7 SPILLOVER EFFECTS AND FINANCIAL MARKET INTEGRATION IN CEE: A CROSS-ASSET ANALYSIS[1]

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Abstract

This paper analyses the degree of connectedness across equity, foreign exchange, bond, and CDS markets among Central and Eastern European (CEE) countries. By employing a unified Diebold–Yilmaz connectedness framework, univariate GARCH models, and GLS event regressions, we provide a multimarket and multicountry de-sign that documents both cross-country and cross-asset linkages. We simultaneous-ly explore the static and dynamic connectedness, offering a comprehensive picture of the existing patterns of comovements during turbulent periods, including the COVID-19 crisis and the Russia–Ukraine war. Moreover, we highlight the regime-dependent nature of financial integration regarding return and volatility spillovers in the CEE region. The findings indicate that CEE countries are more connected among themselves than with Germany, particularly regarding government bonds and CDS spreads. The estimates reveal that the dynamic connectedness levels increase dur-ing turbulent times, highlighting strong contagion effects, particularly in equity mar-kets. In the case of government bonds, the economic fundamentals prevail over con-tagion effects during crisis periods.

Keywords: *connectedness; equity; foreign exchange; bonds; CDS*

JEL CODE: *D53; F3; F36; G15*

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1. Introduction

In recent decades, financial connectedness has been driven by financial innovation, unconventional monetary policies, and cross-border capital flows, while EU-level regulation has further reinforced integration. Although interconnectedness can support growth, risk-sharing, and financial development, it also amplifies the propagation of shocks, making the monitoring of spillovers essential for financial stability.

This trade-off is especially salient in Central and Eastern Europe (CEE), where integration with the euro area is both a strategic objective and a channel for importing instability in stress episodes. We therefore examine Czechia, Hungary, Poland, and Romania—the region's most developed markets—while excluding Bulgaria and Croatia because their exchange-rate arrangements imply a different monetary–financial transmission mechanism and reduce cross-country comparability.

Since the early 1990s, privatization, liberalization, and stabilization reforms have supported the build-up of market infrastructures. Recent financial and economic disruptions, i.e., the GFC, the ESDC, the COVID-19 pandemic, the tapering of asset purchases by major central banks in 2021, and the multiple crises generated by the war in Ukraine in 2022, have driven different degrees of volatility spillovers among developed financial markets (Diebold and Yilmaz, 2014; Louzis, 2015; Hu et al., 2024). In addition, the extant literature uncovers that some markets appear to be the largest transmitters of volatility spillovers to other financial markets (Camlica et al., 2017; Bevilacqua, 2018; Chang and Chang, 2023). Even though there are studies examining cross-country spillovers in the CEE area, most of them have focused on a particular market (Kočenda and Moravcová, 2018; Karkowska and Urjasz, 2021)[6]. While the existing literature has extensively analysed financial interdependencies, most studies either focus on a single asset class (particularly equities), restrict attention to developed markets, or analyse emerging European markets only in isolation, without jointly considering equity, foreign exchange, government bond, and sovereign CDS markets, nor the recent sequence of shocks associated with the COVID-19 pandemic and the war in Ukraine. By contrast, relatively little is known about how these different market segments in CEE co-move with each other and with a core euro area benchmark (Germany). Furthermore, few studies manage to precisely identify the source of shocks, specifically, which CEE country acts as the primary transmitter, and to fully capture the structural regime shifts induced by recent major crises.

Against this background, our paper fills a clear gap in the literature on emerging European markets by offering an integrated view of financial connectedness in Central and Eastern Europe. We address four tightly related questions: (1) how strong is cross-country connectedness across equity, foreign exchange, government bond, and sovereign CDS markets in CEE, and how closely are these markets linked to Germany; (2) how do asset classes interact within each CEE country, and which segments act as net transmitters or receivers of shocks at the country level; (3) how does connectedness evolve over time and respond to major turbulent episodes, including the GFC, the ESDC, the COVID-19 pandemic, and the Russia–Ukraine conflict; and (4) to what extent are spillover patterns driven by co-movements in returns, by volatility, or by both.

To answer these questions, we build a unified Diebold–Yilmaz connectedness framework that jointly covers Czechia, Hungary, Poland, and Romania, together with Germany, and spans 2006–2024 across equity indices, exchange rates, long-term government bond yields, and sovereign CDS spreads. We extend the standard return-based analysis by constructing an analogous volatility-based specification (by using a univariate GARCH model). To capture the regime-dependent nature of integration, we recompute the static total spillover index for five distinct subperiods (GFC, ESDC, the pre-COVID, COVID-19, and the initial phase of the Russia–Ukraine

[6] *A more detailed literature review is provided in Section 2.*

war). We then move beyond descriptive time variation by estimating GLS event regressions with AR(1) errors, which formally test whether these crises are associated with statistically and economically meaningful shifts in connectedness. Finally, we decompose the total spillover index into country-specific contributions for each market.

The remaining of the paper is constructed as it follows: Section 2 analyses the background and revises the literature, Section 3 and 4 explain the methodological approach and the data used, Section 5 discusses the results. We conclude in Section 6.

2. Literature review

Significant volatility spillovers generated during the GFC have spurred a considerable body of research investigating financial market interdependence. Most of the papers have focused either on financial stress transmission among different asset markets within the same country, or on cross-country spillovers. Regarding CEE financial market connectedness, research is quite scarce. Most of the studies in this area have focused on equity market connectedness and overlooked the issue of cross-asset spillovers. Moreover, there is a lack of the volatility analysis in the light of recent significant disruptions in the financial markets, i.e., the post-pandemic asset tapering by major central banks, and the Russia–Ukraine war. Furthermore, while providing significant insights, the extant literature has also documented conflicting results.

The first body of research has analysed cross-asset spillovers within the same country, e.g., foreign exchange, bond, and equity markets (Camlica et al., 2017; Chang and Chang, 2023; Hu et al., 2024), while the second one has focused on cross-country spillovers for certain asset markets (Diebold and Yillmaz, 2009, 2014; Dias et al., 2020; Baruník et al., 2020; Karkowska and Urjasz, 2021; Aloui et al., 2022; Yousaf et al., 2023; Cheng et al., 2023; Lang et al., 2024). Some of the studies have extended the analysis, by investigating both cross-asset and cross-country spillovers during extreme risk events (Louzis, 2015; Wu et al., 2023; Mensi et al., 2023; Chen et al., 2023; Yang et al., 2023).

Previous studies dealing with cross-asset spillovers in the same country have not addressed the CEE region. However, there is a consistent body of literature examining cross-country spillovers in the CEE area. Most of these studies have focused on a particular market, such as equities (Reboredo et al., 2015; Nițoi and Pochea, 2016; Hurduzeu et al., 2021; Chirilă and Chirilă, 2022; Samitas et al., 2022; Ciocîrlan and Nițoi, 2023; Dias et al., 2023;), government bonds (Karkowska and Urjasz, 2021; Stoupos and Kiohos, 2022), or FX markets (Andrieș et al., 2016; Kočenda and Moravcová, 2018; Albrecht and Kočenda, 2024). Most of these studies have emphasized a moderate integration of CEE equity markets, higher spillovers during turbulent periods, and idiosyncratic government bond connectedness. Only a few papers have broadened the analysis to include several asset classes (Bevilacqua, 2018; Hung, 2019; Skrinjaric and Sego, 2019; Živkov et al., 2023).

Examining the volatility spillovers among equity, currency, and credit markets, across developed European countries and developing CEE countries, Bevilacqua (2018) found that the equity market is the main transmitter of volatility among these countries, with an important role played by developed equity markets. Hung (2019) analysed volatility spillover effects between exchange rates and equity returns in CEE countries during the 2000–2017 period. The study unveiled unidirectional spillovers of volatility from the equity market to the FX market in Poland, during turbulent times, and non-persistent volatility spillovers between them in Czechia, Romania, and Croatia, in the post-crisis period. There is also evidence of bidirectional volatility spillovers among the CEE FX markets, while the Czech exchange market has an important impact on the other FX markets. In the same vein, Skrinjaric and Sego (2019) focused on the Central, Eastern and South-Eastern European equity and currency markets and their spillover indices. They found that Slovenian and Czech markets were net transmitters of shocks in the system, whereas Croatian

and Ukrainian markets were receivers of shocks from others. Živkov et al. (2023) explored the volatility transmission between stock and forex markets in East European countries and concluded that stock indices with a relatively low number of stocks, such as the Hungarian BUX and Romanian BET, experienced a quite increased volatility spillover from the currency market. The impact of the Russian invasion of Ukraine on the stock market connectedness was analysed by Ciocîrlan and Nițoi (2023). They uncovered increased spillover effects for CEE stock markets during the invasion, noting that it caused a transitory increase in stock market connectedness. Dias et al. (2023) examined the co-movements of the CEE stock markets during the pandemic shock and the Russian invasion of Ukraine and unveiled a significant impact on these regional stock markets.

