UNDERSTANDING THE CONNECTEDNESS OF SHORT TERM INTEREST RATES

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Abstract

I analyze the connectedness of short-term interest rates. In particular, I use the Diebold and Yilmaz methodology to study the behavior of financial connectedness across the 3-month interbank offered rates for 33 countries over the 1991-2014 period. I find that short-term interest rates have become highly interconnected during the financial crises. More importantly, my results reveal that policy interest rate decisions by the central banks have a crucial influence on the connectedness of short-term interest rates. As a next step, I apply variance decomposition to the financial network framework to clearly observe the linkages between the short-term interest rates. The total connectedness index emphasizes both the minor and major crisis episodes around the world. The empirical results show that before the introduction of the single European currency, Euro, in 1999, the bulk of the shock transmission took place among the EU member countries. Once Euro was introduced, the connectedness of the US and the EU short-term interest rates happened to be the most significant. After establishing these general results, I study the directional connectedness across countries during the most important crisis episodes.

Keywords: Financial connectedness, risk measurement, systemic risk, Libor rate, vector autoregression, variance decomposition

Özet

Bu çalışmada kısa vadeli faiz oranlarının bağlanmışlık analizi sunulmaktadır. Özellikle, Diebold-Yılmaz metodolojisini kullanarak 1991-2014 döneminde 33 ülke için 3 aylık bankalararası faiz oranlarının finansal bağlanmışlığının zaman içinde davranışı çalışılmaktadır. Kısa vadeli faiz oranlarının finansal kriz dönemlerinde yüksek ilişkili olduğu bulunmuştur. Daha önemli olarak, elde edilen sonuçlar merkez bankalarının politika faizi kararlarının kısa vadeli faiz oranlarının bağlanmışlığı üzerinde önemli etkiye sahip olduğunu göstermektedir. Varyans ayrıştırması yöntemini finansal ağ sistemine uygulayarak, kısa vadeli faiz oranları arasındaki bağlar detaylı bir şekilde incelenmiştir. Toplam bağlanım endeksi, dünya genelinde büyük ve küçük kriz dönemlerinde artmaktadır. Sonuçlar, tek Avrupa para birimi olan Avro kullanımına başlanmadan önce, şokların ağırlıklı olarak AB üyesi ülkelerden kaynaklandığını göstermektedir. Avro'nun kullanımına geçilmesinden sonra, finansal şokların yayılması açısından ABD ve AB kısa vadeli faiz oranlarının daha önemli konuma geldikleri gözlenmiştir.

Anahtar Kelimeler: Finansal bağlanmışlık, risk ölçümü, sistemik risk, Libor oranı, vektör otoregresyon, varyans ayrıştırması

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1 Introduction

The short- and long-term interest rates are a very important feature of the real economy. Through the variation in interest rate, the variability of savings and investment decisions are affected. Interest rates change in response to a variety of economic events, such as changes in monetary policy, crises in domestic and international financial markets, and changes in the prospects for long-term economic growth and inflation. Shifts in short-term interest rates are usually transmitted to long-term interest rates.

There is a widespread perception that a well operating money market is significant for banks' funding. Central banks commonly direct monetary policy through the control of short-term nominal interest rates by buying and selling short-term debt securities. Expected inflation does not change immediately; hence, central banks can control real interest rates over the short to medium term.

Determination of interbank interest rates is needed for management of money market liquidity and short-term interest rates. Interbank offer rates (which I call as *Libor* rate in the rest of the thesis) is the primary global benchmark for the short-term interest rates. It uses as the basis for the settlement of interest rate contracts on the world's important futures and options exchanges and help to understand the health of financial money markets. Libor rate is used in loan agreements throughout global markets, such as mortgage agreements and student loans.

Prior to the global financial crisis of 2007-09, central banks around the world could effectively rely on conventional monetary policy tools. However, monetary policy settings changed significantly after the crisis. Since the global financial crisis, central banks responded with different unconventional monetary policies. In response to the crisis, Federal Reserve (FED), European Central Bank (ECB), Bank of England (BOE) and Bank of Japan (BOJ) lowered the policy rate to levels very close to zero bound. As a result, in late 2008/early 2009, they started to use quantitative easing (QE) policies. Central banks can affect short-term interest rate even with QE. Soon after the crisis, academic literature focus on the effects of QE policies on the long term yields. Gagnon et al. (2011) measure the effects of large scale asset purchase (LSAP) on interest rates, especially for the 10-

year interest rates. They use event-study methodology and investigate the difference on interest rates for the announcement day, accumulate these differences and find the total effect. They find that LSAP announcements reduced long term yields in Unites States (US). They also compared the effects of the US QE policies to the effects of the similar QE policies in other countries - Japan (2001-2006) and United Kingdom (UK) (2009-2010). They noticed that the effects of the Fed policies are similar to the UK effects, but differ from the Japanese experience. Fratzscher et al. (2013) claim that QE 1 policies were extremely effective in lowering sovereign yields.

This is the first academic research focusing transmission of shocks across Libor rates among the important countries. I find that Libor rates have become highly interconnected during the crisis times. The results reveal that policy interest rate decisions by the central banks have a crucial influence on Libor rates. I use the Diebold & Yilmaz methodology to study the behavior of the total connectedness index over time and show how closely it is linked with the developments in the global financial markets and the decision of the major central banks. I focus on directional connectedness measure, both total and pairwise, and show the close links between various Libor rates. I explain the episodes of the emerging market crises until 1999 and the financial crises of 2000s.

The remainder of this thesis is organized as follows. The next section presents the related research on the literature. Section 3 explains the Diebold & Yilmaz framework. Section 4 describes the dataset. Section 5 and Section 6 contain the full sample static and rolling window dynamic analysis of connectedness, respectively. I conclude in Section 7.

2 Literature Review

Spillovers effects are crucial since it has prominent implications of financial decision. There have been many studies of international spillovers, such as Eun & Shim (1989), Hamao et al. (1990), King et al. (1990), Baele (2005), and Diebold & Yilmaz (2009). Eun & Shim study the international transmission mechanism of stock market movements by estimating a nine-market vector autoregression (VAR) system. Their findings show that innovations in the US are rapidly transmitted to other markets; however, any other market can not explain successfully the US market movements. Hamao et al. investigates the short-run relationship of stock price across Tokyo, London, and New York. They use the autoregressive conditionally heteroskedastic (ARCH) models. Hamao et al. find spillovers only from New York to Tokyo, London to Tokyo, and New York to London. King et al. estimate a multivariate factor model to account for the time-variation the covariances between sixteen national stock markets. Their main finding is that changes in correlations are given primarily by movements in unobservable variables. Baele meausures the size and time-varying nature of spillovers from the aggregate European and US market to 13 local European equity markets. He used a regime-switching model to allow the shock sensitivities to change over time. Diebold & Yilmaz give an intuitive measure of interdependence of asset returns and volatilities. Diebold & Yilmaz (2012) examine the interdependence between financial markets in different countries. They analyze the volatility spillovers across different US asset classes, such as stock, bond, foreign exchange, and commodities. Their empirical findings show that cross-market spillovers were limited until the global financial crisis of 2007-09 and the spillovers from the stock market to other markets increased significantly after the collapse of the Lehman Brothers.

Today's interconnectedness of different markets implies that a shock coming to one country's economy may affect the well being of the other countries' economies thus increasing volatility. Interbank markets are among the most important in the financial system (Allen et al., 2009). Interest rates ensure a key transmission channel for spreading of shocks throughout the economy. Under normal circumstances the short-term interbank markets work well; however, interbank markets stop functioning well in the crisis times.

Change in the short-term rates may have important influences on the economy. The reasons why interbank markets occasionally fail or experience intense tension differ through studies. Bhattacharya & Fulghieri (1994), Heider et al. (2008), and Freixas & Jorge (2008) concentrate on counterparty risk and asymmetric information. Freixas et al. (2010) and Allen et al. (2009) concentrate on the liquidity shocks. Heider et al. study the functioning and possible failure of the interbank market in the presence of counterparty risk. Their model underlines the role of counterparty risk as a significant content to clarify the observed events. Freixas & Jorge (2008) investigates the impact of asymmetric information in the interbank market and establishes its important role in the microfoundations of the monetary policy transmission mechanism. They find that interbank market imperfections induce an equilibrium with rationing in the credit market. Freixas et al. (2010) study the functioning of the interbank lending market and the optimal policy of a central bank in response to both idiosyncratic and aggregate shocks. Their results show that a central bank should use different types of instruments to manage different shocks.

Network is an important tool to analyze spillovers. Using the network methodology, we can easily see the crucial players in the spread of various risks and how important the players are. Applications of network theories to finance center on contagion and financial stability (Allen & Gale, 2000). A network approach strengthens our comprehension of financial systems (Allen & Babus, 2009). Complex linkages among nations and financial institutions may be a potential source of systemic risk (Yellen, 2013). Caballero (2013) evaluates financial integration based on the network of interbank lending and borrowing in the syndicated loan market, and finds that country level indicators of financial connectivity have predictive force for the relation of banking crises. Acemoglu et al. (2013) give a framework for studying the relationship between the financial network architecture and the likelihood of systemic failures due to contagion of counterparty risk. Diebold & Yılmaz (2014) shows that spillover indices defined by variance decompositions are closely related to network connectedness and more sophisticated than the classical network structures. They showed that the total connectedness measure corresponds to the mean degree of a weighted, directed network.

3 The Connectedness Framework

This section explains the concept of Diebold & Yilmaz (2012) connectedness index methodology. The connectedness measurement is built upon the variance decomposition matrix associated with an N-variable vector autoregression. Consider a covariance stationary N-variable vector autoregression VAR(p), $x_t = \sum_{i=1}^{p} \Phi_i x_{t-i} + \varepsilon_t$, where $\varepsilon_t \sim (0, \Sigma)$. The infinite order moving average representation is $x_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i}$, where A_i is an NxN coefficient matrix, expressed as $A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \ldots + \Phi_p A_{i-p}$, with A_0 being an NxN identity matrix and $A_i = 0$ for $i < 0$. The MA representation of VAR is used to estimate the effects of shocks to variable x_i to the forecast of variable x_j for $i, j = 1, 2, .., N$. From this representation, own variance shares are defined as the fraction of H-step-ahead error variances in forecasting x_i due to x_i, and connectedness is defined as fraction of H-step-ahead error variances in forecasting x_i due to shocks x_j for all i, j.

This representation of connectedness requires the derivation of the impulse response function of VAR(p) process. Diebold & Yilmaz's measure is based on the generalized impulse response approach (Koop et al., 1996; Pesaran & Shin, 1998). They show that when the error term ε_t has a multivariate normal distribution, the H-step generalized impulse response function scaled by the variance of the variable is given by:

$$\gamma_j^g(h) = \frac{1}{\sqrt{\sigma_{jj}}} A_h \Sigma e_j, \qquad h = 0, 1, 2, ... \tag{1}$$

where Σ is the variance matrix for the error vector ε, σ_{jj} is the standard deviation of the error term for the j^{th} equation, and e_i is the selection vector with one as the i^{th} element and zeros otherwise.

The last step is to calculate each variable's contribution to each other's H-step-ahead generalized forecast error variance. This is calculated by the following formula:

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

Since the sum of each row of the variance decomposition matrix is not necessarily equal to one, they normalize each entry of the decomposition matrix to obtain the index from

variance decomposition. This is performed by dividing each entry by row sum,

$$\tilde{\theta}_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)} \tag{3}$$

Finally, using the normalized entries of the variance decomposition matrices Diebold & Yilmaz define four different connectedness measures: the total connectedness $C(H)$, the gross directional connectedness received by variable i from all other variables j $C_{i\leftarrow\bullet}$ (from connectedness), the gross directional volatility connectedness transmitted by variables i to all other variables j $C_{\bullet\leftarrow i}$ (to connectedness), and finally, the net directional connectedness transmitted from variable i to all other variables $C_i(H)$ (net connectedness):

$$C(H) = \frac{\sum_{\substack{i,j=1 \\ i\neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} = \frac{\sum_{\substack{i,j=1 \\ i\neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} \tag{4}$$

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

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

$$C_i(H) = C_{\bullet\leftarrow i}(H) - C_{i\leftarrow\bullet}(H) \tag{7}$$

4 Dataset

The Libor is the average interbank interest rate at which a selection of banks on the London money market are prepared to lend to one another. The Libor is an representative rate rather than a true transaction rate (Kwan, 2009). Libor rate used among banks and considered as a good proxy for liquidity. The Libor Fixing evolved in the early 1980s when the BBA developed it to evaluate interbank funding costs at a fixed point in time every day. Libor comes in 7 maturities (overnight, 1 week, 1 month, 2, 3, 6, and 12 months) and in 5 different countries (EU, US, UK, Japan and Switzerland). The Libor rates are announced once per working day at around 11:45 a.m. In the past, the BBA/ICE published Libor rates for 5 more countries (Sweden, Denmark, Canada, Australia and New Zealand) and 8 more maturities (2 weeks, 4, 5, 7, 8, 9, 10 and 11 months).

