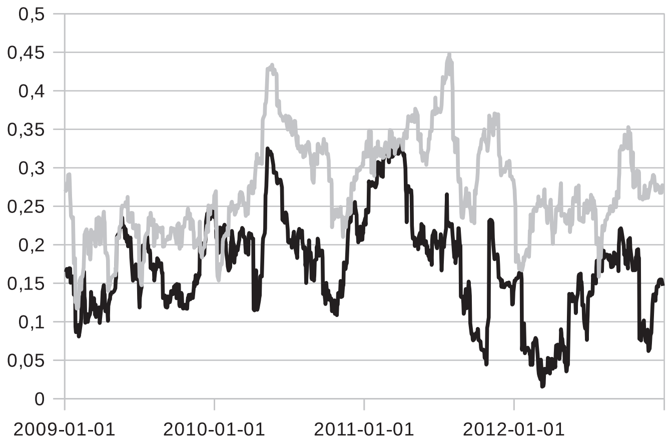

Fig. 4. Kendall's tau: the Czech Republic and Greece (black line) vs the Czech Republic and Hungary (grey line). Source: Own calculations.

dardized residuals, and fitted them to the $u_{i,t}$ series the *t* Student copula with conditional matrix explained by DCC(1,1) model. The estimation results are presented in Table 3.

In Figs. 4 and 5, we have plotted the estimated Kendall's τ (Fig. 4) and tail dependence coefficients (Fig. 5) describing the interrelationships between the Czech Republic and Hungary as well as between the Czech Republic and Greece. First of all, we have observed that both measures – the correlation as well as the probability of tail dependencies – are higher in the case of the Czech-Hungary pair. An interesting pattern can be noticed: the highest peaks in time-variable tail dependence coefficient between the Czech Republic and Hungary are dated: May 2010, July 2011, and the remaining lower two are from November 2011 and October 2012. It hasn't escaped our notice that the first peak corresponds to activation of the first aid package for Greece, while the second to the moment of cutting the nominal value of Greek bonds. The third jump can be associated with the implementation of new regulations in Hungary, concerning foreign-currency debt, as well as with the fifth austerity package implementation in Greece. The fourth jump can be again

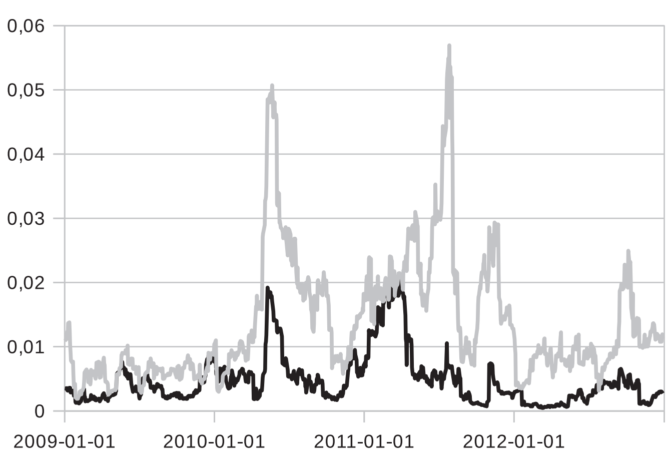

Fig. 5. Tail dependence coefficient: the Czech Republic and Greece (black line) vs the Czech Republic and Hungary (grey line). Source: Own calculations.

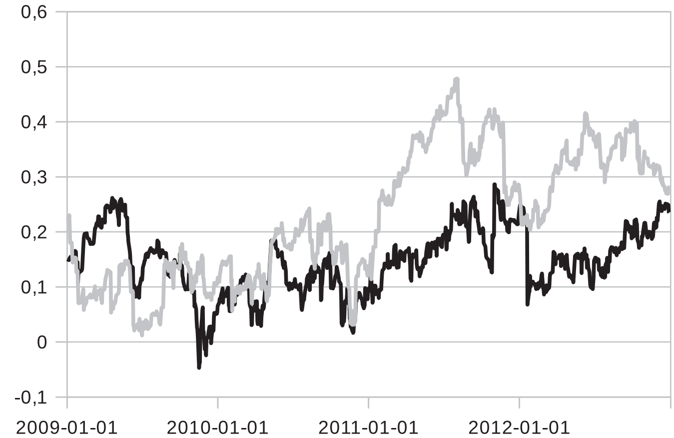

Fig. 6. Kendall's tau: Slovakia and Greece (black line) vs Slovakia and Hungary (grey line). Source: Own calculations.

