DYNAMIC CONNECTEDNESS OF EASTERN EUROPEAN STOCK MARKETS: AN EXTENDED JOINT CONNECTEDNESS APPROACH

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ABSTRACT
This paper examines the dynamic return spillovers among ten Eastern European stock markets using an extended joint connectedness approach. We analyze daily log returns from 2010 to 2024 for equity indices of Serbia, Bosnia and Herzegovina, Croatia, Slovenia, North Macedonia, Romania, the Czech Republic, Hungary, Poland, and Ukraine. We employ the Diebold-Yilmaz connectedness framework, augmented with a Time-Varying Parameter VAR (TVP-VAR) model to capture evolving relationships, and incorporate the extended joint spillover methodology to address bias from normalization. The Connectedness Approach R package is used for implementation. Our results show that these markets exhibit a moderate degree of interconnectedness on average - the Total Connectedness Index is around 25%, indicating that roughly one-quarter of forecast variance is due to cross-market shocks. Spillovers are highly time-varying, with pronounced surges during major crises such as the European sovereign debt crisis, the COVID-19 pandemic, and the Russia-Ukraine conflict. Directional spillover analysis reveals that larger markets (e.g., Romania, Poland, Czech Republic) tend to be net transmitters of shocks, whereas smaller frontier markets (e.g., Serbia, Bosnia, North Macedonia) are net recipients. The extended joint connectedness measures largely confirm the traditional spillover estimates while providing a more theoretically grounded aggregate index. These findings shed light on the evolving integration of Eastern European stock markets, offering insights for portfolio diversification and financial stability monitoring.

Keywords: *Dynamic connectedness, Eastern European stock markets, Spillovers, Extended Joint connectedness*

JEL classification: *C32, G11, G15*

1. INTRODUCTION

The increasing integration of global financial markets has intensified interest in spillovers and interconnectedness among equity markets. Spillovers refer to the transmission of shocks or volatility from one market to another, which is crucial for understanding contagion risks and potential diversification benefits. This topic is especially important for emerging and less-developed markets such as those in Eastern Europe, where financial systems are smaller and potentially more vulnerable to external shocks. Investors and policymakers need to know whether these markets move in tandem or remain segmented; high connectedness can signal contagion risk, whereas low connectedness might imply scope for diversification. Eastern

European stock markets – including those in the Balkans and Central-Eastern Europe - have historically been less developed and less liquid than their Western counterparts. However, the past decade has seen these markets gradually integrate with global financial systems (e.g., through increased economic linkages and, for some countries, European Union accession). Analyzing their dynamic connectedness can reveal how shocks propagate within the region and whether these frontier markets are becoming more intertwined with each other or still offer insulation from global turmoil.

This study focuses on ten Eastern European equity indices from Serbia, Bosnia and Herzegovina, Croatia, Slovenia, North Macedonia, Romania, the Czech Republic, Hungary, Poland, and Ukraine to assess their return spillovers from 2010 through 2024. By examining a long post-2009 period that encompasses the European sovereign debt crisis, periods of relative stability, the COVID-19 shock in 2020, and recent geopolitical tensions (such as the 2022 Russia-Ukraine conflict), we provide a comprehensive view of regional market interconnectedness. Previous studies have examined spillovers in Eastern European markets using approaches such as DCC-GARCH and extensions of the Diebold–Yilmaz VAR framework (Demiralay & Bayraci, 2015; Škrinjarić, 2020, 2021; Syllignakis & Kouretas, 2011) but their evidence mostly covers earlier periods, offering limited insight into COVID-19 or the Russia–Ukraine conflict. More recent work, such as Škrinjarić (2022), incorporates the COVID-19 period, yet little is known about how connectedness in emerging and less-liquid European markets has evolved beyond the pandemic, particularly under subsequent shocks such as global inflation and the Russia–Ukraine war. Our aim is to determine the level and evolution of return spillovers in this region and to identify which markets act as shock transmitters versus receivers in the network. These insights are valuable for portfolio management (e.g., understanding the limits of regional diversification) and for regulators concerned with financial stability in emerging European markets.

To investigate these questions, we employ the Diebold-Yilmaz spillover index framework, which has become a standard approach for quantifying systemic connectedness in finance (Diebold and Yilmaz, 2009, 2012).We address the limitations of the original framework by using a time-varying parameter VAR model (Antonakakis *et al.*, 2018) instead of a rolling window, allowing the connectedness measures to evolve smoothly over time. Furthermore, we incorporate the extended joint connectedness approach recently developed by (Lastrapes and Wiesen, 2021) and extended by (Balcilar *et al.*, 2021) , which provides a more theoretically grounded measure of total spillovers and enables the computation of directional spillovers within that joint framework. Leveraging an extended, recent daily dataset for Eastern Europe, we assess whether smaller frontier stock exchanges are integrating with regional peers and global financial cycles, or whether they remain sufficiently segmented to offer diversification

In summary, our contribution is twofold. First, we provide up-to-date empirical evidence on how ten Eastern European stock markets are interconnected, how those connections change over time, and how global/regional shocks influence the network. Second, we demonstrate the use of an improved connectedness approach - combining the Diebold-Yilmaz methodology, TVP-VAR modeling, and the joint spillover index - which yields more robust insights than traditional methods. The remainder of the paper is structured as follows. Section 2 reviews the relevant literature on connectedness measurement and previous findings. Section 3 outlines the methodology, including the connectedness frameworks and estimation procedure. Section 4 describes the data. Section 5 presents and discusses the empirical results. Section 6 concludes with a summary of findings and implications.

2. LITERATURE REVIEW

Understanding the dynamics of cross-market return spillovers and connectedness has become increasingly crucial for investors, policymakers, and financial analysts, particularly in the context of emerging and frontier markets where vulnerabilities to external shocks are often amplified. The transmission of shocks or volatility from one market or asset class to another has been a central theme in international finance over the past two decades, reflecting the growing integration and susceptibility of markets to systemic events.

The foundational framework of (Diebold and Yilmaz, 2009, 2012; Diebold and Yılmaz, 2014) transformed the empirical study of connectedness by introducing a VAR-based methodology grounded in forecast error variance decompositions (FEVD). This approach enabled a systematic quantification of total, directional (to/from), and net spillovers across markets, offering a unified language for describing interdependencies. Despite its influence, the standard Diebold-Yilmaz (DY) framework has notable drawbacks: its reliance on arbitrarily chosen rolling windows makes estimates sensitive to window length, and the row-normalization procedure can introduce bias that affects the identification of net transmitters and receivers (Caloia *et al.*, 2019).