The US Libor rate is the most dominant benchmark rate around the world, other reference rates exist that seek to capture funding conditions in global financial markets. The Euribor is the second benchmark rate and calculated based on the funding abilities of a larger panel of European banks. Other financial centers, such as Tokyo, Mumbai, Singapore, and Hong Kong feature their own internally calculated rate fixings in Tibor, Mibor, Sibor, and Hibor, respectively. The various rates all employ almost identical methodologies, though they have on occasion arrived at different fixings (Hou & Skeie, 2014).

Hou & Skeie (2014) gives the theoretical components of Libor rate as a combination of term and risk spreads. According to them, Libor rate is the sum of overnight risk free rate over the term, term premium, bank term credit risk, term liquidity risk, and term risk premium. The studies focus on the fractional contribution of these pieces on Libor rate. Acharya & Skeie (2011) suggest that liquidity hoarding during stress drives rising interbank rates; hence, attribute the importance of the risk to liquidity. Smith (2010) argue that up to half of the variation in money market spreads can be explained by the term risk premium. The findings of Taylor & Williams (2008a,b) show that counterparty credit risk as proxied was the underlying component of Libor rate.

Kwan (2009) points out that the interbank funding market is most active in shorter

maturities (three- to six-month). I use 3 month-interbank offered rates to estimate connectedness of short-term interest rates at the country level. My dataset covers the period from January 1991 to March 2014. I work with 5968 observations in that period. The chosen term expresses my intention to compare different crises periods. Furthermore, this period reflects the desire to include as many countries as possible in the analysis. The dataset involves daily interbank rates for 33 countries and I present the dataset in Table 1.

Brazil does not have daily interbank offered rate measure. Hence, I use SELIC rate for Brazil instead of interbank offered rate. SELIC is the Brazilian Central Bank's system for performing open market operations in execution of monetary policy. The SELIC rate is the Bank's overnight rate.

Not all countries Libor rate have the full coverage of the 1991-2014 period. Table 1 summarizes the first date and the last date for which interbank rates is available. All series were obtained from Bloomberg. Figure 1 presents the 3 month-Libor rates. Also, Figure 2 shows the Libor rates after the global financial crisis for the major countries, US, EU, UK and Japan. The central banks of these countries used QE policies after the crisis.

Table 2 presents the descriptive statistics of the 3 month-Libor rates. Mean for Brazil, Greece, Argentina and Turkey are all higher. On the other hand, Japan has the lowest mean, followed by, Switzerland and EU. Median for these countries also high. Argentina has the highest volatility, followed by, Brazil, Turkey and Russia. They are mostly skewed to the left (only China, India and US skewed to the right) and all of them are leptokurtic.

5 Full Sample Analysis

The daily Libor rates data are not available for all countries in sample period. In the full sample analysis, the sample period is divided into the following three periods: (i) from July 7, 1994 to December 24, 1998, (ii) from March 1, 1999 to December 30, 2005, and (iii) from October 9, 2006 to May 31, 2013. In this section, I provide the full-sample static analysis of the connectedness of interbank rates. Diebold & Yilmaz (2009, 2012) full sample connectedness table (for example, Table 3 for the period 1994-98) is a convenient instrument for verifying both the direction and degree of transmissions of shocks to the Libor rates across different countries. The elements in the i^{th} row express the estimated values of contributions from all other countries to i^{th} country, and the elements in the jth column reflect those from j^{th} country to all other countries. "To" connectedness measure the volatility transmitted to other countries, "From" connectedness gives the sum of volatility shocks received from other countries, and "Net" connectedness is the difference between the "to" and "from" connectedness.

Table 3, 4, and 5, respectively, show all pairwise and total connectedness measure corresponding to these sub-periods. Moreover, Figure 3, 4, and 5 present the network results for these periods, respectively. In the rest of the section, I will clarify the full sample connectedness table.

I begin by characterizing full sample connectedness over the sample of July 1994-December 1998. The total connectedness of Libor rates is 29.2% in this period. Western economies in my sample, Belgium, Denmark, Sweden, Germany, France, Ireland and Italy, have high "to" connectedness, ranging between 39 and 80%. US's "to" connectedness is 32%; its "from" connectedness is also high. Belgium and Denmark have the highest "from" connectedness, 53 and 50%, respectively. "From" connectedness of Sweden, Germany, Italy, and Ireland are ranging between 41 and 47%. Libor rates of these countries have positive net connectedness because their "to" connectedness is higher. Also, Czech Republic and Australia have positive net connectedness. US's "from" and "net" connectedness is 32% and 0%, respectively. Belgium have the highest net connectedness, 26%. One of the possible reason is the effect of ERM Crisis. I will give more information

about ERM Crisis in the next section. The second reason might be the establishment of EU because Libor rates of these countries were getting closer in this period. Also, in Figure 3, I understand that Belgium has the highest weighted-out degree, where red color represents higher out-degree as also stated in network visualization under appendix. Belgium is more connected with European Countries such as, Germany, France, Ireland, Italy, Sweden, and Denmark. As you can see in the full sample network system, the Libor rates of peripheral countries, such as Malaysia and Czech Republic are not important nodes because they have lower weighted-out degree, where green color represents lower out-degree. They have weak ties with other countries.

Now, I focus on the sample of March 1999-December 2005. The full sample connectedness is 26.8%. The "to" connectedness of US and EU are the highest, 90% and 87%, respectively. Also, Canada, Switzerland, and Sweden have higher "to" connectedness, ranging from 52 to 60%. Hungary, Argentina, South Africa, and India have lowest "to" connectedness in the sample. Also, "from" connectedness of US and EU are the highest, around 60%. Hungary and Argentina have the lowest "from" connectedness. US and EU's "net" connectedness are also high, 30 and 28% respectively. The interesting result is UK's net connectedness, the lowest degree (-26%). The net connectedness of UK's Libor rate is negative before the global financial crisis. Therefore, I find that UK is the net receiver of connectedness between 2000-2006. Figure 4 gives the visual representation of the connectedness of the above countries. Establishing of EU has a profound impact on world economies, eventually this wave effects short-term interest rates. In my network analysis, the density of network structure decreased when I compare this with Figure 3. Establishing of EU causes profound changes in placement of Libor rates, notably in core countries. Now, US Libor rate is at the center of network system. Libor rates of EU, Canada, Sweden and Switzerland are at the core of network representation. Brazil, Malaysia, and Indonesia look as a group but their connectedness are low. South Africa, India, Hungary, and Argentina also have lower out-degree. The main reason behind this behavior of peripheral countries, they have weak ties with US and EU. However, this case does not hold for Canada, Sweden and Switzerland, which have strong financial link

between US and Eurozone Countries. The centrality and strength of these three core countries show a rising trend. Especially, Canada increases its out-degree excessively because Canada has strong link with US.

Lastly, I concentrate on the sample of October 2006-May 2013. The total connectedness is %26.5 in this period. EU's "to" connectedness is at the peak, 83%. US also have a high "to" connectedness of 72%. UK, Australia, Denmark, Canada, and Sweden's "to" connectedness are ranging between 37 and 47%. EU, Hungary, Denmark, and US have high "from" connectedness. EU and US have the highest "net" connectedness, 38 and 32%, respectively. Australia and Russia also have high "net" connectedness. Hungary has the lowest "net" connectedness, -30%. Its "from" degree is one of the highest, and its "to" degree is only 15%. In Figure 5, I represent the network structure. The global financial crisis has negative effects on the world, and this triggered Eurozone Crisis. Sparse network architecture shows that the spillover effects of Libor of EU and US influence all other Libor rates. Before these crises, the density of the network structure was higher. Now, many nodes have lower weighted-out degree; hence, they have green color representation. These crises causes important changes in placement of Libor rates. EU and US have again the highest out-degree. Nevertheless, UK is getting closer in this period. The net connectedness of UK is higher only in the period of the global financial crisis. The global financial crisis and the Eurozone crisis are the main reason for the movement of UK because UK has strong ties with both US and Eurozone countries. The centrality and strength of Libor rates of UK show an increasing pattern.

6 Dynamic Analysis

In this section, I focus on the dynamics of the total connectedness over time. The full-sample connectedness analysis constructed in Section 5 provides average connectedness dynamics; however, it may miss important secular and cyclical movements (Diebold & Yilmaz, 2009). To point out this problem, Diebold & Yilmaz use rolling sample methodology, and they specify the extent of variation in connectedness over time. In my study, the rolling estimation window width is 200 days, and the predictive horizon for the underlying variance decomposition is 12 days. The dynamics of the total connectedness is presented in Figure 6. The dynamics of TO, FROM, and NET connectedness is presented in Figure 7, 8, and 9, respectively.

The total connectedness index was 40% at the beginning and it fluctuated between 33% and 73% for the whole period. The index jumps to high levels when a central bank changes the policy rate but it decreased immediately. On the other hand, the behavior of the total connectedness index differs significantly in crisis times. The index jumps to high levels when a crisis starts, and stays high during the crisis. Then, it goes back to old levels. The period from August 2002 to June 2007 is relatively tranquil for Libor rates of the US, the EU, and other countries. The connectedness index generally fluctuates around 50%.

Although there is a very close connection between bond prices and interest rates, the total connectedness of Libor rate volatility is quite different from the connectedness of bond market analyzed by Diebold & Yilmaz. The results of my study show that connectedness index of short-term rates have more spikes when I compare it with the connectedness index of bond market. The culprit behind the spikes for short-term rates is the interest rate decisions given by central banks. As I stated before, short-term rates react the policy rate decisions immediately.

In the following subsections, I clarify the behavior of index for all periods in a deeper way.

6.1 The European Exchange Rate Mechanism (ERM) Crisis of 1992-93

The total connectedness index fluctuated in the 30-40% band until the Black Wednesday of 1992. Black Wednesday refers to September 16, 1992 when the British government was forced to withdraw the pound sterling from the European Exchange Rate Mechanism (ERM). Sterling had joined the European Union's (EU) longstanding ERM in 1990 but had struggled to remain inside its designated floating band. Speculators saw a chance to attack Britain's currency. The Italian lira and Spanish peseta were also under pressure, but it was the pound that was grabbing the headlines. George Soros's Quantum Fund led a field of speculators who borrowed UK gilts only to sell them and buy them back later at cheaper prices. They repeated the trick every few minutes, making a profit each time. They made £1 billion from selling sterling they did not own. With the Black Wednesday, the total connectedness index started to increase in September and jumped to 62% in October 1992. The index declined to 35% at the end of 1993.

6.2 The Mexican Peso Crisis of 1994

In March 1994, Mexican peso was under fire. Donaldo Colosio, Mexico's ruling party's presidential candidate was gunned down during a campaign rally on March 23, 1994. Total connectedness started to increase again with this news in March 1994. Between March and November, US Federal Reserve raised its policy rate by 250 basis points. Mexico also suffered from political debates and hence foreign exchange reserves declined rapidly. Mexican government wanted to stop the outflow of foreign currency and the government issued short-term dollar denominated debt (tesabonos) in April. With taking tesabonos, the investors were protected for a potential devaluation of peso; hence, the outflow of foreign currency stopped. The total connectedness index generally fluctuated around 50% during this period. The connectedness index jumped from 48% to 58% on August 15, 1994. U.S. Federal Open Market Committee (FOMC) voted to increase its target for the federal funds rate 50 basis points to 4.75% on that day. Nevertheless, $ 3 billion was pulled out of the country in November.

President Zedillo selected on December 1. Jaime Serra Puche, the new Finance Minister, denied the devaluation of the peso on December 15. The next day,Mexico experienced an outflow of $ 855 million. The new cabinet concluded that the situation was unsustainable. Then, the Central Bank of Mexico announced a lift of the upper band of the exchange rate by 15%, an effective devaluation of the peso on December 20. After the announcement, half of the exchange reserves left the country. The peso was allowed to float freely on December 22. The total devaluation of the peso was around 35% by the end of December 1994. This constant devaluation has caused the Tequila crisis. In January 1995, the connectedness index jumped to 62%. The International Monetary Fund (IMF) and the US announced a rescue package of $ 57.8 billion in this month. Without the help, Mexico would have probably defaulted on its tesabonos. In March 1995, Mexican government announced a tight saving package and hence renewed confidence by investors. The total connectedness index fluctuated around 50-55% band during 1995. Then, the index declined rapidly to 45% at the beginning of 1996.

6.3 The Asian Financial Crisis of 1997

On May 14, 1997, Thailand spent billions of dollars of its foreign reserves to defend the Thai baht against speculative attacks. The total connectedness index increased to 47% in June 1997. Then, the connectedness index reduced to 35-40% band and fluctuated until October 1997. In July, the Asian financial crisis started. Thailand devalued the baht and Thai government asked technical assistance from the IMF. Then Malaysia central bank intervened to defend the ringgit. The Philippine peso was devalued and then the Singapore dollar declined gradually. Indonesia abandoned the rupiahs trading band and allowed the currency to float freely in August. In October 1997, rupiah fell more than 30% in two months and hence Indonesia requested the IMF and the World Bank for help and then the bank lending rates started to decline in Indonesia. The total connectedness index jumped from 40% to 66% on October 10, 1997. By the fall of 1997, the contagion extended its reach to South Korea, Hong Kong and China. Hong Kong raised bank lending rates to 300% to avoid speculative attacks on the Hong Kong dollar. The IMF

agreed to a loan package for Indonesia and the government promised for wide ranging reforms on October 31. In that day, the index was 57% and then it started to decline. In November, South Korea requested IMF aid and the total connectedness index was around 49% at that time. The index started to increase again in December. The IMF approved a $ 57 billion bailout package to South Korea, the largest in history. The upward trend in the total connectedness index continued with the IMF restarted its loan disbursement to Russia in December 1997. Peregrine Investments, Asia's largest private investment bank, filed for liquidation because of its loan investments in Indonesia in January 1998. The connectedness index was 53% at that time and it still continued to increase. In April, Indonesia and the IMF reached a third pact in six months for a bailout. Stanley Fischer, IMF Deputy Director, declared "the worst of the crisis over." The IMF resumed a stalled lending program to Indonesia on May 4, 1998. Students in Indonesia protested the Suharto administration for its economic policies. The total connectedness index reached 57% on May 5, 1998 and then started to decline. Suharto resigned after 32 years in power.