Our study is complementary to that conducted by Louzis (2015). He conducted the analysis for the euro area, while we add to this by exploring CEE countries. These four countries have a common trait given by their transition process to a market economy. Moreover, we extend the approach of Louzis (2015) by including the sovereign CDS market in the analysis, and by taking into consideration recent significant disruptions in the financial markets, i.e., the post-pandemic asset tapering by major central banks, and the Russia–Ukraine war. The growing importance of the sovereign CDS market argues for the need to study its contagion patterns, alongside other asset markets.

3. Research methodology

2.1 Cross-variance decompositions method (Diebold and Yilmaz)

We compute our spillover indices using the cross-variance decompositions method proposed by Diebold and Yilmaz (2009) and further developed in Diebold and Yilmaz (2014). To overcome the shortcomings of the standard Cholesky approach, which depends on variable ordering, Diebold and Yilmaz (2014) proposed the generalized variable decomposition. We also resort to the generalized variable decomposition process that is indifferent to variable ordering and allows for shock correlations. According to this, the $D^{gH} = [d| \quad |nk^{gH}]H$ -step generalized variance decomposition matrix has the following entries:

$$D^{gH} = [d| \quad |nk^{gH}]Hd_{nk}^{gH} = \frac{\sigma_{kk}^{-1}\sum_{h=0}^{H-1}(e_n'A_h\sum e_k)^2}{\sum_{h=0}^{H-1}(e_n'A_h\sum A'e_n)}, H = 1,2 \ldots, \quad (1)$$

where e_k is a selection vector that has one as the k-th element and zeros for the rest, $A_h$is a matrix of coefficients that multiply the lagged shock vector in the moving-average VAR, Σ is the covariance matrix of the shock vector, and σ_{kk} is Σ's Kth element. Since the rows of the D^{gH} do not necessarily add to 1, we compute the connectedness measures on a modified $\tilde{D}_{nk}^{gH}=[\tilde{d}_{nk}^{gH}]$ matrix, where $\tilde{d}_{nk}^{gH} = \frac{d_{nk}^{gH}}{\sum_{k=1}^{N} d_{nk}^{gH}}$.

Using the newly defined $\tilde{d}_{nk}^{gH}$, we describe the pairwise directional connectedness from an n to a k variable as:

$$\varphi_{n\leftarrow k}^{gH} = \tilde{d}_{nk}^{gH} \quad (2)$$

If $\varphi_{n\leftarrow k}^{gH}$ is not equal to $\varphi_{k\leftarrow n}^{gH}$, then there are $\frac{N^2-N}{2}$ net pairwise connectedness measures calculated as $\varphi_{nk}^{gH} = \varphi_{n\leftarrow k}^{gH} - \varphi_{k\leftarrow n}^{gH}\varphi_{n\leftarrow k}^{gH} - \varphi_{k\leftarrow n}^{gH}$.

Based on this normalized pairwise directional measure, we can derive several connectedness measures. The share of forecast error variance of variable n received from all the other variables is given by:

$$\varphi_{n\leftarrow all}^{gH} = \frac{1}{N}\sum_{\substack{k=1 \\ k\neq n}}^{N} \tilde{a}_{nk}^{gH} \tag{3}$$

$\varphi_{n\leftarrow all}^{gH} = \frac{1}{N}\sum_{\substack{k=1 \\ k\neq n}}^{N} \tilde{a}_{nk}^{gH}$ Conversely, k's contribution to all the other variables' forecast error variance is:

$$\varphi_{all\leftarrow k}^{gH} = \frac{1}{N}\sum_{\substack{n=1 \\ n\neq k}}^{N} \tilde{a}_{nk}^{gH} \tag{4}$$

$\varphi_{all\leftarrow k}^{gH} = \frac{1}{N}\sum_{\substack{n=1 \\ n\neq k}}^{N} \tilde{a}_{nk}^{gH}$ Similar to the previous stance, the net total directional connectedness is expressed as $\varphi_{n}^{gH} = \varphi_{all\leftarrow n}^{gH} - \varphi_{n\leftarrow all}^{gH}$. There is a number N of net total directional connectedness measures, corresponding to the investigated variable sets for each country of the sample.

Finally, the sum of the *to* row and *from* column of the $\tilde{D}_{nk}^{gH}=\left[\tilde{a}_{nk}^{gH}\right]$ variance decomposition matrix gives the total connectedness:

$$\varphi^{H} = \frac{1}{N}\sum_{\substack{n,k=1 \\ n\neq k}}^{N} \tilde{a}_{nk}^{gH} \tag{5}$$

Furthermore, in the dynamic connectedness analysis, we follow Diebold and Yilmaz (2012) and use a rolling estimation window of 200 daily observations, a lag length of 2 in the underlying VAR model, and compute all spillover measures from the 10-step-ahead generalized forecast error variance decomposition (h = 10).

2.2 Volatility decomposition

To obtain a time-varying measure of uncertainty for each market, we complement the analysis based on daily returns with a volatility-based specification. Let $r_{i,t}^{(m)}$ denote the daily log return of market $m \in \{\text{equity, foreign exchange, bond, CDS}\}$ in country i at time t, as defined in the data section. We model each return series with a univariate GARCH(1,1) process.

The return is decomposed into a conditional mean and an innovation term:

$$r_{i,t}^{(m)} = \mu_i^{(m)} + \varepsilon_{i,t}^{(m)} \tag{6}$$

where $\mu_i^{(m)}$ is a constant (or a low-order autoregressive component, if needed) and $\varepsilon_{i,t}^{(m)}$ is the mean-zero disturbance term. The innovation is assumed to have a conditionally heteroskedastic variance:

$$\varepsilon_{i,t}^{(m)} | F_{t-1} \sim \left(0, h_{i,t}^{(m)}\right) \tag{7}$$

where F_{t-1} denotes the information set available at time $t-1$, and $h_{i,t}^{(m)}$ is the conditional variance.

The dynamics of the conditional variance follow a GARCH(1,1) specification:

$$h_{i,t}^{(m)} = \omega_i^{(m)} + \alpha_i^{(m)} \left(\varepsilon_{i,t-1}^{(m)}\right)^2 + \beta_i^{(m)} h_{i,t-1}^{(m)} \tag{8}$$

with $\omega_i^{(m)} > 0$, $\alpha_i^{(m)} \geq 0$, $\beta_i^{(m)} \geq 0$ and $\alpha_i^{(m)} + \beta_i^{(m)} < 1$ to ensure a positive and covariance-stationary variance process. The parameters $\omega_i^{(m)}$, $\alpha_i^{(m)}$ and $\beta_i^{(m)}$ are estimated by maximum likelihood under a chosen conditional distribution for the errors (Gaussian or Student-t).

The estimated sequence $\left\{h_{i,t}^{(m)}\right\}$ provides a daily measure of conditional volatility for each country-market pair. To stabilize the variance and reduce skewness, we work with the logarithm of the conditional variance:

$$v_{i,t}^{(m)} = log\left(h_{i,t}^{(m)}\right) \tag{9}$$

Stacking the log-variance series for all markets and countries yields the vector:

$$v_t = \left(v_{1,t}^{(1)}, \ldots, v_{1,t}^{(M)}, \ldots, v_{I,t}^{(1)}, \ldots, v_{I,t}^{(M)}\right)' \tag{10}$$

which is used as the volatility-based input in the connectedness analysis. The same VAR specification and generalized forecast error variance decomposition described in the previous subsection are then applied to v_t, allowing us to compute the Diebold-Yilmaz spillover measures in terms of conditional volatility.

4. Data

We conduct our analysis using daily closing prices of four asset classes in Czechia, Hungary, Poland, and Romania, for a period from May 22, 2006 to March 1, 2024. The sample totals 4,639 observations. We use nominal daily returns (and the corresponding daily volatility measures) without inflation adjustment, since inflation is observed at a much lower frequency and varies only gradually relative to daily price fluctuations, making such an adjustment neither feasible nor informative for high-frequency spillover dynamics.

We present a comprehensive view of CEE financial markets integration by considering the equity, foreign exchange, government bonds and sovereign CDS markets. We selected the representative equity market indices, PX Index, BUX Index, WIG Index and BET Index. For the FX market, we used the daily exchange rates of domestic currencies, i.e., Czech koruna, Hungarian forint, Polish zloty and Romanian leu against the euro. Given our interest in sovereign long-term spillover effects, we focused on the 10-year government bond yields of CEE countries.

Furthermore, we opted for 5-year senior sovereign CDS spreads, as they represent the most liquid type of CDS contract. Additionally, to compute cross-country spillovers, we employed wider market proxies, such as Germany's DAX index, its bond yield and CDS rate, and the euro/U.S. dollar exchange rate. We use Germany as a proxy following other works that acknowledge its role as a driving force in EU financial markets (Cieślik and Wciślik, 2020; Demiralay and Bayraci, 2015).

