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MEASURING CONNECTEDNESS AND NETWORK ANALYSIS IN STOCK MARKETS FOR DEVELOPED AND DEVELOPING COUNTRIES[1]

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Abstract

Countries are experiencing a surge in political, economic, and financial integration, consequently shaping international market linkages. Financial crises can rapidly spread between countries, emphasizing the need to monitor and assess stock market connections. This paper investigates the degree of financial market connectedness using daily stock returns from January 1997 to August 2017 for 13 countries, both developed and developing. The connectedness measure of Diebold and Yilmaz (2009-2012) is applied to examine the connectedness of stock market returns and the direction of spillovers for all stock markets. This study also analyzes the dynamic connectedness from the U.S. stock market to all other stock markets. The results indicate that the U.S. stock market is the most influential stock market to the others. The results of the dynamic analysis show that connectedness changes over time, specifically during turmoil periods. Most developed countries are transmitters of return spillover shocks while developing countries are recipients.

Keywords: *Financial Connectedness, Network Analysis, Spillover Index, Stock Markets.*
JEL Classification: *G15, F30, F36*

GELİŞMİŞ VE GELİŞMEKTE OLAN ÜLKELERİN HİSSE SENEDİ PİYASALARINDA BAĞLANTILILIĞIN ÖLÇÜLMESİ VE AĞ ANALİZİ

Öz

Ülkeler arasındaki siyasi, ekonomik ve finansal entegrasyondaki artış uluslararası piyasa bağlantılarını etkilemektedir. Finansal krizler ülkeler arasında hızla yayılabilmektedir, bu nedenle hisse senedi piyasalarının birbirleriyle olan ilişkilerinin izlenmesi ve ölçülmesi önemlidir. Bu makale gelişmiş ve gelişmekte olan toplam 13 ülke için Ocak 1997'den Ağustos 2017'ye kadar günlük hisse senedi getirilerini kullanarak finansal piyasalardaki bağlantılılık derecesini araştırmaktadır. Diebold ve Yilmaz'ın (2009-2012) bağlantılılık ölçüsü, tüm hisse senedi piyasaları için borsa getirilerinin bağlantılılığını ve yayılmaların yönünü incelemek için uygulanmıştır. Buna ek olarak, çalışmada ABD hisse senedi piyasasının diğer tüm hisse senedi piyasalarıyla dinamik bağlantılılığı analiz edilmektedir. Sonuçlar, ABD hisse senedi piyasasının çeşitli bölgelerdeki diğer hisse senedi piyasalarını en çok etkileyen piyasa olduğunu göstermektedir. Dinamik analiz sonuçları, bağlantılılığın zaman içinde, özellikle de çalkantılı dönemlerde değiştiğini ortaya koymaktadır. Gelişmiş ülkelerin çoğu getiri yayılma şoklarının göndericisi konumundayken, gelişmekte olan ülkeler alıcısı konumundadır.

Anahtar Kelimeler: *Finansal Bağlantılılık, Ağ Analizi, Yayılma Endeksi, Hisse Senedi Piyasaları*
JEL Sınıflandırması: *G15, F30, F36*

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1. Introduction

Following the global financial crisis of 2008, there have been notable transformations in the worldwide economic and financial structure. Markets have become more interconnected, with various sectors exhibiting a more systemic pattern of movement. Due to highly integrated financial markets, financial instability is contagious and can quickly spread to other countries. Policymakers and financial practitioners must recognize the growing interconnectedness within the system and make decisions accordingly. It is essential to measure and monitor market relations to establish "early warning systems" for emerging crises and track the progress of current ones.

Increasing political, economic, and financial integration among countries has led to a significant transformation in international market linkages. This integration has been driven by various factors such as the growth of multinational corporations, advancements in technology, and the liberalization of trade policies (Longin and Solnik, 1995:4). One of the key consequences of this integration is the deepening interdependence between economies. Countries are now more interconnected than ever before, with trade and investment flows playing a crucial role in shaping global economic dynamics. This has resulted in the formation of complex supply chains that span across multiple countries, allowing for the efficient production and distribution of goods and services on a global scale. Moreover, the integration of financial markets has facilitated the flow of capital across borders.

Financial linkages have thus become an important focus of research in international finance. Studies suggest that the transmission of volatility across financial markets intensifies during periods of financial turbulence. Hence, a growing body of literature has examined both the contagion of events and the connectedness of financial systems in both turmoil and tranquil periods. International stock market co-movement has been a topic of great interest to researchers, especially since the 1987 stock market crash, also known as "Black Monday". This event was one of the most severe global financial crises in history, affecting most of the world's major stock markets. Many studies analyze the effect of the crashes on stock markets (Roll, 1989; Hamao et al.,1990; King and Wadhwani, 1990; Lee and Kim, 1993; Calvo and Reinhart, 1996; Ghosh et al., 1999).

Many studies related to financial connections have argued that it is important to identify financial contagion, which manifests as intensified common movements among financial markets. Contagion can be defined as "a significant increase in the probability of a crisis in one country, conditional on a crisis occurring in another country" (Pericoli and Sbracia, 2003:579). Several studies in the financial literature, such as those by Christiansen and Ranaldo (2009), Fratzscher and Chudick (2011), Beirne et al. (2009), and Dooley and Hutchison (2009), have provided evidence of contagion during global financial crisis.

In the financial literature, there exists a lack of consensus regarding the precise definitions of concepts indicating market comovements. Various discussions and models have been dedicated to exploring these concepts. Economists commonly employ terms such as "spillover," "contagion," and "herding behaviors" when examining financial markets, particularly in response to events like crises, crashes, or significant news. In broader terms, contagion and spillovers refer to the "transmission of shocks from one country to others" (Alter and Beyer, 2013: 3). Conversely, terms like "interdependence" and "connectedness" are typically utilized to describe periods of high market comovements during both crisis and stability periods.