6.4 The Russian Crisis of 1998

In May, 1998, Russia's financial system was expanded to the breaking point because of the panic in stock and bond markets. Russia's stock market crashed on June 1, 1998. Japanese government announced that its economy was in a recession on June 12. The IMF announced a package of $ 23 billion emergency loans for Russia on July 13. The Russian market collapsed on August 11 and trading on the stock market was temporarily suspended. The total connectedness index started to increase from 43% to 55-60% band in August. Russia announced a devaluation of the ruble and a 90-day delay on foreign debt repayment, starting panic in Russia. Russia's economic crisis disturbed world markets, flattening stocks and bond markets in Latin America. Wall Street was overwhelmed by the turmoil in Russia and world markets. The Dow Industrial average declined 512 points on August 31, 1998, the second-worst point loss in the Dow's past. The total connectedness index jumped from 44% to 57% and then index stayed around 55% band for a month.

6.5 The Long Term Capital Management Fund & LTCM Crisis of 1998

New York Federal Reserve pushed an alliance of leading US financial institutions to provide a $ 3.5 billion bailout to Long Term Capital Management, one of the largest US hedge funds, on September 23, 1998 since a collapse could worsen the panic in the financial markets. With this news, the total connectedness index raised to 60%. FOMC voted to reduce its target for the federal funds rate 25 basis points to 5.25% on September 29. The index was around 50-55% band in December 1998. The FOMC cut interest rates for a second time to prevent weak financial markets in October.

6.6 Brazilian Crisis of 1998

The IMF, World Bank and leading industrial nations announced a $ 41 billion rescue package for Brazil in November. In Brazil, the congress rejected a key social security tax increase desired by the IMF, causing a disaster in Brazilian markets and stock sell-offs throughout Latin America and on Wall Street on December 3. At this time, the total connectedness index jumped from 55% to 73%. Then, the index declined quickly to 43%. The Brazilian government allowed its real currency to float freely on world markets in January 1999. The connectedness index varied in the 40-50% band until September 1999.

6.7 ECB's Influence

The total connectedness index jumped to 72% in September 1999. The jump was a reaction to monetary policy implemented by European Central Bank (ECB). Christian Noyer, Vice-President of ECB, appeared before the Economic and Monetary Affairs Committee in Brussels on 27 September 1999 when he raised the possibility of the ECB raising interest rates. ECB voted to increase interest rate 50 basis points to 3% on November 4.

6.8 Dot-Com Bubble Burst of 2000

Over 1999 and early 2000, the Fed increased interest rates six times and the economy began to lose speed. The dot-com bubble burst on March 10, 2000, when the technology heavy NASDAQ Composite index peaked at 5,048; more than double its value just a year before. US vs. Microsoft case, which declared Microsoft a monopoly, were widely expected in the weeks before their release on April 3. The next day, the NASDAQ fell from 4,283 points to 3,649 and rebounded back to 4,223. At the time, this day represented the most volatile day in the history of the NASDAQ. The total connectedness index fluctuated around 60% until mid-2000 and decreased gradually afterwards to 47%. The dot-com bubble burst is what caused the stock market crash. The years 1992-2000 were favorable for the stock market and the dot-com boom was in full effect. But things began to take a downturn from September 2000. The total connectedness index increased from 48% to 53% in September. Then, the index decreased to 39% and fluctuated around this until the end of 2000.

The network analysis is given in Figure 10. The dot-com bubble burst effects the whole economy negatively. Sparse network structure is visible and numerous nodes have lower weighted-out degree. As expected, US Libor rate was at the core of network. Also, EU Libor rate was an important node in the network system. The Libor rates of peripheral countries, such as Indonesia, Malaysia, South Africa, Hungary, and India are out of core. Also, Brazil is not in the center. There may be two main underlying reasons behind this behavior of peripheral countries. The Libor rates of these countries are the net receivers. Switzerland, Canada, Denmark, and Sweden are at the center.

6.9 Argentina Crisis of 2001

The recession in Argentina started in mid-1999. The IMF approved an emergency rescue package to Argentina in December, 2000. Then, the total connectedness index started to increase from 39% level. Fed voted to reduce its target for the federal funds rate 50 basis points to 6% on January 3, 2001. The connectedness index jumped to 50% immediately but then returned 44%. Ahmet Necdet Sezer, President of Turkey, triggered the crisis by

throwing a constitution book to Prime Minister Bulent Ecevit at the National Security Council (MGK) meeting on 21 February, 2001. The index jumped to 50% again. Argentine markets began to slide again as turmoil in Turkey lowered confidence in emerging markets. Argentine government did not achieve the IMF's targets. Domingo Cavallo returned as economy minister on 20 March, 2001. Also, Fed reduced federal funds rate 50 basis points on the same day. With these news, the connectedness index jumped from 44% to 63% on a single day. Then, the index declined to 50% and fluctuated around this until June, 2001. Argentina turned to the IMF for help again because of the fall on markets on June. The connectedness index rose up to 62% but then dropped to 48%.

The network system is presented in Figure 11. As you can see in the Figure 11, Libor rate of Argentina was the most crucial node in the network system because it has highest weighted-out degree. An interesting point is that the Libor rate of EU network place was near to out-edge. The underlying reason is that Eurozone Countries have weak trade relationship. The US Libor rate was not one of the most important nodes in the network structure. Brazil come close to center in that time, because Brazil and Argentina has strong ties. Libor rates of the Japan and the UK are at the center. The Libor rate of these countries are not at the center for the most part of these periods. Other Libor rates at the center of network system are Hungary, Canada, Australia, and India.

6.10 9/11 Terrorist Attacks

The total connectedness index jumped to 60% on September 18, 2001. The jump was a reaction to terrorist attacks launched by the Islamic terrorist group al-Qaeda upon the US on September 11, 2001. The destruction of the Twin Towers and other properties caused serious damage to the economy and had an important effect on global markets, closing Wall Street until September 17.

The network analysis on September 13, 2001 is given in Figure 12. The terrorist attack causes crucial changes in placement of Libor rates. The US Libor rate was at the center. Also, Canada's Libor rate was an important node since the strong financial link between US. The Libor rate of Argentina is out of core. After the crisis in Argentina, Peso's Libor

rate is not connected more with the other countries. The Libor rates of EU, UK, Hong Kong, Denmark, and Australia are at the center of network architecture.

6.11 WorldCom Scandal of 2002

WorldCom, the second largest long distance phone company in the US, announced that it had overstated earnings in 2001 and the first quarter of 2002 by more than $ 3.8 billion on June 25, 2002. The announcement stunned financial analysts and had a noticeable effect on the financial markets. WorldCom filed for bankruptcy protection on July 21 because WorldCom's stock price fell drastically. The total connectedness index fluctuated in the 52-58% band until mid-2002 and then declined to 45% level. On August 8, the company announced that it had also manipulated its reserve accounts in recent years, affecting an additional $ 3.8 billion.

6.12 Iraq War

The total connectedness index jumped to 55% level with the increasing tension between Iraq and US on November 8, 2002. United Nations (UN) Security Council Resolution called on Iraq to cooperate with UN inspection teams and not to obstruct UN forces. The connectedness index fluctuated between 43-55% during the Iraq war.

The total connectedness index was stable from mid-2003 to mid-2007. The index was generally varied between 45-50% in this period. The spikes were related to monetary policy changes and political issues. The connectedness index increased with the London bombings in July 2005. The second spike was in December 2005 and related to interest rate decision given by ECB. The ECB increased interest rate 25 basis points to 2.25% in December 2005 and this also increased the total connectedness index.

6.13 Global Financial Crisis of 2007-09

The total connectedness index was unstable during the global financial crisis. The short-term jump in June 2007 was related to interest rate decision given by Fed. On June 28, 2007, FOMC voted to maintain its target for the federal funds rate at 5.25%. This led to an

immediate jump in the index from 45% to 51%; yet, the effect was short-term as the index immediately declined to the 43% level. Bear Stearns closed two hedge funds that invested in mortgage-backed securities on July 31. BNP Paribas, France's largest bank, stopped payments on three investment funds on August 9. On August 10, the Federal Reserve Board announced that it "will provide reserves as necessary ... to promote trading in the federal funds market at rates close to the FOMC's target rate of 5.25 percent. In current circumstances, depository institutions may experience unusual funding needs because of dislocations in money and credit markets. As always, the discount window is available as a source of funding." The connectedness index jumped to 58% with this announcement.

The pairwise connectedness plots on August 1, 2007 and August 21, 2007 for the liquidity crisis in Figure 13 and14 show that Libor rate of US came to the center of network system. The announcement causes profound changes in placement of Libor rates. The big changes in the placement show that the impacts are extremely large. After the announcement, sparse network system can be observable and many nodes have lower weighted-out degree, presented by green nodes. US Libor rate and EU Libor rate was getting closer. Also, South Korea, Denmark and Canada was getting closer to US.

The connectedness index varied between 55-60% band until the end of 2007. Northern Rock, the United Kingdom's fifth-largest mortgage lender, faced a liquidity crisis and required a loan from British government. On September 14, Bank of England (BOE) provided liquidity support. FOMC reduced its target for the federal funds rate 50 basis points to 4.75% on September 18. Also, Federal Reserve Board reduced the primary credit rate from 6.25% to 5.25% in a month. In November, liquidity in interbank funding markets was diminished since financial market pressures intensified at that time. On December 11, FOMC reduced its target for federal funds rate to 4.25% and Federal Reserve Board reduced the primary credit rate to 4.75%. The index started to decline in January 2008. The decreasing path of the total connectedness index stopped when the investment bank Bear Sterns was bought out by JP Morgan on March 14. In March and April, FOMC reduced its target for the federal funds rate 100 basis points to 2% and Federal Reserve Board reduced the primary credit rate 100 basis points to 2.25%. The total connectedness

index started to increase from 51% at the end of April. The index jumped to 58% on May 30, 2008. Bank of America acquired Countrywide Financial Corporation on June 5. FOMC released a statement about the financial market turmoil and noted that the "downside risks to growth have increased appreciably." on August 17. The connectedness index was around 50% until September 2008.

The total connectedness index started to increase again in September. The US government rescued Fannie Mae and Freddie Mac on September 7. Bank of America intended to purchase Merrill Lynch & Co. for $ 50 billion on September 15. The connectedness index increased to 57% with the bankruptcy of Lehman Brothers Holdings on September 15. This bankruptcy intensified worldwide financial panic and hence the connectedness index continued to rise. HBOS, the UK's largest mortgage lenders, was rescued by Lloyds TSB after a significant drop in its share price on September 17. Two American banks, Washington Mutual and Wachovia Corporation, collapsed at the end of September 2008.

Ireland went into recession and the government wanted to insure the whole Irish banking system. Ireland became the first European country to get into recession. In October, Iceland's three biggest commercial banks - Glitnir, Kaupthing, and Landsbanki - collapsed. Eight central bank including the Fed, the ECB, and the BOE cut their interest rates by 50 basis points to relax the pressure on stock markets on October 8. The total connectedness index hiked to 64% with these monetary decisions and stayed high for a while. On October 24, PNC Financial Services Group Inc. purchased National City Corporation and hence they created the fifth largest US bank.

The FOMC established a target range for the effective federal funds rate of 0 to 0.25% on December 16, 2008. Also, the Federal Reserve Board reduced the primary credit rate to 0.50%. The US Treasury Department purchased bank stocks under the Capital Purchase Program in that period. The connectedness index increased to 72% and started to decline. Fannie Mae reported a loss of $ 15.2 billion in the fourth quarter of 2008 and $ 58.7 billion for 2008 on February 2009. The connectedness index was 60% at that time and stayed around this level between March and June 2009. The connectedness index had an increasing path from July to September 2009. One of the possible reason was the

spillover effects of the global crisis. Some central banks changed their interest rates in that period. After reaching 62% in September, the connectedness index declined sharply to 48% in December 2009.

The network system on Figure 15 and 16 compares the effect of Quantitative Easing I (QE I) on the connectedness of Libor rates. The system in Figure 15 shows the expansion of QE period. Switzerland was at the core of network at the beginning of QE because The Swiss National Bank lowered interest rate from 2% to 1% on November 20, 2008. The network place of US Libor rate was near to out-edge. It was not a crucial node in the network system. The same situation was held on EU Libor rate. The system in Figure 16 shows the phase out of QE. US Libor rate came to the center of network. Its out-degree was the highest. US and EU placement was getting closer. UK, Japan, Hong Kong, South Korea was getting closer to US. The emerging economies, China, Turkey became more effective.