To address these limitations, (Antonakakis *et al.*, 2018) and (Antonakakis *et al.*, 2020) introduced the time-varying parameter VAR (TVP-VAR) approach, which models interdependencies as smoothly evolving processes without the need for fixed subsamples, thereby producing more stable and responsive spillover estimates. Building on this, (Lastrapes and Wiesen, 2021) proposed the Joint Connectedness Index (JCI), which corrects the normalization bias and yields a theoretically consistent measure of systemic connectedness. (Balcilar *et al.*, 2021) extended this to the Extended Joint Connectedness Index (EJCI), which retains the advantages of JCI while preserving bilateral net spillover measures, an essential feature for understanding directional dominance between markets. Further methodological advances have expanded the analytical toolkit: frequency-domain decompositions (Baruník and Křehlík, 2018) disentangle short- and long-term spillover components; quantile-based frameworks (Chatziantoniou *et al.*, 2021) capture asymmetries across market states; and DCC-GARCH-based R^2 measures (Cocca *et al.*, 2024) reveal nonlinear and time-varying dependencies in high-frequency data.

Empirical applications to global and developed markets have yielded important insights into the nature and drivers of financial interconnectedness. (Diebold and Yilmaz, 2012) reported that total return spillovers among major global equity markets averaged around 65%, rising sharply during the 2008 Global Financial Crisis. (Baruník and Křehlík, 2018) showed that short-term spillovers dominate in turbulent periods, while long-term spillovers are more relevant during stable market phases. (Gabauer and Gupta, 2018) found that volatility spillovers among the G7 equity markets are highly time-varying, with the United States persistently acting as the dominant net transmitter of shocks. (Antonakakis *et al.*, 2020) documented that global financial uncertainty strongly amplifies connectedness across asset classes, particularly between equities and commodities. (Bouri *et al.*, 2021) demonstrated that during the COVID-19 pandemic, technology and healthcare sectors in developed markets emerged as net transmitters, while energy and travel-related sectors became net receivers. Collectively, these studies highlight that connectedness intensifies during crises, that transmission roles vary across sectors and regions, and that ignoring time variation and bias correction can distort conclusions about systemic risk and diversification opportunities.

Additionally, empirical research on spillover dynamics in emerging and frontier markets is expanding, with Eastern Europe providing a particularly active strand of the literature. (Syllignakis and Kouretas, 2011) analyze financial contagion across Central and Eastern European (CEE) equity markets using a dynamic conditional correlation (DCC-GARCH) framework, showing that connectedness with developed markets rises sharply during crises, thereby eroding diversification opportunities for emerging markets. Similarly, (Demiralay and Bayraci, 2015) study selected CEE stock markets volatility spillover and find that volatility transmission intensifies in turbulent periods, underscoring the structural vulnerability of emerging European markets to external shocks. Within the Diebold–Yilmaz (DY) framework, (Dumitrescu, 2015) shows that Eastern European equities were disproportionately affected by volatility and illiquidity spillovers during the Eurozone debt crisis, while (Louzis, 2013) finds that Euro area peripheral bonds shifted from receivers of return spillovers to transmitters of shocks under stress periods. Complementary evidence comes from (Cevik *et al.*, 2017) who apply asymmetric causality tests and reveal that negative shocks generate stronger spillovers in CEE markets, and (Özer *et al.*, 2020), who use frequency-domain causality to show that SEE markets experience both short- and long-term spillovers, largely driven by transmissions from advanced economies. Building on these foundations, (Škrinjarić, 2020) applies the generalized DY VAR framework to SEE and CEE equities and finds that these markets function largely as net receivers of shocks, with spillovers intensifying during crises. Subsequent work expands the framework: (Škrinjarić, 2021) incorporates asymmetric decompositions to show that downside spillovers dominate and that penalizing exposure to downside transmitters improves risk-return trade-offs.; (Škrinjarić *et al.*, 2021) apply realized semivariances to demonstrate that negative shocks drive stronger transmission and alter systemic risk assessments; and (Škrinjarić, 2022) higher-order moments (volatility, skewness, kurtosis), finding that these distributional features materially influence regional interconnectedness over time and are especially pronounced during crises. At the broader level, (Gamba-Santamaria *et al.*, 2019) employ a DCC-GARCH extension of the DY methodology to show that volatility spillovers surge during crises and originate mainly from advanced markets, while (Fountas *et al.*, 2024) demonstrate that uncertainty spillovers amplify return spillovers across stocks, bonds, and foreign exchange, with heterogeneous effects across both developed and emerging markets, and that European countries were particularly vulnerable during COVID-19.

While the literature on spillovers in Eastern European markets is substantial, two gaps remain. First, few studies provide a unified, daily-frequency analysis that jointly spans both advanced markets, such as Poland, Hungary, and Czechia and frontier markets, such as Serbia, Bosnia and Herzegovina, and North Macedonia, across major stress episodes (the European debt crisis, COVID-19, and the Russia–Ukraine conflict), which hinders inference on how roles and magnitudes evolve in crises. Second, prior applications for the region predominantly rely on rolling-window implementations; to our knowledge, no study applies a time-varying-parameter (TVP) model coupled with an Extended Joint Connectedness framework to this regional set, which is crucial for capturing smoothly evolving spillovers during multiple crises. To address this, we apply the Extended Joint Connectedness framework within a TVP-VAR to daily equity returns from ten Eastern European markets. This approach enables a granular assessment of the magnitude, direction, and evolution of return spillovers, while correcting for normalization bias and preserving bilateral net dynamics. By conditioning explicitly on the key systemic stress episodes: the European debt crisis, the COVID-19 pandemic, and the Russia-Ukraine conflict, we deliver a time-varying characterization of systemic interdependence in Eastern Europe that is informative for both policy and portfolio design.