All data were extracted from the Refinitiv Datastream. Missing observations in the data series were adjusted by repeating the closing value of the previous day. The series were transformed by calculating first log differences.

5. Results

5.1. Cross-country financial markets connectedness

5.1.1. Static connectedness

Using the spillover method, we examine the cross-country static connectedness across equity, foreign exchange, government bond, and sovereign CDS markets, analyzing both spillovers in returns (Table 1) and those in volatility (Appendix A). We also construct a network diagram to visually represent the relationship between the markets and identify their role as either transmitters or receivers (Appendix B). Furthermore, we disaggregate the TSI by periods to assess whether this connectedness is regime-dependent (Appendix C).

Return Connectedness Analysis. In the first step, we focus on examining the static connectedness based on daily returns. The results show that the degree of integration varies significantly across the four asset classes.

The equity market stands out as the most integrated segment, with a TSI of 54.2%, implying that over half of the forecast error variance is driven by cross-border shocks. Sovereign CDSs follow with 33.9%, whereas the FX and government bond markets show much weaker links, at 25.2% and 11.5% respectively (Table 1).

Table 1. Cross-country return connectedness

Equity market connectedness

	DAX	PX	BUX	WIG	BET	**From**
DAX	44.0	15.5	13.9	18.1	8.4	56.0
PX	15.5	42.2	14.6	16.0	11.6	57.8
BUX	14.6	15.6	45.9	16.1	7.9	54.1
WIG	17.8	16.1	15.1	43.0	7.9	57.0
BET	11.2	15.1	9.6	10.2	53.9	46.1
To	59.1	62.4	53.1	60.5	35.8	270.9
Net	3.1	4.6	-1.0	3.5	-10.3	**Total**
TSI						54.2%

Foreign exchange market connectedness

	EUR/USD	CZK/EUR	HUF/EUR	PLN/EUR	RON/EUR	**From**
EUR/USD	86.3	2.5	5.0	5.4	0.8	13.7
CZK/EUR	2.0	74.2	8.6	14.1	1.0	25.8
HUF/EUR	3.7	7.9	65.9	17.1	5.4	34.1
PLN/EUR	3.9	12.3	16.1	62.9	4.8	37.1
RON/EUR	0.5	1.2	7.1	6.4	84.7	15.3

To	10.1	24.0	36.9	43.0	11.9	126.0
Net	-3.6	-1.8	2.8	5.9	-3.4	**Total**
TSI						25.2%

Government bond yield connectedness

	Germany	Czechia	Hungary	Poland	Romania	**From**
Germany	99.0	0.1	0.4	0.4	0.1	1.0
Czechia	0.1	89.3	3.4	6.6	0.6	10.7
Hungary	0.3	2.1	79.2	16.9	1.5	20.8
Poland	0.3	3.7	14.6	80.7	0.7	19.3
Romania	0.1	0.6	2.8	2.1	94.4	5.6
To	0.8	6.5	21.2	26.0	2.9	57.4
Net	-0.2	-4.2	0.4	6.7	-2.7	**Total**
TSI						11.5%

Sovereign CDS rates connectedness

	Germany	Czechia	Hungary	Poland	Romania	**From**
Germany	88.3	2.1	3.6	3.7	2.3	11.7
Czechia	1.8	68.1	9.5	11.6	9.0	31.9
Hungary	1.9	6.8	57.0	17.8	16.5	43.0
Poland	2.1	8.6	18.8	57.6	12.8	42.4
Romania	1.5	7.4	17.7	14.2	59.2	40.8
To	7.3	24.9	49.6	47.2	40.6	169.7
Net	-4.4	-7.0	6.6	4.8	-0.2	**Total**
TSI						33.9%

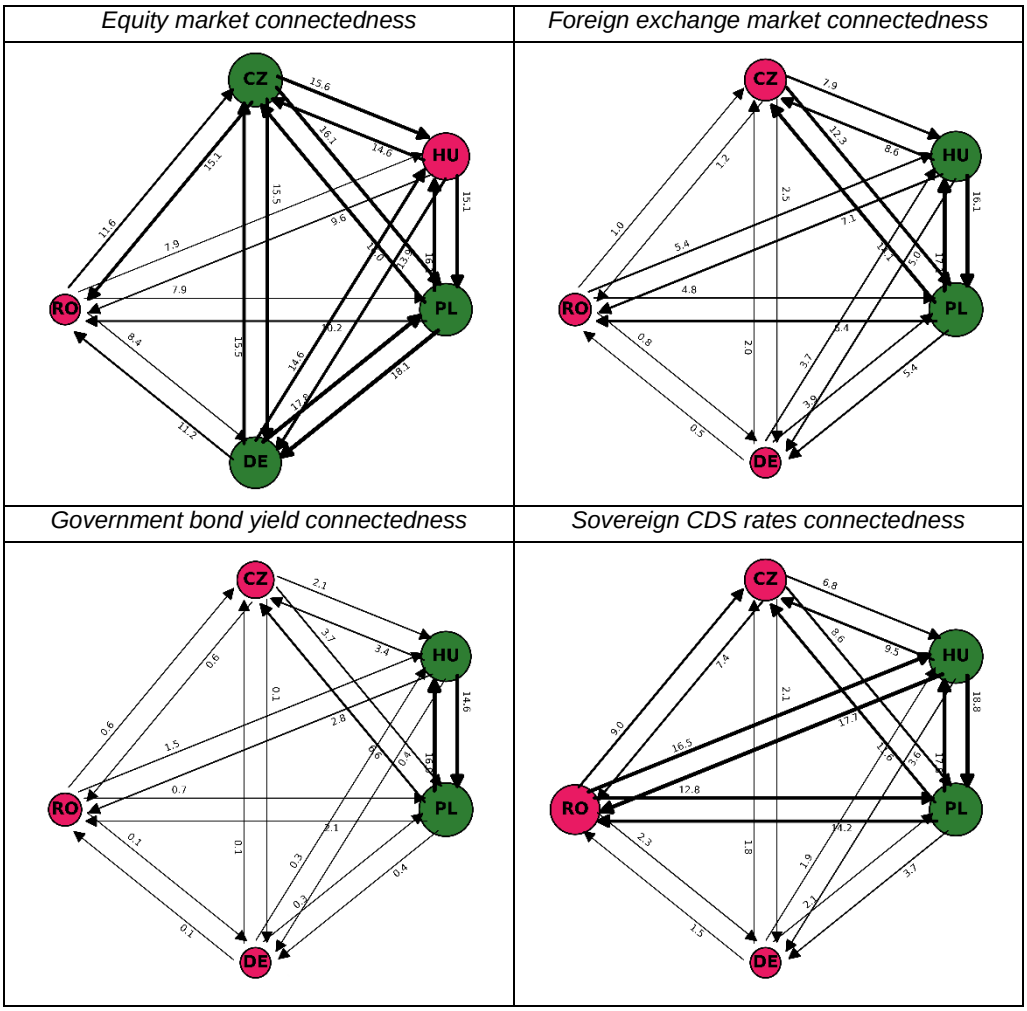
Regarding the equity market, the results indicate a strong but asymmetric transmission mechanism. While shocks originating *From others* explain between 46.1% and 57.8% of the forecast error variance for individual markets, the sources of these spillovers are concentrated. Poland and Czechia act as the dominant net transmitters, generating 60.5% and 62.4% of the volatility shocks to the system, respectively. Moreover, Germany emerges as a key transmitter of spillovers to Poland, Czechia, and Hungary, highlighting a higher degree of integration with the German equity market (Figure 1). Conversely, the BET Index manifests a weaker connection with other markets, functioning primarily as a net receiver (transmitting only 35.8%). This decoupling appears driven by structural factors, such as lower capitalization compared to Poland and Czechia, consistent with the copula-based findings of Reboredo et al. (2015).

We see a different pattern in the FX and government bond markets, where domestic factors seem to outweigh cross-border shocks. The TSI for the FX market stands at just 25.2%, indicating a lower level of integration compared to equity markets. Specifically, own-country shocks account for between 62.9 and 86.3% of the conditional variance of exchange rate changes, while the highest value of shocks received *From others* reaches only 37.1% (in the case of Polish zloty). Furthermore, integration with the German FX market is marginal, contributing only 10.1% to the system's volatility shocks. This confirms the findings of Bevilacqua (2018), who argues that equity markets in Europe are more integrated than FX markets. This low integration can be attributed to the diversity of exchange rate regimes. Currencies with tightly administered rates, such as the Romanian leu and Czech koruna, act as net receivers, whereas the more volatile Hungarian forint and Polish zloty generate most of the observed regional spillovers (Figure 1).

The government bond market appears to be largely isolated, with own-country shocks accounting for between 79.2% and 99% of the conditional variance. An important finding here is the regional clustering effect, where CEE bond markets show a mild connectivity among themselves but

remain decoupled from the German market. These outcomes highlight the asymmetry between Germany and the emerging countries, with the low degree of integration being a consequence of the divergent economic fundamentals. Our results are in line with Karkowska and Urjasz (2021), who also reveal that government bond yields in CEE countries are more connected with each other than with European sovereign bond markets. This reflects a lack of sovereign integration and raises questions regarding the adoption of the euro currency in these countries.

