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Bing Li, Zefang Liao

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Highlights:

- The currency network gets more scattered in the post-crisis period, which helps to increase the systemic resilience to the crisis.
- The currency connections tend to be more internal, i.e., preferring linking within the same geographic region, showing the rise of trade protectionism as well as regional integration.
- The European currencies maintain strong association and keep their clustering feature stable before and after the crisis.

Finding changes in the foreign exchange market from the perspective of currency network

Bing Li[a, b,*] , Zefang Liao[c]

[a] Business School, University of Shanghai for Science and Technology (USST)
334 Jungong Road, Shanghai 200093, China

[b] Financial Research Center, Fudan Development Institute (FDDI), Fudan University
220 Handan Road, Shanghai 200433, China
[*]Corresponding author. E-mail address: libing@usst.edu.cn

[c] College of Economics and Management, Shanghai Ocean University
999 Huchenghuan Road, Shanghai 201306, China
E-mail address: zfliao@shou.edu.cn

Finding changes in the foreign exchange market from the perspective of currency network

Abstract:

This research examines the foreign exchange (FX) market from the perspective of currency network. We construct the network based on correlations between exchange rates of 37 currencies from 2006 to 2012. The minimum spanning tree (MST) is used to generate a simplified network and bootstrap technique is employed to test the reliability of links. The full correlation matrices are further analyzed to support and test the robustness of the results from the MSTs. Specifically, we compare the results in the pre-crisis period (2006-2007) and the post-crisis period (2011-2012) to show the impact of the 2008 global financial crisis on the FX market. We have the following findings: (a) the currency network is more scattered in the post-crisis period; (b) the connections between currencies tend to be more internal within the geographic region after the crisis; (c) the European currencies maintain strong connections and keep their clustering feature stable.

Key words: currency network; foreign exchange market; minimum spanning tree; E-I index

JEL Classification: F31; G15; C82

Finding changes in the foreign exchange market from the perspective of currency network

1. Introduction

The process of globalization is closely linking financial markets worldwide, leading to the formation of economic networks. As one of the most important markets in the global financial system, the foreign exchange (FX) market has experienced a large increase in recent decades. According to the triennial survey conducted by Bank for International Settlements (BIS), global FX turnover averaged $5.1 trillion per day in 2016, down from $5.4 trillion in 2013 for the appreciation of the US dollar, but up with a 27.5% increase by comparison with $4.0 trillion in 2010 [1].

The FX market has received attention from several disciplines such as economics, physics and systems science. The network approach from systems science and econophysics seems to provide a new paradigm to touch the complexity of the FX market with the interaction of world currencies. From the network perspective of the FX market, the currencies (or exchange rates) are considered as nodes and the pairwise correlations between them as the links, and thus a similarity based network can be constructed [2,3].

Mizuno et al. [4] derived a hierarchical structure of the currency network and found the clusters and key currencies by analyzing 26 currencies and 3 metals from January 1999 to December 2003. Kwapień et al. [5] analyzed daily time series of FX data and studied the topology of the weighted minimum spanning trees and the temporal evolution of the network for the period of January 1999 to June 2008. They found that the FX network was dominated by two strong clusters of nodes

related to the US dollar (USD) and Euro (EUR) and that this network underwent a significant structural change, i.e., the USD-related cluster released its ties while the EUR node was attracting more ties.

Jang et al. [6] examined the temporal changes of currency network in relation to the history of the currency crises for 1990-2008. Around currency crises, the coupling strength of currencies decreased and the currency cluster changed. Keskin et al. [7] studied the topology of correlation networks among 34 major currencies for the full years of 2007-2008. The bootstrap technique was used to test the reliability of the links in the minimum spanning trees and the tree in 2007 was more stable than in 2008. The USD and EUR were the predominant currencies and they were linked by other currencies according to the geographic location and economic ties.

Based on the previous research, this paper attempts to find changes in the FX market by focusing on the time horizon from January 2006 to December 2012, covering the pre and post periods of the 2008 global financial crisis. The topological properties of the currency network in the pre- and post-crisis periods are studied and compared. The geographic and market classification are also used to test linking tendency between currencies.

The rest part of this paper is organized as follows: Section 2 describes the dataset used in this research; Section 3 explains research methods and gives the results of data analysis; Section 4 further discusses the analysis results; Section 5 concludes with limitations and future work.

