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Frequency Connectedness and Network Analysis in Equity Markets: Evidence from G-7 Countries☆

Hisse Senedi Piyasalarında Frekans Bağlantılılığı ve Ağ Analizi: G-7 Ülkeleri Üzerine Bir Uygulama

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ABSTRACT

In this study, we explore the cross-market volatility transmissions between equity markets in G-7 countries by employing the frequency connectedness method. By implementing this approach, we estimate the dynamic interaction mechanism of systemic risk among strongly interconnected financial markets during financial calm and distress periods. Additionally, we exhibit network topologies of directional spillovers to capture the financial connectedness of G-7 countries. The findings of the study propose that systemic risk contagion between G7 countries intensifies during financial turmoils and underlines the importance of an effective regulatory framework to monitor financial stress.

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ÖZ

Bu çalışmada, G-7 ülkelerinin hisse senedi piyasaları arasındaki piyasa oynaklık aktarımlarını incelemek için frekans bağlantılılığı yöntemini uygulamaktayız. Bu yaklaşımla, yüksek bağlantılılığa sahip finansal piyasalar arasındaki sistemik riskin dinamik aktarım mekanizması finansal durgunluk ve karışıklık dönemlerinde incelenmektedir. Ek olarak; G-7 ülkelerinin finansal bağlantılılığını yakalamak için, yönlü yayılmaların ağ topolojisini sunmaktayız. Çalışmanın bulguları G-7 ülkeleri arasındaki sistemik risk bulaşıcılığının finansal türbulans dönemlerinde şiddetlendiğini göstermekte ve finansal stresin izlenmesi için etkili bir denetim mekanizmasının önemini vurgulamaktadır.

1. Introduction

The capitalist economic system has been hit by deep and severe financial turmoils since the 1929 financial crisis. Among these financial imbalances, the 2008 financial crisis (GFC) is arguably the most acute one and the economic system is still vulnerable despite more than a decade after the crisis. The GFC first emerged in the US financial system and quickly dispersed throughout the world. The literature has been curious on the contagion of financial crisis since then.

Despite there is no consensus on "financial contagion", scholars have focused on the term both empirically[1] and qualitatively[2]. Some studies directly link the term to a rapid surge in correlations (Baig and Goldfajn, 1998, Berg and Pattillo, 1999), whereas some others associate financial contagion to escalated comovements in asset returns

[1] See Calvo and Reinhart (1996), Masson (1999), Claessens *et al.* (2001), Schinasi and Smith (2001), Karolyi (2003).

[2] See Bae *et al.* (2003), Salgado *et al.* (2000), Corsetti *et al.* (2001), Kodres and Pritsker (2002), Dungey *et al.* (2004), Rodriguez (2007), Gardini and Angelis (2012),

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following a financial crisis (Valdés, 1997; Frankel and Schmukler, 1998).

Systemic risk can be linked to the uncertainty reflecting the whole market stemmed from a component of the financial system. Systemic risk can be estimated by employing the GARCH models by scholars (Celik, 2012; Engle *et al*., 2014; Mensi *et al*., 2018). Likewise, we focus on the systemic risk contagion among G-7 stock markets using the realized volatilities of G-7 stock market indexes estimated by the GARCH (1,1) model[3]. We concentrate on the contagion dispersed by the stock markets since a vast amount of systemic risk spilled via the equity market channel during the GFC. Additionally; we aim to detect short-term connectedness between G-7 equity markets and accordingly we compute connectedness on the $(\pi, \pi/4)$ band which reflects roughly 1 to 4 days connectedness.

This study contributes to the extant literature in three ways: First; we gauge systemic risk contagion among the stock markets of most advanced countries by implementing a seminal methodology. Second; we estimate the total spillover index in a 200-day moving window on the $(\pi, \pi/4)$ frequency band which properly responds to prominent financial stress incidents. Finally; we identify the network topology of directional TO/FROM spillovers between G-7 equity markets.

We proceed with the study as follows: Section 1 reviews the related literature on financial contagion. Section 2 consists of the data and the empirical model of the study. Section 3 discusses the empirical results. Finally, Section 4 draws some conclusions.