Figure 1. Network diagram for cross-country return connectedness



Note: Node colours and sizes, as well as arrow thickness, are based on the static Diebold–Yilmaz spillover measures. Green nodes denote net transmitters of shocks (NET = TO − FROM > 0), while red nodes denote net receivers (NET < 0). The size of each node is proportional to its total directional spillover To index, so larger nodes transmit stronger shocks to the rest of the system. The thickness of each arrow is proportional to the corresponding bilateral spillover coefficient (in %), with arrows pointing from the source market to the destination market; when shown, the numeric label on each arrow reports this underlying connectedness value.

Finally, the sovereign CDS market acts as an intermediate transmission channel. The connectivity here is higher than in the FX or government bond markets, reinforcing the risk patterns observed in equities. Hungary and Poland again emerge as the primary net transmitters of sovereign credit risk (with *To others* values exceeding 40%), suggesting that stress in these markets propagates rapidly to the rest of the region. Germany, by contrast, acts largely as a receiver. This evidence highlights that while financial integration is robust in riskier asset classes like equities and CDSs, the foundational markets of bonds and currencies remain driven by local monetary and fiscal fundamentals. These results align with Tiwari et al. (2018), who also found that equity and sovereign CDS markets represent the largest sources of spillovers across asset classes.

Volatility Connectedness Analysis. In a second step, we replicate the static connectedness analysis using volatility rather than daily returns (Appendix A). For each market and country, we estimate a univariate GARCH(1,1) model and employ the logarithm of the conditional variance within the Diebold–Yilmaz framework. The volatility-based spillover tables confirm that cross-country contagion remains present, but it is weaker than in returns and exhibits a different configuration. The resulting indices equal 39.5% for equities, 12.1% for foreign exchange, 10.5% for government bonds, and 22.0% for CDSs. Hence, cross-border transmission is still clearly detectable, yet smaller in magnitude when measured through volatility, while the market ranking is preserved: equities remain the most integrated segment and government bonds the least integrated one.

Equity volatilities display the strongest cross-country linkages. Between 29.4% and 44% of each national volatility series' forecast error variance is explained by shocks originating in the other markets, and Poland stands out as the dominant net transmitter, sending 52% of its volatility shocks to the rest of the system. Germany also plays a non-negligible transmitting role, whereas Czechia, Hungary, and Romania absorb more volatility than they export; for Romania, domestic shocks remain predominant, with 70.6% on the diagonal and only 29.4% explained by the other markets. By contrast, volatility spillovers in FX and government bonds are modest and largely consistent with segmentation: own-country shocks account for 79.3–97.5% of exchange-rate volatility and 84.9–94.7% of bond-yield volatility, the "From others" column rarely exceeds 20%, and net positions are small in absolute terms. Poland and Hungary appear slightly more integrated in both segments, with their currencies and yields transmitting and receiving somewhat more volatility than those of Germany, Czechia, and especially Romania, but overall, these markets remain anchored in domestic monetary and fiscal conditions. This pattern is consistent with Karkowska and Urjasz (2021), who identify CEE markets as a local source of volatility exports, and with Stoupos and Kiohos (2022), who document heterogeneous and disparate integration across non-euro CEE bond markets.

Finally, the CDS volatility table occupies an intermediate position between equities and the more segmented FX and bond markets. The TSI of 22.0% implies that roughly one fifth of CDS volatility is imported from abroad, with Hungary and Poland emerging as clear net transmitters of sovereign credit-risk volatility (net spillovers of about 11–12 percentage points), while Germany, Czechia, and Romania behave mainly as receivers.

TSI event analysis. To assess regime dependence, we recompute the static Diebold–Yilmaz total spillover index for five subperiods—the GFC, the ESDC, Pre-COVID-19, COVID-19, and the Russia–Ukraine war—separately for returns and volatilities in the four markets (equity, foreign exchange, government bonds, and sovereign CDS). The results in Table 2 and Appendix C reveal pronounced time variation in integration: for every market, and for both return- and volatility-based measures, spillovers are lowest in the Pre-COVID window, while each crisis episode is associated with a clear increase in the TSI. This pattern indicates that cross-country and cross-asset linkages in the CEE region are strongly regime-dependent and intensify under stress.

Equity connectedness is consistently high and synchronized, reaching a peak of 68.9% during COVID-19. FX spillovers also rise markedly in turbulent periods (33.1%–36.9%), yet fall to only 12.1% in the Pre-COVID regime, implying greater scope for currency diversification in tranquil times (Table 2).

Table 2. Disaggregated TSI by periods/ Event analysis

	GFC	ESDC	Pre-COVID-19	COVID-19	WAR
Total Spillover Index - Return					
Equity market	61.7%	57.7%	41.7%	68.9%	47.9%
Foreign exchange market	35.4%	33.1%	12.1%	36.9%	23.5%
Government bond market	16.0%	11.3%	13.1.%	33.3%	31.5%
Sovereign CDS market	59.6%	59.1%	17.4%	31.0%	29.8%

Bond and CDS markets, however, display an asymmetric crisis profile. Sovereign CDS spillovers dominate during the GFC and the ESDC (around 60%), reflecting the centrality of credit risk in those episodes, whereas government bonds become a more important conduit in the most recent shocks, with spillovers roughly doubling during COVID-19 and remaining elevated during the war. This suggests a shift in transmission channels: earlier crises were propagated primarily through sovereign credit and equity, while the pandemic and the Russia–Ukraine conflict increased the systemic role of CEE government bond markets.

Volatility-based indices reinforce this interpretation and underline the exceptional character of the COVID-19 shock (Appendix C). Equity volatility spillovers reach a record 65.2% during the pandemic, and FX volatility peaks at 38.5%. Bond volatility spillovers also rise sharply, tripling during COVID-19 to 32.8% and staying high in the war period, whereas CDS volatility is highest in the earlier crises (44.6%–46.1%). Overall, the subperiod evidence delivers three robust messages: crisis windows uniformly generate higher spillovers than the tranquil regime, the market composition of spillovers is episode-specific—equity and CDS dominating the GFC/ESDC, bonds and FX gaining relative prominence in COVID/war—and COVID-19 emerges as the broadest and most synchronized shock, particularly in volatility. Taken together, these findings show that CEE financial integration is not monotonic but conditional on regime and shock type, thereby sharpening the interpretation of our full-sample static and dynamic connectedness results.

5.1.2 Dynamic connectedness

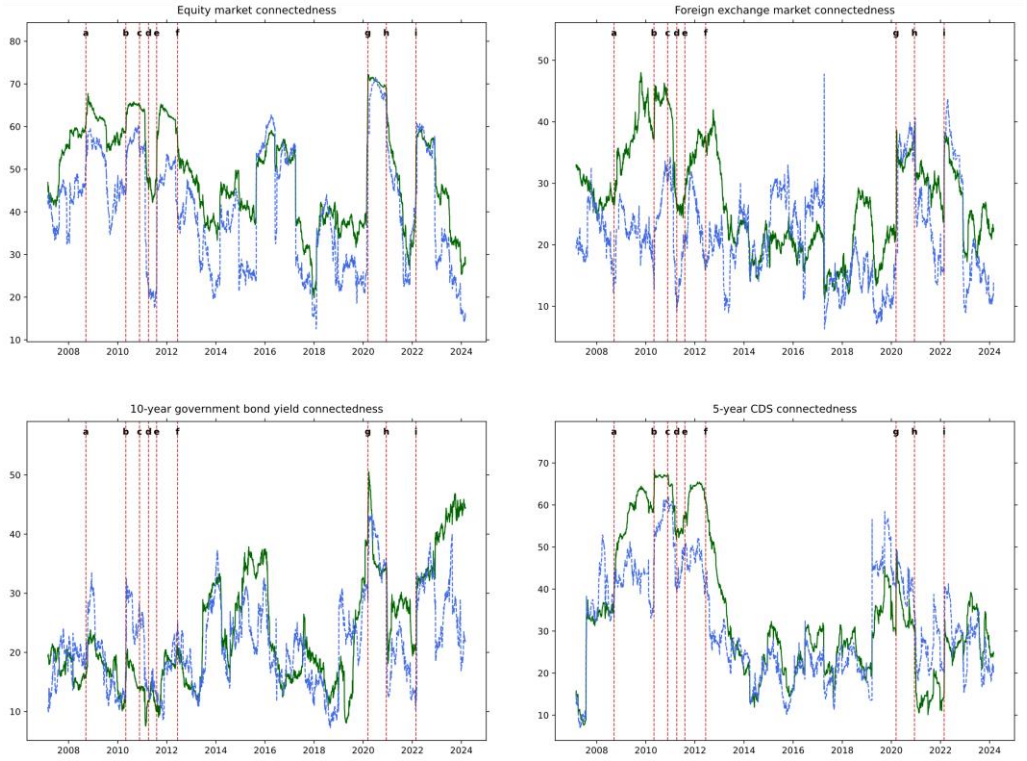
Furthermore, we investigate the dynamic connectedness and explore the time-varying characteristics of spillovers, both for spillovers in returns and those in volatility. Figure 2 depicts the time-varying connectedness indices corresponding to the four financial markets, by overlapping the connectedness indices with a few turbulent events.