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3. METHODOLOGY

We employ the connectedness framework within a time-varying parameter VAR (TVP-VAR) setting, extended through the bias-corrected Joint Connectedness methodology. The framework builds on Diebold and Yilmaz (2009, 2012), who introduced forecast error variance decompositions (FEVD) from vector autoregressions (VAR) to measure total, directional, and net spillovers across markets. Following Antonakakis et al. (2018, 2020), we estimate a TVP-VAR model via the Kalman filter, which enables both coefficients and volatilities to evolve smoothly over time and avoids the limitations of fixed rolling windows. In the TVP-VAR(1) specification, the system is defined as:

$$\gamma_t = \beta_t \gamma_{t-1} + \varepsilon_t$$

where γ_t is a $K \times 1$ vector of returns, β_t is the time-varying coefficient matrix, and $\varepsilon_t \sim N(0, \sum_t)$ are innovations with a time-varying variance-covariance matrix $\sum_t$.

Applying the Wold representation to the TVP-VAR yields:

$$\gamma_t = \sum_{h=0}^{\infty} A_{h,t} \epsilon_{t-h,}$$

where $A_{0,t} = I_k$ and $A_{h,t} = \beta_t A_{h-1,t-1}$ for h ≥ 1. This representation enables computation of the generalized FEVD without orthogonalization (Koop et al., 1996; Pesaran & Shin, 1998), capturing the fraction of forecast error variance in one market explained by shocks in another.

The EJC approach adjusts the generalized spillover table $gSOT_{ij,t}$ so that each row's sum matches the bias-corrected joint connectedness share $S^{jnt}_{from,i,t}$. The scaling factor is:

$$\lambda_i = \frac{S^{jnt}_{from,i,t}}{S^{gen}_{from,i,t}}$$

where $S^{gen}_{from,i,t}$. is the row-normalized share in the generalized framework. The bias-adjusted, direction-preserving bilateral spillovers are then:

$$jSOT_{ij,t} = \lambda_i \times gSOT_{ij,t}, \qquad i \neq j,$$

$$jSOT_{ii,t} = 1 - S^{jnt}_{from,i,t}.$$

This ensures that:

$$\textstyle\sum_{j \neq i} jSOT_{ij,t} = S^{jnt}_{from,i,t}, \quad \sum_{j \neq i} jSOT_{ij,t} = S^{jnt}_{to,i,t}.$$

By construction, the VAR-TVP-EJC framework captures time-varying, bias-corrected, and bilateral connectedness measures without losing directional interpretation, making it well-suited for studying interconnected equity markets.

4. DATA

We utilize daily data for ten Eastern European stock market indices over the period January 1, 2010, to December 31, 2024. The sample includes the BELEX15 from the Belgrade Stock Exchange in Serbia, the BIRS from the Banja Luka Stock Exchange in Bosnia and Herzegovina, the CROBEX from the Zagreb Stock Exchange in Croatia, the SBITOP from the Ljubljana Stock Exchange in Slovenia, the MBI10 from the Macedonian Stock Exchange in North Macedonia, the BET from the Bucharest Stock Exchange in Romania, the PX from the Prague Stock Exchange in the Czech Republic, the BUX from the Budapest Stock Exchange in Hungary, the WIG20 from the Warsaw Stock Exchange in Poland, and the PFTS from the PFTS Stock Exchange in Ukraine.

The selection of these indices ensures broad coverage of Eastern European markets. It encompasses EU member states such as Poland, Hungary, the Czech Republic, Croatia, Slovenia, and Romania, as well as EU candidate or neighboring markets, including Serbia, North Macedonia, and Bosnia and Herzegovina, together with the distinct case of Ukraine. This composition allows us to capture both relatively developed emerging markets and smaller frontier markets within the region.

We use daily log returns to ensure stationarity and interpret connectedness as return spillovers: $r_{i,t} = \ln\left(\frac{P_{i,t}}{P_{i,t-1}}\right)$. ADF and Phillips-Perron tests confirm stationarity by rejecting unit roots for all return series (Table 1). The mean returns are close to zero, with the highest values observed for MBI10 (0.036%) and BUX (0.035%). Daily volatility ranges between 0.7% and 1.3%, being relatively higher in Poland and Hungary (WIG20 and BUX) and lower in Bosnia and North Macedonia (BIRS and MBI10). The return distributions exhibit left skewness and heavy tails, as indicated by the Jarque-Bera statistic ($p < 0.01$). Ljung-Box Q(20) tests on both returns and squared returns are significant, suggesting serial correlation and volatility clustering. Accordingly, we estimate connectedness in the return domain using a VAR specification.

Table 1: Descriptive statistics

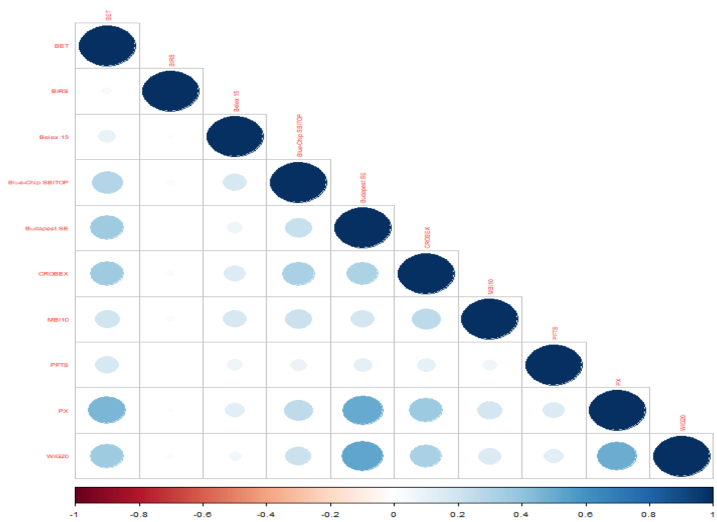
Asset	Mean	SD	Min	Max	Skewness	JBtest	ADFtest	PPtest	Q20	Q2_20
BET	0.00033	0.01039	-0.11892	0.09088	-1.293	57445.75***	-39.74**	-3463.86**	72.23***	799.33***
BIRS	-0.00002	0.00858	-0.11219	0.0945	0.262	120985.2***	-42.03**	-3489.61**	74.74***	947.66***
Belex 15	0.00014	0.00747	-0.07408	0.08229	-0.369	24488.4***	-38.95**	-3892.57**	86.33***	1549.87***
Blue-Chip SBITOP	0.00014	0.00874	-0.09383	0.05959	-1.008	17002.42***	-40.27**	-3786.76**	66.15***	1357.03***
Budapest SE	0.00035	0.01283	-0.12268	0.10674	-0.689	12827.47***	-44.65**	-3629.7**	44.91***	1384.86***
CROBEX	0.00012	0.00711	-0.10732	0.08563	-1.805	224300.71***	-40.29**	-4392.35**	149.2***	1392.65***
MBI10	0.00036	0.00797	-0.09848	0.06791	-1.1	99289***	-39.2**	-2930.39**	229.65***	2917.59***
PFTS	-0.00004	0.01157	-0.11379	0.24432	2.471	738054.38***	-38.25**	-2738.75**	332.15***	130.48***
PX	0.00012	0.01007	-0.0816	0.07369	-0.671	8582.91***	-41.55**	-3691.77**	49.16***	2418.44***
WIG20	-0.00003	0.01313	-0.14246	0.08099	-0.611	8909.94***	-44.51**	-3662.43**	28.11	1034.55***