2. Dataset

This study attempts to find changes in the FX market from the network perspective. Especially, we focus on the temporal changes by comparing network properties in the following two periods:

2006-2007 and 2011-2012, respectively corresponding to the pre and post periods of the 2008 global financial crisis.

Foreign exchange data are collected from the database of IMF Exchange Rates [8]. By selecting "SDRs per currency unit", we can get 51 currencies with daily exchange rate data in 2012, and 48 currencies in 2006. These data are exchange rates denominated by Special Drawing Right (SDR). Since the pegged exchange rates may introduce spurious linkage [5], we remove some currencies that are closely pegged to USD, EUR, or Singapore dollar (SGD). Thus, we get a common set of 37 currencies during the period of 2006-2012. Table A gives a list of currencies, including market classification (MC) and geographic regions (GE).

3. Research method and Data Analysis

3.1. Minimum spanning tree

Correlation matrix is used to construct the network model [2-7]. Cross-correlation coefficients are computed using the following equations:

$$r_i(t) = log\, p_i(t) - log\, p_i(t - \Delta t) \ , \tag{1}$$

$$c_{ij} = \frac{\langle r_i \cdot r_j \rangle - \langle r_i \rangle \langle r_j \rangle}{\sqrt{\left(\langle {r_i}^2 \rangle - \langle r_i \rangle^2\right)\left(\langle {r_j}^2 \rangle - \langle r_j \rangle^2\right)}} \ , \tag{2}$$

where $p_i(t)$ is the exchange rate of currency *i* at the time *t*, $r_i(t)$ represents the logarithmic return of currency *i* in the time interval of Δt, which is one day in this study. Equation (2) calculates the correlation coefficient between currency *i* and currency *j* where $\langle \cdot \rangle$ represents the mean in the given time period, which is one or two years in this study.

By directly using the correlation matrix, we can construct a complete network where all the nodes (currencies) are fully connected with each other. Filtering techniques help to construct a

compact network model that may decrease noises or remove loose connections. The idea of filtering is to extract a subset from the complete network by considering the weights of the links, i.e., the values of correlation coefficients in the correlation-based network. Minimum spanning tree (MST) is one filtering technique that is widely used for its simplicity and reliability to describe the network by retaining important interactions [3-7].

MST can represent a fully connected symmetric graph with $N\times(N-1)/2$ links by using only $N-1$ links. MST is a spanning tree where the sum of the $N-1$ distances is less than or equal to the other spanning trees. The edge distances satisfy the following three axioms of Euclidean distance.

(i) $d_{ij} = 0$ if and only if $i = j$

(ii) $d_{ij} = d_{ji}$

(iii) $d_{ij} \leq d_{ik} + d_{kj}$

The correlation coefficients cannot satisfy all these axioms and they can be converted by the following equation:

$$d_{ij} = \sqrt{2(1 - c_{ij})}\ , \tag{3}$$

where c_{ij} is the correlation coefficient calculated from equation (2), and d_{ij} is defined as the distance between currency i and currency j. Based on this $N\times N$ matrix of d_{ij}, we can use Kruskal's algorithm to construct MST [7, 9].

Moreover, reliability of links in MST is considered and bootstrap technique is used to associate a reliability value with each link [7]. By using the bootstrap procedure (i.e., randomly selecting T rows allowing repetitions for n times), we can obtain n samples in the period under study. T denotes the observation number of time series in the period (e.g., T=499 in 2011-2012, equal to the trading days). These samples are used to construct n correlation matrices and can thus derive n

MSTs (n=1000 in this paper). Then the links in the original MST are counted if they still exist in the derived samples. Assuming the counted number is n_e (n_e<n) for the link between currency i and currency j, then the reliability ratio r_{ij} is calculated as $r_{ij}=n_e/n$, which can indicate if a link is stable to some extent.

Fig. 1. Minimum spanning tree for the currency network in 2006-2007

Fig. 2. Minimum spanning tree for the currency network in 2011-2012

Fig. 1 shows the MST for the time period of 2006-2007. Correlation coefficients and reliability values are shown on the corresponding edges. Similarly, Fig. 2 shows the MST for the time period of 2011-2012. Table 1 gives the statistics of correlations and bootstrap reliability in the MSTs. The mean reliability is 0.72 (sd=0.26) in 2006-2007 and 0.79 (sd=0.21) in 2011-2012, indicating more stable linkage in the post-crisis period. The difference in the correlations is not so obvious as reliability values.