TSI return connectedness. Figure 2 indicates that equity-market connectedness stayed elevated throughout 2008–2012. It spiked after Lehman's collapse and intensified during the Greek, Spanish, and Italian bailouts. Draghi's "whatever it takes" pledge briefly eased tensions, but connectedness surged to its sample peak above 70% when the pandemic was announced, then fell sharply after successful vaccine trials. Russia's invasion of Ukraine later pushed the index back toward 60%, confirming that equity integration strengthens in turbulent times.

FX connectedness is lower, exceeding 50% only during the GFC and rising again in the sovereign debt crisis; until the pandemic it averaged about 20%. Unlike equities, neither COVID-19 nor the Ukraine war generated increases above GFC levels, underscoring the more endogenous nature

of exchange rates and supporting the view that currencies are less integrated than equities, in line with (Bevilacqua, 2018).

Figure 2. Time-varying cross-country return and volatility connectedness in the CEE



Note: (a) Lehman Brothers default. (b) Greek bailout. (c) Ireland requests assistance. (d) Portugal requests assistance. (e) Contagion reaches Italy and Spain. (f) Spanish bailout. (g) World Health Organization declares the outbreak of a pandemic. (h) COVID-19 vaccine successful trial results announcement. (i) Russia invades Ukraine. The green line represents the time-varying connectedness indices for spillovers in returns, while the blue line corresponds to those in volatility.

Bond-yield connectedness was limited until 2014: neither the GFC nor early bailouts produced strong contagion, suggesting that fundamentals dominated. Spillovers increased after 2014, consistent with the stabilizing effects of the ECB's quantitative easing programmes, but the pandemic triggered unprecedented yield spillovers and the Ukraine shock lifted the index to around 45%.

CDS spreads display a different profile, closely tracking the GFC and the European debt crisis. Lehman and subsequent bailouts, especially Greece and Portugal, produced large jumps, followed by a decline after the Spanish bailout until 2020, when COVID-19 and the war renewed contagion. CDS connectedness remains higher than bond connectedness despite reflecting similar sovereign risk, highlighting the value of multiple sovereign-risk indicators.

TSI volatility connectedness. Adding the volatility-based TSI to Figure 2 yields a similar time profile to the return-based measure, but with a generally lower average level. In equities, the two

series move closely together, as return-based spikes are mirrored by volatility surges, while volatility connectedness stays relatively subdued in tranquil periods, suggesting more persistent and inertial linkages.

The divergence is larger in FX and bonds. Although the return-based TSI rises during the GFC, ESDC, COVID-19, and the Russia–Ukraine war, volatility spillovers remain moderate, consistent with the dominance of domestic drivers and limited cross-border volatility transmission. Still, the partial convergence around the ESDC and 2020–2022 indicates that systemic shocks temporarily synchronize FX and bond volatilities, in line with Albrecht and Kočenda (2024).

In CDS markets, return and volatility dynamics overlap more strongly, with pronounced peaks during the ESDC and COVID-19 and smaller gaps than in FX or bonds, implying that sovereign risk propagates through both spread co-movements and volatility synchronization. Overall, the volatility evidence corroborates the dynamic results: connectedness is strongest in equities and CDS, while FX and bond volatility transmission is weaker and becomes material mainly in systemic crises.

Contribution of each country to TSI dynamic (Return/ Volatility). Figure 3 and Appendix D decompose the TSI into country-specific contributions for both returns and volatility across all four segments, thereby tracking how each market shapes regional connectedness over time.

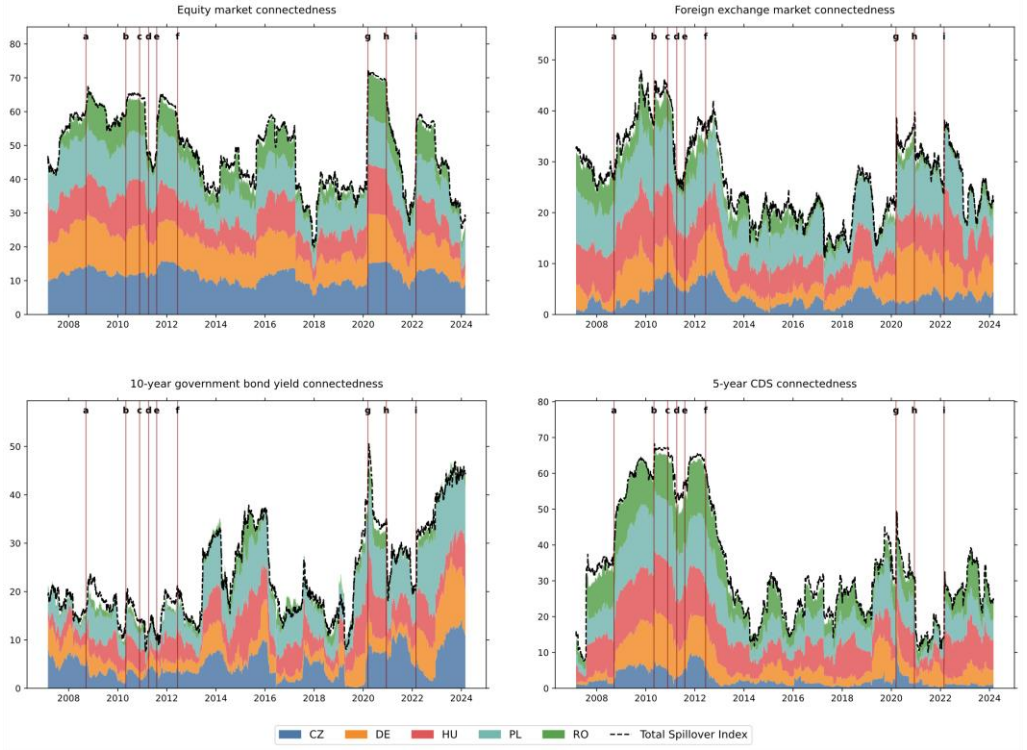
In equities, the return-based decomposition is relatively balanced: Czechia and Poland each contribute about 23% of total spillovers, followed by Germany (around 21%) and Hungary (around 19%), while Romania remains peripheral but non-negligible (about 12%). In volatility terms, Poland becomes the largest contributor (about 26%) and Romania's share rises slightly to roughly 14%, indicating comparatively stronger linkages when connectedness is measured through volatility. When the TSI is computed from equity volatility, Poland becomes the main contributor (about 26% of total connectedness), while the shares of the Czech Republic and Germany remain close to 21% each.

FX connectedness is more centralized. In returns, Poland, and Hungary account for around 30% and 26%, Germany holds an intermediate share (about 18%), and Czechia and Romania contribute only 11–13% (Figure 3). The same hierarchy holds for volatility, with the zloty and the forint again leading (about 28% and 24%) and Germany contributing around 21%, consistent with the greater influence of floating regimes relative to the managed currencies of Czechia and Romania. When focusing on FX volatility, the ranking remains similar (Appendix D).

Government bonds show an even clearer dominance of Poland. In returns, Poland explains roughly 31% of connectedness, followed by Hungary (23%) and Czechia (21%); Germany contributes about 17% and Romania only 7%. Volatility results are similar, with Poland still central (about 29%) and Hungary second (about 22%); Romania rises to around 13% but remains the least influential, underscoring the pivotal role of the Polish yield curve in regional rate spillovers. When the index is constructed from bond yield volatility, the picture remains broadly unchanged

The CDS market exhibits a distinct tri-polar structure dominated by CEE sovereigns. In returns, Hungary leads (about 27%), followed by Poland (25%) and Romania (22%), while Germany and Czechia play smaller roles (about 16% and 7%). This configuration is reinforced in volatility terms, where Poland and Hungary each account for roughly 28–29% and Romania retains a high share (about 22%) (Appendix D). The decomposition based on CDS volatility confirms this tri-polar structure. Unlike bonds, therefore, CDS connectedness is driven by the region's major sovereign issuers, with Romania markedly more influential here than in any other segment.