6.14 European Crisis

In October 2009, a new government led by George Papandreou was elected in Greece. The new socialist government found evidence that Greece's budget deficit was twice as much as was announced. Fitch and Standard & Poor's downgraded Greece's credit rating to below investment-grade status in December 2009. Then, the total connectedness index started to increase. After spending billions to support banks, Ireland government implemented saving measures that included increasing the retirement age. In January 2010, the Greek government declared the Stability and Growth Programme to cut deficit. The aim was reducing the deficit around 10% by 2012. The connectedness index was around 50%. In February 2010, Spanish government announced an austerity plan that would increase the retirement age. The connectedness index increased in March. This increase was related to new financial package including additional public-sector pay cuts and tax increase proposed by Papandreou. S&P downgraded Greek debt ratings to junk bond status on April 29. Also, S&P downgraded Portuguese and Spanish bonds. Then, the total connectedness index returned to 50% level again. Greek government announced deficit

reduction by 41.5% for the first quarter on May 27 and hence the connectedness index jumped to 56%. Then it started to decline until August. The connectedness index started to increase from 46%. The 10-year Irish government bond premium surged to a record 6.5% premium against the German bond in November 2010. Ireland started talks with the EU over a bailout. A new election was called on November 22. European ministers agreed a bailout for Ireland on November 28. The connectedness index was 53% at the time and started to decline again until May 2011. The ECB bailed out Portugal on May 5, 2011. The connectedness index increased from 46% to 55% on a single day and declined to 47%.

The total connectedness index jumped to 63% in August 2011 since S&P downgraded US sovereign debt. The network analysis in Figure 17 shows that US Libor rate is at the core on that day with Libor rates of Switzerland and Canada. Also, out-degree of Euribor rate is high. The total connectedness index fluctuated between 50 and 57% until the end of 2011. Italian Prime Minister Silvio Berlusconi was undermined by his personal scandals in August 2011. Italy's rate of indebtedness was second among euro-zone countries at the time and Berlusconi proposed $ 66 billion in tax increases and spending cuts. Swiss franc appreciated dramatically against the Euro in September. S&P downgraded Italy's credit rate in the same month. In November 2011, S&P downgraded Belgium's credit rate too.

The total connectedness index continued to decrease until July 2012. The index started to increase from 38%. The culprit behind this increasing path was the financial conditions in Spain. The level of Spanish borrowing reached a record high. The Spanish government requested $ 125 billion from the European Union to recapitalize its banks. In July, the European Central Bank, the Central bank of the Republic of China, the South African Reserve Bank, the Bank of Korea and the Danmarks Nationalbank lowered their interest rates. There was an upward trend in the connectedness index until April 2013. In this period, some emerging countries' central banks including India and Turkey lowered their interest rates.

6.15 After mid-2013

The connectedness index reached 47% on April 18. Federal Reserve Chairman Ben Bernanke's speech on May 21 about the possible stopping of QE policies in late 2013 increased volatility in financial markets around the world. The total connectedness index was around 43%.

The total connectedness index jumped to 47% on June 12, 2013. The reason for the spike could be the 2013-14 protests in Turkey. The protests, begun on 28 May 2013, were initially a contest against the urban development plan for Istanbul's Taksim Gezi Park. The government's encroachment on Turkey's secularism and the violation of the rights of freedom of the press, of expression, and assembly had led to subsequent protests and strikes that took place across Turkey. The index declined to 40% in August 2013.

The total connectedness index fluctuated between 40-45% band from August 2013 to March 2014. The index had an increasing pattern from August to December 2013. ECB cut the interest rate 25 basis points to 0.25% on November 7, 2013. On December 18, the Federal Reserve announced that it would start to taper its aggressive bond-buying program to $ 75 billion a month beginning in January 2014. The FOMC also announced it would lower its monthly long-term Treasury bond purchases to $ 40 billion and mortgage-backed securities to $ 35 billion a month, both reductions of $ 5 billion. After Fed decision, several central banks including Brazil, South Africa, and India increased their interest rates because these emerging markets wanted to protect themselves from the spillover effects of Fed operations. After protests in Turkey, Central Bank of the Republic of Turkey (TCMB) increased the interest rate from 4.5% to 10% on January 29. Bank of Israel (BOI) declined the interest rate from 1% to 0.75% on February 24. The connectedness index was around 45% at these times. The increasing tension between Ukraine and Russia caused an uncertainty in the global economy in the beginning of 2014. Russian President Vladimir Putin ordered military exercises in western Russia on February 26. U.S. President Barack Obama warned "there will be costs" for Russian military intervention in Ukraine. Central Bank of Russia increased the interest rate from 5.5% to 7% on March 3, 2014. The total connectedness index was 45%.

7 Conclusion

In this thesis, I investigated the connectedness of the interbank rates for 33 countries over the period from 1991 to 2014. Using Diebold & Yilmaz (2012) methodology, I calculated and analyzed the behavior of the total and directional connectedness. In particular, I focus on the effects of monetary policy on Libor rates and their connectedness. I recognize that Libor rates have become highly interrelated during the crisis times. Furthermore, my results reveal that interest rate decisions have an important impact on the connectedness of Libor rates.

To assess the contribution of each country to the connectedness over the sample, I used static analysis for three periods. To understand the linkages in a better way, I also used the network results for the same periods. The results of full sample showed how interbank rates around the world are closely connected to each for the period of 1991-2014. The behavior of the total connectedness index revealed the major crisis episodes around the world, including the ERM Crisis, the Mexican Crisis, the Asian Financial Crisis, the Russian Crisis, the Brazilian Crisis, the Argentina crisis, the Global Financial Crisis, and European Crisis. The index also helped me to point out the minor crisis, including LTCM Crisis, Dot-Com Bubble Burst, and WorldCom Scandal.

The results show that in the pre-European Money Union period the bulk of the shock transmission took place among the European Countries, including Belgium, Germany, France, Italy, Ireland, Sweden, and Denmark . The net connectedness of US Libor rate is low in this period.

Libor rates of US and Euro are the main sources of shocks in 2000s. The net connectedness of UK Libor rate is negative before the Global Financial Crisis. So, I can conclude that UK is the net receiver of connectedness between 2000-2006. The net connectedness of UK is higher only in the period of the global financial crisis. After the crisis, the US and the EU Libor rate began to be more dominant.

The behavior of the total connectedness index reveals that it can be used an a systemic risk indicator. I also presented dynamics of directional “to”, “from” and “net” connectedness indices for Libor rates of 33 countries. Applying variance decomposition to the

financial network framework helps me to find that QE policies implemented by the Fed since the collapse of Lehman Brothers in September 2008 leads to a decreasing pattern for connectedness of US Libor rate.

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A Network Visualization

A network represents a group of nodes and the links (edges) between them. The nodes of the network describe financial institutions and markets, and the edges describe direct or indirect relations between two financial markets in financial systems. The approach of my study focused on weighted directed network. I use financial network architecture where nodes are the Libor rates and edges are their corresponding connectedness value. Its network topology is fully-connected mesh network because connectedness value cannot be zero empirically. Diebold & Yılmaz framework creates an excellent base to work on empirical financial networks. Now, I give the technical details.

The software program that we use to visualize and analyze 3-months Libor rates is Gephi, which is an open-source software developed by Bastian et al. (2009). Gephi includes many features for both network visualization and analysis which consists of filtering, ranking, importing and other built-in functions. My network system has up to 33 nodes and 1056 directional weighted edges, which makes Gephi ideal software due to its compatibility with large networks. Throughout this part, I explain how each network graph presented should be interpreted.

Filtering: By the help of this feature we can remove edges or nodes according to some of their properties.

Layout: I use ForceAtlas2 method, developed by Jacomy et al. (2011), is the latest force-directed graph layout of Gephi, in my analysis. This layout uses energy-model; nodes repulse each other whereas edges try to keep these nodes together. After iterations, the balance between nodes and edges finalize visualization of network. If a node has higher weighted degrees, its relative centrality will be higher; hence, more central nodes tend to locate in core zone. As an important comment, the locations of nodes are relative to each other such that the same network values can be represented in two different graphs; however, their relative positions stay same.

Node Color: The intensity of node color, from light green to dark red, is proportional to the out strength of a node. Lowest degree is represented with light green and highest degree with dark red correspondingly. I used spline editor of Gephi ranking tool to make a

better approximation on coloring nodes. The main analogy of this editor is to color nodes according to their distribution on whole network instead of linear function of ranking.

Node Size: Size of nodes is proportional to gross domestic product (GDP) values of countries for given year. Similar to node color, spline editor help me in the distribution of node size.

Edge Thickness: In my network architecture, two nodes are connected with two links; where direction of each link can be understood by its arrow direction. I choose straight edges instead of curved edges for the sake of visualization. Two edges between two nodes overlaps; where thickness of highest weighted edge dominates other. Hence, in the visualization, we can observe only the thicker edge. On the other hand, the arrow size is proportional to corresponding edge weight.

B Tables

Ticker	Name	First Day	Last Day
USD	United States Dollar	03.01.1991	17.03.2014
EUR	Euro Member Countries	31.12.1998	17.03.2014
GBP	United Kingdom Pound	03.01.1991	17.03.2014
JPY	Japan Yen	03.01.1991	17.03.2014
DEM	Deutsche Mark	03.01.1991	29.12.1998
FRF	French Franc	03.01.1991	29.12.1998
ITL	Italian Lira	03.01.1991	29.12.1998
BEF	Belgian Franc	03.01.1991	29.12.1998
IEP	Irish Pound	31.05.1991	24.12.1998
ATS	Austrian Schilling	03.01.1991	29.12.1998
GRD	Greek Drachma	23.11.1993	05.12.1995
CHF	Switzerland Franc	03.01.1991	17.03.2014
NOK	Norway Krone	03.01.1991	17.03.2014
SEK	Sweden Krona	03.01.1991	17.03.2014
CAD	Canada Dollar	03.01.1991	31.05.2013
DKK	Denmark Krone	03.01.1991	17.03.2014
CNY	China Yuan Renminbi	09.10.2006	17.03.2014
BRL	Brazilian Real	05.07.1994	17.03.2014
ARS	Argentina Peso	22.04.1997	30.12.2011
RUB	Russia Ruble	25.02.1999	17.03.2014
ILS	Israel Shekel	16.11.2000	17.03.2014
INR	India Rupee	02.12.1998	17.03.2014
AUD	Australia Dollar	03.01.1991	31.05.2013
IDR	Indonesia Rupiah	11.04.1997	17.03.2014
KRW	Korea (South) Won	17.08.2004	17.03.2014
PLN	Poland Zloty	13.08.1996	17.03.2014
CZK	Czech Republic Koruna	02.04.1993	17.03.2014
TL	Turkey Lira	02.08.2002	17.03.2014
HUF	Hungary Forint	06.05.1997	17.03.2014
HRK	Croatia Kuna	03.01.2001	17.03.2014
ZAR	South Africa Rand	02.02.1999	17.03.2014
HKD	Hong Kong Dollar	28.08.1992	17.03.2014
MYR	Malaysia Ringgit	03.01.1991	31.05.2011

Table 1: Periods of Interbank Offered Rates

	ARS	ATS	AUD	BEF	BRL	CAD	CHF	CNY	CZK
Mean	16.22	5.76	5.70	6.03	20.35	3.94	2.21	3.66	5.51
Median	11.94	4.92	5.38	5.38	16.95	4.00	1.64	3.88	3.56
Maximum	117.13	9.87	11.95	13.28	173.23	11.38	9.47	6.46	40.13
Minimum	2.44	3.10	2.96	3.07	7.11	0.40	0.00	1.20	0.37
Std. Dev.	18.50	2.43	1.50	2.55	14.64	2.12	2.27	1.33	4.94
Skewness	3.61	0.60	1.38	0.37	3.45	0.44	1.44	-0.21	1.36
Kurtosis	16.63	1.74	5.83	1.52	24.11	2.98	4.55	2.04	5.28
Observations	3774	2066	5766	2066	5062	5766	5968	1907	5388

	DEM	DKK	EUR	FRF	GBP	GRD	HKD	HRK	HUF
Mean	5.77	4.29	2.49	6.49	4.94	20.07	3.36	5.05	9.54
Median	5.05	3.72	2.27	5.99	5.30	18.25	3.44	4.97	8.45
Maximum	9.93	23.50	5.39	15.20	14.13	80.00	16.57	11.90	21.20
Minimum	3.10	0.23	0.18	3.28	0.50	14.65	0.07	0.55	2.73
Std. Dev.	2.46	3.13	1.48	2.73	2.81	7.24	2.67	2.52	4.16
Skewness	0.50	1.49	0.09	0.42	0.21	4.18	0.66	0.15	1.05
Kurtosis	1.63	6.10	1.89	1.90	3.22	26.79	3.51	2.25	3.52
Observations	2066	5968	3902	2066	5968	529	5541	3386	4329

