参赛队员姓名：马睿妍　齐琪　赵秋琬

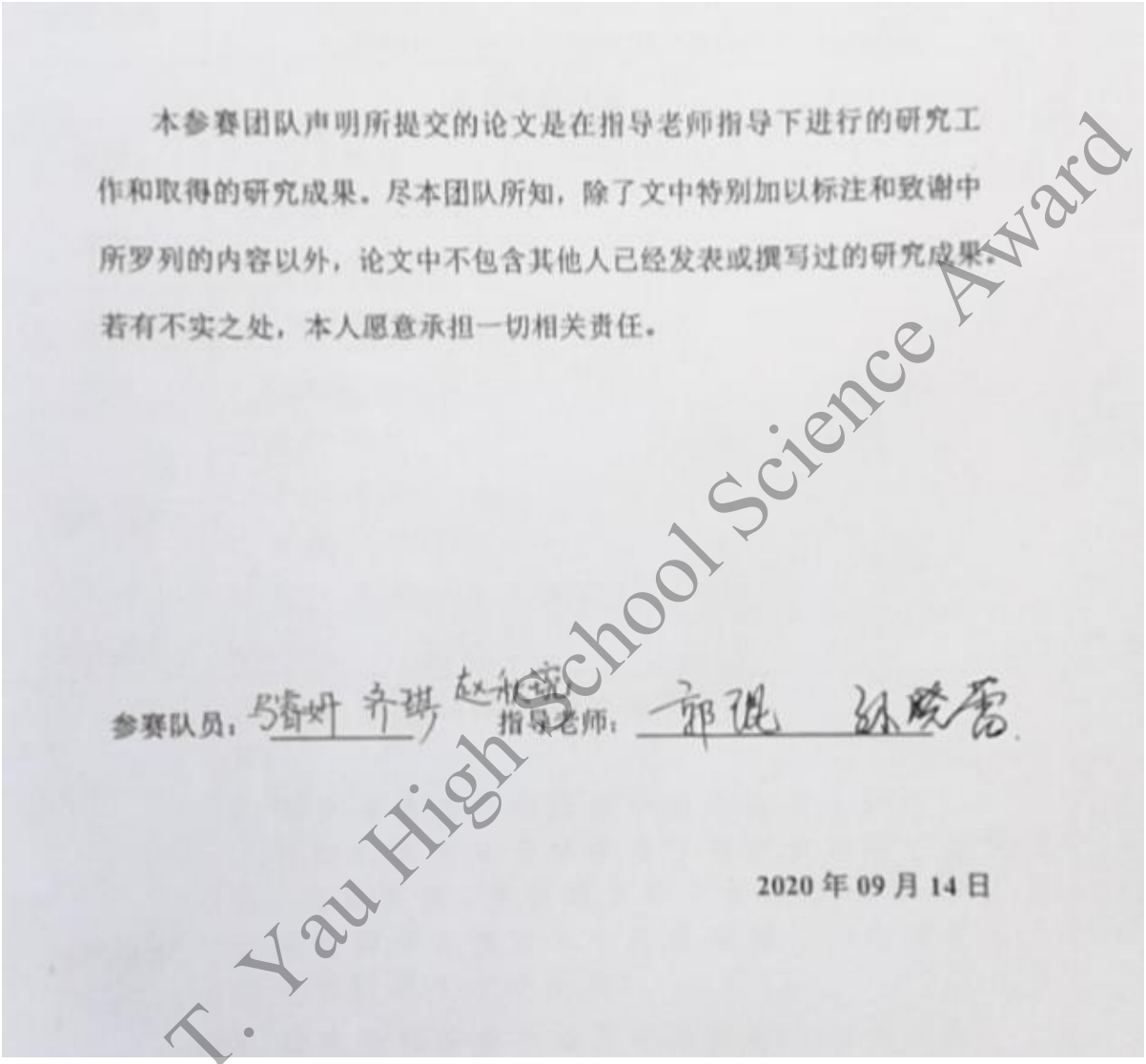
中学：北京四中国际校区

省份：北京

国家/地区：中国

指导教师姓名：郭琨　孙晓蕾

论文题目：Information spillover of stock returns across G20 countries: Evidence from a novel directional tree approach



本参赛团队声明所提交的论文是在指导老师指导下进行的研究工作和取得的研究成果。尽本团队所知，除了文中特别加以标注和致谢中所罗列的内容以外，论文中不包含其他人已经发表或撰写过的研究成果。若有不实之处，本人愿意承担一切相关责任。

参赛队员：[illegible]　指导老师：[illegible]

2020 年 09 月 14 日

Information spillover of stock returns across G20 countries: Evidence from a novel directional tree approach

Authors: Ruiyan Ma [a], Qi Qi [a], Qiuwan Zhao [a]

[a] Beijing No.4 High School International Campus, Beijing 100031, China

Supervisors: Kun Guo [b], Xiaolei Sun [c]

[b] Research Center on Fictitious Economy & Data Science, Chinese Academy of Sciences, Beijing 100190, China

[c] Institutes of Science and Development, Chinese Academy of Sciences, Beijing 100190, China

Abstract: This paper investigates the information spillover of the global stock returns across the G20 countries using the graph theory method. By combining the Granger causality test with the minimal spanning tree approach, this paper proposes a novel directional tree structure that can effectively capture the core information transmission across stock returns intuitively. The findings show that the integration degree of stock returns across the G20 countries shows volatility over time and usually exhibits sudden spikes when black swan events occur, such as the COVID-19 pandemic. Specifically, the stock returns of the G20 countries present obvious regional clustering, in which European countries' stock returns have stronger associations. In the G20 stock returns system, the French stock market tends to be at the core most of the time, while the Chinese stock market is only linked with other Asian countries' stocks and is still at the fringe position in the system.

Keywords: Minimal spanning tree, Granger causality test, G20 stock returns, information spillover

1. Introduction

The stock market has an extremely important role in the economic system of the world. With the global economic and financial integration process, the linkages among the stock markets of various countries have become increasingly close. The price fluctuations or crisis events in the stock market of a certain country will spread to other markets in the form of risk shock through various channels, such as trade, investment and even investor expectation. The 2008 financial crisis further strengthened the linkages among stock markets at the global level, and the effects of risk contagion continued to appear, which also

brought new challenges to cross-market risk supervision. Therefore, the process of accurately identifying the linkages that are present in the global stock market has become a hot, albeit challenging, topic in the current academic and financial market.

In 2020, due to the impact of COVID-19, the uncertainty in the global economy has been magnified, the linkages in the global stock market have surged and systemic risks have further increased. Affected by the plunge in price of crude oil, the Kuwait stock index once fell by more than 10% and the Saudi stock market fell by more than 9%. Similarly, the Qatar and United Arab Emirates (UAE) stock market indexes fell by more than 8%. The impacts of the foregoing have also spread to global stock markets. Major European and Asia-Pacific stock indexes have also experienced sharp declines across the board. Australia, Thailand, the UAE and other multinational stock indexes have recorded their largest single-day declines since the 2008 financial crisis. Countries such as Japan and Russia have officially entered a technical bear market. The S&P 500 index of United States plunged by 7%. It also triggered the first-layer circuit breaker. The Brazilian and Canadian stock markets also triggered the circuit breaker mechanism due to oversold losses. However, China's financial market would be more opened while accelerating the connection with the international stock market. Further, it means that the Chinese stock market may face more severe external risk shocks. It is necessary to explore the linkages within the international stock markets from a global perspective to better prevent the current price fluctuations and risk shocks that may come from other countries' stock markets.

Based on a global perspective, this article selects the G20 as the research object. It includes the G7, the BRICS, and seven other important economies. These countries account for more than 80% of the world's international trade and around 90% of the gross national product. The economic ties between China and the other G20 member states are also extremely close. Therefore, taking the G20 as the research object includes both developed

and emerging market countries, thus identifying the price and risk correlations between global stock markets more comprehensively and representatively. Different from previous studies, this article raises three questions: 1) Is there obvious coordination among the stock markets of major countries (G20) in the world? 2) Are there dynamics in the relationship between the stock markets of these countries and, if so, how do they reflect on some major black swan events? 3) Which countries' stock markets are at the core of the G20's stock market system, and which countries' stock markets are more closely related?