Figure 3. Total Spillover Index - Return



5.1.3 Event regression for the dynamic spillover

Next, we formally quantify the impact of major crisis episodes on the magnitude of spillovers by estimating an event-study regression for the dynamic spillover indices. For each market $m \in \{\text{equity}, \text{FX}, \text{bonds}, \text{CDS}\}$, we use the time-varying total spillover index TSI_t^m derived from the Diebold–Yilmaz framework, as the dependent variable and regress it on a set of crisis dummies capturing the main events considered in the paper. The baseline specification is given by:

$$TSI_t^m = \alpha^m + \beta_{\text{GFC}}^m D_t^{\text{GFC}} + \beta_{\text{ESDC}}^m D_t^{\text{ESDC}} + \beta_{\text{COVID}}^m D_t^{\text{COVID}} + \beta_{\text{WAR}}^m D_t^{\text{WAR}} + u_t^m, \quad (11)$$

$$u_t^m = \phi^m u_{t-1}^m + \varepsilon_t^m. \quad (12)$$

where D_t^{GFC} , D_t^{ESDC} , D_t^{COVID} and D_t^{WAR} are zero–one indicators for the GFC (15.09.2008–30.06.2009), the ESDC (01.05.2010–31.07.2012), the COVID-19 episode (01.03.2020–30.11.2020) and the initial phase of the Russia–Ukraine war (24.02.2022–31.12.2022), respectively. The coefficients β^m measure the average shift in the level of connectedness in each market during a given episode, relative to tranquil periods. The disturbance term u_t^m is modelled as a first–order autoregressive process, which allows us to explicitly account for the strong persistence and serial correlation typically observed in spillover indices. The model is estimated using generalized least squares (GLS) with AR(1) errors.

Table 2 and Appendx E present the GLS estimates quantifying the impact of major crises on dynamic spillover indices for both returns and volatility.

Table 2. The event regressions for the dynamic spillover indices

Spillovers based on returns				
Label	(1) Equity	(2) Forex	(3) Bonds	(4) CDS
Constant	44.50*** (295.03)	24.54*** (203.85)	23.35*** (159.15)	28.69*** (149.80)
GFC	18.56*** (30.22)	9.38*** (19.13)	-3.27*** (-5.49)	24.87*** (31.88)
ESDC	14.68*** (38.20)	11.76*** (38.33)	-7.79*** (-20.90)	33.40*** (68.42)
COVID-19	25.61*** (40.63)	9.03*** (17.91)	14.05*** (23.00)	6.44*** (8.05)
WAR	11.60*** (19.52)	6.89*** (14.52)	9.92*** (17.21)	-2.17*** (-2.87)
R-squared	0.450	0.309	0.244	0.552

For equity markets, connectedness rises sharply in all episodes. In return terms (Table 2), the COVID-19 pandemic triggered the largest increase (around 26 points), followed by the GFC, the ESDC, and the Russia–Ukraine war. Volatility-based estimates (Appendx E) confirm this pattern, showing even stronger reactions, particularly during the pandemic. FX markets also exhibit increased integration during turbulence, albeit with more modest magnitudes (between 6 and 12 points for returns). Volatility spillovers rise significantly across all crises, with particularly strong synchronization during global and geopolitical shocks like COVID-19 and the war. The bond market reveals a distinct pattern. While the pandemic and the war substantially raised connectedness, earlier crises (GFC and ESDC) were associated with negative coefficients for returns, implying market segmentation and flight-to-quality rather than contagion. However, volatility spillovers generally increased during GFC, COVID-19, and the war, suggesting that while yields diverged, volatility patterns synchronized. Sovereign CDS spillovers reacted most intensely to GFC and ESDC, causing massive jumps in return connectedness (25–33 points) and highlighting the credit risk channel's role. Moreover, volatility analysis confirms strong positive responses to all crises, underscoring the CDS market's sensitivity to systemic stress.

5.2 Country-level financial market connectedness

5.2.1 Static connectedness

In this subsection, we examine the static country-level connectedness for the selected financial markets in Czechia, Hungary, Poland, and Romania (Table 3). The results point to substantial cross-asset heterogeneity within each economy. Hungary records the highest within-country connectedness (TSI = 22.0%): although own shocks still explain 74.8%–83.5% of the variance, cross-market linkages are meaningful, with CDS (To others = 25.3%) and equities (24.1%) acting as the main transmitters, while FX is the most exposed receiver (From others = 25.2%). Overall, equities emerge as the key net propagator, whereas bonds and FX behave mainly as net receivers.

Poland ranks second (TSI = 16.3%) and exhibits a clear market segmentation. Government bonds are largely insulated (95.7% own shocks; To others = 4.6%), while FX is more integrated, both absorbing (From others = 21.9%) and transmitting shocks (To others = 21.3%). Equities are the dominant net transmitter, with a strong channel leading toward FX (pairwise spillover = 11.2%),

implying that contagion is primarily equity-driven, whereas the bond market remains a relatively stable and marginal source of systemic risk.

Romania shows low interconnectedness (TSI = 8.4%), comparable to Czechia. Bonds are the most resilient and isolated segment (98.0% own shocks; To others = 1.4%), whereas the CDS market forms the domestic hub, recording the highest transmission (To others = 12.8%) and reception (From others = 12.3%), with notable spillovers from CDS to equities (7.2%). Thus, sovereign credit risk is the primary channel for both the generation and absorption of vulnerability, while bonds serve as an anchor.

Czechia is the least connected (TSI = 7.0%). Bond yields are virtually decoupled (99.8% own variance; 0.2% impact), CDS is the main receiver (From others = 11.2%), largely influenced by equities (8.1%), and equities are the main source of outbound volatility (To others = 11.0%). Net positions further indicate FX as the only material net transmitter (1.3%), suggesting that currency-market volatility is a key driver of domestic uncertainty.

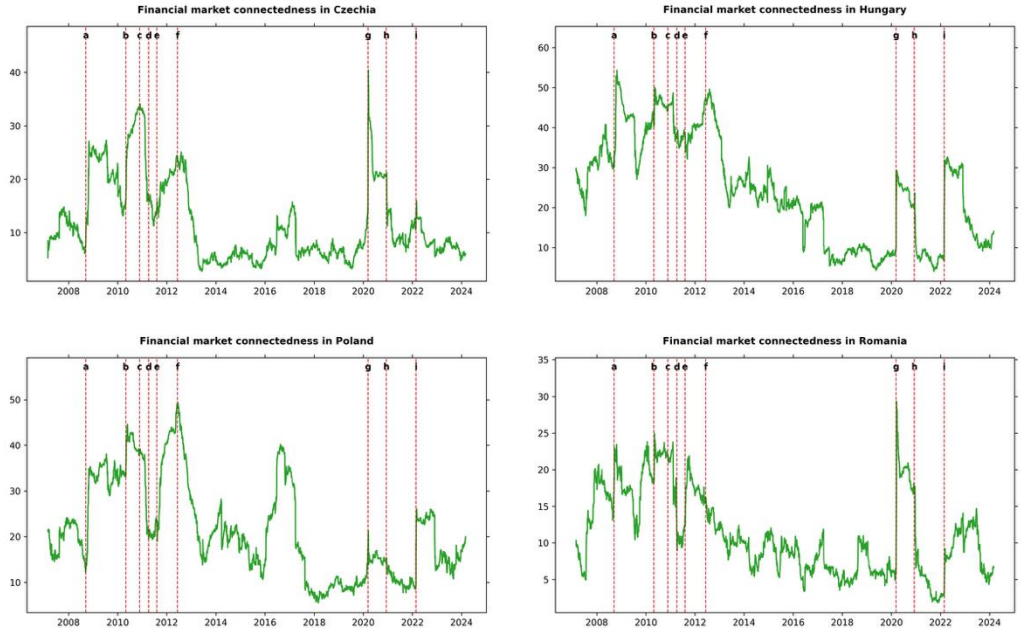
Table 3. Static return connectedness of asset classes in CEE countries

	Equity index	**Exchange rate**	**Government bond yield**	**CDS rates**	**From**
Czechia					
Equity index	88.9	3.7	0.1	7.4	11.1
Exchange rate	2.9	94.6	0.0	2.5	5.4
Government bond yield	0.1	0.0	99.8	0.1	0.2
CDS rates	8.1	3.0	0.1	88.8	11.2
To	11.0	6.7	0.2	10.0	27.9
Net	-0.1	1.3	0.0	-1.2	**Total**
TSI					7.0%
Hungary					
Equity index	78.7	7.3	3.9	10.2	21.3
Exchange rate	8.7	74.8	6.6	9.9	25.2
Government bond yield	5.1	6.2	83.5	5.2	16.5
CDS rates	10.3	9.8	5.0	74.9	25.1
To	24.1	23.3	15.5	25.3	88.1
Net	2.8	-1.9	-1.0	0.2	**Total**
TSI					22.0%
Poland					
Equity index	80.9	10.0	0.8	8.3	19.1
Exchange rate	11.2	78.1	1.9	8.8	21.9
Government bond yield	1.1	1.9	95.7	1.3	4.3
CDS rates	8.6	9.4	1.8	80.2	19.8
To	20.9	21.3	4.6	18.3	65.1
Net	1.7	-0.6	0.3	-1.5	**Total**
TSI					16.3%
Romania					
Equity index	88.8	3.6	0.4	7.2	11.2
Exchange rate	3.4	91.8	0.3	4.5	8.2
Government bond yield	0.7	0.3	98.0	1.0	2.0
CDS rates	7.1	4.4	0.7	87.7	12.3
To	11.3	8.3	1.4	12.8	33.7
Net	0.1	0.1	-0.6	0.5	**Total**
TSI					8.4%

5.2.2 Dynamic connectedness

While the static country-level connectedness reveals the average spillover transmission for the selected financial markets, the dynamic connectedness captures the time-varying spillover effects over the sample period. From Figure 3, we can identify several spillover transmission cycles over the selected period in CEE countries. Moreover, it is evident that crisis events were the main catalysts for rising financial market connectedness in all analyzed countries, with the highest levels recorded by Hungary and Poland.