(Source: Author's compilation)

As an initial measure of interdependence, we calculate unconditional Pearson correlations of daily returns (Figure 1). Correlations are generally positive but display considerable heterogeneity. Central European EU members, Poland (WIG20), Hungary (BUX), and the Czech Republic (PX), exhibit relatively strong co-movements, with coefficients in the 0.4-0.6 range. Croatia and Slovenia also show moderate correlations with each other and with neighboring markets.

In contrast, the smaller and more peripheral markets of Bosnia (BIRS), Serbia (Belex15) and North Macedonia (MBI10), as well as Ukraine's PFTS, record much lower correlations, often below 0.2, reflecting idiosyncratic dynamics and limited foreign participation. Overall, while Eastern European equities move together to some extent, integration remains partial, underscoring the need for a spillover analysis that captures directional transmission and influence beyond simple contemporaneous correlations.

Figure 1: Heatmap of unconditional Pearson correlations



(Source: Author's compilation)

5. EMPIRICAL RESULTS

5.1 Static spillover analysis

We begin by examining the full-sample spillover estimates, which provide an aggregate perspective on the degree of connectedness among the ten Eastern European stock markets over the 2010-2024 period. Table 2 reports the spillover matrix and summary statistics derived from the Extended Joint Connectedness framework. Each off-diagonal element of the matrix measures the share of forecast error variance in the returns of the market listed in the row that can be attributed to shocks originating from the market in the corresponding column, averaged across the entire sample. The diagonal elements capture own-market effects, while the off-diagonal entries quantify cross-market spillovers, thereby offering a comprehensive view of how shocks are transmitted across the region's equity markets.

Table 2: Spillover table using EJC

Market	BET	BIRS	Belex 15	Blue-Chip SBITOP	Budapest SE	CROBEX	MBI10	PFTS	PX	WIG20	**FROM**
BET	67.09	0.61	0.92	3.60	5.60	4.74	1.72	1.69	8.24	5.79	**32.91**
BIRS	1.20	92.03	0.65	1.07	0.96	0.86	1.05	0.61	0.62	0.95	**7.97**
Belex 15	1.90	0.78	85.51	2.99	1.13	1.90	2.43	0.75	1.75	0.87	**14.49**
Blue-Chip SBITOP	4.38	0.77	2.07	75.96	2.51	4.67	2.43	0.86	3.20	3.14	**24.04**
Budapest SE	5.60	0.48	0.44	2.18	61.34	3.26	1.60	1.39	10.68	13.03	**38.66**
CROBEX	4.90	0.74	1.03	4.09	3.37	73.55	2.41	1.41	4.58	3.93	**26.45**
MBI10	2.44	0.51	2.01	2.64	1.99	3.31	82.41	0.78	2.00	1.90	**17.59**
PFTS	2.06	0.46	0.64	0.81	1.58	1.28	0.79	88.53	1.75	2.09	**11.47**
PX	8.53	0.43	0.73	2.84	10.28	4.44	1.50	1.56	58.59	11.10	**41.41**
WIG20	5.87	0.63	0.50	2.25	13.17	3.71	1.46	1.74	11.29	59.37	**40.63**
TO	**36.89**	**5.43**	**8.98**	**22.48**	**40.59**	**28.18**	**15.39**	**10.78**	**44.10**	**42.80**	**255.62**
Inc.Own	103.97	97.45	94.49	98.44	101.93	101.73	97.81	99.32	102.68	102.17	TCI
NET	**3.97**	**-2.55**	**-5.51**	**-1.56**	**1.93**	**1.73**	**-2.19**	**-0.68**	**2.68**	**2.17**	**25.56**

NPT	8.00	1.00	0.00	3.00	8.00	4.00	3.00	4.00	8.00	6.00	

(Source: Author's compilation)

Several notable patterns emerge from Table 2. The diagonal entries are generally dominant, indicating that own shocks explain the majority of forecast error variance across markets. In most cases, own-share contributions lie between 60% and 90%, underscoring the persistence of domestic or idiosyncratic drivers. The smaller Balkan markets, Bosnia (BIRS), Serbia (BELEX15), and North Macedonia (MBI10), display particularly high own-shares, exceeding 85%, consistent with their relatively low integration and limited exposure to regional spillovers. By contrast, the larger Central European EU members, Poland (WIG20), the Czech Republic (PX), Romania (BET), and Hungary (BUX), exhibit lower own-shares, in the range of 58-67%, meaning that one-third or more of their return variance is explained by shocks from other markets. This contrast highlights a dual structure in the region: frontier markets that remain largely segmented and more developed markets that are increasingly interconnected with both regional and global financial systems. Similarly, (Syllignakis & Kouretas, 2011) find stronger spillovers in larger CEE markets than in smaller Balkan markets, reinforcing the dual-market structure.