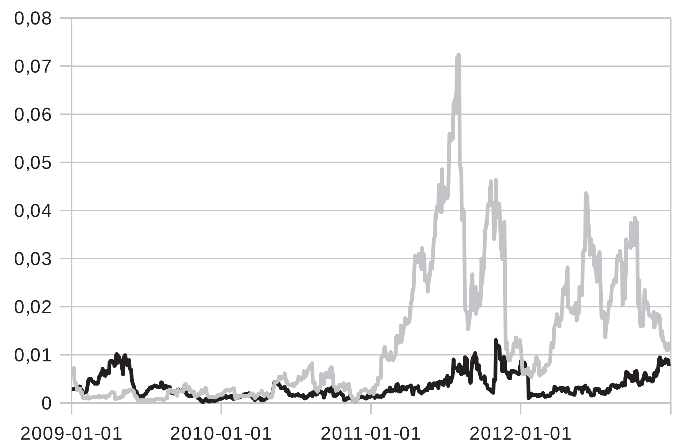

Fig. 7. Tail dependence coefficient: Slovakia and Greece (black line) vs Slovakia and Hungary (grey line). Source: Own calculations.

attributed to the deteriorating situation in Greece during the negotiations of the seventh austerity package that was eventually implemented in November 2012. The same peaks are observed in the case of the Greek-Czech tail-dependence, and an additional one was present in March 2011, when a series of downgrades of Greek bonds took place.

We need to point out that the "Greek events" caused jumps in spreads of both – the Czech Republic and Hungary. If we take a closer look at the dynamics of the Czech and Hungarian spreads (Fig. 1), we notice that they do not behave in a similar way, but at the key "Greek-points" they set off a similar reaction. As the jumps are the tail-events, they are visualised through the lambda coefficient much better than through the Kendall's τ. This confirms the results obtained by Kliber (2014) that the Greek crisis contributed to bolstering of the relationships between the Czech Republic and Hungary.

The situation is different for Slovakia (see Figs. 6 and 7). In the first phase of the crisis Slovakia seemed quite immune to spillovers and crisis transmission. Even in May 2010 no growth in interrelationships between Slovakia and Greece (or between Slovakia and Hungary) was discernible. However, as of November 2010 (when Hungary implemented the unpopular pension policy[2]), the interrelations between

[2] Prior to 2010 the mandatory pension system in Hungary was a two-pillar one: the first was the social security pillar, while the second – obligatory private one. Since November 2010 the system has become "nationalized" – the entrance to the private system is not mandatory and most of the savings were removed from the private pillar to the state one. The legislation, however, imposed firm penalties upon those Hungarians who did not transfer their pension assets back into the state system – see e.g. Maśniak and Lados (2014).

Hungary and Slovakia started to grow. Kendall's τ reached its maximum in August 2011 (0.47). The peak may be attributed to the Greek or Hungarian problems (described later in the text) and to the downgrade of the American credit rating from AAA to AA+ by S & P (as a consequence of which the global markets experienced sharp falls of stock prices). The interrelations remained high until the end of the period under analysis.

The same conclusions can be derived from the plot of tail dependence coefficients. The probability of transmission of extreme events was low throughout the period, but in the case of Hungary it grew rapidly in the mid-2011. The four peaks observed are from August 2011, November 2011, June 2012, and October 2012. The last three are connected with important political events in Greece.

If we compare the situations of the Czech Republic and Slovakia, we can see that in the first crisis period both republics were immune to the crisis transmission from Hungary as well as from Greece. However, already in March the probabilities of the crises transmission grew for Czech Republic. If we analyse the peaks of the "Hungarian" tail dependence coefficient, i.e. the probabilities of the extreme events transmission, it is clear that they do not always overlap. The common peaks are: October/November 2011 and October 2012. For the Czech Republic the first peak was in May 2010, while in the case of the Slovakia it was in August 2011. The first can be attributed to the Greek problems, while the second may have spurred for several reasons.