	IDR	IEP	ILS	INR	ITL	JPY	KRW	MYR	NOK
Mean	13.19	7.50	4.17	8.14	9.58	1.05	3.68	4.86	5.07
Median	9.41	6.25	4.13	8.45	9.13	0.40	3.51	3.61	4.99
Maximum	57.79	32.88	9.82	13.20	21.94	8.25	6.14	14.90	27.21
Minimum	4.12	3.31	0.66	4.27	3.28	0.05	2.41	2.11	1.61
Std. Dev.	10.43	3.23	2.33	2.10	2.92	1.74	1.03	2.28	2.79
Skewness	2.51	2.86	0.58	-0.16	0.36	2.57	0.64	0.83	1.25
Kurtosis	9.27	14.88	2.61	1.90	3.30	9.28	2.15	2.57	6.65
Observations	4346	1958	3417	3921	2066	5968	2459	5251	5968

	PLN	RUB	SEK	TL	USD	ZAR
Mean	9.42	12.07	4.64	16.95	3.46	8.72
Median	5.67	7.41	3.93	15.58	3.66	8.11
Maximum	27.28	67.00	34.00	56.00	7.63	16.90
Minimum	2.65	4.33	0.47	4.74	0.23	5.06
Std. Dev.	6.89	10.48	3.41	11.47	2.21	2.67
Skewness	1.03	2.88	1.63	1.65	-0.20	0.38
Kurtosis	2.58	12.62	7.53	5.31	1.53	2.19
Observations	4516	3863	5968	2981	5968	3880

Table 2: Descriptive Statistics

	ATS	AUD	BEF	BRL	CAD	CHF	CZK	DEM	DKK	FRF	GBP	HKD	IEP	ITL	JPY	MYR	NOK	SEK	USD	**FROM**
ATS	69.14	1.01	2.48	0.07	0.46	1.58	0.03	17.54	1.06	1.35	0.52	0.03	0.69	0.81	0.64	0.02	0.21	0.32	2.05	30.86
AUD	0.91	76.48	0.26	0.12	5.50	1.12	0.58	1.13	0.77	0.34	0.80	1.53	0.57	0.60	0.35	0.26	0.94	0.32	7.39	23.52
BEF	1.11	0.18	46.19	0.14	0.22	0.82	0.03	5.69	9.07	11.94	1.41	0.05	10.98	4.85	0.36	0.06	1.43	4.85	0.62	53.81
BRL	0.41	0.55	7.46	78.66	0.11	0.20	0.05	0.54	1.20	1.89	1.11	0.38	3.11	0.59	1.50	0.10	0.88	1.08	0.17	21.34
CAD	0.48	4.93	0.44	0.45	77.51	0.37	0.07	1.09	1.32	1.02	0.64	0.93	0.59	1.44	0.54	0.11	0.59	1.00	6.49	22.49
CHF	1.27	1.24	1.24	0.13	0.39	78.93	0.58	7.25	0.59	1.11	0.94	0.19	0.69	0.86	0.50	0.06	0.22	0.71	3.12	21.07
CZK	0.03	1.05	0.03	0.01	0.05	0.56	96.45	0.01	0.02	0.05	0.01	0.15	0.03	0.13	0.05	1.21	0.06	0.02	0.06	3.55
DEM	11.62	0.80	7.32	0.22	1.33	5.57	0.03	56.35	2.83	2.67	1.42	0.03	0.99	2.08	1.47	0.04	0.75	1.47	3.03	43.65
DKK	0.70	0.27	11.00	0.14	0.53	0.38	0.01	2.45	49.45	4.89	0.70	0.13	4.82	5.95	0.09	0.02	4.25	13.89	0.33	50.55
FRF	1.28	0.16	15.15	0.34	0.22	0.43	0.05	2.25	5.73	56.64	0.48	0.01	6.40	4.69	0.90	0.03	0.89	3.62	0.74	43.36
GBP	0.37	0.97	2.43	0.92	0.85	1.28	0.06	2.06	0.95	1.20	76.29	0.29	4.56	1.25	0.42	0.09	0.44	1.59	4.00	23.71
HKD	0.09	4.15	0.39	0.57	0.80	0.23	0.14	0.13	0.46	0.07	0.09	90.91	0.04	0.06	0.35	0.34	0.85	0.14	0.19	9.09
IEP	0.52	0.23	14.33	0.32	0.46	0.47	0.12	1.03	5.46	6.46	3.33	0.14	58.21	3.00	0.27	0.04	0.98	3.55	1.09	41.79
ITL	0.62	0.52	6.63	0.05	1.14	0.33	0.03	2.06	6.86	6.67	0.94	0.05	2.68	57.96	0.32	0.17	1.10	10.59	1.30	42.04
JPY	0.88	0.48	0.77	0.53	5.94	0.66	0.03	1.80	0.35	1.16	0.43	0.40	0.76	0.81	83.44	0.02	0.09	1.13	0.33	16.56
MYR	0.04	0.27	0.18	0.03	0.15	0.16	4.44	0.05	0.06	0.12	0.21	0.33	0.12	0.07	0.04	93.55	0.13	0.01	0.04	6.45
NOK	0.29	0.91	2.54	0.07	0.33	0.29	0.03	1.45	3.30	1.25	0.30	1.02	1.58	1.68	0.11	0.09	78.26	5.73	0.76	21.74
SEK	0.32	0.27	6.79	0.12	0.80	0.27	0.01	1.52	16.28	2.67	0.92	0.07	3.38	9.04	0.52	0.03	3.79	52.26	0.94	47.74
USD	1.37	6.51	1.17	0.42	6.11	2.80	0.08	3.02	0.69	0.82	3.65	0.25	1.09	1.47	0.57	0.06	1.10	1.28	67.53	32.47
TO	22.31	24.50	80.61	4.63	25.37	17.54	6.35	51.08	56.99	45.69	17.90	5.96	43.08	39.38	8.98	2.76	18.72	51.30	32.64	
NET	-8.55	0.98	26.79	-16.71	2.89	-3.53	2.81	7.43	6.44	2.33	-5.80	-3.13	1.28	-2.66	-7.58	-3.68	-3.02	3.55	0.17	29.25

Table 3: Full Sample Connectedness Table (July 7, 1994 - December 24, 1998)

	ARS	AUD	BRL	CAD	CHF	CZK	DKK	EUR	GBP	HKD	HUF	IDR	INR	JPY	MYR	NOK	PLN	RUB	SEK	USD	ZAR	**FROM**
ARS	96.81	0.23	0.03	0.39	0.13	0.35	0.03	0.15	0.46	0.07	0.06	0.01	0.06	0.04	0.01	0.28	0.14	0.08	0.25	0.37	0.03	3.19
AUD	0.14	63.79	0.04	6.03	2.73	0.31	2.42	3.35	1.73	1.05	0.14	0.05	0.23	0.92	0.07	0.58	0.41	0.91	1.70	13.38	0.01	36.21
BRL	0.05	0.11	90.29	0.37	0.19	0.19	0.06	0.05	0.04	0.11	0.11	1.95	0.21	0.05	5.06	0.30	0.02	0.05	0.65	0.05	0.08	9.71
CAD	0.12	4.89	0.03	47.20	4.70	0.66	2.80	8.21	1.69	1.64	0.11	0.24	0.32	1.51	0.17	0.86	0.55	1.21	4.36	18.52	0.22	52.80
CHF	0.15	1.87	0.01	4.74	49.84	1.11	3.40	12.11	1.31	0.52	0.05	0.06	0.17	4.83	0.07	1.68	0.96	1.71	6.47	8.91	0.04	50.16
CZK	0.41	0.30	1.07	1.17	1.54	86.78	0.75	1.35	0.70	0.26	0.06	0.20	0.11	0.26	0.22	0.52	0.60	1.12	1.07	1.38	0.12	13.22
DKK	0.05	1.75	0.07	3.12	3.80	0.60	60.92	13.66	0.91	1.14	0.04	0.03	0.73	0.43	0.05	1.76	0.32	0.72	6.81	3.05	0.02	39.08
EUR	0.11	3.00	0.03	6.79	9.66	0.79	8.68	40.39	1.23	0.57	0.04	0.02	0.25	2.28	0.09	2.61	0.64	1.44	10.44	10.91	0.02	59.61
GBP	0.42	3.40	0.08	4.37	4.91	0.79	2.01	6.56	60.22	0.42	0.04	0.05	0.14	1.12	0.14	1.25	0.44	0.77	4.17	8.49	0.21	39.78
HKD	0.11	2.49	0.11	3.66	1.55	0.07	1.67	2.65	0.85	73.07	0.13	0.32	0.15	2.43	0.33	0.25	0.29	0.55	1.22	7.71	0.38	26.93
HUF	0.05	0.18	0.02	0.30	0.11	0.08	0.09	0.16	0.06	0.10	97.56	0.03	0.06	0.29	0.06	0.04	0.35	0.11	0.04	0.13	0.18	2.44
IDR	0.05	0.08	2.06	0.34	0.04	0.23	0.15	0.19	0.05	0.36	0.01	92.73	0.28	0.04	1.78	0.27	0.04	0.39	0.06	0.28	0.57	7.27
INR	0.16	0.36	0.31	0.94	0.12	0.46	0.28	0.32	0.23	0.08	0.07	0.57	93.11	0.31	0.33	0.69	0.19	0.68	0.23	0.43	0.12	6.89
JPY	0.02	1.05	0.09	2.33	6.79	0.22	0.55	4.10	0.23	0.21	0.02	0.03	0.12	71.38	0.08	1.10	1.40	3.08	1.68	5.50	0.02	28.62
MYR	0.01	0.23	3.28	1.17	0.04	0.25	0.04	0.26	0.04	0.08	0.04	6.67	0.33	0.01	86.92	0.14	0.04	0.08	0.15	0.03	0.20	13.08
NOK	0.28	0.84	0.33	1.20	2.66	0.47	2.08	5.41	0.05	0.28	0.06	0.08	0.25	1.15	0.23	75.40	0.44	0.58	5.99	1.95	0.25	24.60
PLN	0.13	0.31	0.08	1.05	2.00	0.84	0.65	1.83	0.50	0.14	0.26	0.06	0.33	5.66	0.05	0.41	83.44	0.15	0.53	1.35	0.21	16.56
RUB	0.24	0.84	0.04	1.52	2.51	1.23	0.41	1.90	0.18	0.35	0.02	0.45	0.16	2.79	0.08	0.09	0.43	81.71	2.08	2.93	0.05	18.29
SEK	0.04	1.52	0.06	4.41	6.80	1.02	5.90	13.54	0.84	0.22	0.12	0.03	0.14	1.25	0.10	4.15	0.36	1.34	52.06	5.21	0.89	47.94
USD	0.23	8.68	0.06	15.32	6.87	0.63	2.34	10.86	2.15	2.92	0.04	0.16	0.08	2.80	0.02	1.02	0.73	1.64	3.97	39.43	0.07	60.57
ZAR	0.11	0.31	0.11	1.02	0.42	0.05	0.50	1.09	0.12	0.22	0.20	0.57	0.07	0.25	0.22	0.35	0.07	0.20	1.06	0.34	92.73	7.27
TO	2.90	32.44	7.92	60.24	57.58	10.35	34.81	87.75	13.39	10.73	1.62	11.58	4.21	28.42	9.15	18.34	8.43	16.83	52.94	90.91	3.67	
NET	-0.29	-3.77	-1.79	7.44	7.42	-2.87	-4.27	28.14	-26.39	-16.20	-0.81	4.31	-2.68	-0.20	-3.93	-6.26	-8.13	-1.47	5.00	30.34	-3.60	26.87

Table 4: Full Sample Connectedness Table (March 1, 1999 - December 30, 2005)