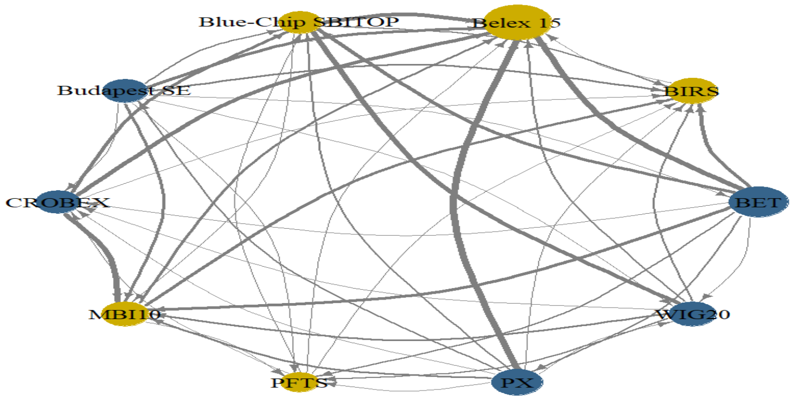
The off-diagonal entries in Table 2 reveal which cross-market linkages are most pronounced. While most spillover shares are modest, typically in the 1-5% range, a few notable bilateral connections stand out. Poland's WIG20 emerges as a key transmitter, with shocks spilling over significantly to Hungary (BUX) and the Czech Republic (PX), where contributions exceed 10% of forecast variance. Hungary and the Czech Republic also act as important transmitters, with Hungary in particular exerting meaningful influence on Poland and Romania. These patterns underline the role of the larger Central European EU markets as the main hubs of regional shock propagation. By contrast, spillovers from the smaller Balkan markets, Bosnia (BIRS), North Macedonia (MBI10), and Serbia (BELEX15), are negligible, generally below 1%, reflecting their limited capacity to influence neighboring or larger markets. Overall, the evidence points to an asymmetric structure in which Central European markets drive regional dynamics, while the smaller frontier markets remain peripheral and predominantly receivers of external shocks. This hub-and-periphery structure is consistent with (Dumitrescu, 2015), who shows that Eastern European markets are disproportionately affected by volatility shocks from the EU cores, and with (Cevik et al., 2017), who find asymmetric transmission led by larger markets.

In aggregate terms, the system's Total Connectedness Index (TCI) is 25.6% (Table 2), implying that roughly one quarter of forecast error variance is attributable to cross-market spillovers, while the remaining 74% reflects domestic shocks. This points to a moderate degree of interdependence: integration is significant enough to allow contagion risk yet limited enough to preserve diversification potential. For comparison, studies on developed markets typically report much higher connectedness, often above 50% and rising sharply during crises. For instance, Youssef et al. (2021), using a TVP-VAR framework for major advanced and emerging economies, document an average TCI of about 65%, peaking near 80% during the COVID-19 outbreak.

In addition, Figure 2 provides a complementary perspective through a network representation of net pairwise spillovers. Node size reflects the absolute value of the Net Spillover Index (NET), with larger nodes exerting stronger net influence, while color indicates direction (blue for net transmitters, yellow for net receivers). Edges are directional and weighted by the magnitude of spillovers. The network reveals a Central European core of transmitters, led by

Romania (+3.97), the Czech Republic (+2.68), and Poland (+2.17), followed by Hungary (BUX) and Croatia (CROBEX) as moderate contributors. On the other hand, Serbia (BELEX15) emerges as the strongest receiver (-5.51), alongside Bosnia (BIRS), North Macedonia (MBI10), Slovenia (SBITOP), and Ukraine (PFTS). Overall, the network depicts a multipolar structure, with a Central European transmitter core radiating shocks to a periphery of receivers, consistent with the moderate but non-trivial systemwide connectedness reported in Table 2.

Figure 2: Net pairwise directional connectedness



(Source: Author's compilation)

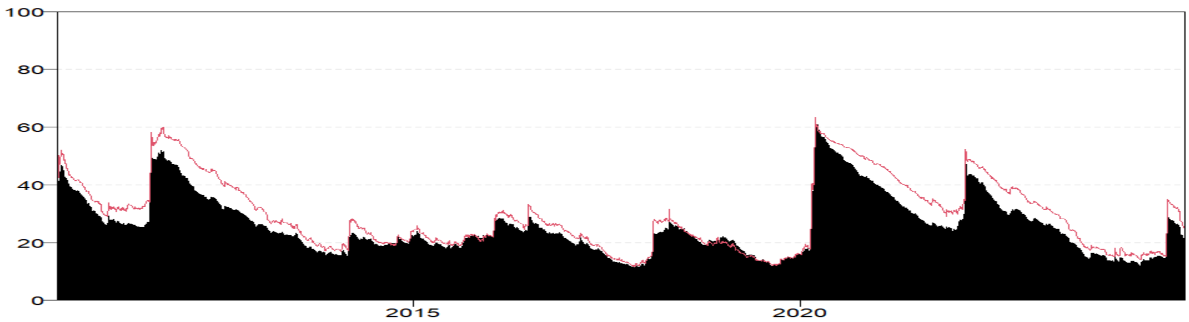
To assess robustness, we compare the EJC results against two widely used alternatives: (i) the standard Diebold–Yilmaz framework, based on a static VAR with row normalization, and (ii) a connectedness measure from a TVP-VAR estimated without the EJC adjustment (see Appendix, Tables 1 and 2). The three approaches yield broadly consistent outcomes. Total connectedness is of similar magnitude, 30.99% under VAR-DY and 29.27% under TVP-VAR, as well as the classification of net transmitters and receivers remains unchanged. As expected, the row-normalization in the DY variant produces somewhat more extreme net values, whereas the EJC adjustment moderates them slightly. Nonetheless, the core-periphery structure and the relative market rankings are preserved across specifications. Overall, the small discrepancies observed indicate that the regional system is relatively balanced and not overly sensitive to methodological choice (Balcilar *et al.*, 2021).

5.2 Dynamic evolution of connectedness

The full-sample results provide an average picture, but the dynamic perspective is essential for understanding how connectedness evolves across time. A key contribution of this study is to trace these dynamics and identify how global and regional shocks alter the degree of integration among Eastern European markets. Figure 3 presents the Dynamic Total Connectedness Index (TCI) for the period 2010-2024, estimated using both the EJC (shaded area) and the TVP-VAR (red line). In parallel, Figure 4 displays the time-varying net spillovers for each market, again comparing the two approaches.