Focusing on the three issues raised above, this paper proposes a new dynamic research framework based on the graph theory. The main innovations are as follows: 1) This paper constructs a minimum spanning tree (MST) of the G20 countries' stock returns and applies a series of measurement indexes of the importance of points and edges to quantitatively identify the core relationships among the stock markets of the G20 countries. 2) This paper uses the rolling window method to dynamically analyse the relationships between the stock returns of the G20 countries and identifies the dynamic characteristics of stock market information fusion. 3) This paper proposes a new directed MST by introducing the Granger causality test, which is an effective measure of the information overflow relationships between the G20 countries' stock markets.

The remaining parts of this paper is organized as follows: Section 2 constitutes a literature review, Section 3 introduces the methodology proposed in this paper, Section 4 comprises the data and the fifth part presents an empirical result analysis to realise the dynamic characteristics of the G20 stock market correlation network. Finally, a summary will be given.

2. Literature review

With the continuous advancement of economic globalisation and international financial integration, the linkages in globe stock market have always constituted one of the

hotspots in the academic research field. However, most of them pay special attention to the US stock market. For example, Rua and Nunes (2009) provided a new look into the co-movements of major developed countries including, Germany, Japan, the UK and the US over the last four decades using wavelet analysis. Gjika and Horváth (2013) used GARCH models to investigate the correlations among stock markets in Central Europe from 2001 to 2011. Lehkonen and Heimonen (2014) analysed the differentiations in the other developed economies including Canada, Hong Kong, Australia, UK, Germany and Japan with respect to the US. In the research on the relevance of regional stock markets in the Americas, the Middle East and the Asia-Pacific, the influence of the US stock market cannot be ignored. For instance, Johnson and Soenen (2003) found that from 1993 to 1999, there was a statistically remarkable high ratio correlation between the eight Stock markets in the Americas and the U.S. stock markets over the same period. Grahama et al. (2013) examined the co-movement of selected Middle East and North Africa region stock markets with the US stock market from June 2002 to June 2010. Lee and Cho (2017) showed that pairings of macroeconomic variables between the major countries in the Pacific Basin can explain the stock market co-movements of the region from 1990 to 2012.

With the continuous advancement of economic globalisation and financial integration, more and more scholars are committed to studying the linkage of stock markets from a global perspective. For example, Lucey and Zhang (2010) used bivariate GARCH models to examine the impact of cultural distance on global market connection for emerging markets in 1995–2007. Based on the new method of Fryzlewicz and Oh (2011), Jach (2017) quantified the time-varying, dualistic and multivariate coordinated movements of global stock market returns on different time scales.

In last several years, as the rapid flourishing of China's financial market, the linkage characteristics between the Chinese stock market and other stock markets have also begun

to merit research focus. In particular, during the US financial crisis and the Sino-US trade friction period, the linkage characteristics of the stock market attracted a huge amount of scholars.

Focusing on the linkage of China's stock market with other stock markets in the Asia-Pacific region, Huang et al. (2017) used the CCK model to study herd behaviour on the A-share market and the Hong Kong stock market. They confirmed that herd behaviour was one of the channels of contagion in the A-share market and the Hong Kong stock market during the two crises. Li and He (2017) studied the China stock market's international influence since its succession to the World Trade Organization (WTO) based on the Copula-DCC-GARCH approach. They found that its co-movement with Asian stock markets is the closest, followed by the BRICS. It also has a significant influence in European and US stocks. On the linkage between the Chinese stock market and the stock markets of major developed countries, Xu et al. (2018) used a vine copula-CAViaR model to estimate financial risk spillover effects. They found that the impacts of more serious events that happened in the US and/or in the Japan on China stock markets are larger than those of positive events, which can be summarised as "risk shared without profit sharing". Compared to China and other countries, the US stock market has a stronger risk response capacity and revenue sharing. Feng and Zhao (2020) used the GARCH-BEKK model to study the overflow effects of the stock markets of major developed countries on China's stock market, and found that the volatility overflow effects of Chinese stock markets on the that of major developed countries have shown a slight weakening. Highlighting the period before and after the Sino-US trade war, Rao et al. (2019) used the ECM model to investigate the co-movement of Chinese and American stock markets. They found that the correlation between Chinese and U.S. stock markets fell after the trade war ended, and the dependence of China's stock market on the US stock market weakened.

Generally, native and overseas researchers have performed numerous continuous study on the linkage characteristics of the stock market which have important reference value for this research. However, most of the existing research rely on econometric models. It will limit the applicability of the model to a certain extent when the number of research samples increases. Moreover, the global stock market is essentially a social and economic network with market linkage (Schweitzer et al., 2009; Brockmann and Helbing, 2013). Viewing the linkage structure and dynamic evolution of multiple stock markets from the perspective of a complex system also brings certain difficulties in model construction. Therefore, this research pays special attention to the linkage characteristics of the G20 stock market at different stages, such as the financial crisis, the European debt crisis and the COVID-19 in 2020, and proposes some new findings.

3. Global stock market modelling

With the development of global economic integration, global financial market instruments, such as stocks, are increasingly showing a trend of co-movement. With the shock from some black swan events, global stocks tend to show more similar jumps and falls. This collective behaviour in the global stock market system can be well described by a graph that can represent the topological structure of the links between countries' stocks. Therefore, in this section, an MST approach is introduced to reflect the most important core relationships between global stocks.

This section includes three subsections. First, the unconditional correlation matrix of stock returns is used to construct the basic MST. In this MST, each country's stock is considered as the node and their linkages are designated as edges by using a distance measure. Second, dynamic MST is modelled by using a rolling window approach to calculate the time-varying indicators of the MST structure. It can disclose the evolution of the information co-movement under the different international macroeconomic

environments. Finally, a new directional MST is constructed by combining the Granger causality test with the traditional MST. Then, the direction of information spillover between pairwise stock returns can be finally verified. By integrating these three parts, a comprehensive outline of the relationships between countries' stock returns can be effectively presented.

3.1 MST modelling

Before constructing the MST, the correlation coefficients of the countries' stock returns should be calculated:

$$C_{ij}^{T} = \frac{\sum_{t=1}^{T}(r_{i,t} - \bar{r_i})(r_{j,t} - \bar{r_j})}{\sqrt{\sum_{t=1}^{T}(r_{i,t} - \bar{r_i})^2 \sum_{t=1}^{T}(r_{j,t} - \bar{r_j})^2}} \quad (1)$$

where C_{ij}^{T} presents the unconditional correlation coefficient, r_i is the stock return of country i, which is calculated by the logarithmic difference of stock prices, $\bar{r_i}$ is the sample mean of $r_{i,t}$.

Following most previous literature (Ji and Fan, 2016; Mantegna, 1999; Gower, 1966)), distance d_{ij} should be calculated based on the correlation coefficient C_{ij}^{T}. Each correlation is converted to a metric distance by using $d_{ij} = \sqrt{2(1 - C_{ij}^{T})}$, where d_{ij} is the distance between stock i and stock j. Thus, small d_{ij} imply high co-movement.

As a special tree, MST has a specific advantage of depicting the node structure. It can also provide an intuitive way to filter the important edges in the system. In general, for a N nodes complex system, there are $N(N-1)/2$ possible edges, while only $N-1$ most important edges are left in the MST. In this paper, the widely used Prim's algorithm is applied to form the MST (Prim, 1957).

In order to determine the structure of the MST and identify the get the important

characters of the system, some measures are introduced.

(1) Market system integration

To depict the degree of integration of the whole stock system, an indicator called market system integration index is built.

$$L(t) = \frac{N-1}{\sum_{d_{ij} \in MST} d_{ij}} \tag{2}$$

where $L(t)$ is the market system integration index, N is the number of nodes and d_{ij} is the distance in the MST. A higher value of $L(t)$ implies a higher integration degree of the whole system.

(2) Market degree centrality

The market degree centrality is the sum of the edges incident to the node.

$$d(i) = \sum_{j=1}^{N} a_{ij} \tag{3}$$

where $d(i)$ is the market degree centrality of node i, and $a_{ij} = 1$ if node i and node j have an edge in the MST, otherwise, $a_{ij} = 0$.

(3) Market betweenness centrality

The betweenness centrality is can measure the role of a node as a bridge in the MST.

$$B(i) = \frac{2}{N(N-1)} \sum_{(j,l)} \frac{\sigma_{jl(i)}}{\sigma_{jl}}, \qquad j \neq i \neq l \tag{4}$$

where $\sigma_{jl(i)}$ is the number of the shortest paths from j to l passing through i and σ_{jl} is the number of the shortest paths from j to l.