	AUD	BRL	CAD	CHF	CNY	CZK	DKK	EUR	GBP	HKD	HRK	HUF	IDR	ILS	INR	JPY	KRW	NOK	PLN	RUB	SEK	TL	USD	ZAR	**FROM**
AUD	76.86	0.19	2.17	1.16	0.16	0.17	1.50	2.71	2.09	1.64	0.16	0.34	0.91	0.36	0.16	0.49	0.28	1.33	0.63	0.57	0.83	0.73	4.48	0.05	23.14
BRL	0.15	94.96	0.23	0.05	0.25	0.47	0.09	0.33	0.10	0.05	0.50	0.08	0.41	0.11	0.25	0.18	0.06	0.10	0.35	0.97	0.03	0.12	0.09	0.07	5.04
CAD	5.86	0.28	62.25	0.41	0.34	0.07	2.19	4.65	1.54	3.37	0.38	0.17	0.50	0.32	0.80	0.49	1.29	1.15	0.05	0.31	0.57	0.40	12.31	0.31	37.75
CHF	2.11	0.11	0.52	63.73	0.30	1.68	0.84	9.12	5.82	1.74	0.17	0.22	0.28	0.30	0.42	0.39	1.71	1.76	0.04	2.58	0.71	1.23	4.14	0.07	36.27
CNY	1.02	0.20	0.23	0.81	89.15	0.21	0.07	1.51	0.47	0.09	0.05	0.35	0.07	0.72	0.54	0.11	0.62	0.35	1.48	1.23	0.21	0.15	0.27	0.08	10.85
CZK	0.51	0.44	0.17	2.38	0.20	71.56	2.81	4.81	6.01	0.22	0.31	0.88	1.33	0.14	0.16	0.75	1.29	0.99	1.24	0.73	0.38	1.30	0.88	0.49	28.44
DKK	3.02	0.21	0.75	0.76	0.39	3.65	57.61	10.15	6.15	0.98	0.19	0.30	0.91	0.45	0.74	1.15	0.26	4.48	0.46	1.35	3.25	1.90	0.46	0.42	42.39
EUR	2.93	0.31	1.90	3.40	1.20	1.62	3.54	55.57	8.79	1.19	0.19	0.25	0.04	0.31	0.31	2.69	0.05	3.80	0.85	0.08	5.45	0.25	5.13	0.15	44.43
GBP	4.51	0.06	0.84	4.19	0.32	3.35	4.74	11.26	51.62	3.60	0.08	0.37	0.43	0.17	0.47	0.73	0.13	1.30	0.27	0.11	3.24	0.68	7.45	0.08	48.38
HKD	0.76	0.06	2.83	0.80	0.05	0.15	1.98	3.42	1.58	61.93	0.15	2.07	0.28	0.15	0.17	0.86	0.05	1.22	0.17	0.42	0.78	0.36	19.67	0.08	38.07
HRK	0.43	0.47	0.31	0.60	0.13	0.14	0.54	0.26	0.21	0.08	91.50	0.30	0.08	0.91	0.07	0.23	0.91	0.24	0.40	0.45	0.54	0.10	0.93	0.17	8.50
HUF	1.39	0.34	6.39	1.24	0.15	2.03	9.11	0.82	0.38	2.95	0.53	54.37	0.46	0.49	0.31	0.11	1.37	3.42	0.38	1.09	5.94	2.44	4.00	0.27	45.63
IDR	2.19	0.43	1.16	0.30	0.19	0.87	1.66	0.32	0.43	1.17	0.29	0.58	81.82	0.74	1.08	0.76	2.10	0.68	0.33	0.68	0.66	0.89	0.32	0.36	18.18
ILS	6.11	0.73	0.32	0.99	0.19	0.66	2.14	1.01	5.19	0.70	0.48	0.16	1.03	75.43	0.49	0.54	0.07	0.18	0.44	0.64	0.82	0.55	0.77	0.35	24.57
INR	0.48	0.11	1.07	0.71	0.11	0.12	0.28	1.04	0.50	0.97	0.09	0.48	1.16	0.94	87.66	0.44	0.91	0.51	0.20	0.81	0.70	0.11	0.57	0.02	12.34
JPY	0.62	0.07	2.52	0.25	0.18	0.28	0.70	6.62	0.55	0.38	0.13	0.09	0.06	0.29	0.57	80.05	0.44	0.46	0.72	0.45	0.28	0.41	3.69	0.19	19.95
KRW	0.94	0.08	2.62	2.22	0.34	0.99	1.16	2.18	0.42	0.30	0.75	1.80	0.46	0.41	0.84	0.29	78.43	1.46	0.35	0.98	1.41	0.41	0.89	0.26	21.57
NOK	6.07	0.17	1.15	3.02	1.48	0.38	1.26	2.63	2.76	0.85	0.25	1.02	0.82	0.34	0.29	0.07	1.70	64.86	0.33	0.96	5.95	0.42	2.57	0.65	35.14
PLN	0.42	0.42	0.33	0.45	1.10	2.23	2.76	4.24	0.51	0.29	0.51	0.36	0.30	0.29	0.29	1.81	0.25	0.69	78.15	0.68	0.88	2.67	0.22	0.14	21.85
RUB	0.96	0.44	0.89	0.67	2.14	0.54	1.60	0.89	0.33	0.21	0.09	0.38	2.30	0.59	1.18	0.26	1.22	1.84	0.36	80.22	1.27	0.84	0.17	0.58	19.78
SEK	1.62	0.05	4.21	0.63	3.15	0.17	0.32	3.57	0.86	0.42	0.20	1.60	0.24	0.31	0.73	0.23	0.55	2.04	0.30	1.76	73.98	0.25	1.76	1.04	26.02
TL	0.71	0.19	1.12	0.10	0.34	0.95	2.76	1.49	0.22	1.10	0.27	2.40	1.05	0.28	0.31	0.85	1.22	0.37	0.48	0.29	0.69	80.87	1.70	0.24	19.13
USD	2.30	0.07	6.12	0.79	0.08	0.16	0.76	9.40	2.55	12.37	0.30	0.62	0.16	0.20	0.15	1.47	0.23	1.03	0.29	0.10	0.54	0.31	59.89	0.12	40.11
ZAR	0.41	0.14	0.68	0.21	0.19	0.89	0.44	0.64	0.30	0.25	0.12	0.10	0.63	0.06	0.10	0.13	0.11	0.47	0.38	0.46	1.80	0.35	0.32	90.81	9.19
TO	45.53	5.59	38.53	26.14	12.99	21.80	43.22	83.06	47.75	34.94	6.22	14.92	13.90	8.90	10.43	15.03	16.80	29.91	10.50	17.70	36.95	16.90	72.81	6.20	
NET	22.39	0.55	0.78	-10.13	2.14	-6.64	0.83	38.63	-0.63	-3.12	-2.28	-30.70	-4.28	-15.67	-1.91	-4.93	-4.76	-5.23	-11.35	-2.08	10.93	-2.23	32.69	-2.99	26.53

Table 5: Full Sample Connectedness Table (October 9, 2006 - May 31, 2013)

C Figures

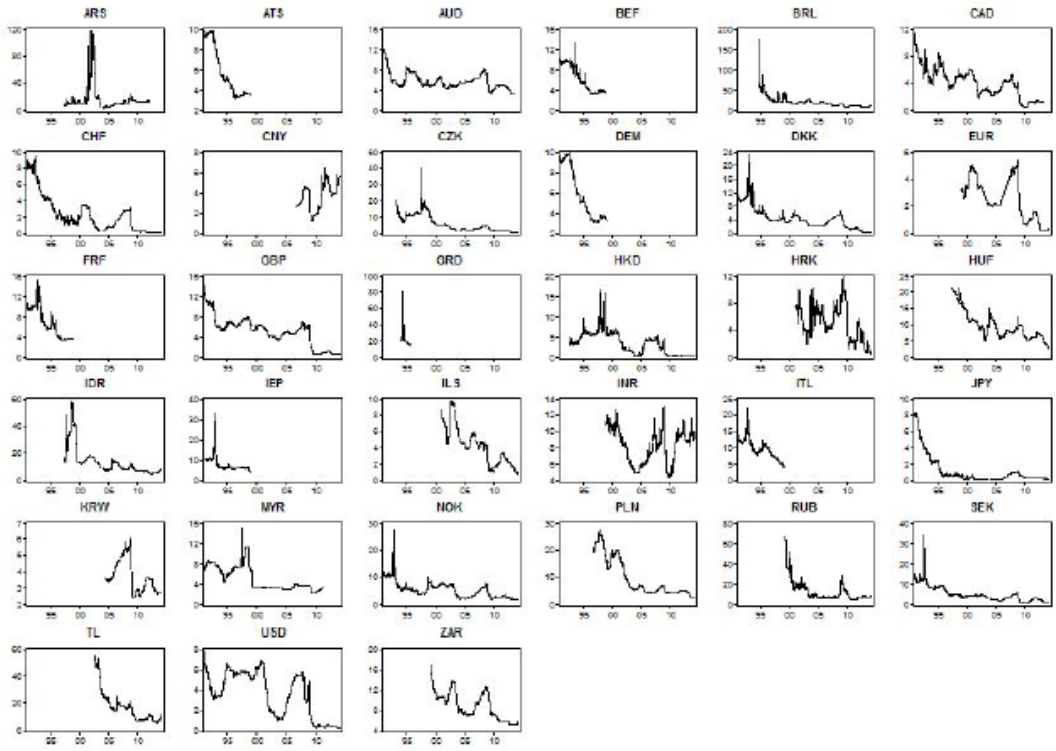

Figure 1: 3 month-Libor Rates

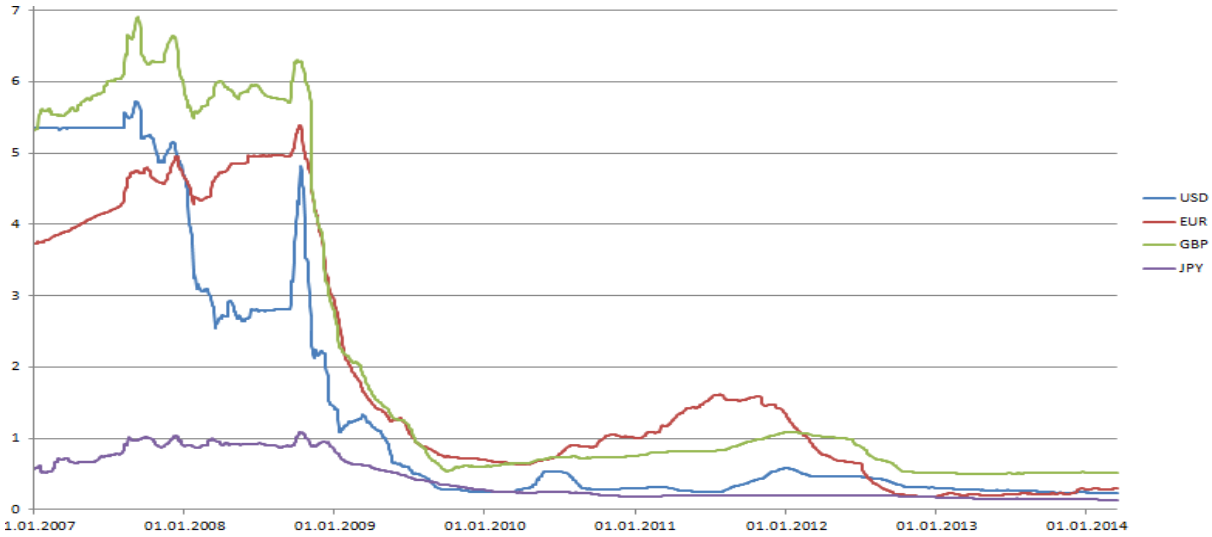

Figure 2: Libor Rates of US, EU, UK, and Japan After the Global Financial Crisis

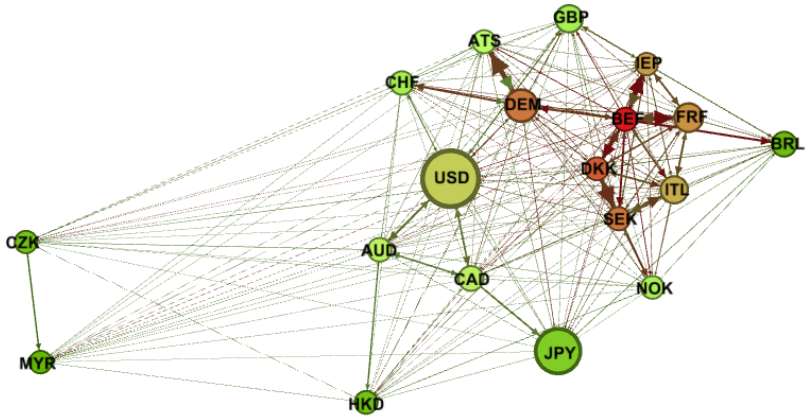

Figure 3: Full-sample Libor rate Network (July 7, 1994 - December 24, 1998 – index=29.2%)

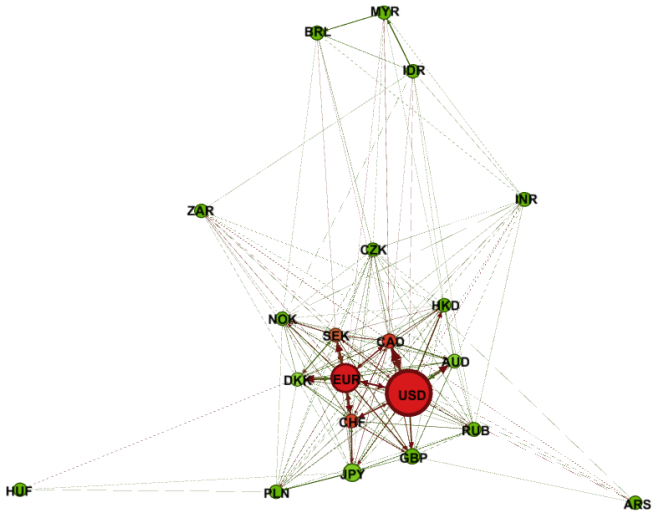

Figure 4: Full-sample Libor rate Network (March 1, 1999 - December 30, 2005 – index=26.8%)

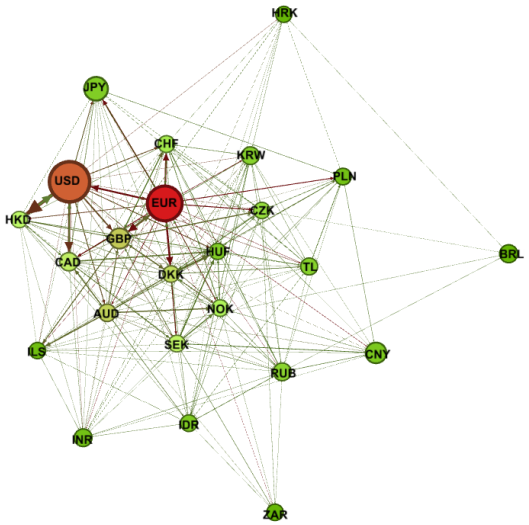

Figure 5: Full-sample Libor rate Network (October 9, 2006 - May 31, 2013 – index=26.5%)