2. Literature Review

Since the pioneer study of Roll (1989) which explored contagious effects of the Black Monday of 1987, scholars have been curious about financial contagion. A strand of this literature links financial contagion to a rapid surge in cross-market linkages and accordingly gauge contagion in terms of elevated correlations (Calvo and Reinhart, 1996; Baig and Goldfajn, 1999; Masih and Masih, 1997; Ghosh *et al*., 1999). Nonetheless, some scholars find this approach inadequate to capture the nature of the financial contagion. Within this group, Billio and Pelizzon (2003) assert that heteroscedasticity and omitted variable problems could lead to biased correlation.

A body of the studies argued that intensified co-movements between financial markets to detect financial contagion. Johnson and Soenen (2002) explored co-movements among stock markets in Asia and detect strong co-movements. Rua and Nunes (2009) analyzed co-movements between equity markets of Germany, Japan, the UK and the U.S. by applying wavelet analysis and detect intensified co-movement at lower frequencies. Haque and Kouki (2010) focused on co-movements between advanced and developing countries by employing the Principal Component Analysis (PCA) to capture financial contagion. Along similar lines, Lin (2012) found intensified co-movements among Asian markets during financial turmoil periods by implementing the ARDL approach. Other studies that detected strong co-movements during financial crises are Chiang *et al*. (2007), Khan and Park (2009), Huyghebaert *et al*. (2010), Kenourgios *et al*. (2011), Aloui and Hkiri (2014).

It is worthwhile mention that studies have implemented various econometric methods such as VAR (Ang and Longstaff, 2013; Samarakoon, 2011; Boubaker *et al*., 2015), DCC-GARCH (Chiang *et al*., 2007; Celik, 2012; Hemche *et al*., 2016), logit-probit models (Luchtenberg and Vu, 2015; Dungey and Gajurel, 2015), minimal spanning and hierarchical trees (He and Chen, 2016), and the Kalman Filter (Shen *et al.*, 2015) to detect contagion.

Owing to rapid spillovers across financial markets during turmoil times, scholars have devoted themselves to gauge connectedness of financial markets by employing quantitative methods. In that regard, Diebold and Yilmaz (2009) developed a new method, known as Diebold-Yilmaz (D-Y) method by which the total, directional, net spillovers among financial indicators are computed by generalized forecast error variance decompositions of a VAR model (Diebold and Yilmaz, 2009). In accordance with this study, Diebold and Yilmaz computed connectedness between various markets[4] (Diebold and Yilmaz, 2010, 2012, 2014 and 2015).

Financial connectedness studies reported different findings. For example, volatility spillovers of stock markets displayed bursts, whereas return spillovers of stock markets didn't display bursts during major market crises (Diebold and Yilmaz, 2009; Yilmaz, 2010). According to Diebold and Yilmaz (2012), the stock market transmitted the highest net directional volatility spillover, whereas the highest gross directional volatility spillover was dispersed by the bond market. Diebold and Yilmaz (2014) asserted that the spillovers soar during the GFC. Diebold and Yilmaz (2015) argued that the US market spilled spillovers to the European markets during the GFC and the direction reversed back in June 2011.

A strand of these studies estimated spillovers between currency markets. For example; spillovers among Euro/Czech Koruna, Euro/Hungarian Forint and Euro/Polish Zloty from January 3, 2003 to June 30, 2009. Empirical results of the study indicate that the volatility spillover index display burst around the 2005, March Dollar crisis and the GFC (Bubák *et al.*, 2011), spillovers between 4 exchange rates (USD/EUR, USD/GBP, USD/JPY and USD/CHF) from 1/6/1986 to 12/30/2011 (Antonakakis, 2012), and spillovers between future contracts over AUD, GBP, CAD, EUR, JPY, CHF in January 2007 and December 2015. The author found over 65% connectedness in 2008 and 2010 among currencies (Baruník *et al*., 2016).

In other spillovers studies, equity market connectedness was estimated by the D-Y method. Tsai (2014) computed spillovers between the stock markets of the US, the UK, Germany, France and Japan in 1990/01 and 2013/05. According to the study, the spillovers between these markets significantly increased after 1998 (Tsai, 2014). Likewise, Guimarães-Filho and Hong (2016) estimated

[3] Optimal lag order selections in the GARCH model is selected by the Akaike Information Criterion (AIC) and the Bayesian Information Criterion in the empirical analysis.