(4) Market closeness centrality

Closeness centrality is calculated as the reciprocal of the distances' sum from one node to all other nodes.

$$C(i) = \frac{1}{\sum_{(i,j)} R_{ij}}, \qquad i \neq j \tag{5}$$

where R_{ij} is the shortest distance from i to j. A large value of closeness centrality implies

that node *i* is at the centre of the system.

3.2 Dynamic MST

To determine the time-varying change of MST, we employ a rolling window process to construct the MST at each point. In order to obtain enough information, we use 66 observations that represent three months as our window length. Then, we can obtain 3244 MSTs in total, according to our sample period.

3.3 Directional MST modelling

In general, traditional MST can only present the closest relationship between markets while failing to identify the direction of information spillover. Thus, we provide a novel methodology that combines the Granger causality test with MST. The Granger causality test to identify the direction of all the existing edges in the MST and then obtain the directional MST.

Series *j* is said to Granger cause series *i* if past values of *j* could help prediction of *i*. Therefore, for each edge in the MST, we apply the Granger causality test between series *i* and series *j* from which the data were used to calculate the correlation in section 2.1. We identify the direction between *i* and *j* by comparing the value of F statistics between the two null hypotheses, namely, *i* does not Granger cause *j* and *j* does not Granger cause *i*. If the former has the larger F statistics, then the direction of e_{ij} is from *i* to *j*. We can repeat this step and confirm the direction of all the edges and obtain a directional MST.

4. Data

We choose countries in the G20 and BRICS as the samples to examine the correlation in the global stock market. Since Saudi Arabia's stock market data are missing, we exclude the country from the sample. All data are chosen from the representative stock price index of each country. The countries selected, their stock price indexes, and the country codes' abbreviations are shown in Table 1. There are 3310 observations selected. The sample

interval is from 10 January 2007 to 14 August 2020. This interval includes the world financial crisis, the debt crisis, the recovery period and the coronavirus period. Therefore, we could divide the data into three stages: the first stage is from 10 January 2007 to 31 December 2013 (the world financial crisis and the debt crisis), as the world financial crisis (commenced in 2008) and the debt crisis (started in 2011) were influential during this period; the second stage is from 1 January 2014 to 31 December 2019 (the recovery period), as the financial circumstances of most countries have begun to recover from the two crises since 2014; the third stage is from 1 January 2020 to 14 August 2020, which is consistent with the time of the coronavirus outbreak. We select the closing prices of the sample countries from their stock price indexes on https://cn.investing.com. Then, we use the following formula to calculate the stock return R_t:

$$R_t = 100 \cdot \ln (P_t/P_{t-1}) \tag{6}$$

In this formula, P_t is the closing price in each country's stock price index. As the trade dates for the stock market in every country are inconsistent, we align all the data and use linear interpolation to fill in the missing information.

We calculate the mean, median, maxima, minima and standard deviation for each country's stock return, as shown in Table 1. If viewed as a whole, only the stock returns of Japan, Britain, France and Italy have negative means. Yet, the medians of their stock returns are all positive, so we can estimate that the four countries often have positive stock returns. The remaining 14 countries all have positive means and medians for their stock returns, showing that these countries' stock markets have escalating trends during the sample interval. Among the 18 countries, Argentina's stock return has the largest standard deviation and range, demonstrating its high probability to fluctuate.

Table 2 shows the correlations between the stock return of each country in the full sample interval. The correlations of stock returns during the world financial crisis, the

recovery period and the coronavirus period are shown in schedules 1–3, respectively. From the regional perspective, countries in Europe (Britain, France, Germany, Italy) consistently have strong correlations between their stock markets. However, China's stock market has a relatively low correlation with that of most countries in Asia. In terms of time, the correlations between each country's stock market intensify during the world financial crisis and the coronavirus outbreak, demonstrating an increase in global stock market correlation. As for the salient features of different stages, during the world financial crisis, Brazil, Canada and Mexico have the highest correlation in their stock markets compared to the other two stages. During the coronavirus outbreak, Canada's stock price return demonstrates a significant increase in its correlation with that of other countries.

Table 1 Sample selection and basic statistics

Country	Stock Market Index	Abbreviation	Mean	Median	Maximum	Minimum	Std. Dev.
China	Shanghai Securities Composite Index	CHN	0.005	0.076	9.034	-9.256	1.647
Korea	South Korea's KOSPI Index	KOR	0.017	0.061	11.284	-11.172	1.283
Japan	Tokyo Nikkei-225 Index	JPN	-0.01	0.049	9.494	-12.715	1.51
India	S&P CNX NIFTY Index	IND	0.044	0.071	16.334	-13.904	1.456
Indonesia	Jakarta Composite Index	IDN	0.017	0.109	7.623	-11.306	1.316
South Africa	South Africa 40 Index	ZAF	0.008	0.038	7.907	-16.604	1.366
Russia	MOEX Russia Index	RUS	0.02	0	25.226	-36.109	1.998
Brazil	Bovespa Index	BRA	0.018	0.079	13.023	-18.75	1.798
Turkey	ISE National-100 Index	TUR	0.032	0.026	12.128	-14.651	1.649
United Kingdom	UK 100 Index	GBR	-0.001	0.011	9.393	-11.456	1.256
French	CAC 40 Index	FRA	-0.003	0.018	10.595	-13.098	1.481
Germany	Global X DAX Germany ETF Index	DEU	0.02	0.057	10.797	-13.055	1.447
Italy	Italy 40 Index	ITA	-0.022	0.009	10.874	-18.201	1.699
Australia	S&P/ASX 200 Index	AUS	0.006	0.056	6.766	-10.203	1.172
United States of America	NASDAQ-100 Index	USA	0.056	0.123	10.368	-16.955	1.421
Canada	S&P/TSX Composite	CAN	0.012	0.081	11.294	-16.999	1.22
Mexican	S&P_BMV IPC Index	MEX	0.021	0.038	9.945	-16.278	1.208
Argentina	S&P Merval Index	ARG	0.113	0.145	13.9	-47.692	2.351

Table 2 The overall correlation of each group of data

	CHN	KOR	JPN	IND	IDN	ZAF	RUS	BRA	TUR	GBR	FRA	DEU	ITA	AUS	USA	CAN	MEX	ARG
CHN	1	0.341	0.293	0.261	0.28	0.244	0.19	0.185	0.163	0.205	0.195	0.187	0.161	0.286	0.127	0.167	0.156	0.137
KOR	0.341	1	0.593	0.474	0.517	0.422	0.384	0.287	0.34	0.399	0.38	0.396	0.319	0.59	0.224	0.296	0.301	0.202
JPN	0.293	0.593	1	0.332	0.39	0.377	0.322	0.223	0.258	0.354	0.354	0.341	0.299	0.559	0.182	0.273	0.242	0.187
IND	0.261	0.474	0.332	1	0.461	0.408	0.375	0.318	0.358	0.42	0.417	0.417	0.378	0.413	0.246	0.329	0.302	0.206
IDN	0.28	0.517	0.39	0.461	1	0.378	0.358	0.253	0.342	0.348	0.34	0.317	0.292	0.452	0.165	0.248	0.269	0.209
ZAF	0.244	0.422	0.377	0.408	0.378	1	0.543	0.474	0.452	0.638	0.625	0.608	0.55	0.44	0.414	0.534	0.474	0.348
RUS	0.19	0.384	0.322	0.375	0.358	0.543	1	0.406	0.484	0.57	0.558	0.543	0.506	0.332	0.332	0.441	0.399	0.298
BRA	0.185	0.287	0.223	0.318	0.253	0.474	0.406	1	0.359	0.509	0.502	0.483	0.457	0.286	0.614	0.693	0.633	0.503
TUR	0.163	0.34	0.258	0.358	0.342	0.452	0.484	0.359	1	0.525	0.516	0.507	0.469	0.309	0.341	0.376	0.371	0.277
GBR	0.205	0.399	0.354	0.42	0.348	0.638	0.57	0.509	0.525	1	0.896	0.851	0.792	0.434	0.514	0.611	0.518	0.387
FRA	0.195	0.38	0.354	0.417	0.34	0.625	0.558	0.502	0.516	0.896	1	0.93	0.89	0.403	0.532	0.593	0.519	0.395
DEU	0.187	0.396	0.341	0.417	0.317	0.608	0.543	0.483	0.507	0.851	0.93	1	0.842	0.379	0.549	0.578	0.521	0.382
ITA	0.161	0.319	0.299	0.378	0.292	0.55	0.506	0.457	0.469	0.792	0.89	0.842	1	0.349	0.485	0.547	0.467	0.367
AUS	0.286	0.59	0.559	0.413	0.452	0.44	0.332	0.286	0.309	0.434	0.403	0.379	0.349	1	0.213	0.33	0.239	0.184
USA	0.127	0.224	0.182	0.246	0.165	0.414	0.332	0.614	0.341	0.514	0.532	0.549	0.485	0.213	1	0.726	0.602	0.428
CAN	0.167	0.296	0.273	0.329	0.248	0.534	0.441	0.693	0.376	0.611	0.593	0.578	0.547	0.33	0.726	1	0.649	0.49
MEX	0.156	0.301	0.242	0.302	0.269	0.474	0.399	0.633	0.371	0.518	0.519	0.521	0.467	0.239	0.602	0.649	1	0.44
ARG	0.137	0.202	0.187	0.206	0.209	0.348	0.298	0.503	0.277	0.387	0.395	0.382	0.367	0.184	0.428	0.49	0.44	1