Forbes and Rigobon (2002) make a clear distinction between contagion and interdependence within financial markets. According to their argument, contagion happens when cross-market linkages significantly increase after a shock, while interdependence refers to a consistently high level of correlation between markets, particularly when they already exhibit significant comovement during stable periods. Building on this framework, many researchers have examined whether the relationship between stock markets tends towards interdependence or contagion

(Edward and Susmel, 2001; Wilson and Zurbruegg, 2004; Bonfiglioli and Favero, 2005; Corsetti et al., 2005; Cheung et al., 2008).

Stock market comovements increase in time and have high volatility in a financial crisis (Avouyi-Dovi and Neto, 2004; Corsetti et.al., 2005). From the 1990s, economists argued that market comovements vary over time. Bekaert and Harvey (1995), Longin and Solnik (1995), Karolyi and Stulz (1996), and Solnik et al. (1996) found that stock market integration fluctuates over time. They found that during periods of high volatility, correlations between countries tend to increase. Particularly following the global financial crisis of 2008, the number of studies analyzing how the crisis affected equity markets increased. (Sun and Zhang, 2009; Kazi et al., 2011; Dajcman et.al., 2012; Lee and Jeong. 2014).

The literature offers various methodologies for analyzing market relations, with cross-market correlation coefficients (King and Wadhwani (1990), Lee and Kim, (1993), Forbes and Rigobon (2002), Avouyi-Dovi and Neto (2004), Wilson and Zurbruegg (2004)), and different GARCH models (Karolyi (1995), Edward and Susmel (2001), Beirne et.al. (2009), Mukherjee and Mishrab (2010), Horvath and Poldauf (2012), Padhi and Lagesh (2012), Bala and Takimoto (2017)), DCC models (Cheung et.al. (2008), Lahrech and Sylwester (2011), Kazi et al. (2011), Min and Hwang (2012), Dajcman et.al. (2012), Hwang et.al. (2013), Lee and Jeong (2014), Ozer-Imer and Ozkan (2014), Albulescu et.al. (2015)) being among the most commonly used models.

In recent years, studies on stock market relations have shifted towards measuring interdependencies rather than merely testing for contagion or interdependence. Diebold and Yilmaz (2011) introduced the term "connectedness" to describe financial market relations and proposed a novel method, the Spillover Index (later referred to as the Connectedness Index), which is non-pairwise and directional. This methodology has been adopted by numerous studies to analyze stock market relations in both turbulent and tranquil periods (Cheung et al., 2008; Schmidbauer et al., 2013; Zhou et al., 2012; Erkol, 2015; Nguyen, 2015; Demirer et al., 2015; Bostancı and Yilmaz, 2015; Chen and Wu, 2016; Guimaraes-Filho and Hong, 2016; Zhang, 2017; Lundgren et al., 2018; Yoon et al., 2019; Bagheri and Ebrahimi, 2020; Bahloul and Khemakhem, 2021; Attarzadeh and Balcilar, 2022). Table 1 shows the methodologies and findings of previous research analyzing the stock markets relations.

Table 1: **Studies Analyzed Stock Market Relations**

Author(s)	Methodology	Findings
King and Wadhwani (1990)	Cross-market correlation coefficient	There is contagion between the US, the UK and Japan stock markets. Correlations increase high volatility periods.
Hamao et.al (1990)	GARCH-M	There are significant price-volatility spillovers between countries.
Lee and Kim (1993)	Explanatory factor analysis	There is significant increase in the correlation coefficient between markets during the 1987 Crash.
Longin and Solnik (1995)	Multivariate GARCH	International market correlation increases in high volatility period.
Karolyi (1995)	Bivariate GARCH	The effect of US crisis on Toronto stock market is smaller and temporary.
Karolyi and Stulz (1996)	Multivariate ARCH	Large shocks to wide base stock market positively affect the return correlations.
Edward and Susmel (2001)	SWARCH	Latin American stock markets have interdependent volatility process.
Forbes and Rigobon (2002)	Cross-market correlation coefficient	The high level of comovement during crisis periods refer to interdependence.
Avouyi-Dovi and Neto (2004)	Cross-market correlation coefficient	Conditional correlation vary over time and tend to rise in high volatility periods. The highest degree of comovement is observed across the US with Canada and Mexico.

Table 1(Continued): **Studies Analyzed Stock Market Relations**

Author(s)	Methodology	Findings
Wilson and Zurbruegg (2004)	Cross-market correlation coefficient	There is contagion from Thailand to other Asian stock markets.
Corsetti et. al. (2005)	Standard factor model	The idea of "no contagion, only interdependence" is doubtful. There is some interdependence, some contagion between the stock markets.
Bonfiglioli and Favero (2005)	Co-integration analysis	There is not long-run interdependnece between the U.S. and German stock markets. Hovewer there in the short run there is contagion and interdependence.
Cheung et. al. (2008)	DCC and Spillover Index	There is interdependence between the U.S. and EMEAP stock markets. Contagion is observed only regionally.
Kazi et.al (2011)	DCC-GARCH	There exists "contagion effect" between countries during global financial crisis period.
Lahrech and Sywester (2011)	DCC-MGARCH	The comovements between countries increse over time.
Horvath and Poldauf (2012)	BEKK-GARCH	Correlations between stock markets generally increase in global crisis period.
Dajcman et.al. (2012)	DCC-GARCH and wavelet analysis	Over the sample period, financial crises did not consistently increase stock market movements across all measures.
Min and Hwang (2012)	DCC-MGARCH	Stock market correlations initially rise in the early stages of a financial crisis, and in the second stage there is a further increase due to herding behavior in certain markets.
Padhi and Lagesh (2012)	BEKK-GARCH and DCC	The comovements of stock markets vary depending on the scale and also change over time.
Chow et.al. (2013)	Rolling window estimaiton	The dependence between East Asia stock market increases.
Hwang et.al. (2013)	DCC-EGARCH	There is a positive spillover effect from the U.S. stock market to developing stock markets and presence of contagion.
Lee and Jeong (2014)	DCC- MGARCH	Market integration process is dynamic.
Ozer-Imer and Ozkan (2014)	DCCR	The volatilities of currencies at least double for almost all the currency returns after global financial crisis.
Diebold and Yilmaz (2010)	Spillover Index	Volatility spillovers between markets remained limited until the 2008 global financial crisis, but evidence suggests spillovers from the bond market to other markets emerged post-crisis.
Schmidbauer et. al. (2013)	Connectedness Index	An upward trend is observed in the spillover index during crises periods.
Zhou et.al. (2012)	Connectedness Index	The U.S. demonstrated the highest level of volatility spillover to other markets during the mortgage crisis.
Diebold and Yilmaz (2015b)	Connectedness Index	Time-varying connectedness between the volatilities of the stock returns of the most important financial institutions in the United States for the period leading up to and during the global financial crisis of 2008.
Erkol (2015)	Connectedness Index	During a crisis or a crash, return and volatility spillovers demonstrate distinct behaviors.
Demirer et. al. (2015)	Connectedness Index	The interconnectedness of global banks fluctuates in line with global market integration. During crises, there is a notable surge in the interconnectedness of global banks.
Chen and Wu (2016)	Connectedness Index	Comovements and connectedness among commodity markets have intensified during the global financial crisis.
Guimaraes-Filho and Hong (2016)	Connectedness Index	Asian stock markets have significant spillover effects on certain global markets.