Figure 3. Time-varying cross-country return connectedness in the CEE



Note: (a) Lehman Brothers default. (b) Greek bailout. (c) Ireland requests assistance. (d) Portugal requests assistance. (e) Contagion reaches Italy and Spain. (f) Spanish bailout. (g) World Health Organization declares the outbreak of a pandemic. (h) COVID-19 vaccine successful trial results announcement. (i) Russia invades Ukraine.

In Czechia, the TSI rose to 25% following the Lehman Brothers bankruptcy and peaked at 33% during the ESDC amid the Greek and Irish bailouts. Notably, the COVID-19 pandemic triggered a historic record of 40%, surpassing previous crises. While fiscal and monetary policies helped mitigate tensions, the index remained volatile. Moreover, the invasion of Ukraine had a negligible impact compared to previous events. The GFC had a profound impact on Hungary, with the Lehman default pushing connectedness to a record high of 55%. The ESDC also caused significant spikes (48%), particularly during the Greek, Irish, and Spanish bailouts. Although COVID-19 and the invasion of Ukraine increased transmission to 30%, these levels remained well below the peaks of the 2008–2012 period. In Poland, dynamic connectedness rose to 34% after the Lehman default, but reached its highest value of 50% during the ESDC. Between 2016 and 2018, idiosyncratic shocks caused another peak of 40%. Interestingly, the COVID-19 pandemic and the invasion of Ukraine played a relatively minor role, with the index reaching only 20% and 25%, respectively. By contrast, Romania was less affected by the GFC and debt crisis, with peaks around 24%. Surprisingly, the COVID-19 pandemic impacted Romanian market connectedness

more than previous financial crises, triggering a rise to 30%. In addition, the invasion of Ukraine had a neutral or low effect on the index.

6. Conclusions

This paper explores the financial connectedness of CEE markets across equity, foreign exchange, government bond, and sovereign CDS markets. By employing a unified Diebold–Yilmaz connectedness framework, univariate GARCH models, and GLS event regressions, we provide a multimarket and multicountry design that enables us to document both cross-country and cross-asset linkages. The empirical analysis utilizes a dataset spanning the sample period from May 2006 to March 2024.

Our findings contribute to the literature in four key aspects. First, the static cross-country evidence demonstrates that spillovers are clearly present across the CEE markets, although they are weaker when measured through volatility rather than returns. Integration is strongest in the equity and sovereign CDS markets, whereas FX and government bonds remain largely anchored in domestic fundamentals, reflecting heterogeneous exchange-rate regimes and divergent macroeconomic conditions. Moreover, CEE markets are typically more interconnected among themselves than with Germany—particularly in bonds and CDS markets—suggesting that, despite EU-wide integration efforts, the region continues to behave as a distinct cluster.

Second, the dynamic analysis confirms a pronounced regime-dependent nature of connectedness: it rises sharply during turbulent periods, with the strongest contagion effects observed in equity markets. Furthermore**,** volatility-based dynamics largely mirror return-based patterns, albeit at lower average magnitudes. FX contagion remains comparatively subdued, consistent with the idiosyncratic nature of regional currencies, while bond connectedness increases materially only during specific episodes, such as the COVID-19 pandemic, when yield spillovers became unusually strong. Country-level decompositions further indicate that Poland is the main contributor to cross-country connectedness across most segments, followed by Hungary; Czechia and Germany contribute primarily to equity and sovereign bond spillovers but less so to the CDS market, whereas Romania remains comparatively peripheral in the equity, FX, and bond segments, yet becomes notably influential in the sovereign CDS market, especially in terms of volatility.

Third, the event-study regressions corroborate that crisis episodes intensify spillovers, albeit asymmetrically across markets: equity and sovereign credit risk segments act as persistent channels of regional transmission, while bond-market linkages remain more contingent on the nature and origin of the specific shocks.

Fourth, intra-country results highlight heterogeneous cross-asset integration: Hungary and Poland display the highest domestic cross-market connectedness, whereas Romania and Czechia remain more segmented, with variance still dominated by own-market shocks. The vulnerability of these systems to crises also differs: Czechia and Romania experience their most severe stress during the pandemic, while Hungary and Poland show higher sensitivity to the GFC and ESDC, and the Ukraine invasion appears secondary relative to earlier global shocks across all four countries.

Our results offer direct implications for financial stability and macroprudential policy in emerging Europe. The elevated and time-varying connectedness observed across CEE equity, FX, government bond, and sovereign CDS markets—together with their links to Germany—shows that shocks can propagate rapidly across both countries and asset classes, particularly during periods of stress. Consequently**,** CEE authorities therefore should not treat domestic segments as insulated, but rather integrate spillover metrics into regular monitoring frameworks. In this

respect, total and directional connectedness measures can complement standard indicators, providing timely signals of rising systemic risk.

The distinction between net transmitters and net receivers is highly policy-relevant. Our TSI decompositions indicate that certain markets—notably Poland and Hungary across several segments—behave as regional hubs, whereas others remain peripheral in the equity, FX, and bond markets, yet become central to sovereign CDS spillovers. This heterogeneity calls for differentiated macroprudential approaches. In net-transmitting markets, authorities may need stronger countercyclical buffers and measures designed to restrain procyclical leverage and risk-taking in key propagation channels. In net-receiving markets, the priority shifts toward resilience building—including strengthening local-currency funding capacity, supporting longer-term investor bases, and maintaining adequate FX buffers—to absorb shocks originating elsewhere in the region or from the euro area core. The regime-dependent nature of connectedness further implies that policy should be explicitly state-contingent and cross-asset in scope. Since transmission channels shift across episodes—from equity and CDS segments in the GFC and ESDC toward bonds and FX during COVID-19 and the Russia–Ukraine conflict—stress tests and surveillance should account for crisis-level cross-market propagation consistent with the magnitudes documented in our subperiod analysis. Moreover, the fact that volatility-based spillovers are often lower on average, yet potentially more persistent during stress underscores the importance of monitoring volatility-driven channels. Finally, the persistent linkages between the CEE markets and Germany highlight the importance of pan-European coordination. Policy actions in the euro area core that affect sovereign premia, exchange rates, or long-term rates are likely to generate significant spillovers to neighbouring non-euro and euro-candidate economies, strengthening the case for closer coordination with the European Central Bank and the European Systemic Risk Board in the design and communication of major policy measures. At the same time, our results support efforts to deepen local capital markets, broaden domestic investor bases, and improve transparency in sovereign debt and FX markets; such steps can reduce shock amplification and foster a more resilient integration of the CEE region into the European financial system.

A natural extension for future research would be to broaden the country coverage to additional CEE markets (e.g., Bulgaria) and to reassess cross-market connectedness, with a particular focus on identifying the effects of EU accession.

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Appendices

Appendix A. Cross-country volatility connectedness

Equity market connectedness

	DAX	PX	BUX	WIG	BET	**From**
DAX	60.4	11	8.4	15.1	5.1	39.6
PX	11.8	56	10.2	14.3	7.7	44
BUX	10.2	10.5	58.2	14.5	6.6	41.8
WIG	14.3	11.7	10	57.4	6.6	42.6
BET	5.4	9.7	6.1	8.1	70.6	29.4
Contribution to others	41.7	43	34.8	52	25.9	197.3
Contribution including own	102.1	99	93	109.4	96.5	**Total**
TSI						39.50%

Foreign exchange market connectedness

	EUR/USD	CZK/EUR	HUF/EUR	PLN/EUR	RON/EUR	**From**
EUR/USD	89.8	2.1	2.8	5.1	0.2	10.2
CZK/EUR	1.3	88.7	3.4	6.2	0.4	11.3
HUF/EUR	2.3	3	84.4	9.5	0.6	15.6
PLN/EUR	5	5.9	9	79.3	0.8	20.7
RON/EUR	0.3	0.6	1	0.6	97.5	2.5
Contribution to others	8.9	11.6	16.1	21.4	2.2	60.3
Contribution including own	98.8	100.3	100.6	100.7	99.7	**Total**
TSI						12.10%