Table 1

The statistics of correlations and bootstrap reliability in MSTs

Besides, from the dashed curves enclosing the regions of the Asia/Pacific or Europe (color online), Fig. 1 and Fig. 2 show that these two regions are more connected. Their clustering feature seems to be stable before and after the 2008 crisis. The market types (distinguished by different shapes in Fig. 1 and Fig. 2) show no obvious clustering feature as the geographic regions.

3.2. Average path length

Some network metrics can be used to quantify topological properties of the MST graphs such as average path length (APL) and centrality measures. The APL is defined as the mean of the shortest paths between any two currencies, which can (adversely) reflect how closely the currencies are connected in the whole network.

Table 2 gives the statistics of APLs from 2006 to 2012. The mean value is bigger in 2011-2012 than in 2006-2007, showing that the FX network tends to get more scattered or distributed after the crisis. Referring to annual values, the APLs seem to be nearly stable in 2007-2009, increase in 2010-2011 and decrease in 2012.

Table 2

Average path length of the currency networks (MSTs)

3.3. E-I index

The clustering feature has been shown in the MST graphs. Here we use a ratio, called E-I index, to quantify this feature or the linking tendency in geographic regions or market types. Moreover, this ratio can also show the changes in the post-crisis period.

Krackhardt and Stern [10] define the E-I index as follows:

$$\text{E-I index} = \frac{EL - IL}{EL + IL}, \tag{4}$$

where *EL* represents the number of external links, and *IL* represents the number of internal links. The geographic or market classification is used to distinguish the external and internal links, e.g.,

the links between currencies in the same geographic region are internal while the links between members from different regions are external.

Table 3

E-I index analysis for geographic group

Table 4

E-I index analysis for market group

Table 3 shows the links within the regional group (internal) or not (external). A positive E-I index means that the group members tend to link outside, while a negative one shows the members' preference for linking inside. Therefore, the negative E-I index indicates the existence of strong ties in the group and its members are clustering together to some extent. The Asia-Pacific and European regions prefer linking inside both in 2006-2007 and in 2011-2012. This internal tendency is further strengthened for the Asia-Pacific group in 2011-2012. The European currencies are strongly connected and the clustering feature is stable before and after the crisis. The American group also tends to be more internal in the post-crisis period.

Similar analysis is also applied to market classification. Table 4 shows outside preference for the developed group and the frontier group in both periods. The emerging market group shows a weak tendency of internal connection.

3.4. Correlation distributions

The previous analyses are based on the MSTs, filtered from the correlation matrices. In this part the complete correlation matrices are examined to further demonstrate the robustness of the analysis results from the MSTs.

Table 5

Correlation statistics

Table 5 gives the statistics of correlations from 2006 to 2012. The mean (median) reached the highest value in 2010 and the lowest value in 2012 (2011). The mean and median values are bigger in 2006-2007 than in 2011-2012. Consistent with the previous result about a bigger APL in 2011-2012, these results indicate looser connections between currencies or a more scattered network.

3.5 Principal component analysis

Correlation matrices are further examined by principal component analysis. Table 6 gives the total variance explained by the preceding three components. In both periods, the preceding two components can explain more than 86% of the variance, and the first component is predominant and can explain over 75% of the variance.

Table 6

Total variance explained by the preceding components

Fig. 3. Principal component analysis of correlation matrix in 2006-2007

Fig. 4. Principal component analysis of correlation matrix in 2011-2012

Fig. 3 and Fig. 4 illustrate the results of principal component analysis by using the preceding two components as horizontal and vertical axes respectively. The European currencies are well aligned by the first component (horizontal axis), indicating their strong clustering feature in 2006-2007 and in 2011-2012, consistent with the result in the MSTs. To some extent, the Asia-Pacific currencies also show the clustering feature, but not so strong as the European group since they cover a bigger range with more variation.

4. Discussion

From the analysis of the MST graphs, the European currencies show strong ties and an obvious clustering feature. The Asia-pacific currencies also demonstrate their geographic connections. These clustering features are stable in the pre- and post-crisis period. These findings are consistent with some previous research [2,7] and can be explained by regional trade and economic integration, which may lead to close relationship between currencies.