Figure 3 demonstrates that the connectedness of Eastern European stock markets is highly time-varying, fluctuating markedly in response to global and regional shocks. During 2010-2012, connectedness was elevated, with a pronounced spike in late 2011 that coincides with the Eurozone sovereign debt crisis, a period of severe financial stress. Contagion from Western European bonds and banking markets spilled over into Eastern Europe, particularly affecting EU member states. At its peak in late 2011, the TCI reached nearly 50%, compared with baseline levels around 25-30% during calmer periods, indicating that spillovers intensified as markets moved more closely in tandem under stress. This is consistent with (Syllignakis and Kouretas, 2011), who identify sharp increases in dynamic correlations between CEE and developed markets during the Global Financial and Eurozone debt crises. Importantly, even non-EU markets such as Serbia and Bosnia exhibited stronger linkages during this period, likely transmitted through regional banks and shifts in investor sentiment. This interpretation is supported by Figure 4, where their net spillover positions turn sharply negative, confirming that these smaller markets were primarily absorbers of external shocks during the crisis.

Figure 3: Dynamic Total Connectedness index (TCI)



(Source: Author's compilation)

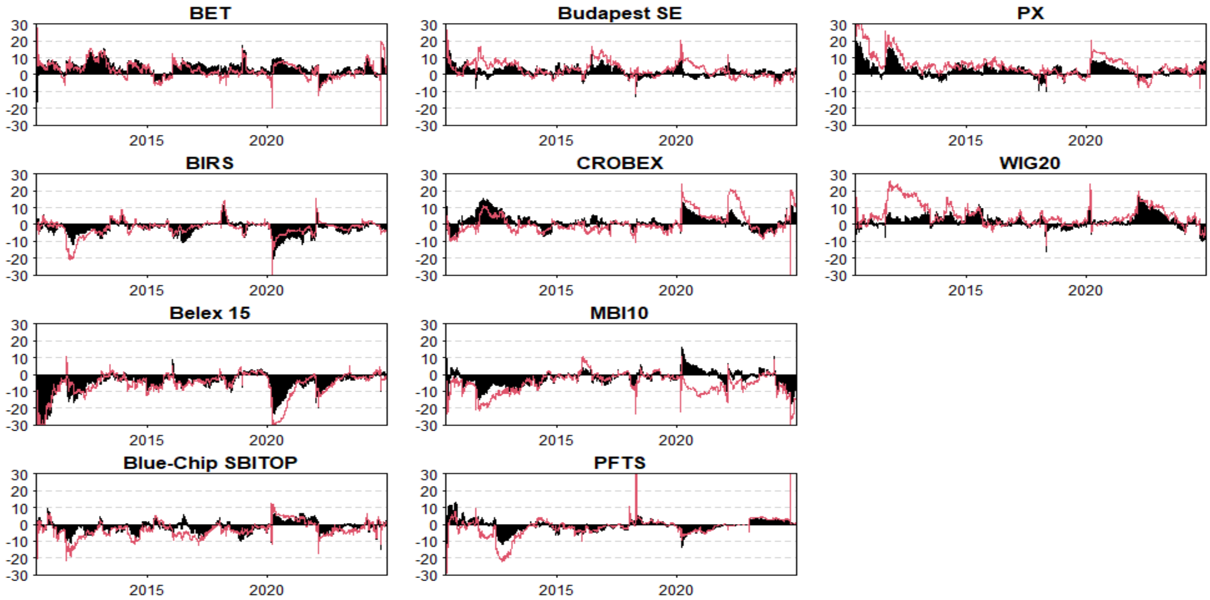
In the mid-2010s (2013-2019), the TCI stabilized at relatively low levels, fluctuating mostly between 15-25%. This reflected a period of economic recovery and relative calm in global markets, with local factors dominating regional dynamics. Only modest increases are visible during external disturbances such as the Chinese market turbulence (2015-2016) and the Brexit referendum, but their effects on Eastern Europe were limited. As seen in Figure 4, net transmitter and receiver roles were stable: Poland, the Czech Republic, and Hungary consistently acted as mild transmitters, while the smaller Balkan markets remained receivers.

A dramatic shift occurred in early 2020 with the onset of the COVID-19 pandemic. In March 2020, the TCI spiked to its highest level in the sample, reaching around 60%, indicating unprecedented synchronization as markets reacted to a common global shock. Similar COVID-19 spillover spikes are documented in the broader literature (Aslam et al., 2021; Rehman et al., 2022; Youssef et al., 2021). After the initial crash, connectedness declined but remained above pre-pandemic baselines for much of 2020, reflecting sustained policy-driven co-movements.

Another pronounced episode arose in late 2021-2022 during the escalation of the Russia-Ukraine conflict. The TCI increased from around 20% in late 2021 to nearly 40% in early 2022, reflecting tighter co-movements as geopolitical tensions unfolded. Unlike COVID, this rise was less abrupt but more persistent, maintaining elevated levels for much of 2022. By 2023-2024, connectedness reverted toward mid-2010s baselines, with only minor spikes linked to global inflation shocks and monetary policy shifts, suggesting no lasting structural increase in regional integration.

Furthermore, Figure 4 shows that Poland (WIG20), the Czech Republic (PX), and Hungary (BUX) consistently emerge as net transmitters, with positions remaining above zero across most of the sample. By contrast, Serbia (BELEX15), Bosnia (BIRS), and North Macedonia (MBI10) are persistent net receivers, with their positions becoming more negative during major crises, such as late 2011, March 2020, and early 2022, indicating disproportionate absorption of external shocks. In calmer periods, these markets revert toward mildly negative or near-zero values, reflecting limited but ongoing dependence on regional spillovers. A notable exception appears in the immediate post-COVID rebound, when North Macedonia's MBI10 briefly turns net positive under the EJC specification. This shift, absent in the TVP-VAR results, underscores how methodological differences can affect the classification of smaller and less liquid markets.

Figure 4: Dynamic Net Spillover



(Source: Author's compilation)

6. CONCLUSION

Our findings indicate that Eastern European equity markets display a moderate degree of interconnectedness. The Total Connectedness Index averages around 25%, implying that roughly one-quarter of return variance is driven by cross-market shocks. This suggests that while these markets are not isolated, showing meaningful co-movement and contagion, they remain less tightly integrated than major global markets. Accordingly, diversification opportunities persist within the region, although they tend to diminish during periods of financial turbulence.

We find clear evidence that connectedness in Eastern European equity markets is highly dynamic and event-driven. Periods of global or regional turmoil, such as the European debt crisis (2011-2012), the COVID-19 pandemic (2020), and the Russia-Ukraine conflict (2022), coincide with sharp spikes in the Total Connectedness Index, as markets moved more closely in tandem under stress. By contrast, during calmer periods such as the mid-2010s, spillovers subsided, and markets were more segmented, with domestic factors exerting a stronger influence on returns.