[4] See Financial and Macroeconomic Connectedness website: http://financialconnectedness.org.

spillovers among Asian equity markets in 1996/01 and 2015/10 and asserted that China is the main source of financial shock with large spillovers (Guimarães-Filho and Hong, 2016).

Other strand of spillover studies estimated spillovers between bond markets by implementing the D-Y approach. Antonakakis and Vergos (2013), computed spillovers between Euro states government bond spreads between 03/03/2007 and 06/18/ 2012. Empirical findings of the study reveal that the bond yield spread shocks stemmed from the periphery have larger effects compared to the shocks originated by the core states(Antonakakis and Vergos, 2013). Along similar lines, Bostanci and Yilmaz (2020) identified spillovers between Sovereign CDS (SCDS) for 38 countries from 2009:2 to 2014:4. The authors argued that emerging markets play an important role in dispersing systemic risk after the GFC (Bostanci and Yilmaz, 2020).

It can be argued that the D-Y studies have reconciled some stylized facts. First; the major financial markets are dominated by strong connectedness. Second; the total spillover index soars around financial as well as political upheavals and alleviates around calm times.

Baruník and Křehlík (2018) introduced a seminal approach, "the frequency connectedness", by which connectedness between financial indicators is computed on different cycles (short-, medium-, and long-) based on the spectral representation of the VAR model. In the model, the connectedness of indicators are estimated by Fourier transforms of IRFs on a given frequency band. This groundbreaking methodology has gained attention by scholars and studies computed connectedness between various markets by implementing the frequency connectedness method (Polat, 2019; Maghyereh et al., 2019).

The frequency connectedness approach has some superiorities over conventional connectedness measures and the D-Y method. First; the methodology ensures measuring connectedness over different cycles (short-, medium-, and long-). Second, the methodology provides to detect how cross-correlations between financial assets affect the connectedness. Third, it allows us to estimate directional TO/FROM spillovers on different frequency bands. All in all; the method ensures estimations that are order invariant in the selected VAR model.

3. Data and Methodology

3.1. Data

Our data set consists of stock market indexes of G7 countries (S&P 500 for the US, FTSE for the UK, S&P/TSX for Canada, NIKKEI for Japan, DAX for Germany, CAG for France and FTSE MIB for Italy) covering January 2, 1998 and December 5, 2018 period[5].

3.2. Methodology

Consider the following N-variable VAR model:

$$x_t = \sum_{i=1}^{q} \Phi_i x_{t-1} + \varepsilon_t \quad (1)$$

where x_t is the $N \times 1$ vector of asset variables, ε_t, is $N \times 1$ vector of white noise with $\varepsilon_t \sim N(0, \Omega)$.

The MA representation of the VAR model can be given as follows:

$$x_t = \Psi(\mathrm{L})\varepsilon_t \quad (2)$$

where $\Psi(\mathrm{L})$ can be computed from $\Phi(L) = [\Psi(\mathrm{L})]^{-1}$.

Define frequence response function as $\Psi(e^{-iw}) = \sum_h e^{-iwh}\Psi_h$ where Ψ_h is the Fourier transform of the coefficients.

A Fourier transform of $MA(\infty)$ filtered series represents the spectral density of x_t at frequency w as follows:

$$S_X(W) = \sum_{h=-\infty}^{\infty} E(x_t x'_{t-h}) e^{-iwh} = \Psi(e^{-iw})\Omega\, \Psi'(e^{+iw}) \quad (3)$$

The generalized causation spectrum over frequencies $w \in (-\pi, \pi)$ is defined as:

$$\tau(w)_{j,k} = \frac{\sigma_{kk}^{-1} \left|\Psi(e^{-iw})\Omega\right|^2_{j,k}}{\left(\Psi(e^{-iw})\Omega\, \Psi'(e^{+iw})\right)_{jj}} \quad (4)$$

where $\Psi(e^{-iw}) = \sum_h e^{-iwh}\, \Psi_h$.