The average path length of the MST graphs gets bigger in 2011-2012, indicating a more scattered network structure, consistent with the increased tree length around currency crisis found in [6]. This result can be explained by the impact of the crisis on the currency network. A more distributed structure can increase the resilience to economic and financial risks. The changes in world trade or transnational capital flows can also give some explanations for their impact on

trading volumes between currencies in the FX market.

Further analysis on degree centrality (i.e., the number of the links with other currencies) shows that some currencies such as USD and EUR play important roles in the FX market, similar with the result in [2]. Although the USD retains its important position as a predominant currency, linking currencies has declined, which may result from the diversified international investment and settlement currencies. Besides, PLN and MYR are also showing strong connections with other currencies, which may be explained by their increasing role in the regional trades. The PLN (Poland) may bridge the Western and Eastern European countries in the FX market as well as in the regional economy.

E-I index analysis investigates if there exists a group with internal linking preference in the currency network. The geographic regions show the different patterns. The Asia-Pacific and European currencies show their internal linking tendency with more strength and stability, indicating stronger association within their geographic region. The American currencies seem to change to prefer the internal linkage in the post-crisis period. Behind the scenes, the rise in regional trade protectionism may explain these changes. With the regional integration increased, cooperation with the economies outside may be weakened.

The complete correlation matrices are used to test the robustness of the analysis results from the MST graphs. The smaller mean and median show the weaker connection between currencies in the post-crisis period, supporting the previous result from the MSTs and indicating a more loosely connected network. Moreover, principal component analysis also demonstrates the clustering feature of the geographic regions such as the European and Asia-Pacific areas. Specifically, strong and stable connections between the European currencies reflect better regional integration in

Europe to some extent, shedding some light on the Euro crisis.

5. Conclusion

The FX market is studied from the perspective of currency network. By using SDR-denominated exchange rates of 37 currencies, we construct the correlation-based networks in 2006-2007 and 2011-2012, corresponding to the pre- and post-crisis period separately. The MST graphs as well as the full correlation matrices are analyzed to demonstrate some changes in this market. The currency network gets more scattered in the post-crisis period, which helps to increase the systemic resilience to the crisis. The currency connections tend to be more internal, i.e., preferring linking within the same geographic region, showing the rise of trade protectionism as well as regional integration. The European currencies maintain strong association and keep their clustering feature stable before and after the crisis.

Two limitations exist in this paper. Firstly, the investigated time period can be further extended to include more recent data and find new changes. Secondly, the network is constructed based on similarity (i.e., correlations of exchange rates) and a flow-based network may explore more bilateral details by considering trading volumes between currencies. These can also be future work.