Table 1(Continued): **Studies Analyzed Stock Market Relations**

Author(s)	Methodology	Findings
Diebold and Yilmaz (2016)	Connectedness Index	The U.S. exhibited high directional connectedness to Europe during 2007-2008.
Zhang (2017)	Connectedness Index	Major oil shocks have a notable impact on stock markets.
Lundgren et al. (2018)	Connectedness Index	During the global financial crisis and European sovereign debt crisis, most uncertainties serve as significant channels for transmitting volatility connectedness.
Yoon et al. (2019)	Connectedness Index	The S&P 500 is the largest contributor to the return spillover shocks for the equity markets in the Asia-Pacific region.
Bagheri and Ebrahimi (2020)	Connectedness Index	European and American stock markets are net transmitters of shocks to other markets.
Bahloul and Khemakhem (2021)	Connectedness Index	The degree of connectedness fluctuates over time, with a notable increase in spillover transmission observed particularly after the onset of the COVID-19 pandemic.

In this study, we use the methodology of Diebold and Yilmaz (2009, 2012) and estimate the connectedness between some developed and developing countries. In addition, we analyze dynamic spillovers from the most influential stock markets, the S&P 500, to other stock markets.

2. Data and Methodology

2.1. Data

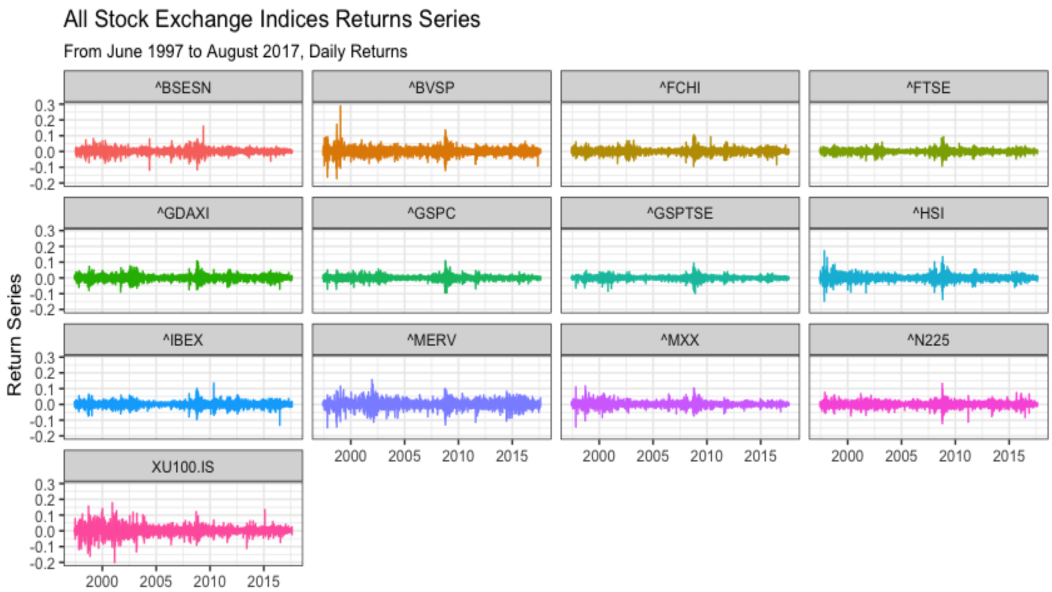
Our analysis utilizes the daily adjusted closing prices of 13 stock market indices denominated in local currencies. This diverse selection of indices provides a comprehensive view of the global market. The sample comprises advanced economies like Germany, France, the United Kingdom, Canada, the United States, China, and Japan, as well as emerging economies like Argentina, Brazil, India, Mexico, Spain, and Turkey, from various regions across the globe. Table 2 provides a list of the stock markets included in the sample.

Table 2: **Stock Markets of Countries**

Countries	Names of Stock Markets	Names of Indices
Turkey	Istanbul Stock Exchange	BIST100
Spain	Madrid Stock Exchange	IBEX 35
Germany	Frankfurt Stock Exchange	DAX 30
France	NYSE Euronext Paris	CAC 40
UK	London Stock Exchange	FTSE 100
Mexico	Mexican Stock Exchange	IPC MEXICO
Canada	Toronto Stock Exchange	S&P/TSX
US	New York Stock Exchange	S&P 500
Brazil	Sao Paulo Stock Exchange	IBOVESPA
Argentina	Buenos Aires Stock Exchange	MERVAL
Hong Kong	Hong Kong Stock Exchange	HANG SENG INDEX
Japan	Tokyo Stock Exchange	NIKKEI 225
India	Bombay Stock Exchange	SP BSE Sensex

The data for this analysis were obtained from Yahoo Finance and Google Finance and cover the period from June 1, 1997 to August 18, 2017. To assess stock market connectedness, we computed daily returns by measuring the change in daily log closing prices for all indices. Figure 1 shows the return series of all stock indices across different stock markets.