5. Empirical results

5.1 Static correlation network analysis

Using the full sample data to construct a correlation network (Figure 1), four colours are used to indicate different regions, including the Asia-Pacific region, the Americas, Europe and Africa. It can be seen that the linkage of the world stock market has obvious geographical attributes. There are extensive connections in the stock markets of all continents and countries, but the degree of connection is not the same. Generally, the stock markets in Europe, the Americas and Africa are more interconnected, but the stock markets in Asia and these three continents are slightly less interconnected. To further simplify the complexity of the network, only the edges with weights ranked in the top 25% are selected. The modified correlation network is shown in Figure 2. From the perspective of each state, it can be seen that in Europe, there is a correlation between the French and British, German and Italian stock markets, but Russia and Turkey are less relevant to them; in the Americas, the US, Canada, Brazil and Mexico stock markets have greater relevance, but the Argentine stock market is slightly less relevant to them; the Asia-Pacific region is strongly interconnected, and within it, Japan, South Korea and Australia are strongly correlated, Indonesia and South Korea are strongly correlated, while the stock market of China and India show greater independence and are not closely correlated with the aforementioned countries. At the same time, the correlation between the Asia-Pacific region and the rest of the world is weak.

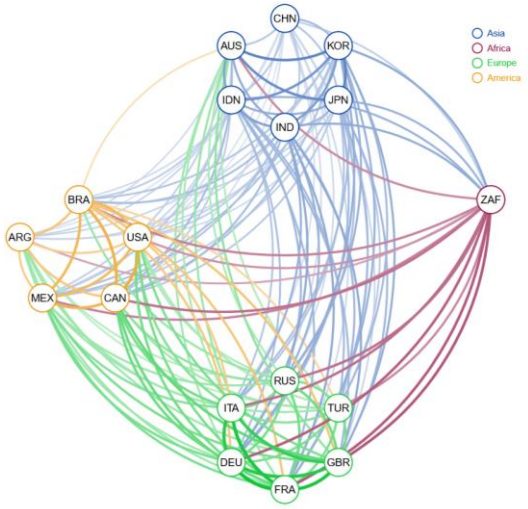


Figure 1. Correlation network of full sample data

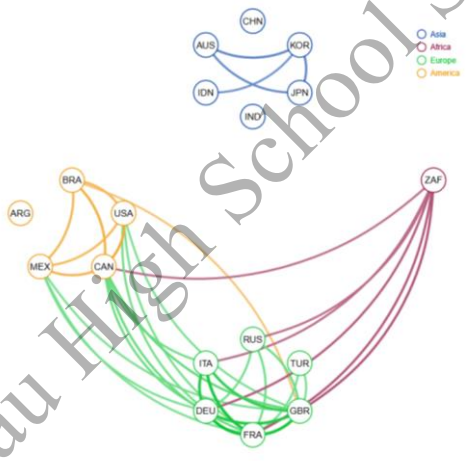


Figure 2. Correlation network of the highest weighed 25% sides

The weighed degree of each node is shown in Figure 3. The countries with the highest weighting degrees are France, the UK, Germany and Italy. That is, the stock markets of European countries are of great importance in the complex network of global stock markets. Meanwhile, US stocks are less correlated with other countries in the world than that of most European countries. In addition, except for European countries, the South African and Canadian stock markets have a strong correlation with the stock markets of other countries. The influence of Asian stock markets is relatively low, especially the Chinese stock market, which has the lowest weighting among the 18 analysed samples. It can be found that

although the degree of openness of Chinses stock market has increased year by year in recent years, its internationalisation still has a long way to go.

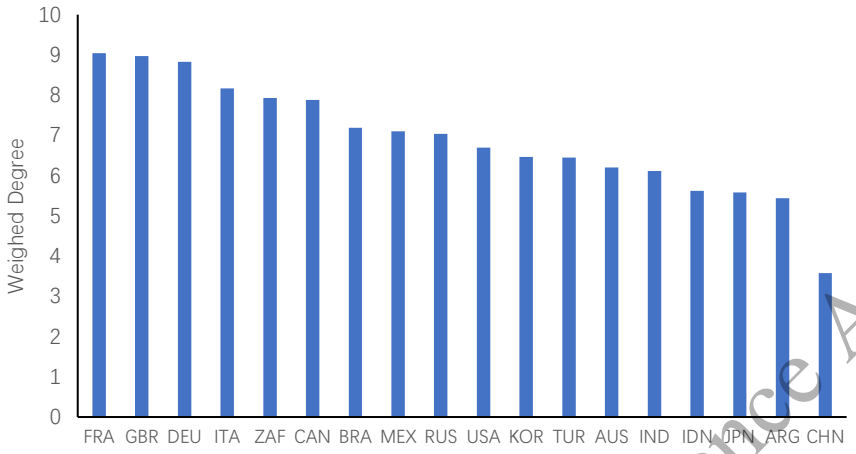


Figure 3. Weighed degree of the stock market of different countries

5.2 Analysis of each stage's MST

Based on the three stages' correlation networks, we use Kruskal to form the MST, as shown in Figure 4–6. The degree centrality, closeness centrality and betweenness centrality of the nodes in the three stages are presented in Table 3.

During the world financial crisis and the debt crisis (stage 1), the stock markets in Britain, South Africa, Canada and France have the strongest correlation, and the stock markets in Korea and Australia have the second strongest correlation. China's stock market does not have a close correlation with those in other countries. Korea, Australia, South Africa, Britain, France, Brazil and Canada are relatively significant countries in each geographical area. Britain has a degree centrality of 5, betweenness centrality of 0.667 and closeness centrality of 0.425—all three are the largest in stage 3.