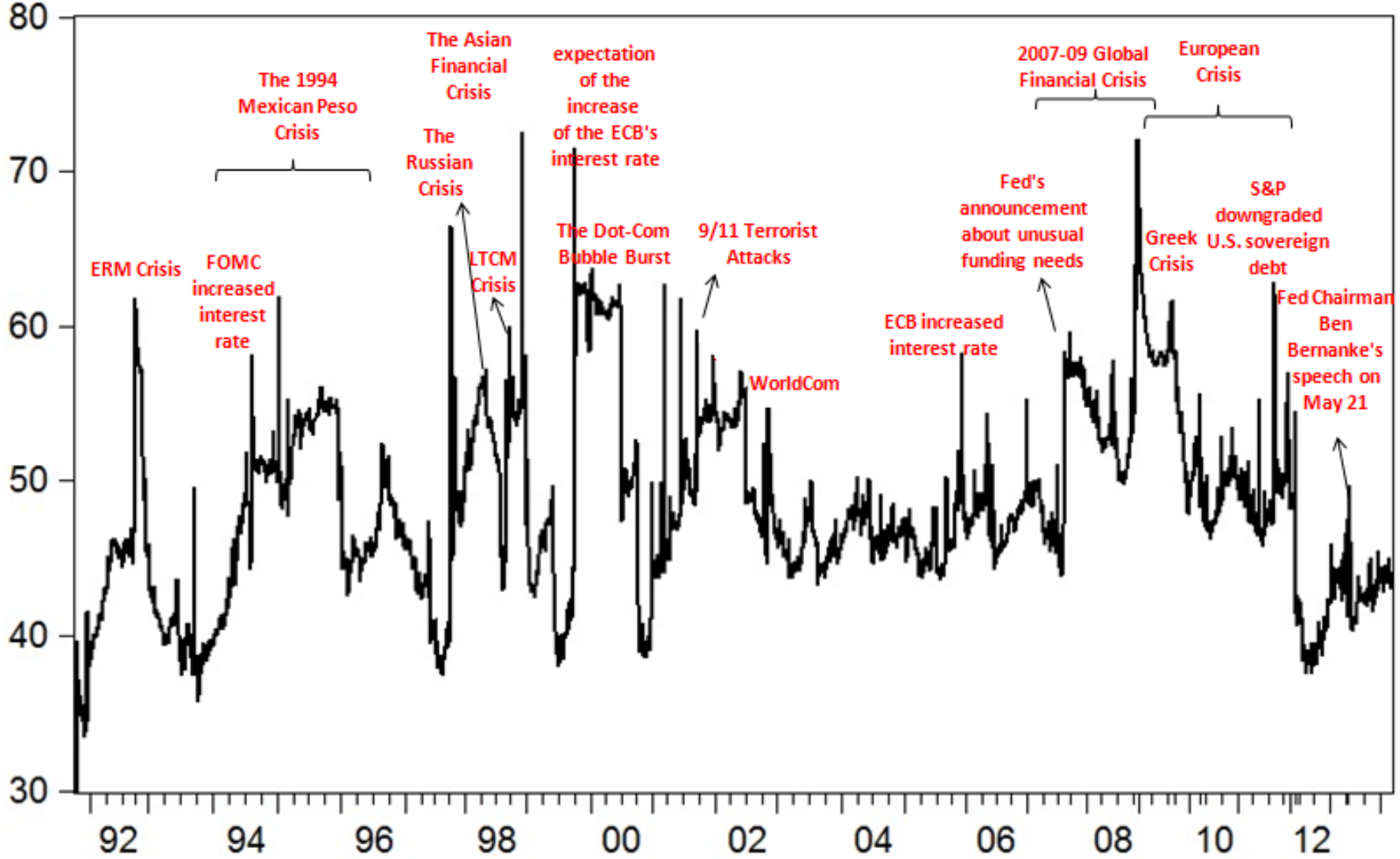

Figure 6: Dynamics of Total Connectedness Index

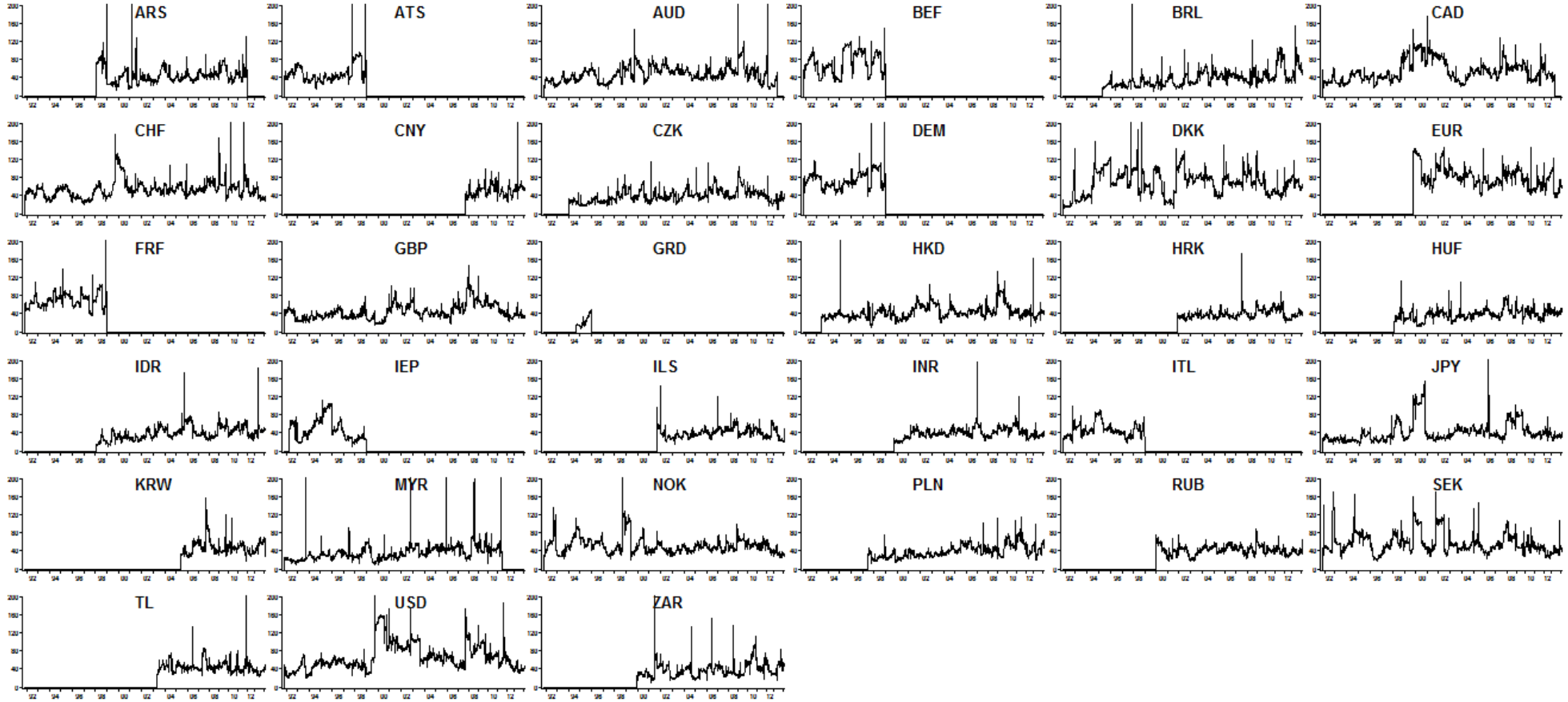

Figure 7: Dynamics of To Connectedness Index

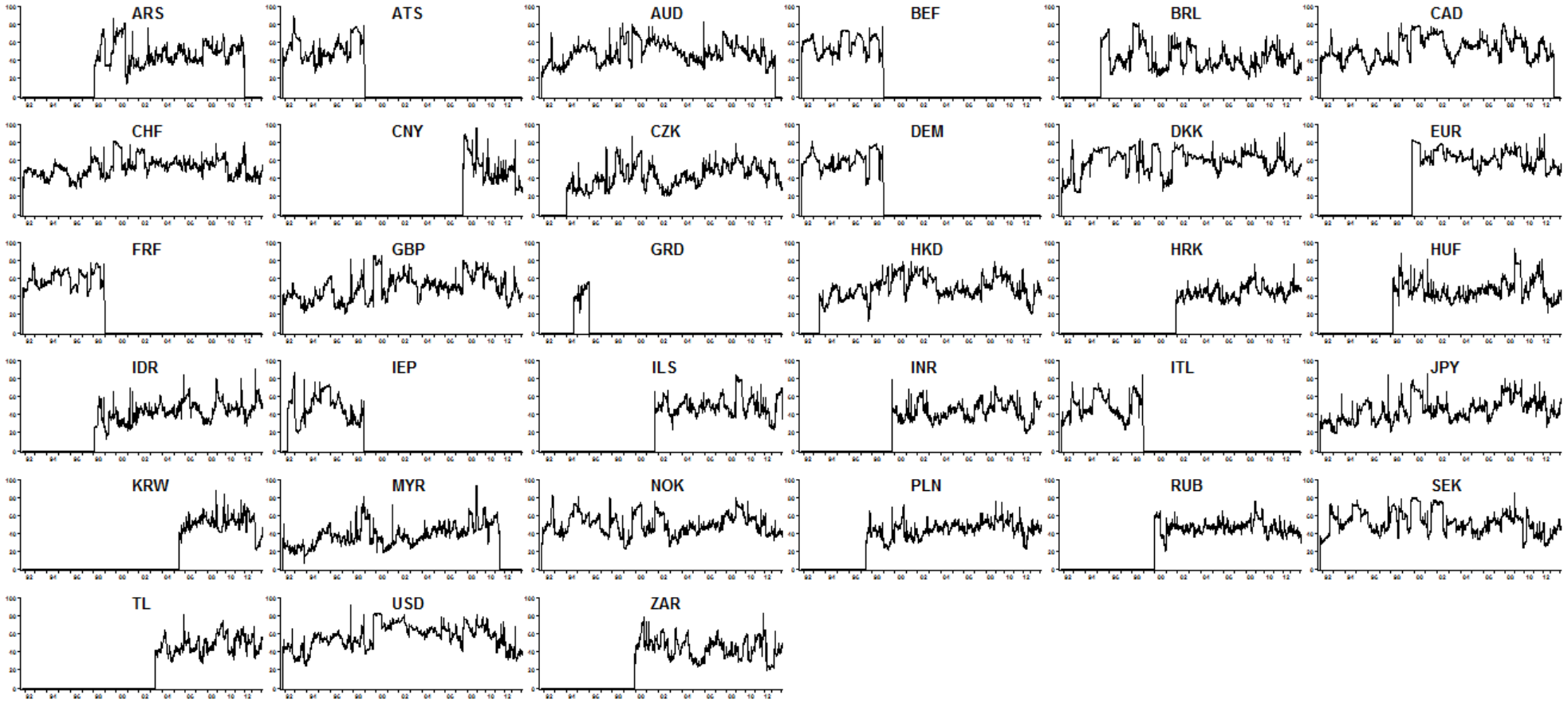

Figure 8: Dynamics of From Connectedness Index

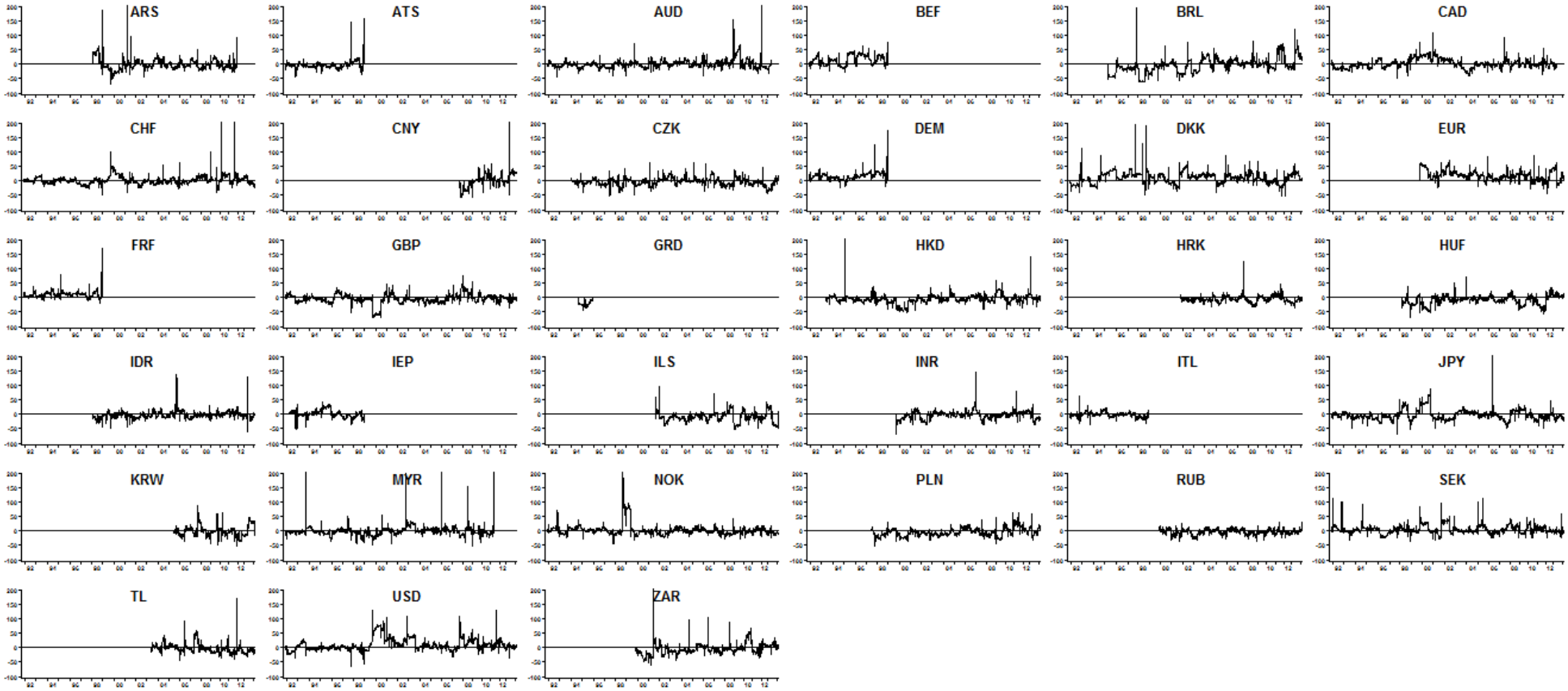

Figure 9: Dynamics of Net Connectedness Index

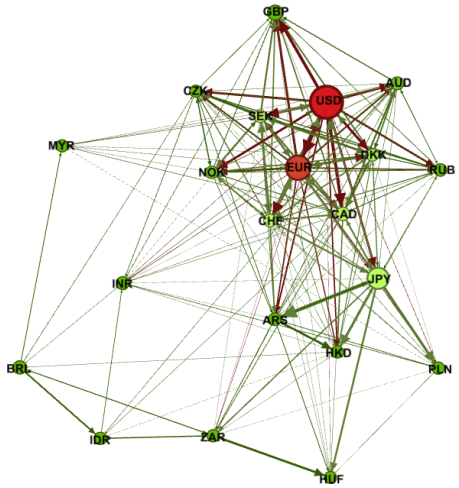

Figure 10: Connectedness Analysis – Dot-Com Bubble Burst of 2000 (March 9, 2000 – index=61.4%)

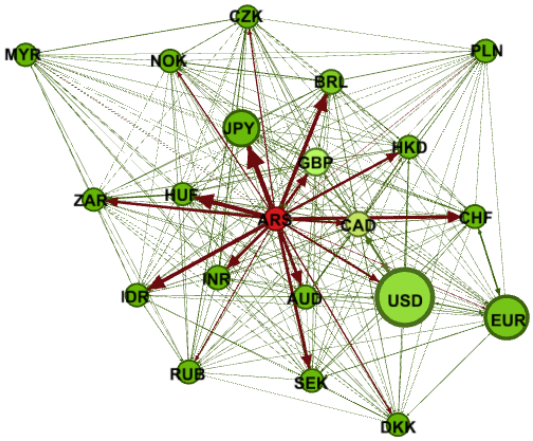

Figure 11: Connectedness Analysis – Argentina Crisis (March 20, 2001 – index=62.6%)

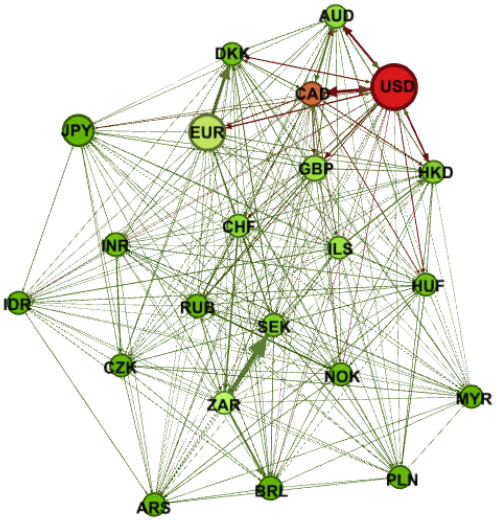