Figure 1: **All Stock Exchange Indices Returns Series**



Note: *The indices represented in Yahoo Finance for each stock indices as fallows: ^BSESN (SP BSE Sensex,), ^BVSP (IBOVESPA), ^FCHI(CAC40), ^FTSE (FTSE 100), ^GDAXI (DAX 30), ^GSPC (S&P 500); ^GSPTSE (S&P/TSX), ^HSI (HANG SENG INDEX), ^IBEX (IBEX 35), ^MERV (MERVAL), ^MXX (IPC), ^N225 (NIKKEI 225), XU100.IS (BIST100).

Table 3: **Correlation Matrix**

	BIST.100	**SP.500**	**FTSE.100**	**NIKKEI.225**	**HONG. SENG.INDEX**	**IBOVESPA**	**MERVAL**	**IPC.MEXICO**	**IBEX.35**	**DAX**	**SP.TSX**	**SP.BSE. SENSEX**	**CAC.40**
BIST-100	1,00	0,38	0,21	-0,35	0,02	0,23	0,29	0,19	0,37	0,32	0,11	0,37	0,37
SP-500	0,38	1,00	0,05	-0,08	0,12	**0,50**	0,33	0,34	0,18	0,09	0,49	0,25	0,18
FTSE-100	0,21	0,05	1,00	0,12	0,01	0,03	0,15	0,33	0,77	**0,75**	0,27	0,04	**0,84**
NIKKEI-225	-0,35	-0,08	0,12	1,00	**0,39**	0,01	-0,16	-0,18	0,03	0,09	0,30	0,04	0,00
HONG-SENG-INDEX	0,02	0,12	0,01	**0,39**	1,00	0,20	-0,01	0,15	0,00	-0,09	0,34	0,15	0,04
IBOVESPA	0,23	0,50	0,03	**0,01**	0,20	1,00	0,59	0,19	0,13	0,03	0,36	0,28	0,12
MERVAL	0,29	0,33	0,15	**-0,16**	-0,01	0,59	1,00	0,12	0,28	0,04	0,22	0,21	0,20
IPC-MEXICO	0,19	0,34	0,33	**-0,18**	0,15	0,19	0,12	1,00	0,38	0,30	0,12	0,11	0,36
IBEX-35	0,37	0,18	0,77	**0,03**	0,00	0,13	0,28	0,38	1,00	0,70	0,22	0,12	0,87
DAX	0,32	0,09	0,75	**0,09**	-0,09	0,03	0,04	0,30	0,70	1,00	0,20	0,07	0,75
SP/TSX	0,11	0,49	0,27	**0,30**	0,34	0,36	0,22	0,12	0,22	0,20	1,00	0,04	0,37
SP-BSE-SENSEX	0,37	0,25	0,04	**0,04**	0,15	0,28	0,21	0,11	0,12	0,07	0,04	1,00	-0,07
CAC-40	0,37	0,18	0,84	**0,00**	0,04	0,12	0,20	0,36	0,87	0,75	0,37	-0,07	1,00

Table 3 shows a simple correlation matrix between variables. It shows that all major developed European stock markets are highly correlated with each other. The table also shows that the developing countries tend to be less correlated. In particular, the Mexican and Indian stock markets have very low correlations. On the other hand, Chinese stock markets only have a higher correlation with the Japanese stock market, and low correlations with all other markets (less than 10% on average). Clearly, these results are snapshots of the sample period.

2.2. Methodology

We estimate stock market connectedness using the Diebold and Yilmaz connectedness measure proposed in a series of studies (Diebold and Yilmaz 2009-2012). This measure quantifies connectedness in a vector autoregressive (VAR) model by using forecast error variance decompositions. Our approach measures financial connectedness based on the portions of forecast error variations attributed to the shocks occurring elsewhere in the system. For each asset i, in an N-variable VAR, the measure of connectedness is the sum of the shares of its forecast error variance coming from shocks to asset j, for all $j \neq i$.

The variance decomposition base on a covariance stationary N-variable VAR (p), which represented as:

$$x_t = \sum_{i=1}^{p} \Phi_i x_{t-1} + \varepsilon_t \tag{1}$$

It can rewrite the system into a moving average and representation as:

$$x_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i} \tag{2}$$

where the NxN coefficient matrices A_i satisfies that $A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \ldots + \Phi_p A_{i-p}$, with A_0 an NxN identity matrix and $A_i = 0$ for $i < 0$.

Variable j's contribution to variable i's H-step-ahead generalized forecast error variance is:

$$\theta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e'_i A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e'_i A_h \Sigma A'_h e_i)^2} \tag{3}$$

where Σ is the covariance matrix for the error vector ε , σ_{jj} is standard deviation of ε_j, the error terms for the j^{th}, and e_i is the selection vector with one for the $i^{th}$and zero elsewhere.

Since the effects of variables i and variable j to each other are not identical, each entry of the generalized variance decomposition matrix, $\theta_{ij}^{g}(H)$, can be normalized by the row sum,

$$\tilde{\theta}_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)} \tag{4}$$

where $\sum_{j=1}^{N} \tilde{\theta}_{ij}^{g}(H) = 1$ and $\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H) = N$ by construction. $\tilde{\theta}_{ij}^{g}(H)$ is the pairwise directional connectedness from j to i at horizon H.