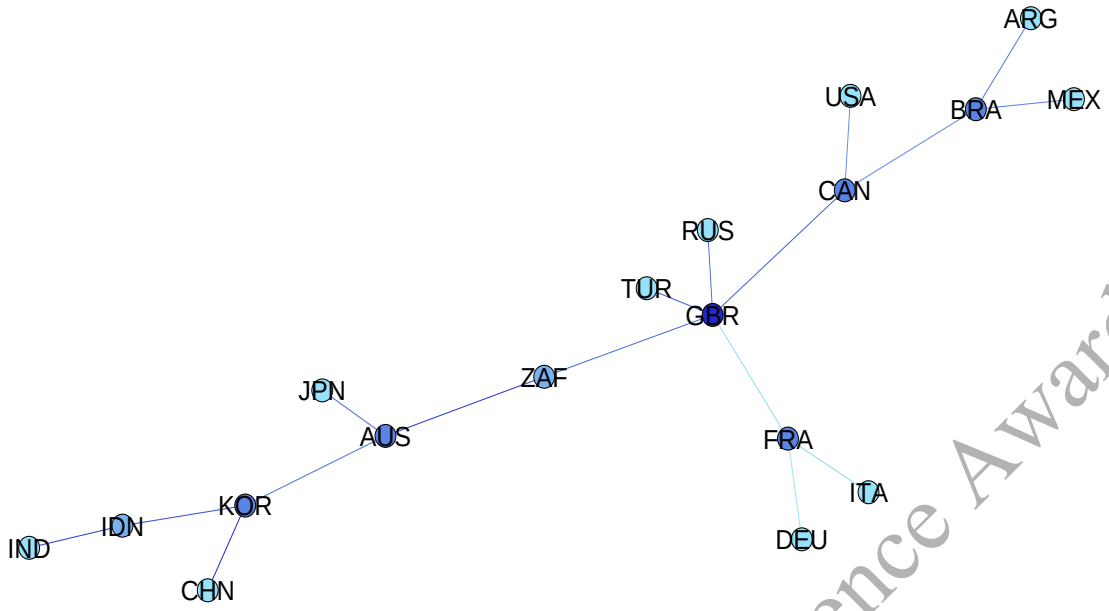


Figure 4. Indirected MST of stage 1

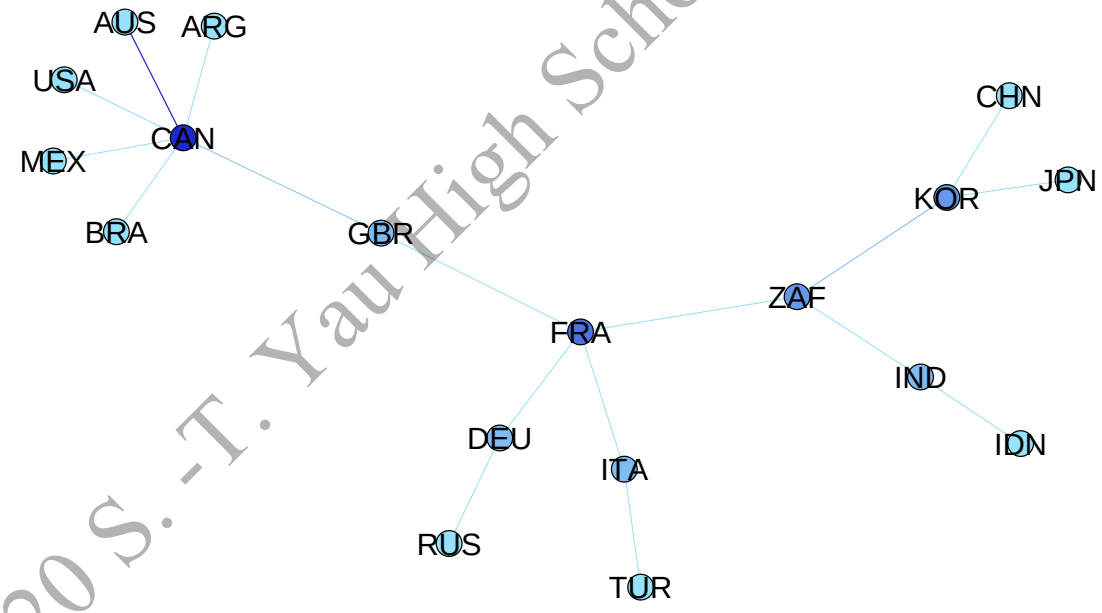


Figure 5. Indirected MST of stage 2

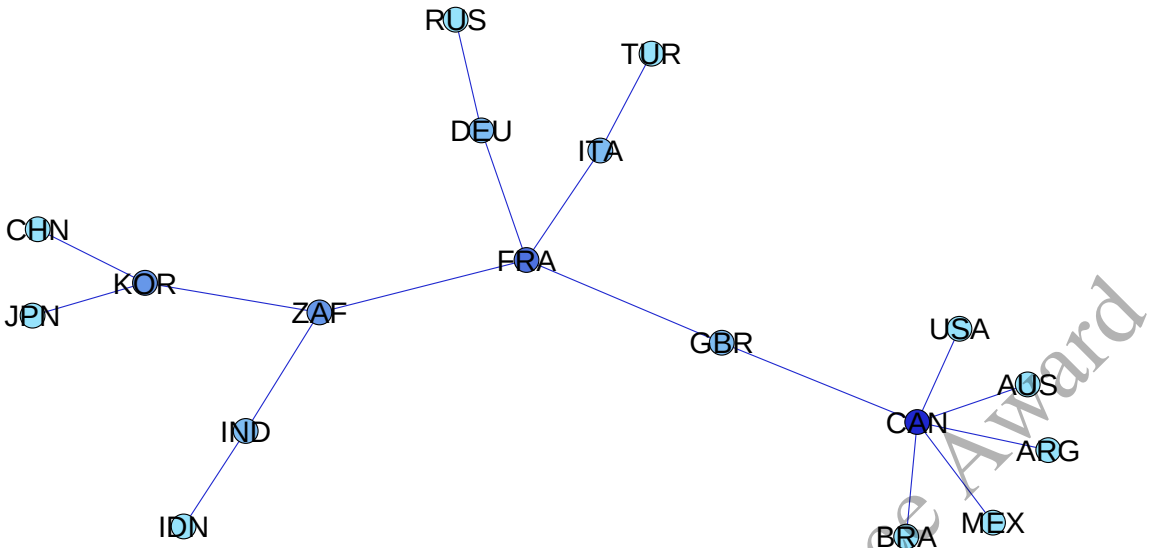


Figure 6. Indirected MST of stage 3

Table 3. Degree, closeness and betweenness centrality of each country

Area	Country	degree centrality			betweenness centrality			closeness centrality		
		Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
Asia-Pacific	CHN	1	1	1	0.000	0.000	0.000	0.224	0.262	0.236
	KOR	3	4	3	0.288	0.373	0.203	0.283	0.347	0.304
	JPN	1	2	1	0.000	0.105	0.000	0.258	0.270	0.236
	IND	1	2	2	0.000	0.392	0.105	0.189	0.415	0.293
	IDN	2	1	1	0.105	0.000	0.000	0.230	0.262	0.230
	TUR	1	1	1	0.431	0.000	0.431	0.386	0.333	0.386
	AUS	3	1	1	0.000	0.000	0.000	0.304	0.288	0.250
Africa	ZAF	2	1	3	0.203	0.000	0.000	0.283	0.288	0.266
Europe	RUS	1	1	1	0.000	0.000	0.000	0.304	0.288	0.250
	GBR	5	4	2	0.667	0.660	0.431	0.425	0.486	0.405
	FRA	3	5	4	0.203	0.379	0.641	0.327	0.395	0.447
	DEU	1	1	2	0.000	0.000	0.105	0.250	0.288	0.327
	ITA	1	1	2	0.000	0.000	0.105	0.250	0.288	0.327
Americas	MEX	1	1	1	0.418	0.000	0.000	0.340	0.215	0.266
	ARG	1	1	1	0.000	0.000	0.000	0.266	0.288	0.266
	BRA	3	1	1	0.359	0.379	0.458	0.354	0.395	0.354
	USA	1	1	1	0.000	0.000	0.000	0.224	0.288	0.266
	CAN	3	5	6	0.000	0.000	0.000	0.224	0.288	0.266

In the recovery period (stage 2), the stock markets in Canada, France, Britain and Korea have strong correlations with the ones in other countries; their importance in the

world also rises from the last period. The degree centrality of the stock markets in France and Canada is 5, the largest in stage 2. The degree centralities of the stock markets in Australia, South Africa, Britain and Brazil decrease from stage 1. Britain's stock market has a betweenness centrality of 0.660 and a closeness centrality of 0.486, the largest in stage 2, revealing the considerable leverage of Britain's stock market.

During the coronavirus period (stage 3), Canada's stock market has a strong correlation with the stock markets in Australia and countries in the Americas (Argentina, America, Mexico, Brazil). Countries in the European stock market (Britain, France, Germany, Italy) have strong correlations, with France being at the centre of the correlation map. Countries in Asia-Pacific (South Africa, Korea, Indonesia) also share close correlations. Korea's stock market's degree centrality decreases from stage 2, but still plays a central role in the Asian stock market. The degree centrality of Canada's stock market is 6, the largest in this stage. France's stock market has a betweenness centrality of 0.641 and a closeness centrality of 0.447. Both are the largest in stage 3, demonstrating the close relationships between France and other nations.

In the three stages, the stock markets of Britain, France, Canada and Korea have relatively high degree centralities, betweenness centralities and closeness centralities compared to that of the nations in the same area. Thus, they continue to be significant in the world stock market. We calculate the market system integration index of each MST. As shown in Figure 7, the coronavirus period has the highest market system integration index of 1.47, showing the strongest correlation between each nation's stock market and the highest systematic risk of the world stock market in stage 1. However, the index of the world financial crisis is 1.04, the smallest in the three stages, demonstrating the relatively weak correlation between each nation's stock market and the low systematic risk of the world stock market in stage 2.