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Figure

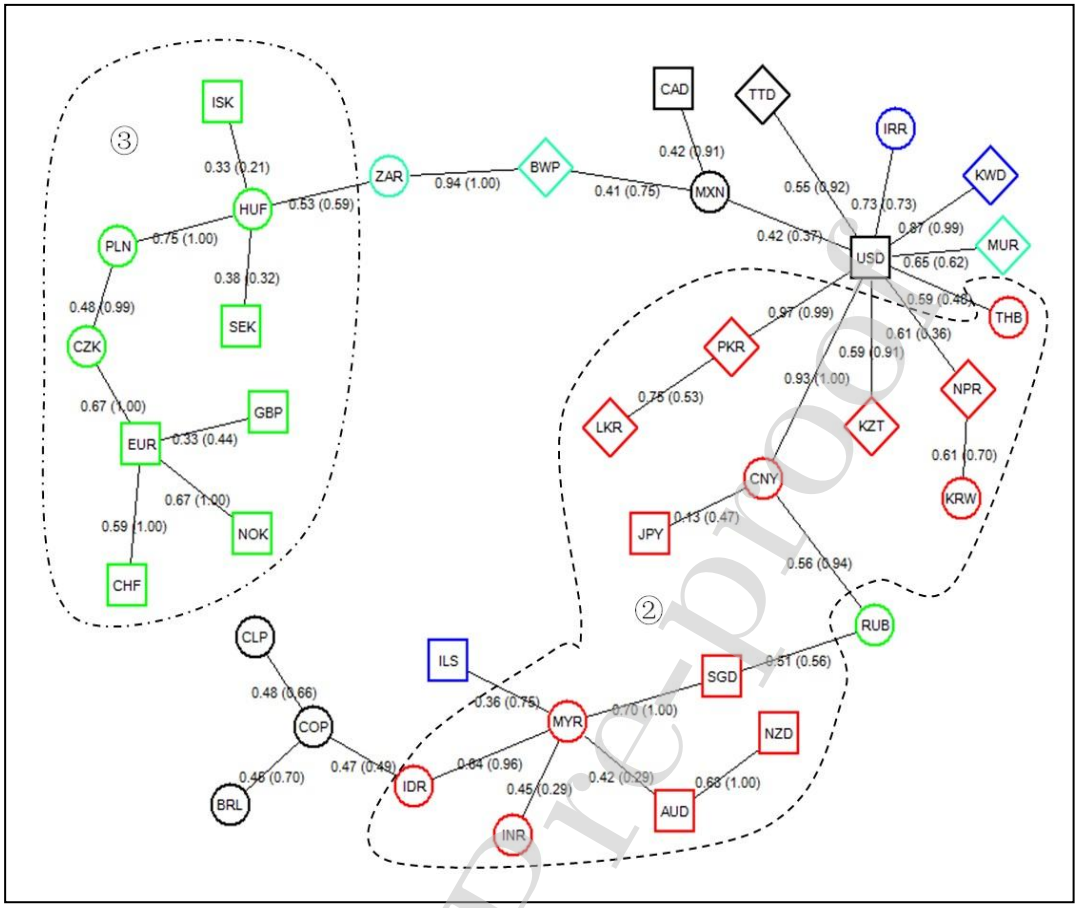

Fig. 1. Minimum spanning tree for the currency network in 2006-2007

* Market Classification (MC) distinguished by shapes: 1-Developed Markets (square); 2-Emerging Markets (circle); 3- Frontier Markets (diamond).

* Geographic region (GE): 1-Americas (black); 2-Asia/Pacific (red); 3-Europe (green); 4-Middle East (blue); 5-Africa (aquamarine). The regions 2 and 3 are enclosed by dashed curves. The regions are also distinguished by colors online.

* The numbers on the edge are correlation coefficients with the corresponding reliability ratios in parentheses. The capitals are currency codes in Table A in the appendix.

** From the dashed curves enclosing the regions of the Asia/Pacific or Europe, currencies in these two regions are more connected and clustering together. The USD has a dominant position in this period. The EUR, MYR and HUF are also showing strong connections with other currencies.