Consistent with these definitions Diebold and Yılmaz (2012) define total connectedness, directional connectedness and net connectedness are given by the equations (5)-(7):

-Total directional connectedness to market i from all other markets j is

$$C_{i\leftarrow\blacksquare}(H) = \frac{\sum_{\substack{j=1\\ j\neq i}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \times 100 = \frac{\sum_{\substack{j=1\\ j\neq i}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} \times 100 \tag{5}$$

- Total directional connectedness from market i to all other markets j is

$$C_{\blacksquare\leftarrow i}(H) = \frac{\sum_{\substack{j=1\\ j\neq i}}^{N} \tilde{\theta}_{ji}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ji}^{g}(H)} \times 100 = \frac{\sum_{\substack{j=1\\ j\neq i}}^{N} \tilde{\theta}_{ji}^{g}(H)}{N} \times 100 \tag{6}$$

-Finally, total (system-wide) connectedness is

$$C(H) = \frac{\sum_{\substack{i,j=1\\ i\neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} = \frac{\sum_{\substack{i,j=1\\ i\neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} \tag{7}$$

For a better understanding of all this, Diebold and Yilmaz (2009, 2012, 2015a) created a table called the “connectedness table”. This table is constructed with the full set of variance decompositions. It provides an understanding of the connectedness measures and the relationship between these measures. The upper-left block is called “variance decomposition matrix,” and denoted by $D^H = d_{ij}$. The last column of connectedness table contains row sums which show "from" connectedness, and the bottom row contains column sums which shows "to" connectedness, and lastly, the bottom-right cell contains the grand average which shows total connectedness, in all cases for $i \neq j$.

Table 4: **Connectedness Table**

	x_1	x_2	$\cdots$	x_N	***From others***
x_1	d_{11}^H	d_{12}^H	$\cdots$	d_{1N}^H	$\sum_{j=1}^N d_{1j}^H, j \neq 1$
x_2	d_{21}^H	d_{22}^H	$\cdots$	d_{2N}^H	$\sum_{j=1}^N d_{2j}^H, j \neq 2$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
x_N	d_{N1}^H	d_{N2}^H	$\cdots$	d_{NN}^H	$\sum_{j=1}^N d_{Nj}^H, j \neq N$
To others	$\sum_{i=1}^N d_{i1}^H$ $i \neq 1$	$\sum_{i=1}^N d_{i2}^H$ $i \neq 2$	$\cdots$	$\sum_{i=1}^N d_{iN}^H$ $i \neq N$	$\frac{1}{N}\sum_{i,j=1}^N d_{ij}^H$ $i \neq j$

The "off-diagonal entries" of D^H are the pieces of the N forecast-error variance decompositions. From the connectedness point of view, they represent the "pairwise directional connectedness".

The pairwise directional connectedness from j to i is defined as

$$C_{i\leftarrow j}^H = d_{ij} \tag{8}$$

Additionally, the net pairwise directional connectedness is defined as

$$C_{ij}^H = C_{j\leftarrow i}^H - C_{i\leftarrow j}^H \tag{9}$$

The sums of off-diagonal row and column, namely "from" and "to" in the connectedness table indicate the total directional connectedness measures. The sum of its off-diagonal elements gives the fraction of the H-step forecast error variance of variable 1 that is due to shocks in other variables. Total directional connectedness from others to i is defined as

$$C^H{}_{i\leftarrow\blacksquare} = \sum_{\substack{j=1\\ j\neq i}}^N d_{ij}^H \tag{10}$$

and the directional connectedness from others to j is defined as

$$C^H{}_{\blacksquare\leftarrow j} = \sum_{\substack{i=1\\ i\neq j}}^N d_{ij}^H \tag{11}$$

The net total directional connectedness is defined as

$$C^H{}_i = C^H{}_{\blacksquare\leftarrow i} - C^H{}_{i\leftarrow\blacksquare} \tag{12}$$

The last connectedness measure is obtained with the sum of all of the off-diagonal entries in D^H. The total connectedness also equal to the sum of the “from” column or “to” row,

$$C^H = \frac{1}{N}\sum_{\substack{i,j=1\\ i\neq j}}^N d_{ij}^H \tag{13}$$

It is clear that there is only one total connectedness measure since the sum of "from" connectedness and "to" connectedness equal to each other.

3. Empirical Results

3.1. The Full-Sample Connectedness

We estimate the connectedness between stock market returns by applying the methodology of Diebold and Yılmaz (2009-2012). Similar to Diebold and Yılmaz (2012), we use 10-day-ahead volatility forecast error in the model. We also perform a sensitivity analysis on the VAR order and, like Klößner and Wagner (2014), choose VAR (2). Connectedness table of stock market returns is given in Table 5.

Table 5: **Connectedness Table**

	BIST.100	**SP.500**	**FTSE.100**	**NIKKEI.225**	**HONG.SENG**	**IBOVESPA**	**MERVAL**	**IPC.MEXICO**	**IBEX.35**	**DAX**	**SP.TSX**	**SP.BSE.SENS**	**CAC.40**	**FROM**
BIST.100		**35,03**	5,0	0,7	0,0	**25,3**	0,1	9,3	0,3	0,4	**9,7**	0,1	1,2	87,10
SP.500	0,9		**9,8**	9,4	1,9	1,7	7,7	4,7	0,5	11,4	0,6	0,3	**12,4**	82,45
FTSE.100	0,1	**55,24**		1,5	0,5	1,4	0,1	1,0	2,8	0,5	0,5	0,0	3,7	67,29
NIKKEI.225	4,7	**82,68**	5,3		0,6	0,6	0,3	0,9	1,1	0,8	1,0	1,2	0,1	99,30
HONG.SENG	2,6	**75,71**	3,2	5,1		5,4	0,4	5,6	0,0	0,8	0,2	0,4	0,8	100,39
IBOVESPA	0,1	**22,42**	2,7	4,6	**13,2**		1,7	**14,4**	3,9	17,0	6,1	9,1	**12,8**	107,93
MERVAL	1,8	**12,56**	**13,54**	1,0	**10,5**	5,6		**22,3**	0,2	7,8	**15,1**	2,1	4,9	97,39
IPC.MEXICO	1,0	**22,05**	2,2	2,1	8,7	5,7	0,9		0,1	3,4	8,8	2,7	6,5	64,15
IBEX.35	0,1	**51,97**	**14,95**	1,1	0,5	5,1	1,1	3,6		0,3	1,5	0,1	7,9	88,20
DAX	0,1	**50,73**	**15,3**	1,6	0,2	1,2	0,2	1,5	1,2		2,5	0,2	6,7	81,39
SP.TSX	0,5	**16,57**	**11,4**	2,6	0,9	**9,7**	0,7	3,9	1,0	6,9		2,2	11,8	68,21
SP.BSE	3,9	**61,35**	1,5	2,3	0,6	**9,6**	0,1	7,1	1,1	0,1	0,4		3,2	91,08
CAC.40	0,1	**61,02**	**13,45**	1,1	0,5	1,0	0,2	**12,6**	2,1	0,2	0,9	0,1		93,24
TO	15,8	**547,3**	98,4	25,2	38,1	72,2	13,5	86,9	14,2	49,9	47,2	18,4	72,1	**84,3**