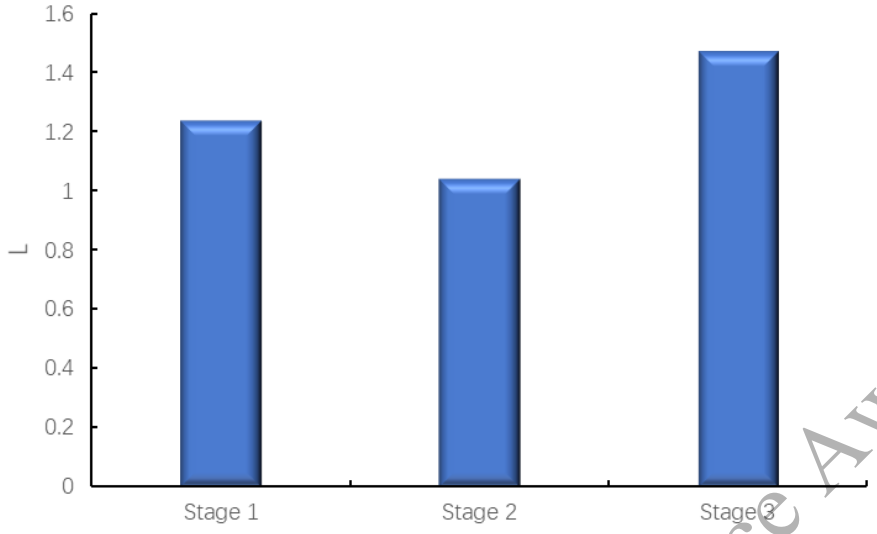


Figure 7. Market system integration index of the three stages

5.3 Dynamic MST analysis

The dynamic MST based on the sliding window obtains the dynamic market system integration index. As shown in Figure 8, the index basically fluctuates at around 0.08, and the overall correlation is relatively stable. However, it also shows obvious jumps in local periods. A series of black swan or grey rhino events have an impact on the overall systemic risk level. The market system integration index rose significantly during the global economic crisis of 2008/4-2009/4, indicating that global stocks have become more closely related. This is because from 2001 to 2004, the low interest rate policy implemented by the Federal Reserve stimulated the development of the real estate industry in the United States, and Americans' enthusiasm for buying houses continued to rise.

However, the Federal Reserve raised interest rates several times in order to save the decline of the dollar, address inflation and curb real estate overheating. As a result, the interest rate of subprime mortgages went higher and higher. The rates of delinquency and foreclosure also increased. Subsequently, the downturn in the real estate market gradually reached the limit of the burden of homebuyers, and banks began to have a large number of defaulting customers. These homebuyers stopped paying loans and formed bad debts. At

this point, the subprime mortgage crisis in the United States emerged, and it has further spread to other economies through financial and trade channels. The subprime mortgage crisis in the United States has gradually evolved into a global financial crisis. Since financial risks surfaced in February 2007, the largest financial group in the United States began to reduce lending, New Century Financial Corporation issued a profit warning, HSBC Holdings in the UK increased its provision for bad debts of subprime loan business, the hedge funds of Bear Stearns, the fifth largest investment in the United States, collapsed, and the German Industrial Investment Bank and BNP Paribas suffered huge losses due to their investments in subprime mortgage bond funds. The current US financial crisis spread rapidly across the globe like a plague. From the plummet of the US stock market due to the financial crisis, to the European, Latin American, Australia and Asia-Pacific stock markets that were also affected and fell sharply, we can see the scope and speed of the spread of the crisis. As a result, the dynamic integration degree increased significantly around 2008, that is, the global stock market fell at the same time and the stock market linkage was significantly enhanced.

During the period of COVID-19 after April 2020, the dynamic integration level increased significantly at approximately 0.06 to 0.11. The recent outbreak of the epidemic has spread to all corners of the globe, leaving no stocks immune to the panic. The stock markets in the US, Europe and Asia-Pacific plummeted. The market uncertainty caused by the epidemic left investors in fear, which led to increased panic and then to a collective decline in the stock market. Therefore, around April 2020, the dynamic integration degree fluctuates to the highest level during the sample period, indicating that the uncertainty in the global market increased. The global stock market fell at the same time, and there was a strong linkage.

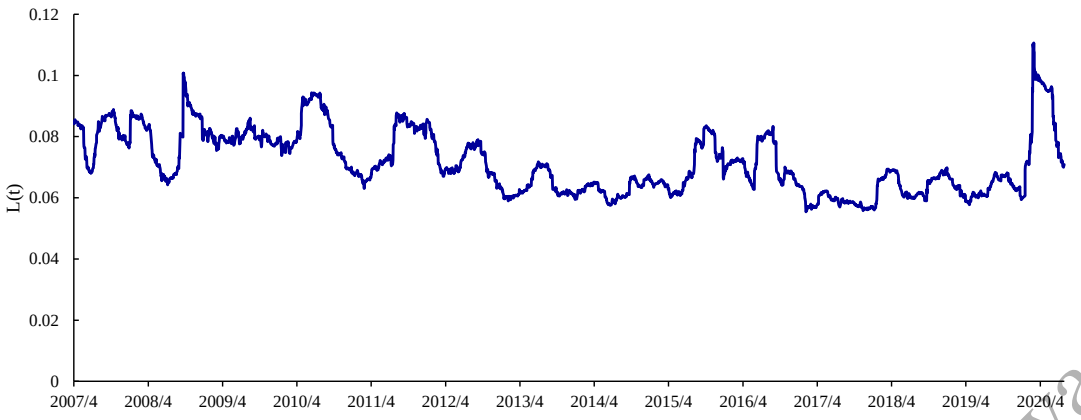


Figure 8. Dynamic degree of integration of MST

The evolution of the node with the largest degree centrality in the time-varying minimum spanning tree is shown in Figure 9. Generally, European countries have the most frequent occurrences in all continents and are in the most important position in the global stock market. Looking further at the countries, we can find that FRA has the largest number of points during the period 2007–2020, indicating that its degree centrality is the highest and the most important in the global stock market. At the same time, there are also many points for DEU, GBR and CAN, indicating their high degree centrality and important roles in the global stock market.

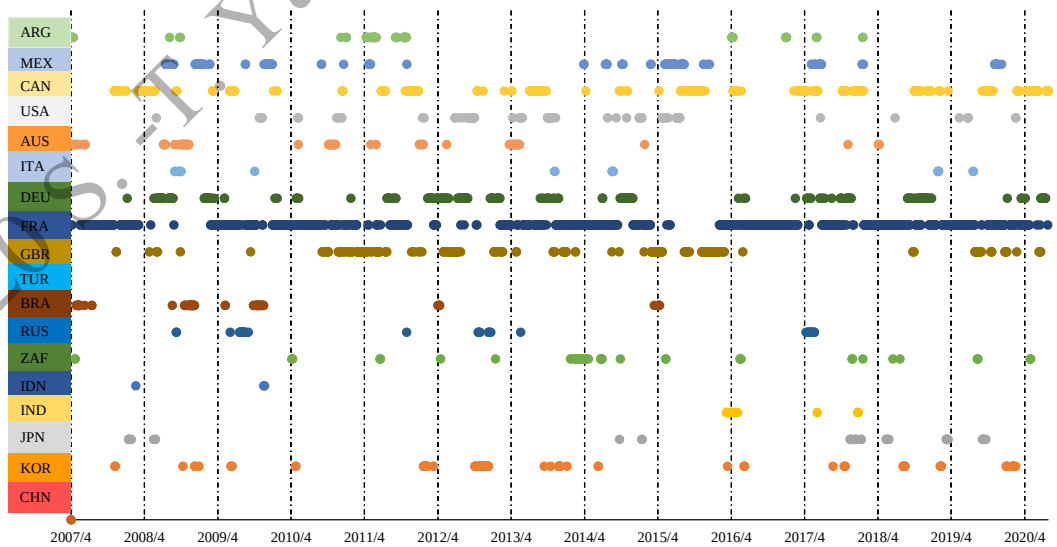


Figure 9. Evolution of the node that has the largest degree centrality

The frequency of the edge with the smallest distance in the dynamic MST is shown in Figure 10. That is, the edge with the highest frequency in the dynamic MST is FRA-DEU (2874 times), FRA-GBR (209 times), FRA-ITA (157 times) and DEU-ITA (4 times). It can be seen that the interconnection of European countries is strongly related. Among them, France has the strongest connection with other European countries and plays a very crucial role in European stock markets.