First and foremost, Fontana and Scheicher (2016), who analysed the possible determinants of the CDS-bond basis change (i.e. the difference between the bond and sovereign CDS spreads), noted that in November 2011 liquidity of the European bond market deteriorated drastically, resulting also in the increase of the haircuts and a negative basis (e.g. Spain and Italy). The decrease of liquidity implies deterioration of credit quality, and if the process was pan-European, it could lead to the increase of the risk of extreme events transmission. As at the end of November the ECB, the Swiss National Bank, the US Federal Reserve, and the central banks of Great Britain, Canada and Japan provided global financial markets with additional liquidity (ECB Press Release, 2011) As a result, the tension on markets relieved, as well as the probability of the extreme events transmission.

Secondly, the growth of probability of extreme events transmission could have been caused by the domestic situation in Greece. At the end of October 2011, at the meeting of the Eurozone members, the agreement on a 50% write-off of Greek sovereign debt held by banks was reached, and another bailout package for Greece was prepared. Surprisingly, the Greek Prime Minister Papandreou, announced that a referendum would be held, in which Greek would decide on the package and austerity measures. The Prime Minister eventually gave up on the idea of the referendum, but this statement could have put pressure on the global market participants, signalling problems in the internal Eurozone policy.

To make things more complicated, the situation in Hungary was also unfortunate. In November 2011 the government was forced to ask for an IMF bailout package (Csaba, 2012). Most probably, however, the growth of extreme events transmission probability was caused by all of the abovementioned events and intensified by the change of the economy rating of the United States from AAA stable to AAA negative.

In Fig. 8. we have presented the estimates of Kendall's τ for the relationships between Slovakia and the Czech Republic. The picture substantiates our previous expectations as the relationships between the two countries grew. The moment of change was the year of 2011. We can speculate that with the effective steps taken by the ECB and the IMF, the situation on the international markets gradually stabilized. In the second half of 2012, international investors, trying to diversify their portfolios, started buying the bonds of mature emerging markets in Europe (see: NBP, 2012, 2013). This pushed the prices of the bonds up and their yields down. The common trends in the CEE markets might have been the reason for the growth of interdependencies among them.

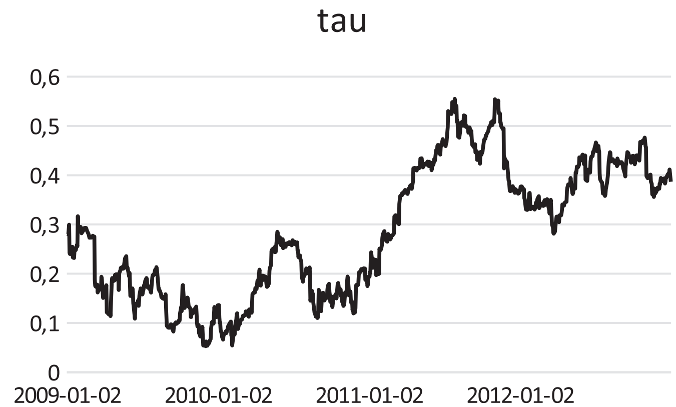

Fig. 8. Kendall's tau: Slovakia and the Czech Republic. Source: Own calculations.

6. Discussion

In this article we have presented an analysis of the changes of interdependencies between the two Central-European economies: the Czech and Slovak Republic by comparing them with two European economies most severely hit by the debt crisis: Greece and Hungary. Our study covers the period of 2009–2012, i.e. the most turbulent period of the Greek and Hungarian crises. The starting and end point of the period in question had not been chosen randomly. The sample period commences in 2009, with the onset of the financial crisis in Europe (and the moment of joining the Eurozone by Slovakia), and ends in 2012, in the year of Greek CDS default.

Let us discuss the possible explanation of the obtained results. In specialist literature, several possible channels of contagion are emphasised The crisis can be transmitted, for instance, through trade (e.g. Glick and Rose, 1999) or financial linkages (e.g. Kaminsky and Reinhart, 2000; Dieder et al., 2008). From the analysis of the trade statistics between Greece and the CEE economies, it is clear that the share of foreign direct investment to Greece of the total FDI (in bn. CZK) was not substantial – see Table 4. Export to Greece over the years 2009–2012 did not exceed 1% in Slovakia (while export to Hungary oscillated around 8% of total export – based on the statistics provided by the CEIC database). Thus, neither export nor import to Greece was high enough to constitute a significant channel for contagion. Since neither the Czech nor Slovak Republic was severely exposed to the Greek debt, the possibility of negative impact of Greek insolvency on the functioning of the Czech and Slovak economies was minor. Therefore, it is not surprising, that the probability of extreme events transmission from the Greek market to the Czech and Slovak markets, expressed through the parameter λ, was very low and grew incidentally

Table 4
Foreign Direct Investment – the Czech Republic as a percentage of total FDI flow in mln CZK.