Note: * (VAR(2) model with 10-day forecast horizon.)
**Cells left blank are each variable's own contributions.

For each of the stock markets, the connectedness table shows the pairwise directional connectedness for each of the stock markets. The values that indicate a significant spillover effect are shown in bold type. For each market, the sum of each row represents the value of connectedness from all other stock markets. The sum of each column represents the value of connectedness to other stock markets. The main point of the table is that the U.S. stock market has remarkably high spillovers to all other stock markets. However, only a few markets show noteworthy spillovers back to the U.S. stock market. The U.S. has the highest total directional connectedness to other markets. The system's total connectedness is 84.3, as shown in the bottom right cell of the table. This suggests that these markets are strongly connected.

The table shows that the US stock market has the highest level of connectedness with major Asian stock markets. Specifically, it has a connectivity of 82.68% with Japan, 75.71% with Hong Kong, and 61.35% with India. However, these markets have relatively low levels of connectedness to the US stock market. The Asian stock market is the most affected by the US stock market compared to the other stock markets analyzed.

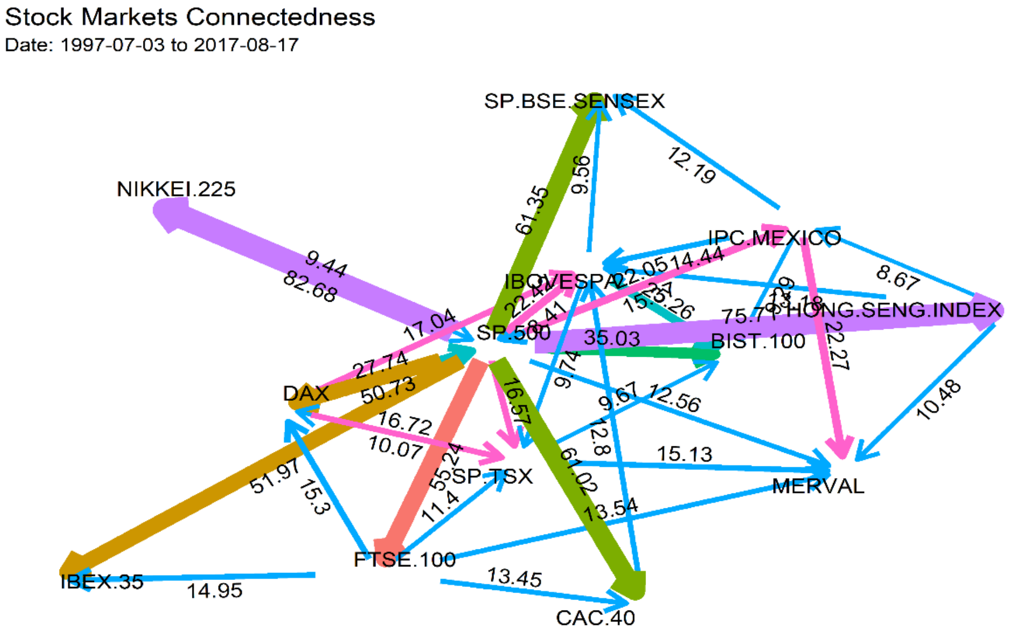
The U.S. stock market has the second highest degree of connectedness to the European stock market, after the Asian stock market. Specifically, the US stock market has significant spillovers to the French (61.02%), British (55.24%), Spanish (51.97%), German (50.73%) and Turkish (35.03%) stock markets ranked from highest to lowest. Finally, the American stock markets such as Brazil (22.42%), Mexico (22.05%), Canada (16.57%), and Argentina (12.56%) have relatively low level of connectedness from the U.S. stock market.

The stock markets of the United States, the United Kingdom, and Germany, which are classified as developed markets, show higher levels of connectedness to others. Although they also display connectedness from others, the significant levels of "from connectedness" for these stock markets primarily originate from each other. Furthermore, their "from connectedness" measures are lower than their "to connectedness". When developed markets experience shocks, they create significant connections to other stock markets.

Another remarkable result of the analysis id that the developing markets like India, Turkey, Argentina, Spain, and Brazil show high levels of connectedness from others, but often lack significant connectedness to other markets. This means that shocks from developed markets can easily affect these economies, while shocks in emerging markets typically affect other emerging market economies.

The economies of European countries, such as France, Germany, Spain, and the U.K., are closely tied to the U.S. stock market. These markets are significantly connected with each other as well. In contrast, the Indian, Argentine, Brazilian, and Spanish stock markets do not show significant connectedness to other markets. This suggests that while shocks may affect these markets, they have minimal impact on the returns of other markets. Hong Kong, on the other hand, does not have significant connections 'from' other economies, which means that shocks in those economies do not significantly affect its stock market returns.

Figure 2: **Network Topology of Equity Market Connectedness**



Note: *The countries are represented by stock market indices as follows, Turkey (BIST.100), Spain (IBEX.35), Germany (DAX.30), France (CAC.40), UK (FTSE.100), Mexico (IPC.MEXICO), Canada (SP.TSX), US(SP.500), Brazil (IBOVESPA), Argentina (MERVAL), Hong Kong (HONG.SENG.INDEX), Japan (NIKKEI.225), India (SP.BSE.SENSEX).