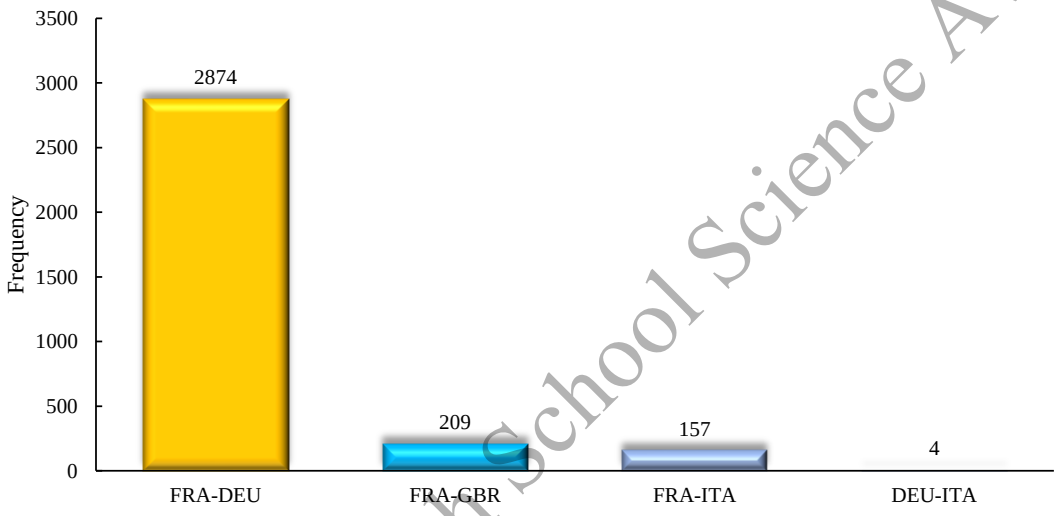


Figure 10. Frequency of the edge that has the smallest weight in the dynamic MST

5.4 Analysis of directed MST based on the Granger causality test

Directed MST network of each stage is obtained using the Granger causality test. The first stage is shown in Figure 11. The UK has the largest outdegree, mainly affecting countries in the European region. Countries without outdegrees are Turkey, Russia, Mexico, Australia and France. France is influenced by Italy, Germany and the UK to a small extent. Australia is affected by three countries, and it is the most affected country. Countries without indegrees are India, Indonesia, China, Japan, Italy, Germany, Argentina and the US. India, Indonesia and China, three Asian countries, indirectly affect Australia by influencing South Korea. Argentina, Brazil and the US also indirectly affect the UK by influencing Canada.

The second stage is shown in Figure 12. The countries without indegree are Canada, Germany and Australia. Canada has the largest outdegree, having a strong influence on four American countries and the UK. The countries without outdegrees include Italy, Russia, Turkey, South Africa, China, India, Brazil, Mexico, the US and Argentina. Canada, France and South Korea have strong, direct connections with other countries inside their regions. France influences four European countries, but it is also influenced by Germany.

The third stage is shown in Figure 13. Canada is the country with the largest outdegree, affecting the US, Australia and Argentina, which being simultaneously affected by Brazil and Mexico. Canada influences Argentina most significantly. The countries without indegree are Brazil, Mexico, Russia, Indonesia and Japan. The countries without outdegrees include the US, Australia, Argentina, Turkey, Germany and China. Germany is influenced by France and Russia. The connection between European countries have weakened compared to the second stage. South Africa has a close relationship with Asian countries. It is influenced by India and also influences South Korea.

China only has a correlation with South Korea. In the first stage, South Korea is affected by China; in the second and third stages, China is affected by South Korea.

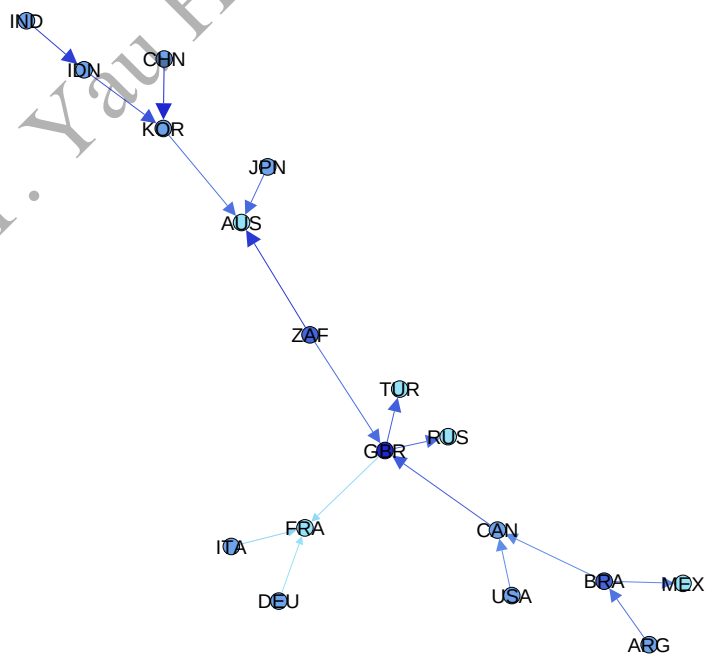


Figure 11. Directed MST of stage 1

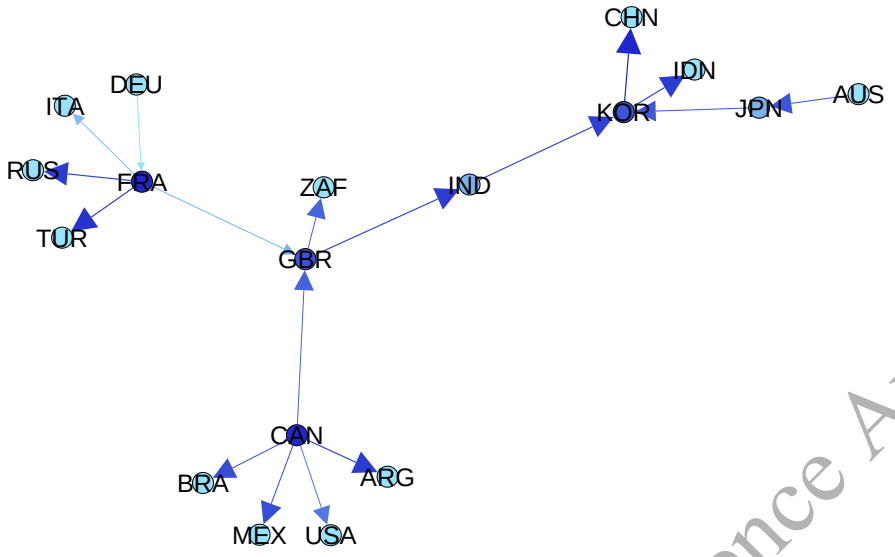


Figure 11. Directed MST of stage 2

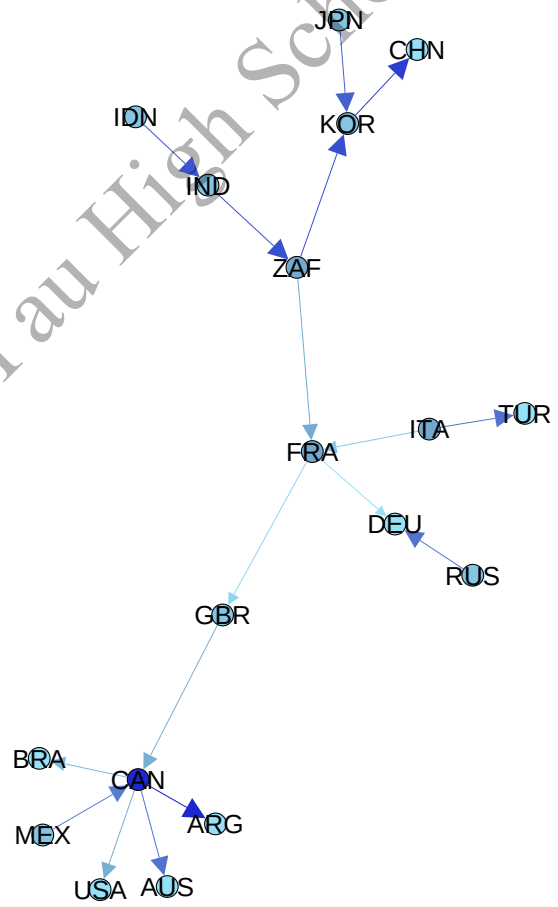


Figure 12. Directed MST of stage 3

6. Conclusions

This paper proposes a new method of directed MST, which comprehensively analyses the dynamics, direction and strength of the relationships among the stock markets of the G20 countries, especially the new characteristics of these stock market relationships during the COVID-19 pandemic. Some new conclusions were drawn.