Scaled generalized variance decompositions on $d = (a, b)\colon a, b \in (-\pi, \pi), a < b$ is identified as $\left(\breve{\theta}_d\right)_{j,k} = (\theta_d)_{j,k} / \sum_k (\theta_\infty)_{j,k}$.

The within connectedness on d is introduced as follows:

$$C_d^w = 100.\left(1 - \frac{Tr\{\breve{\theta}_d\}}{\sum \breve{\theta}_d}\right) \quad (5)$$

The frequency connectedness on d is given as:

$$C_d^f = 100.\left(\frac{\sum \breve{\theta}_d}{\sum \breve{\theta}_\infty} - \frac{Tr(\breve{\theta}_d)}{\sum \breve{\theta}_\infty}\right) = C_d^w \frac{\sum \breve{\theta}_d}{\sum \breve{\theta}_\infty} \quad (6)$$

Where $Tr\{.\}$ Is the trace operator, $\sum \breve{\theta}_d$ takes the sum of all elements of the $\breve{\theta}_d$.

4. Empirical Results

The realized volatilities of the returns of the stock market indexes are calculated by employing $GARCH(1,1)$ model. Figure 1 exhibits the dynamics of realized volatility of the volatilities in Jan 2, 1998 and Dec 5, 2018.

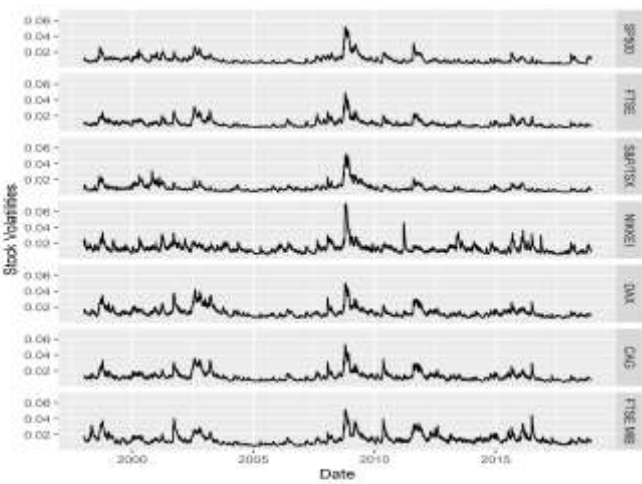

Figure 1. Volatilities of Stock Market Indexes in January 2, 1998 and December 5, 2018.

[5] The data set of the study has been collected from the Bloomberg database.

As seen in Figure 1, the volatilities of the stock market indexes of G-7 countries create proper signs to financial distress and calm periods. The indexes skyrocket around the GFC sharing a common pattern and reach their peak values. The realized volatilities of the stock market indexes for the Euro member states (Germany, France, and Italy) and the United Kingdom surge during the 2010-2012 European Sovereign Debt Crisis (ESDC) and at around the Brexit referendum.

4.1. Spillover Index

We estimate connectedness between the stock market indexes by implementing the frequency connectedness approach. We compute frequency connectedness for 100-day-ahead forecasts in the VAR model[6] in a 200-day rolling window on the band $(\pi, \pi/4)$ by conducting the VAR-LASSO estimations with an automatic selection of the LASSO penalty using cross-validation. Figure 2 shows overall spillovers on the band $(\pi, \pi/4)$ with prominent financial stress events.