In terms of directional spillovers, our results reveal a clear core-periphery structure within the regional network. The larger and more internationally integrated markets, particularly Poland, the Czech Republic, Romania, and Hungary, consistently act as net transmitters of shocks. Their size, liquidity, and stronger links to global investors position them as sources of volatility that influence neighboring markets. By contrast, smaller markets such as Serbia, Bosnia and Herzegovina, and North Macedonia function primarily as net receivers. They exert little influence on others but remain vulnerable to spillovers from larger regional players and global shocks. Slovenia and Ukraine also lean toward net receiver status, although Slovenia, as an EU member, exhibits more intermediate behavior, while Ukraine's dynamics in 2022 were atypical due to war-related disruptions.

The findings carry important implications for both investors and policymakers. For investors with exposure to Eastern European equities, the results suggest that diversification within the region is beneficial but limited. In calmer periods, cross-market spillovers remain moderate, allowing portfolios to spread across countries to achieve meaningful risk reduction. However, during episodes of global or regional stress, correlations rise sharply, and diversification benefits erode. Investors should therefore remain attentive to these dynamics and consider hedging strategies when systemic risks are anticipated. For policymakers and regulators, the evidence highlights the critical importance of monitoring cross-market spillovers. Recent crises have demonstrated that even small markets in the Western Balkans remain highly vulnerable to external shocks, underscoring the need for sustained oversight of contagion risks.

The main limitation of this study is its focus on only stock index returns. Future research could broaden the scope to include other asset classes, such as bonds or exchange rates, to assess whether similar dynamics emerge. It would also be valuable to explore frequency-dependent spillovers, distinguishing between short and long-term connectedness, to better understand whether co-movements are driven by high-frequency speculative activity or by lower-frequency fundamental linkages.

REFERENCES

Antonakakis, N., Chatziantoniou, I., & Gabauer, D. (2020), "Refined measures of dynamic connectedness based on time-varying parameter vector autoregressions", *Journal of Risk and Financial Management*, Vol. 13 No. 4, p. 84.

Antonakakis, N., Gabauer, D., Gupta, R. and Plakandaras, V. (2018), "Dynamic connectedness of uncertainty across developed economies: A time-varying approach", *Economics Letters*, Vol. 166, pp. 63-75.

Aslam, F., Ferreira, P., Mughal, K. S. and Bashir, B. (2021), "Intraday volatility spillovers among European financial markets during COVID-19", *International Journal of Financial Studies*, Vol. 9 No. 1, p. 5.

Balcilar, M., Gabauer, D. and Umar, Z. (2021), "Crude Oil futures contracts and commodity markets: New evidence from a TVP-VAR extended joint connectedness approach", *Resources Policy*, Vol. 73, 102219.

Baruník, J. and Křehlík, T. (2018), "Measuring the frequency dynamics of financial connectedness and systemic risk", *Journal of Financial Econometrics*, Vol. 16 No. 2, pp. 271-296.

Bouri, E., Cepni, O., Gabauer, D. and Gupta, R. (2021), "Return connectedness across asset classes around the COVID-19 outbreak", *International Review of Financial Analysis*, Vol. 73, 101646.

Caloia, F. G., Cipollini, A. and Muzzioli, S. (2019), "How do normalization schemes affect net spillovers? A replication of the Diebold and Yilmaz (2012) study", *Energy Economics*, Vol. 84, p. 104536.

Cevik, E. I., Korkmaz, T. and Cevik, E. (2017), "Testing causal relation among central and eastern European equity markets: Evidence from asymmetric causality test", *Economic Research-Ekonomska Istraživanja*, Vol. 30 No. 1, pp. 381-393.

Chatziantoniou, I., Gabauer, D. and Stenfors, A. (2021), "Interest rate swaps and the transmission mechanism of monetary policy: A quantile connectedness approach" *Economics Letters*, Vol. 204, 109891.

Cocca, T., Gabauer, D. and Pomberger, S. (2024), *Clean Energy Market Connectedness and Investment Strategies: New Evidence from DCC-GARCH R2 Decomposed Connectedness Measures* (SSRN Scholarly Paper No. 4810641), Social Science Research Network.

Demiralay, S. and Bayraci, S. (2015), "Central and Eastern European stock exchanges under stress: A range-based volatility spillover framework", *Finance a Uver: Czech Journal of Economics & Finance*, Vol. 65 No. 5.

Diebold, F. X. and Yilmaz, K. (2009), "Measuring financial asset return and volatility spillovers, with application to global equity markets", *The Economic Journal*, Vol. 119 No. 534, pp. 158-171.

Diebold, F. X. and Yilmaz, K. (2012), "Better to give than to receive: Predictive directional measurement of volatility spillovers", *International Journal of Forecasting*, Vol. 28 No. 1, pp. 57-66.

Diebold, F. X. and Yılmaz, K. (2014), "On the network topology of variance decompositions: Measuring the connectedness of financial firms", *Journal of Econometrics*, Vol. 182 No. 1, pp. 119-134. https://doi.org/10.1016/j.jeconom.2014.04.012

Dumitrescu, S. (2015), "European equity market return, volatility and liquidity spillover dynamics during the Eurozone debt crisis", *Financial Studies*, Vol. 19 No. 2.

Fountas, S., Kontana, D. and Tzika, P. (2024), "Uncertainty and financial asset return spillovers: Are they related? Empirical evidence from three continents", *Empirical Economics*, Vol. 67 No. 5, pp. 1891-1918.

Gabauer, D. and Gupta, R. (2018), "On the transmission mechanism of country-specific and international economic uncertainty spillovers: Evidence from a TVP-VAR connectedness decomposition approach", *Economics Letters*, Vol. 171, pp. 63-71.

Gamba-Santamaria, S., Gomez-Gonzalez, J. E., Hurtado-Guarin, J. L. and Melo-Velandia, L. F. (2019), "Volatility spillovers among global stock markets: Measuring total and directional effects", *Empirical Economics*, Vol. 56 No. 5, pp. 1581-1599.

Koop, G., Pesaran, M. H. and Potter, S. M. (1996), "Impulse response analysis in nonlinear multivariate models", *Journal of Econometrics*, Vol. 74 No. 1, pp. 119-147.