	FDI flow - inwards		FDI flow - outwards	
	Greece	Hungary	Greece	Hungary
2008	0.24%	0.69%	NA	−0.57%
2009	0.03%	4.33%	NA	−0.10%
2010	0.31%	0.73%	NA	−1.54%
2011	−0.92%	−0.79%	NA	−1.34%
2012	0.02%	0.47%	NA	−0.41%
2013	NA	0.80%	10.23%	0.07%

Note: Data on FDI flows are presented on net bases (capital transactions' credits less debits between direct investors and their foreign affiliates). Net decreases in assets or net increases in liabilities are recorded as credits, while net increases in assets or net decreases in liabilities are recorded as debits. Hence, FDI flows with a negative sign indicate that at least one of the components of FDI is negative and not offset by positive amounts of the remaining components. Source of data; CEIC database.

at the most turbulent moments of the Greek crisis. Such growth can be explained only by the fear and panic on the market (see also Gomez-Puig and Sosvilla-Rivero (2016)). Although the Czech Republic and Slovakia are associated by the investors with the CEE region, they still are members of the European Union. Therefore, in the moments of distress, they respond to the pan-European growth of risk even though the reaction is weak in the period in question.

Therefore, we can say that our results corroborate to some extent the results obtained by Pragidis et al. (2015) who argued that the Greek crisis was seen by investors (even from other peripheral countries) as a unique and independent case In the opinion of the authors, it was the first time since the implementation of the euro currency that the market practitioners began to pay attention to the macro fundamentals of each country and evaluate each EU country's sovereign debt market individually.

The reaction of the Czech and Slovak Republics to the Hungarian crisis also supports the abovementioned conclusion. Trade linkages among the CEE countries are much stronger than between the Central and Mediterranean parts of Europe. Sobański (2015) shows that export within the CEE economies accounted for 20.6% of the total export in 2009, growing to 22.4% in 2012. When it comes to import, the intra-group trade amounted to 17.9% in 2009, and grew to 19.3% of the total import in 2012. The CEE intra-area trade is especially important to Slovakia, while the Czech Republic is more integrated with Western Europe. In terms of debt exposure, neither Slovak nor Czech banks were exposed to the Hungarian debt. Still, the financial markets of the CEE countries are documented to be interrelated (e.g. Olbrys and Majewska, 2013; Buettner and Hayo, 2010; Kliber and Kliber, 2009 and many others). However, neither the Czech Republic nor Slovakia seemed to have reacted dramatically to the Hungarian problems. Probability of the extreme events transmission from Hungary was indeed higher than the one associated with Greece, but nevertheless it did not exceed 6% in the case of the Czech Republic or 7% in the case of Slovakia. Up to 2010 the value of Kendall's τ oscillated around 0.23 for the Czech Republic - Hungary pair, and 0.15 for Slovakia - Hungary. Only later did it grow reaching as much as 0.5.

With the results of our study we may boldly formulate one more conclusion. Bearing in mind that the reaction of the developed Western economies to the Greek crisis was stronger than the reaction of the CEE economies, it is plausible that – despite the fact that the countries had joined the European Union six years ago – they are still considered to be “new members” by investors. Slovakia, although part of the Eurozone, is identified as a mature emerging market rather than a state of the Eurozone.

7. Conclusions

In the article we have presented an analysis of the changes of interdependencies between the two Central-European economies: the Czech and Slovak Republics by comparing them with two European economies most severely hit by the debt crisis: Greece and Hungary. Since Slovakia adopted the euro in 2009, our assumption was that the Greek crisis could have had a bigger impact on Slovakia, while the Hungarian crisis was expected to have affected the Czech Republic. In order to check this hypothesis we have estimated the multivariate copula-GARCH models for the bond spreads of the four economies. The reference spread was the German one. The results have undermined our hypotheses.