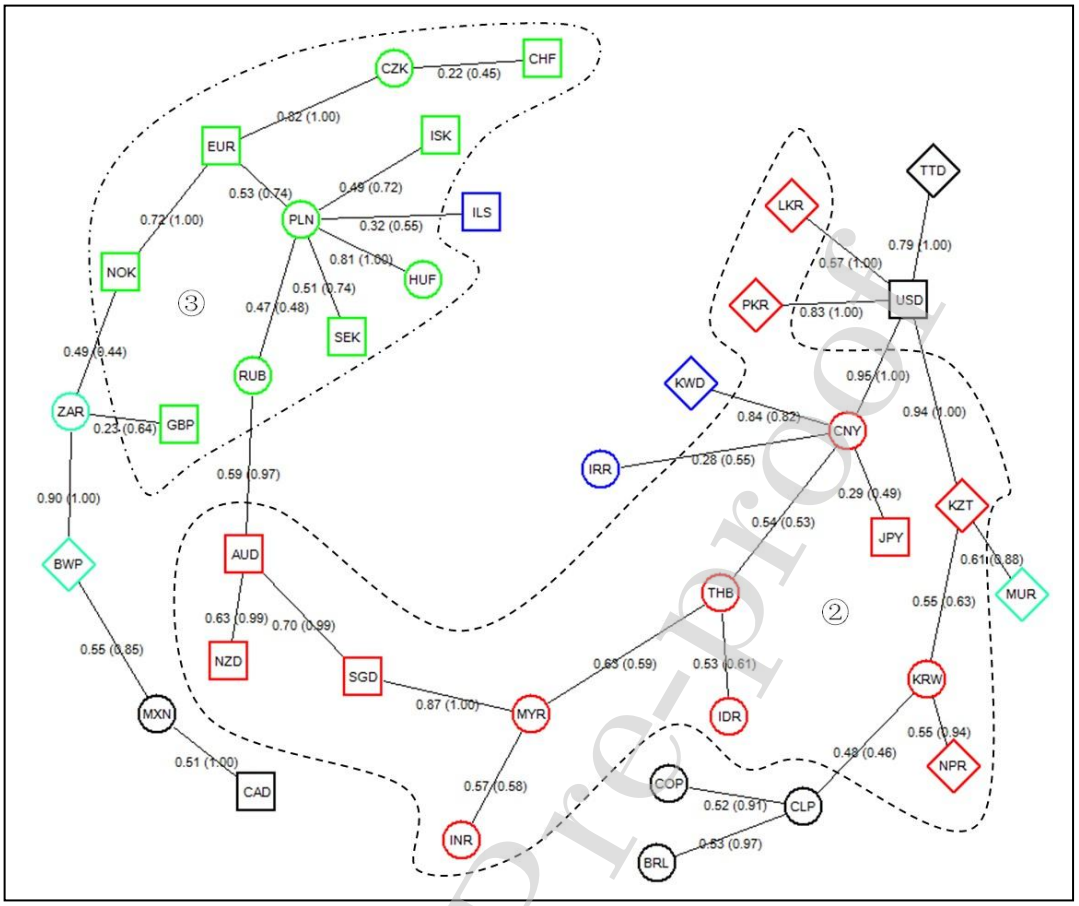

Fig. 2. Minimum spanning tree for the currency network in 2011-2012

* Symbols are the same as in Fig. 1.

** Similar with Fig.1, the currencies in the regions of the Asia/Pacific or Europe retain their clustering feature. The USD retains its important position with decreased linkages. The PLN and CNY show their strong connections with other currencies in this period.

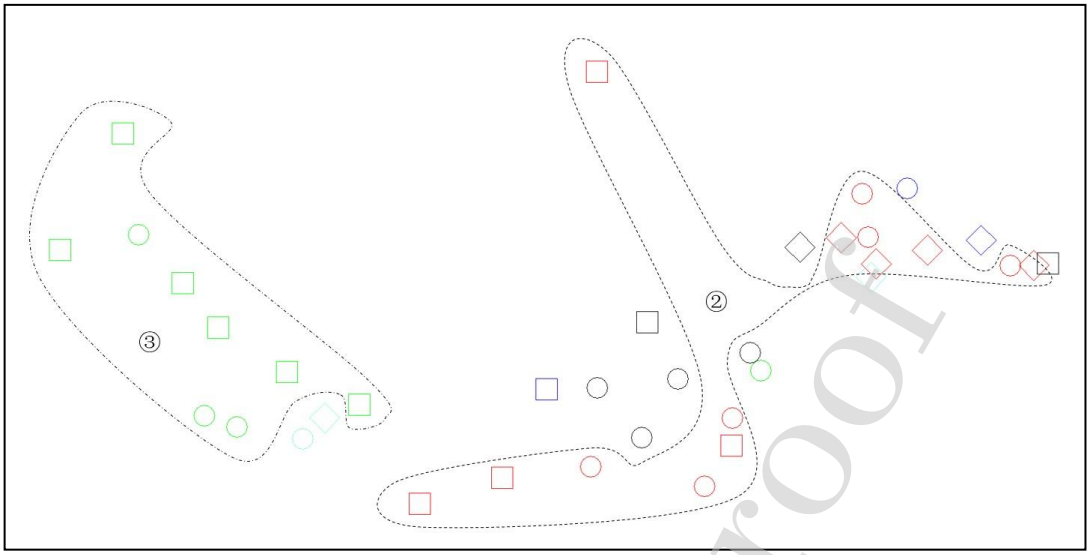

Fig. 3. Principal component analysis of correlation matrix in 2006-2007

* Horizontal and vertical axes are two principal components.

* Market Classification (MC) distinguished by shapes: 1-Developed Markets (square); 2-Emerging Markets (circle); 3- Frontier Markets (diamond).

* Geographic region (GE): 1-Americas (black); 2-Asia/Pacific (red); 3-Europe (green); 4-Middle East (blue); 5-Africa (aquamarine). The regions 2 and 3 are enclosed by dashed curves. The regions are also distinguished by colors online.