Lastrapes, W. D. and Wiesen, T. F. (2021), "The joint spillover index", *Economic Modelling*, Vol. 94, pp. 681-691.

Louzis, D. P. (2013). *Measuring return and volatility spillovers in Euro area financial markets*.

Özer, M., Kamenković, S. and Grubišić, Z. (2020), "Frequency domain causality analysis of intra- and inter-regional return and volatility spillovers of South-East European (SEE) stock markets", *Economic Research-Ekonomska Istraživanja*, Vol. 33 No. 1, pp. 1-25.

Pesaran, H. H. and Shin, Y. (1998), "Generalized impulse response analysis in linear multivariate models", *Economics Letters*, Vol. 58 No. 1, pp. 17-29.

Rehman, M. U., Ahmad, N., Shahzad, S. J. H. and Vo, X. V. (2022), "Dependence dynamics of stock markets during COVID-19", *Emerging Markets Review*, Vol. 51, 100894.

Škrinjarić, T. (2020), "CEE and SEE equity market return spillovers: Creating profitable investment strategies", *Borsa Istanbul Review*, Vol. 20, S62-S80.

Škrinjarić, T. (2021), "Asymmetric spillovers between the stock risk series: Case of CESEE stock markets. In Patnaik, S., Tajeddini, K. and Jain, V. (Eds.), *Computational*

Management: Applications of Computational Intelligence in Business Management (pp. 97-135). Springer International Publishing.

Škrinjarić, T. (2022), "Higher moments actually matter: Spillover approach for case of CESEE stock markets", *Mathematics*, Vol. 10 No. 24, 4811.

Škrinjarić, T., Golubić, Z. and Orlović, Z. (2021), *Asymmetric spillovers on European stock markets: "Good" and "bad" volatility approach*.

Syllignakis, M. N. and Kouretas, G. P. (2011), "Dynamic correlation analysis of financial contagion: Evidence from the Central and Eastern European markets", *International Review of Economics & Finance*, Vol. 20 No. 4, pp. 717-732.

Youssef, M., Mokni, K. and Ajmi, A. N. (2021), "Dynamic connectedness between stock markets in the presence of the COVID-19 pandemic: Does economic policy uncertainty matter?", *Financial Innovation*, Vol. 7 No. 1, p. 13.

APPENDIX

Table 1: Spillover analysis using VAR

Market	BET	BIRS	Belex 15	Blue-Chip SBITOP	Budapest SE	CROBEX	MBI10	PFTS	PX	WIG20	FROM
BET	56.79	0.10	0.60	4.92	7.45	6.99	2.43	1.80	11.40	7.51	43.21
BIRS	0.12	99.11	0.02	0.06	0.20	0.06	0.17	0.17	0.01	0.08	0.89
Belex 15	2.35	0.07	84.34	2.45	1.12	3.02	2.71	0.59	2.61	0.75	15.66
Blue-Chip SBITOP	6.28	0.11	1.80	66.97	4.01	7.32	3.12	0.57	5.10	4.72	33.03
Budapest SE	6.86	0.00	0.36	2.80	53.39	5.22	1.87	0.77	13.70	15.03	46.61
CROBEX	7.42	0.06	1.28	6.19	5.89	59.57	4.54	0.66	7.74	6.64	40.43
MBI10	3.76	0.02	1.70	3.22	2.78	6.20	76.57	0.37	3.02	2.35	23.43
PFTS	2.77	0.00	0.34	0.36	1.59	0.90	0.35	89.31	2.30	2.08	10.69
PX	10.16	0.05	0.74	3.22	13.06	6.40	1.76	1.14	50.55	12.91	49.45
WIG20	6.77	0.04	0.22	2.60	15.10	5.64	1.59	0.96	13.54	53.54	46.46
TO	46.49	0.46	7.06	25.81	51.21	41.76	18.54	7.03	59.43	52.08	309.86
Inc.Own	103.28	99.57	91.40	92.79	104.60	101.32	95.10	96.34	109.99	105.62	cTCI/TCI
NET	3.28	-0.43	-8.60	-7.21	4.60	1.32	-4.90	-3.66	9.99	5.62	34.43/30.99
NPT	6.00	3.00	0.00	2.00	8.00	5.00	2.00	4.00	8.00	7.00	

Source: Author's compilation

Table 2: Spillover analysis using TVP-VAR

Market	BET	BIRS	Belex 15	Blue-Chip SBITOP	Budapest SE	CROBEX	MBI10	PFTS	PX	WIG20	FROM
BET	60.36	0.73	1.11	4.33	6.76	5.76	2.03	2.06	9.84	7.02	39.64
BIRS	1.21	92.05	0.64	1.12	0.96	0.89	1.00	0.60	0.62	0.91	7.95
Belex 15	2.24	0.81	83.68	3.28	1.25	2.24	2.75	0.81	1.95	0.98	16.32
Blue-Chip SBITOP	5.32	0.91	2.46	71.04	3.05	5.55	2.88	1.07	3.90	3.83	28.96
Budapest SE	6.25	0.52	0.49	2.44	57.38	3.67	1.78	1.55	11.81	14.13	42.62
CROBEX	5.99	0.87	1.27	4.77	4.07	68.10	2.80	1.78	5.58	4.77	31.90
MBI10	3.16	0.56	2.40	3.43	2.59	4.39	77.40	0.95	2.63	2.49	22.60
PFTS	2.63	0.47	0.68	0.91	2.00	1.55	0.89	86.08	2.16	2.63	13.92
PX	9.24	0.47	0.81	3.19	11.21	4.92	1.63	1.64	54.78	12.10	45.22
WIG20	6.35	0.67	0.51	2.54	13.89	4.07	1.63	1.78	12.14	56.41	43.59
TO	42.40	6.01	10.37	26.01	45.79	33.03	17.40	12.25	50.63	48.86	292.74
Inc.Own	102.76	98.06	94.05	97.05	103.17	101.13	94.79	98.33	105.40	105.27	cTCI/TCI
NET	2.76	-1.94	-5.95	-2.95	3.17	1.13	-5.21	-1.67	5.40	5.27	32.53/29.27
NPT	6.00	1.00	0.00	3.00	7.00	4.00	2.00	5.00	9.00	8.00	

(Source: Author's compilation)