In addition to the information provided, the network graph analysis also reveals some details in Figure 1 about the structure of connectedness based on pairwise connectedness measures. In the figure we can see that the thickness of the lines is a measure of the weight of directional spillovers. This means that the thicker the line, the stronger the spillover effect between the connected stock markets. Furthermore, the colors of the lines in the graph provide additional information about the strength of the spillovers. Purple lines indicate the strongest spillovers, followed by green, red, brown, light green, pink, and finally blue, which represents the weakest spillovers. As depicted in the figure, the U.S. stock market holds a central position in the network system. This suggests that it has a significant influence on other stock markets. Following the U.S. stock market, the German stock market exhibits the second-highest level of connectedness. However, it is important to note that the connectedness level of the German market is relatively low compared to the U.S. stock market. Interestingly, the analysis also highlights that the German stock market plays a crucial role in generating significant spillovers to other European stock markets. This implies that changes and fluctuations in the German market can have a notable impact on the performance of other European markets.

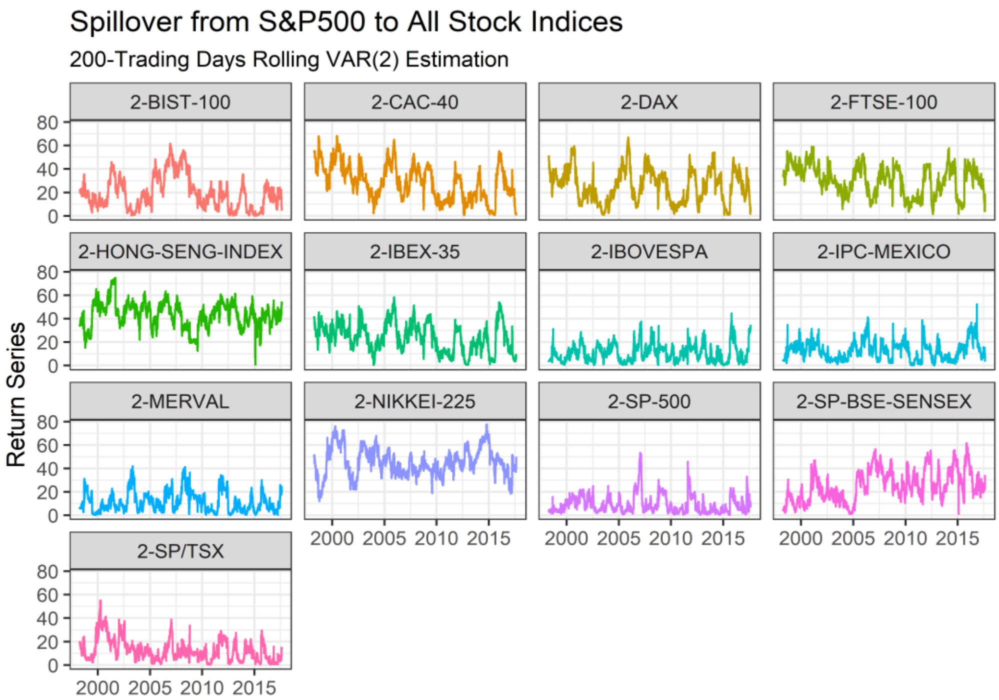
3.2. The Dynamic Pairwise Directional Connectedness from the U.S. to Other Stock Markets

In full sample analysis, we observe that the U.S. stock markets exhibit significantly high levels of correlation with all other stock markets. Figure 3 provides a visual representation of these transmissions; the first graph illustrates the linkage between the U.S. stock market and the Turkish stock market. Two distinct cycles stand out, one coinciding with the September 11, 2001 attacks, and the other with the 2007-2009 global financial crisis. During these periods, transmission from the U.S. stock market to the Turkish stock market showed a significant increase. Spillover reached its peak in 2001 and 2008, peaking at around 62% in 2007. This increase in spillover demonstrates the impact of these external shocks on the Turkish market. Despite the severity of the global financial crisis, the Turkish stock market exhibited notable resilience by maintaining high transmission levels throughout the crisis. Towards the end of the crisis, correlation gradually decreased, almost returning to pre-crisis levels, hovering around 20%. However, in late 2014, a corruption investigation involving key figures in the Turkish government led to a significant increase in spillover, reaching 35%. This event highlights the influence of local factors on the correlation between U.S. and Turkish stock markets. The decision by the Federal Reserve to end its Asset Purchase Program in 2015 resulted in a decrease in spillover range ranging from 1% to 10%, but with the rise in interest rates in the U.S. financial markets in mid-2015, connectedness increased to 30%. The Turkish stock market exhibits a strong correlation with changes in U.S. monetary policy. Since then, the connectedness has fluctuated between 15% and 25%. These data underscore the ongoing impact of external factors on the financial connection between U.S. and Turkish stock markets, emphasizing the importance of monitoring global events and policy decisions to understand the dynamics of stock market connections.

The following charts clearly demonstrates the return connectedness from the U.S. to European countries, such as France, Germany, Spain, and the U.K. The 'to' connectedness of the U.S. stock market to these stock markets decreased sharply at the beginning of 2007, only to increase during the global financial crisis period. The figure clearly demonstrates the return connectedness from the U.S. to European countries, such as France, Germany, Spain, and the U.K. The 'to' connectedness of the U.S. stock market to these stock markets decreased sharply at the beginning of 2007, only to increase during the global financial crisis period. This data provides strong evidence of the impact of the Federal Reserve's policies on the global financial market. However, after the Federal Reserve ended its asset purchase program, it plummeted to low levels in early 2015. The connectedness of all European stock markets surged to around 50% due to the effect of rising interest rates in the U.S.