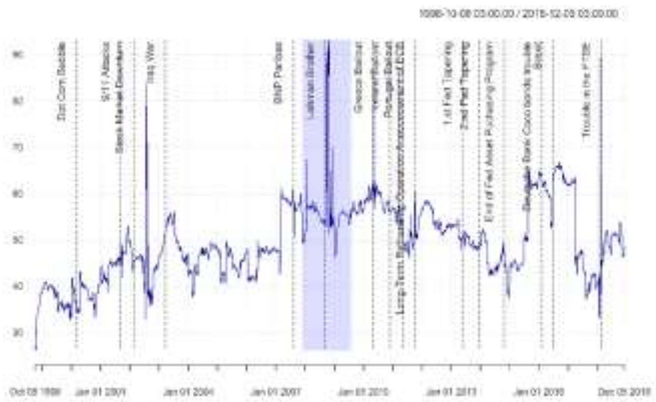

Figure 2. G-7 Stock Market Connectedness on 3.14 to 0.79

As shown in Figure 2, the overall spillover index properly captures prominent financial stress as well as geopolitical events such as Lehman Brothers and the Ireland Bailout. The first peak appears in Jul 2002. Thereafter, the overall spillover index sharply falls and escalates with the Iraq war. The index sharply surges during the periods that cover BNP Paribas, Lehman Brother and TARP release and soars during the European Sovereign Debt Crisis. The overall spillover index reaches its peak value around 2008. Oct 30 shortly after the Lehman Brothers Collapse. The index gradually plunges with the announcement of Long Term Refinancing Operation (LTRO) of the European Central Bank (ECB) and slightly surges around the coco bonds trouble of Deutsche Bank. Finally, the index skyrockets in the first quarter of 2018 which coincides with the fall of 8.4% for FTSE 100, 7.1% for Nikkei and 1.2% of S&P 500.

4.2. Network Analysis

In this subsection, the network topology of G-7 equity markets is presented in the 1998-2018 period. Network topology consists of directional spillovers that exceed a threshold value $(\delta_x := (max(FROM\ directional\ spillovers) \times \gamma,$ where $\gamma = 0.5)$. Figure 4 exhibits the network topology of stock market connectedness between G-7 countries.

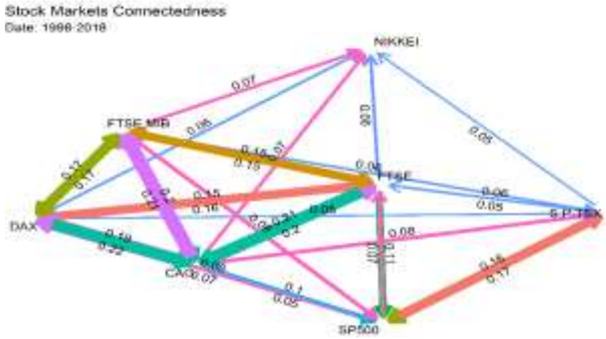

Figure 4. Network Topology of Equity Market Connectedness in 1998-2018

As shown in Figure 4, the equity markets for G-7 European states are dominated by strong financial connectedness (DAX, CAG, FTSE.MIB and FTSE). The network topology also suggests that geographical proximity has an important role in the financial interconnectedness of countries (e.g., S&P 500 and S&P TSX). Countries can be classified into three cluster groups, namely, strongly connected countries (Germany-France, Germany-UK, Germany-Italy, France-UK, US-Canada), moderately connected countries (US-UK, US-Germany, US-France) and weakly connected countries (Japan-Germany, Japan-Italy, Japan-France, Japan-UK, Japan-Canada, Canada-UK, Canada-France, Canada-Italy, Canada-Germany).

5. Conclusion

In this study, we analyze the equity market connectedness of G-7 countries by implementing the methodology of Baruník and Křehlík (2018). Accordingly, we estimate the stock market connectedness of the most advanced countries and identify directional spillovers in a frequency band. Besides, we visualize the network topology of equity market connectedness to detect directional spillovers.

The 200-day moving average index efficiently responses to well-known financial and geopolitical events. Consequently, the total spillover index surges with financial bursts and plunges with financial calm times. The total spillover index reaches its peak value on October 30, 2008, which coincides with the midst of the GFC. These findings are in line with the results in the studies of Diebold and Yilmaz (2009) and Yilmaz (2010).

The network topology reveals the following results: First, the major countries stand at the epicenter of the network and accordingly are the net transmitter of systemic risk. Second; Euro states are strongly connected in terms of receiving/transmitting systemic risk to each other. Third; geographical contiguity plays an essential role in the network graph. These results are also consistent with the findings of the previous D-Y studies.

This study has important policy implications. Since systemic risk spillovers surge during turbulent times, policymakers need to build an effective regulatory framework to monitor the financial sector. In this respect, modern risk management tools such as stress tests could be

[6] The optimal lag for the VAR model is selected as 2 based on the AIC and the FPE.

helpful. Analyzing other types of contagion such as currency and sovereign default risk contagion in addition to equity market contagion is vital owing to the integrity of the financial system and to avoid catastrophic effects of systemic risk propagation via these channels.

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