** The currencies in the Europe are aligned more closely along the horizontal axis, illustrating their strong clustering feature.

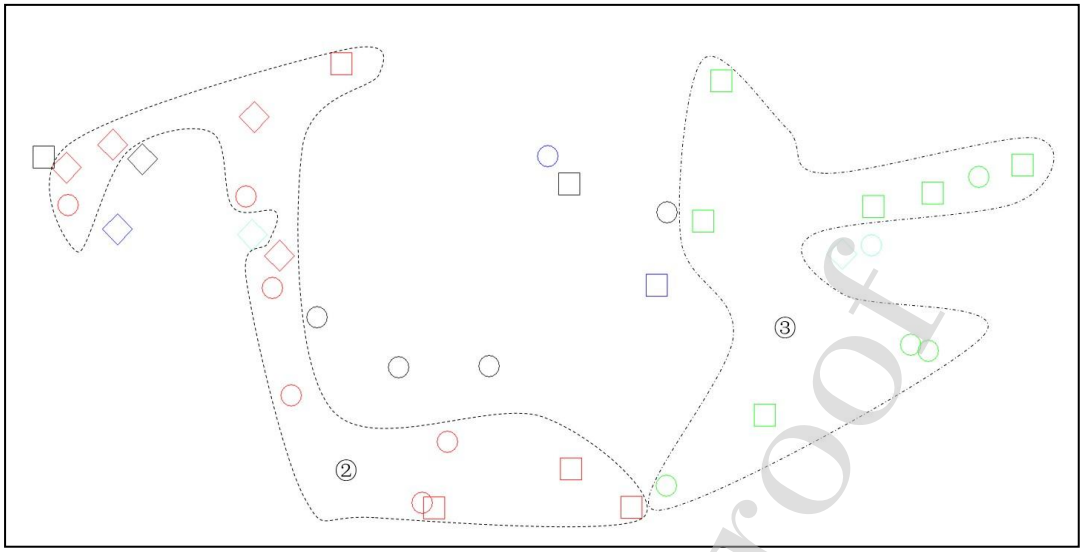

Fig. 4. Principal component analysis of correlation matrix in 2011-2012

* Symbols are the same as in Fig. 3.

** The currencies in the Europe retain their strong clustering feature.

Table 1

The statistics of correlations and bootstrap reliability in MSTs

	2006-2007		2011-2012	
	correlation	reliability	correlation	reliability
Mean	0.57	0.72	0.59	0.79
Std Dev	0.18	0.26	0.19	0.21
Max	0.97	1.00	0.95	1.00
Min	0.13	0.21	0.22	0.44
Median	0.57	0.74	0.55	0.87

** The bigger mean (0.79) and smaller deviation (0.21) of reliability in 2011-2012, indicating more stable linkage in the post-crisis period. The difference in the correlations is not obvious (e.g., the changes in the mean and median are not consistent).

Table 2

Average path length of the currency networks (MSTs)

APL	2006	2007	2008	2009	2010	2011	2012	2006-2007	2011-2012
Mean	5.51	6.03	5.98	6.07	7.18	7.40	6.50	5.83	6.49
Std Dev	2.80	3.36	3.19	3.22	4.21	4.36	3.72	3.30	3.74
Max	13	15	14	15	17	19	17	15	17
Min	1	1	1	1	1	1	1	1	1
Median	5	6	6	6	7	7	6	6	6

** The mean value is bigger in 2011-2012 than in 2006-2007, showing that the FX network gets more scattered after the crisis. Referring to annual values, the APLs seem to be nearly stable in 2007-2009, increase in 2010-2011 and decrease in 2012.

Table 3

E-I index analysis for geographic group

Geographic Area	2006-2007				2011-2012			
	Internal	External	Total	E-I	Internal	External	Total	E-I
America	10	10	20	0.00	8	6	14	-0.14
Asia/Pacific	16	9	25	-0.28	20	9	29	-0.38
Europe	16	3	19	-0.68	16	4	20	-0.60
Middle East	0	3	3	1.00	0	3	3	1.00
Africa	2	3	5	0.20	2	4	6	0.33

** The Asia-Pacific and European regions prefer linking inside both in 2006-2007 and in 2011-2012. This internal tendency is further strengthened for the Asia-Pacific group in 2011-2012. The American group also tends to be more internal in the post-crisis period.