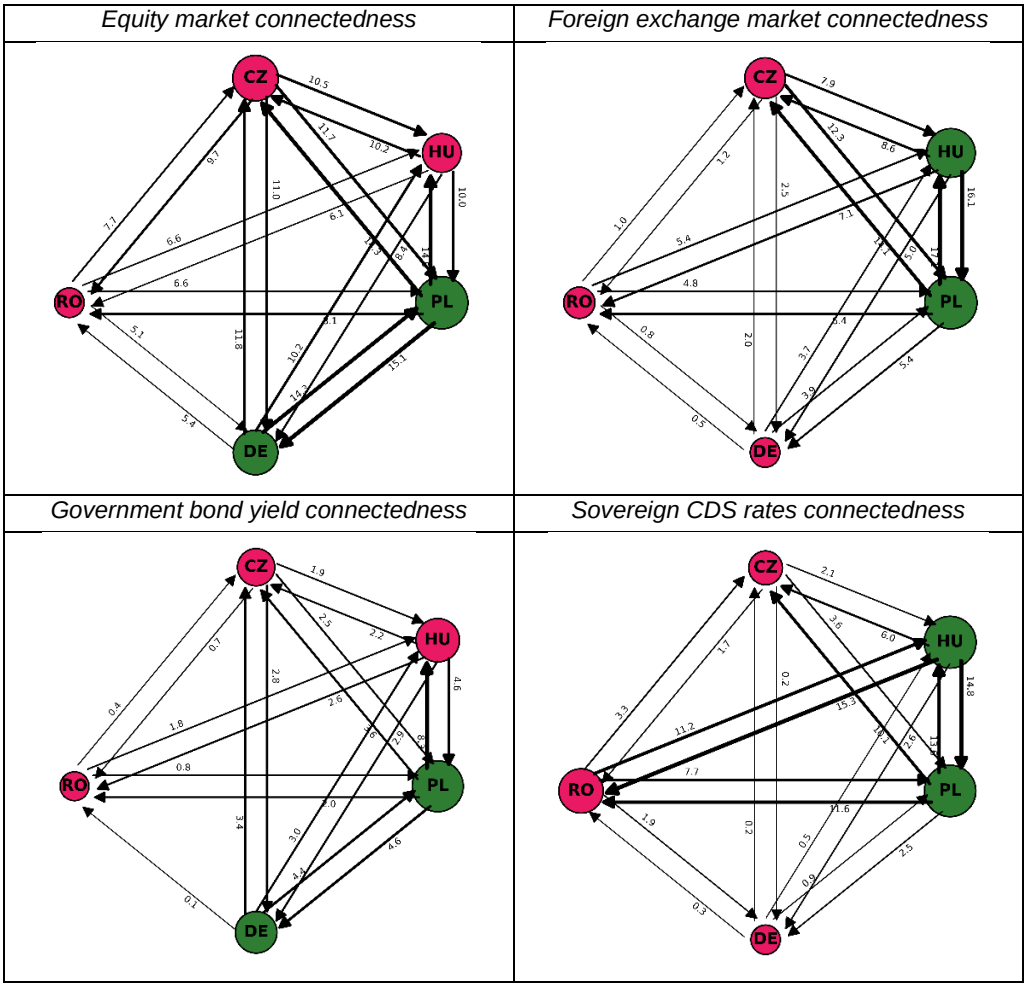
Government bond yield connectedness

	Germany	Czechia	Hungary	Poland	Romania	**From**
Germany	89.7	2.8	2.9	4.6	0	10.3
Czechia	3.4	90.3	2.2	3.6	0.4	9.7
Hungary	3	1.9	84.9	8.3	1.8	15.1
Poland	4.4	2.5	4.6	87.7	0.8	12.3
Romania	0.1	0.7	2.6	2	94.7	5.3
Contribution to others	10.8	7.9	12.3	18.5	3.1	52.6
Contribution including own	100.5	98.2	97.3	106.3	97.7	**Total**
TSI						10.50%

Sovereign CDS rates connectedness

	Germany	Czechia	Hungary	Poland	Romania	**From**
Germany	92.8	0.2	2.6	2.5	1.9	7.2
Czechia	0.2	80.4	6	10.1	3.3	19.6
Hungary	0.5	2.1	72.6	13.6	11.2	27.4
Poland	0.9	3.6	14.8	73	7.7	27
Romania	0.3	1.7	15.3	11.6	71.1	28.9
Contribution to others	1.8	7.7	38.8	37.8	24.1	110.1
Contribution including own	94.6	88.1	111.4	110.8	95.2	**Total**
TSI						22.00%

Appendix B. Network diagram for cross-country volatility connectedness

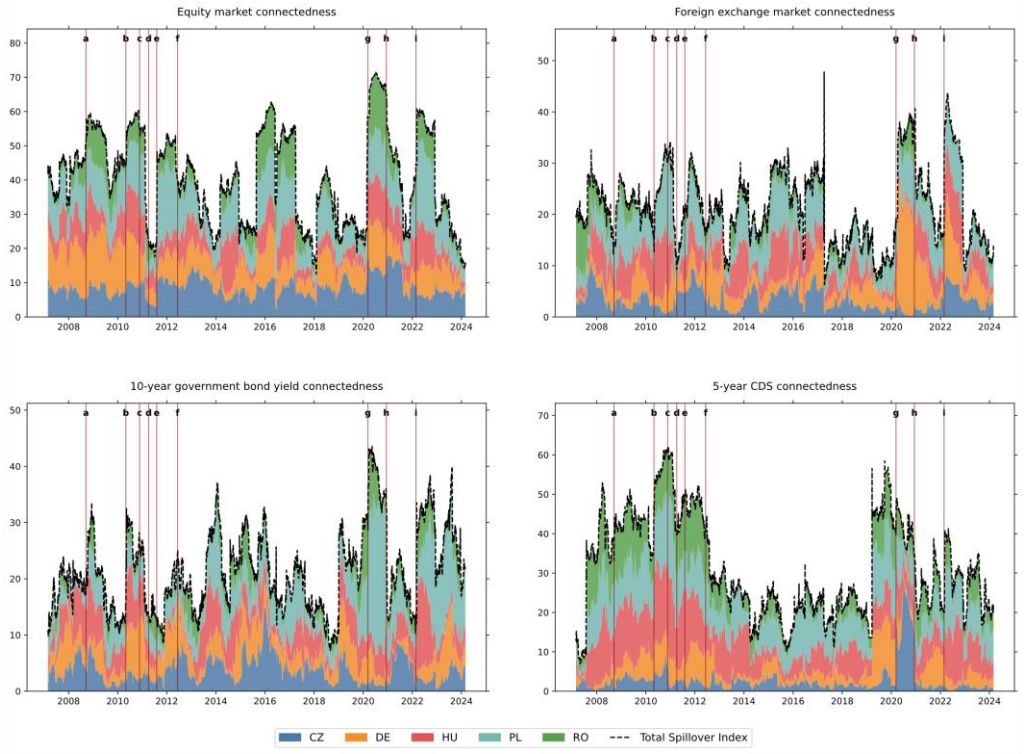


Note: Node colours and sizes, as well as arrow thickness, are based on the static Diebold–Yilmaz spillover measures. Green nodes denote net transmitters of shocks (NET = TO − FROM > 0), while red nodes denote net receivers (NET < 0). The size of each node is proportional to its total directional spillover To index, so larger nodes transmit stronger shocks to the rest of the system. The thickness of each arrow is proportional to the corresponding bilateral spillover coefficient (in %), with arrows pointing from the source market to the destination market; when shown, the numeric label on each arrow reports this underlying connectedness value.

Appendix C. Disaggregated TSI by periods/ Event analysis

Total Spillover Index - Volatility					
Equity market	53.1%	42.9%	32.4%	65.2%	28.6%
Foreign exchange market	23.4%	18.6%	8.9%	38.5%	15.1%
Government bond market	18.1%	8,1%	12.3%	32.8%	29.1.%
Sovereign CDS market	44.6%	46.1%	18.0%	36.7%	25.1%

Appendix D. Contribution of each country to TSI dynamic - Volatility



Appendix E. Spillovers based on volatility

Label	(5) Equity	(6) Forex	(7) Bonds	(8) CDS
Constant	36.44*** (186.74)	19.31*** (176.30)	20.03*** (192.15)	26.71*** (160.46)
GFC	19.07*** (23.05)	4.17*** (8.49)	3.61*** (8.56)	17.44*** (26.34)
ESDC	8.57*** (17.02)	4.08*** (14.72)	-0.46* (-1.71)	23.12*** (55.53)
Covid	32.27*** (37.63)	16.09*** (34.26)	17.75*** (40.29)	14.82*** (21.65)
War	17.80*** (22.71)	14.29*** (29.78)	10.91*** (26.70)	4.21*** (6.52)
R-squared	0.349	0.330	0.345	0.468

*Notes: The table reports GLS estimates with AR(1) errors for the dynamic total spillover indices based on returns. HAC (Newey–West) standard errors are used to compute t-statistics, reported in parentheses. GFC, ESDC, Covid and War are crisis dummies. ***, **, * denote significance at the 1%, 5% and 10% levels, respectively.*