First of all, Slovakia seemed to be more immune to crisis transmission throughout the first phase of the crisis. The bond spreads reacted neither to the Greek nor to Hungarian problems. However, the situation changed in 2011 when dependence between the Slovak and Hungarian spreads increased, while the probability of transmission of extreme events from Hungary increased presumably in response to the Greek problems.

In the case of the Czech Republic, until 2010 the dependence between Czech and Greek spreads seemed to be similar to the dependence between the Czech and Hungarian spreads and oscillated around 0.2. From 2010, the interrelation with Hungary enhanced.

The results obtained in our research have corroborated the phenomenon described in Kliber (2014): the CEE countries are more linked as a group, and the linkages became even stronger in reaction to the Greek events. It can be pictured by the behaviour of the time-varying tail-dependence coefficients. With the occurrence of the key events connected with the Greek crisis, their increase was substantially bigger in the pairs of Czech Republic-Hungary and Slovakia-Hungary, then in the case of the pairs of Czech Republic-Greece and Slovakia-Greece. This conclusion is also in conformity with Gjika and Horvath (2013) who confirmed the increase in correlations between the stock markets of the CEE economies during the crisis. In other words, the reaction of the countries to the pan-European problems was the same, as reflected in the growth of linkages between them. Slovakia did not seem to be more prone to the pan-European problems, despite having adopted the euro; furthermore the country does not seem to be associated by international investors with the Eurozone but rather with the mature emerging markets of the Central Europe.

Appendix A

See Tables A.1–A.5.

Table A.1
Q statistics on standardized residuals – the model of Slovak bond spread's volatility. Null hypothesis: no serial correlation.

	Q-statistics on standardized residuals		Q -Statistics on squared standardized residuals	
	Statistics	*p*-value	Statistics	*p*-value
Q(5)	3.780	0.286	3.651	0.302
Q(10)	7.873	0.446	13.547	0.094
Q(20)	17.162	0.512	24.746	0.132
Q(50)	50.549	0.373	87.635	0.000

Table A.2
Q statistics on standardized residuals – the model of Czech bond spread's volatility. Null hypothesis: no serial correlation.

	Q-statistics on standardized residuals		Q -Statistics on squared standardized residuals	
	Statistics	*p*-value	Statistics	*p*-value
Q(5)	3.225	0.665	3.792	0.285
Q(10)	5.345	0.867	4.344	0.825
Q(20)	20.392	0.434	12.039	0.845
Q(50)	52.305	0.385	33.826	0.939

Table A.3
Q statistics on standardized residuals – the model of Greek bond spread's volatility. Null hypothesis: no serial correlation.

	Q-statistics on standardized residuals		Q -Statistics on squared standardized residuals	
	Statistics	*p*-value	Statistics	*p*-value
Q(5)	6.822	0.146	1.238	0.744
Q(10)	7.605	0.574	2.366	0.968
Q(20)	14.810	0.735	6.746	0.992
Q(50)	46.346	0.581	19.109	1.000

Table A.4
Q statistics on standardized residuals – the model of Hungarian bond spread's volatility. Null hypothesis: no serial correlation.

	Q-statistics on standardized residuals		Q -Statistics on squared standardized residuals	
	Statistics	*p*-value	Statistics	*p*-value
Q(5)	11.560	0.021	6.461	0.091
Q(10)	15.559	0.077	8.663	0.372
Q(20)	25.453	0.146	17.643	0.479
Q(50)	77.896	0.005	33.788	0.940

Table A.5
Individual Nyblom statistics for parameters of each model.

Parameter	SLOVAKIA	CZECH	HUNGARY	GREECE
a_O	0.713	0.021	0.245	0.243
a_1	3.671	–	0.173	0.638
b_1	3.858	–	–	–
gr1 (M)	–	–	–	0.005
gr2 (M)	–	–	–	0.423
ω	0.034	0.123	0.086	1.161
α_1	0.032	0.171	0.118	0.468
β_1	0.129	0.144	–	–
υ	0.805	0.271	0.269	1.132
δ_0	0.044	–	–	–
δ_1	0.040	–	–	–
δ_2	0.034	–	–	–

Note: Asymptotic 1% critical value for individual statistics equals 0.75, while the asymptotic 5% value – 0.47. The values greater than the 1% critical value are put in italics.

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