Table 4

E-I index analysis for market group

Market Type	2006-2007				2011-2012			
	Internal	External	Total	E-I	Internal	External	Total	E-I
Developed markets	8	19	27	0.41	6	17	23	0.48
Emerging markets	18	16	34	-0.06	20	18	38	-0.05
Frontier markets	2	9	11	0.64	2	9	11	0.64

** The developed group and the frontier group show outside preference in both periods. The emerging market group shows a weak tendency of internal connection.

Table 5

Correlation statistics

Correlation	2006	2007	2008	2009	2010	2011	2012	2006-2007	2011-2012
Mean	0.092	0.116	0.099	0.120	0.141	0.115	0.076	0.101	0.098
Std Dev	0.356	0.292	0.307	0.333	0.356	0.332	0.297	0.305	0.299
Max	0.999	0.936	0.987	0.999	0.974	0.965	0.935	0.967	0.948
Min	-0.822	-0.703	-0.772	-0.681	-0.763	-0.770	-0.833	-0.762	-0.742
Median	0.112	0.150	0.100	0.134	0.182	0.095	0.099	0.139	0.096

** The mean (median) reached the highest value in 2010 and the lowest value in 2012 (2011). The mean and median values are bigger in 2006-2007 than in 2011-2012. These results indicate looser connections between currencies or a more scattered network in the post-crisis period.

Table 6

Total variance explained by the preceding components

2006-2007				2011-2012			
Component	Eigenvalue	of Variance	Cumulative	Component	Eigenvalue	of Variance	Cumulative
1	2.829	0.756	0.756	1	2.844	0.757	0.757
2	0.407	0.109	0.865	2	0.412	0.110	0.867
3	0.125	0.033	0.898	3	0.112	0.030	0.897

** In both periods, the preceding two components can explain more than 86% of the variance, and the first component can also explain over 75% of the variance.

Appendix

Table A

Currency information list

No	Currency	Code	Country	MC	GE
1	Australian dollar	AUD	Australia	1	2
2	Botswana pula	BWP	Botswana	3	5
3	Brazilian real	BRL	Brazil	2	1
4	Canadian dollar	CAD	Canada	1	1
5	Chilean peso	CLP	Chile	2	1
6	Chinese yuan	CNY	China	2	2
7	Colombian peso	COP	Colombia	2	1
8	Czech koruna	CZK	Czech Republic	2	3
9	Euro	EUR	Euro Area	1	3
10	Hungarian forint	HUF	Hungary	2	3
11	Icelandic krona	ISK	Iceland	1	3
12	Indian rupee	INR	India	2	2
13	Indonesian rupiah	IDR	Indonesia	2	2
14	Iranian rial	IRR	Iran	2	4
15	Israeli new sheqel	ILS	Israel	1	4
16	Japanese yen	JPY	Japan	1	2
17	Kazakhstani tenge	KZT	Kazakhstan	3	2
18	Korean won	KRW	South Korea	2	2
19	Kuwaiti dinar	KWD	Kuwait	3	4
20	Malaysian ringgit	MYR	Malaysia	2	2
21	Mauritian rupee	MUR	Mauritius	3	5
22	Mexican peso	MXN	Mexico	2	1
23	Nepalese rupee	NPR	Nepal	3	2
24	New Zealand dollar	NZD	New Zealand	1	2
25	Norwegian krone	NOK	Norway	1	3
26	Pakistani rupee	PKR	Pakistan	3	2
27	Polish zloty	PLN	Poland	2	3
28	Russian ruble	RUB	Russia	2	3
29	Singapore dollar	SGD	Singapore	1	2
30	South African rand	ZAR	South Africa	2	5
31	Sri Lanka rupee	LKR	Sri Lanka	3	2
32	Swedish krona	SEK	Sweden	1	3
33	Swiss franc	CHF	Switzerland	1	3
34	Thai baht	THB	Thailand	2	2
35	Trinidad and Tobago dollar	TTD	Trinidad and Tobago	3	1
36	U.K. pound sterling	GBP	United Kingdom	1	3
37	U.S. dollar	USD	U.S.	1	1

* Market Classification(MC):1-Developed Markets; 2-Emerging Markets; 3-Frontier Markets

* Geographic region(GE):1-America; 2-Asia/Pacific; 3-Europe; 4-Middle East; 5-Africa