Another results clearly seen in the figure is that the return connectedness from the U.S. to the major Asian stock markets exhibited notable fluctuations compared to other markets. The measures of connectedness increased significantly during the Asian crisis in 1997 and again after the period of the global financial crisis. In contrast to other stock market connectedness, Japanese stock market connectedness spiked in early 2015, coinciding with the end of the Federal Reserve's asset purchase program. Return connectedness from the U.S. to the stock markets of Argentina, Brazil, and Mexico fluctuated in the relatively low range of 0% to 40% compared with other markets. Plotting American stock markets shows them to be almost identical. The return connectedness from the U.S. to Canadian stock markets was relatively high in the early 2000s. It declined until the September 11 attacks, when turbulent times led to an increase in the correlation. By early 2005, the linkages had fallen to low levels. During the global financial crisis, like all other measures of connectedness, it increased before fluctuating in the 0%-20% range. Finally, as it is clear the the U.S. stock market's own return connectedness reached its peak level during the global financial crisis period (2007-2009). Another notable peak in connectedness was observed in 2012, which may be attributed to the European debt crisis. Otherwise, it fluctuates within the range of 0%-20%.

Figure 3: **Pairwise Directional Connectedness From U.S. Stock Market to Other Stock Markets**



Note: *Pairwise directional connectedness from U.S. stock market to other stock markets, respectively, Turkey, France, Germany, the U.K., Hong Kong, Spain, Brazil, Mexico, Argentina, Japan, the U.S, India, and Canada. (200-days rolling window).

4. Conclusion

In recent decades, crises in one country have been observed to spill over to others not necessarily in the same region. Furthermore, these countries often possess differing economic structures and levels of economic linkage (Pericoli and Sbracia, 2003:571). Particularly, following the 1987 U.S. crisis, there has been an acceleration in studies examining financial market dependencies. Economists have focused on understanding how crises originating in one country or market can spreads to others. While there is debate over whether to characterize market relations as contagion or interdependence, there is a prevailing view that financial markets exhibit high levels of comovement or connections during turmoil periods. Understanding these interconnections is crucial across various aspects. Given the significant role of stock markets in market economies, analyzing financial market connectedness often involves examining stock markets (Diebold and Yilmaz, 2015a:84).

This study provides a comprehensive analysis of financial market connectedness using stock market data. By employing the Diebold and Yilmaz connectedness index methodology (2009-2012), the research examines both static and dynamic return connectedness among developed and developing stock markets across various regions. The analysis of the full sample reveals that the United States exhibits the highest total directional connectedness measure towards other countries, indicating that the U.S. stock market plays a central role in the global network system.

Developed countries such as the United States, the United Kingdom, and Germany demonstrate greater levels of connectedness to other markets, while their from-connectedness measures are relatively lower. On the other hand, developed countries like the United States, Germany, and Japan exhibit higher levels of 'to' connectedness with other markets. In contrast, developing economies such as India, Turkey, Argentina, Spain, and Brazil display higher levels of 'from' connectedness with other markets. However, it is worth noting that most of these developing markets do not exhibit significant levels of 'to' connectedness with other markets and are primarily connected to other developing markets. This suggests that developed countries primarily transmit return spillover shocks, while developing countries tend to receive them. These findings align with the conclusions drawn by Yoon et al. (2019) and Bagheri and Ebrahimi (2020), further reinforcing the notion that developed countries play a crucial role in transmitting financial shocks across global markets, while developing countries are more susceptible to these shocks.

The paper provides a comprehensive analysis of the dynamic directional connectedness between the U.S. stock market and other stock markets. It highlights that the U.S. stock market exhibits the highest level of connectedness measure among all the markets studied. This finding suggests that changes in the U.S. stock market can have a significant impact on other markets worldwide. The study reveals that the level of connectedness from the U.S. stock market to other markets varies over time. This variation is particularly pronounced during periods of turmoil, which aligns with previous research conducted by Schmidbauer et al. (2013), Zhou et al. (2012), Diebold and Yilmaz (2015b), Erkol (2015), and Chen and Wu (2016). These studies consistently demonstrate that changes in connectedness are more prominent during times of market instability.

Furthermore, the paper highlights that spillovers from the U.S. stock market to European countries, including France, Germany, Spain, and the U.K., exhibit similar patterns of connectedness. This suggests that geographical proximity plays a crucial role in the transmission of shocks between markets. Similarly, the study finds that spillovers from the U.S. stock market to certain American stock markets, such as Argentina, Mexico, and Brazil, also display comparable patterns. This indicates that shocks originating in the U.S. can easily impact these markets due to their geographical proximity. The dynamic analysis conducted in the paper also sheds light on specific historical events. For instance, it demonstrates that the European Debt Crisis in 2012 had a significant impact on European countries, while the Asian Crisis in 2001 primarily affected Turkey and Asian markets. These findings highlight how shocks originating in developed or emerging markets can have varying degrees of influence on other markets, depending on the nature and location of the crisis. In conclusion, the paper provides valuable insights into the dynamic connectedness between the U.S. stock market and other stock markets. It emphasizes the importance of considering geographical proximity and the occurrence of significant events when analyzing the transmission of shocks across different markets.

Monitoring and measuring stock market connectedness play a vital role in the decision-making process for both portfolio investors and policymakers. It enables portfolio investors to gain valuable insights into the current market situation, allowing them to make informed investment decisions. By understanding the level of connectedness between different markets, investors can assess potential risks and diversify their portfolios accordingly. Additionally, policymakers heavily rely on monitoring stock market connectedness to implement effective policies. By closely monitoring the interdependencies between markets, policymakers can identify early warning signs of potential crises or collapses. This information empowers them to take timely action and implement measures to mitigate the adverse effects on the overall economy. In addition to immediate benefits, monitoring stock market connectedness contributes to the long-term stability of financial systems. Regulators can identify systemic risks by continuously assessing the level of interconnectedness and implement appropriate regulations to protect the financial sector. This proactive approach helps prevent the spread of shocks between markets and reduces the likelihood of widespread financial crises. Overall, the ability to monitor and measure stock market connectedness provides valuable information for both portfolio investors and policymakers. It enhances decision-making processes, facilitates risk management, and contributes to the stability of financial systems.

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