Figure 12: Connectedness Analysis – 9/11 Terrorist Attacks (September 13, 2001 – index=50.3%)

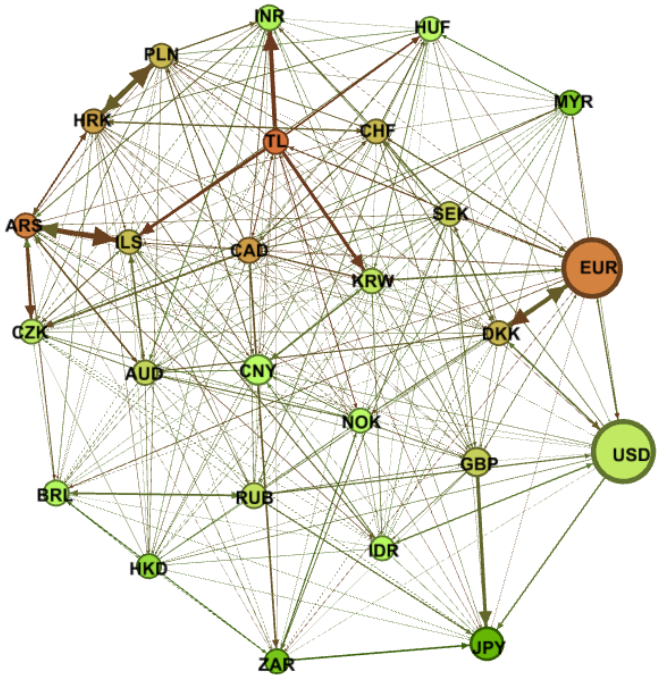

Figure 13: Connectedness Analysis – Before the Liquidity Crisis (August 1, 2007 – index=45.6%)

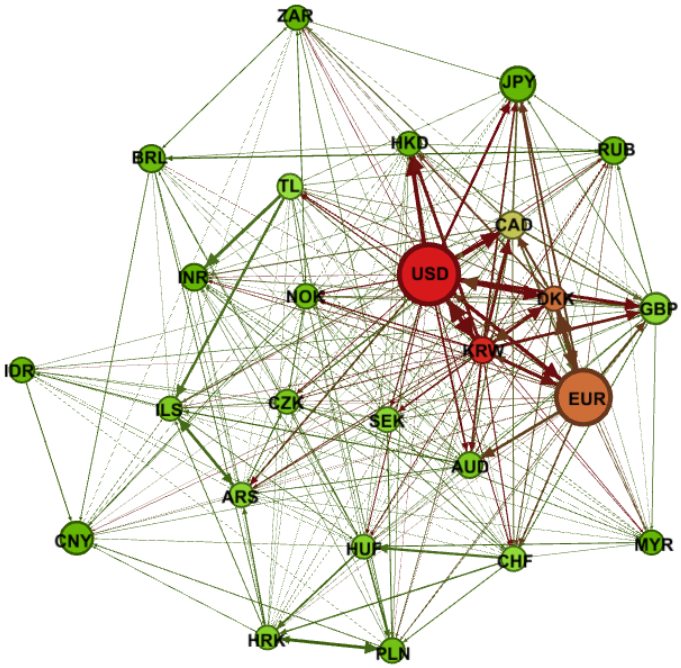

Figure 14: Connectedness Analysis – After the Liquidity Crisis (August 21, 2007 – index=58.3%)

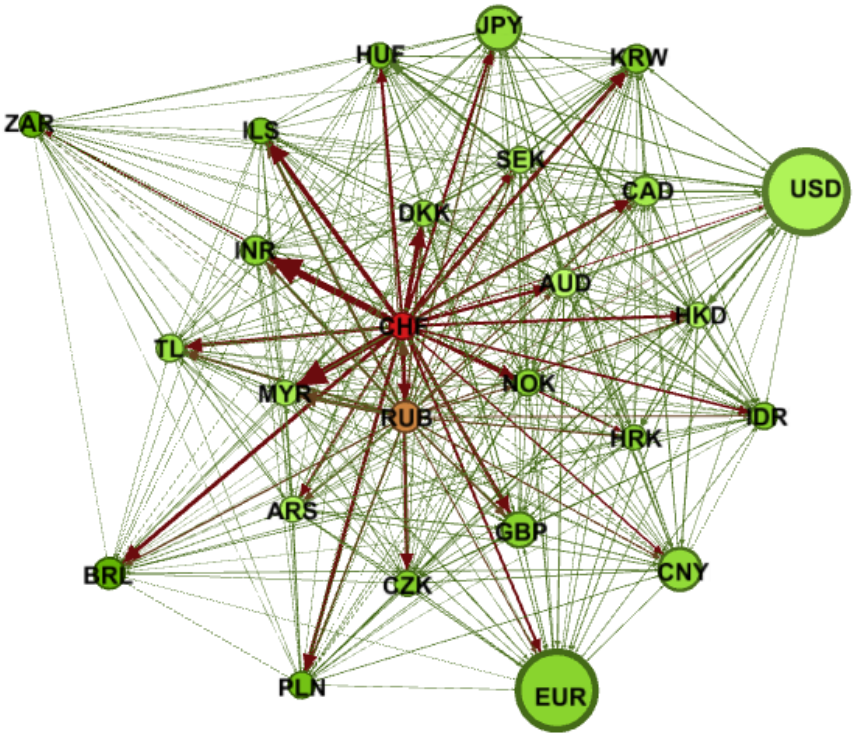

Figure 15: Connectedness Analysis – Expansion QE I (November 25, 2008 – index=77.6%)

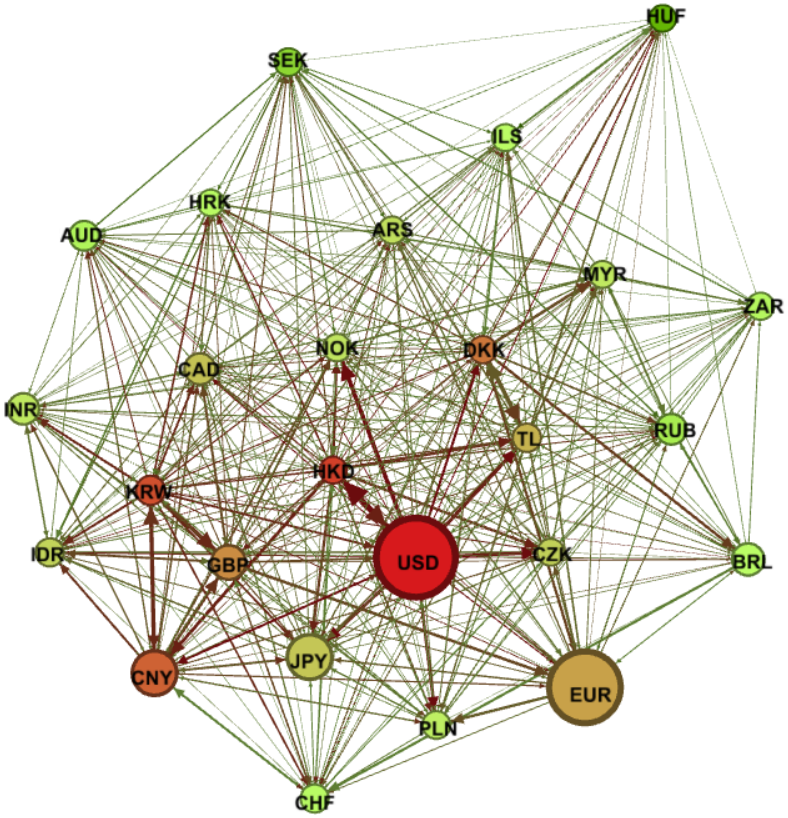

Figure 16: Connectedness Analysis – Phase out of QE I (September 25, 2009 – index=60.6%)

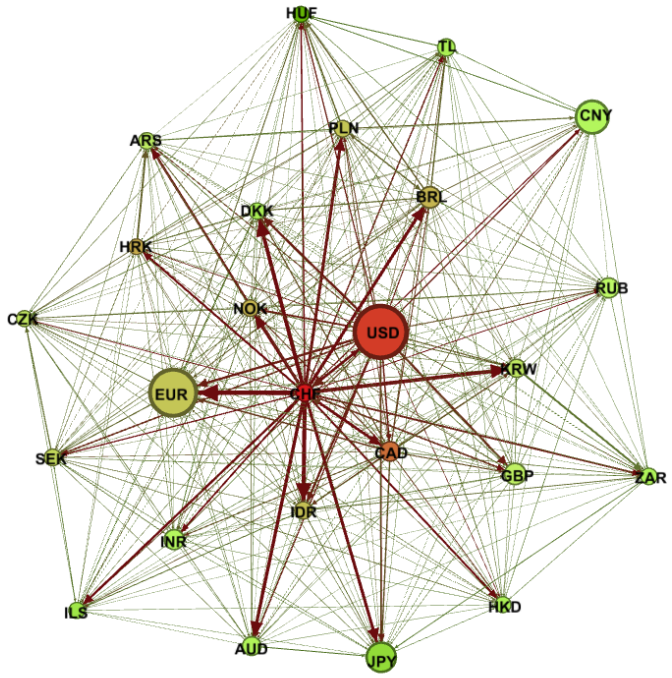

Figure 17: Connectedness Analysis – S&P Decision of US (August 4, 2011 – index=62.1%)