Overall, the European stock market plays the most crucial role. The U.S stock market takes second place. Asian countries, especially China, are more independent, showing weaker relevance with other countries. South Korea's stock market is crucial in the Asia-Pacific region, while Canada's stock market is significant in the Americas. The stock markets of France, Germany, the UK, Italy, Canada and South Africa show strong correlations. The dynamic analysis demonstrates a strong intermediary and correlation between France's stock market and other countries' stock markets. Compared with the recovery period, multiple countries' stock markets show stronger correlations, greater uncertainties and higher systemic risks during financial crisis and the coronavirus pandemic. The directed analysis shows that Canada and France have significant regional influences, while China is less influential and more influenced by other countries.

In summary, the directed MST functions as a new analysis tool for global stock market investors in analysing stock market trends and avoiding systemic risks. Moreover, it demonstrates the new global market dynamics since the COVID-19 pandemic. This new method is theoretically innovative and produces numerous practical results.

Appendix 1 The correlation of each group of data in 1/10/2007-12/31/2013(the world financial crisis and the debt crisis)

	CHN	KOR	JPN	IND	IDN	ZAF	RUS	BRA	TUR	GBR	FRA	DEU	ITA	AUS	USA	CAN	MEX	ARG
CHN	1	0.358	0.305	0.272	0.314	0.236	0.207	0.204	0.184	0.188	0.184	0.174	0.167	0.316	0.095	0.157	0.159	0.189
KOR	0.358	1	0.619	0.464	0.544	0.405	0.431	0.301	0.376	0.39	0.365	0.396	0.324	0.651	0.213	0.276	0.303	0.246
JPN	0.305	0.619	1	0.34	0.444	0.4	0.372	0.244	0.295	0.349	0.329	0.317	0.286	0.625	0.169	0.28	0.25	0.228
IND	0.272	0.464	0.34	1	0.466	0.391	0.402	0.315	0.377	0.406	0.399	0.413	0.378	0.405	0.233	0.286	0.301	0.274
IDN	0.314	0.544	0.444	0.466	1	0.391	0.407	0.267	0.38	0.364	0.35	0.328	0.317	0.517	0.152	0.24	0.272	0.271
ZAF	0.236	0.405	0.4	0.391	0.391	1	0.607	0.505	0.51	0.631	0.613	0.598	0.548	0.435	0.415	0.521	0.487	0.465
RUS	0.207	0.431	0.372	0.402	0.407	0.607	1	0.472	0.556	0.625	0.607	0.599	0.562	0.378	0.376	0.473	0.433	0.427
BRA	0.204	0.301	0.244	0.315	0.267	0.505	0.472	1	0.404	0.532	0.539	0.535	0.482	0.228	0.684	0.728	0.717	0.654
TUR	0.184	0.376	0.295	0.377	0.38	0.51	0.556	0.404	1	0.586	0.574	0.575	0.527	0.348	0.372	0.394	0.409	0.393
GBR	0.188	0.39	0.349	0.406	0.364	0.631	0.625	0.532	0.586	1	0.911	0.866	0.811	0.413	0.514	0.574	0.53	0.501
FRA	0.184	0.365	0.329	0.399	0.35	0.613	0.607	0.539	0.574	0.911	1	0.925	0.904	0.391	0.533	0.566	0.533	0.518
DEU	0.174	0.396	0.317	0.413	0.328	0.598	0.599	0.535	0.575	0.866	0.925	1	0.843	0.367	0.565	0.561	0.551	0.512
ITA	0.167	0.324	0.286	0.378	0.317	0.548	0.562	0.482	0.527	0.811	0.904	0.843	1	0.341	0.48	0.519	0.484	0.493
AUS	0.316	0.651	0.625	0.405	0.517	0.435	0.378	0.228	0.348	0.413	0.391	0.367	0.341	1	0.133	0.246	0.218	0.209
USA	0.095	0.213	0.169	0.233	0.152	0.415	0.376	0.684	0.372	0.514	0.533	0.565	0.48	0.133	1	0.733	0.681	0.57
CAN	0.157	0.276	0.28	0.286	0.24	0.521	0.473	0.728	0.394	0.574	0.566	0.561	0.519	0.246	0.733	1	0.699	0.631
MEX	0.159	0.303	0.25	0.301	0.272	0.487	0.433	0.717	0.409	0.53	0.533	0.551	0.484	0.218	0.681	0.699	1	0.592
ARG	0.189	0.246	0.228	0.274	0.271	0.465	0.427	0.654	0.393	0.501	0.518	0.512	0.493	0.209	0.57	0.631	0.592	1

Appendix 2 The correlation of each group of data in 1/1/2014-12/31/2019(the recovery period)

	CHN	KOR	JPN	IND	IDN	ZAF	RUS	BRA	TUR	GBR	FRA	DEU	ITA	AUS	USA	CAN	MEX	ARG
CHN	1	0.268	0.24	0.225	0.169	0.225	0.143	0.119	0.097	0.215	0.186	0.175	0.124	0.219	0.16	0.167	0.135	0.067
KOR	0.268	1	0.509	0.39	0.366	0.366	0.205	0.18	0.219	0.347	0.338	0.308	0.268	0.434	0.246	0.271	0.237	0.155
JPN	0.24	0.509	1	0.328	0.242	0.302	0.182	0.138	0.157	0.32	0.356	0.323	0.28	0.49	0.188	0.224	0.193	0.124
IND	0.225	0.39	0.328	1	0.343	0.325	0.216	0.181	0.254	0.373	0.364	0.355	0.311	0.327	0.201	0.26	0.237	0.118
IDN	0.169	0.366	0.242	0.343	1	0.294	0.179	0.158	0.221	0.279	0.263	0.238	0.182	0.268	0.154	0.204	0.207	0.128
ZAF	0.225	0.366	0.302	0.325	0.294	1	0.333	0.301	0.267	0.556	0.552	0.53	0.464	0.296	0.331	0.438	0.39	0.212
RUS	0.143	0.205	0.182	0.216	0.179	0.333	1	0.255	0.248	0.367	0.371	0.358	0.334	0.192	0.207	0.3	0.258	0.174
BRA	0.119	0.18	0.138	0.181	0.158	0.301	0.255	1	0.221	0.326	0.296	0.262	0.283	0.148	0.357	0.456	0.435	0.356
TUR	0.097	0.219	0.157	0.254	0.221	0.267	0.248	0.221	1	0.326	0.326	0.3	0.278	0.148	0.23	0.252	0.253	0.152
GBR	0.215	0.347	0.32	0.373	0.279	0.556	0.367	0.326	0.326	1	0.824	0.771	0.7	0.341	0.432	0.551	0.381	0.268
FRA	0.186	0.338	0.356	0.364	0.263	0.552	0.371	0.296	0.326	0.824	1	0.924	0.85	0.281	0.48	0.549	0.406	0.262
DEU	0.175	0.308	0.323	0.355	0.238	0.53	0.358	0.262	0.3	0.771	0.924	1	0.811	0.258	0.47	0.499	0.385	0.237
ITA	0.124	0.268	0.28	0.311	0.182	0.464	0.334	0.283	0.278	0.7	0.85	0.811	1	0.228	0.411	0.488	0.364	0.234
AUS	0.219	0.434	0.49	0.327	0.268	0.296	0.192	0.148	0.148	0.341	0.281	0.258	0.228	1	0.146	0.23	0.156	0.084
USA	0.16	0.246	0.188	0.201	0.154	0.331	0.207	0.357	0.23	0.432	0.48	0.47	0.411	0.146	1	0.634	0.423	0.298
CAN	0.167	0.271	0.224	0.26	0.204	0.438	0.3	0.456	0.252	0.551	0.549	0.499	0.488	0.23	0.634	1	0.459	0.372
MEX	0.135	0.237	0.193	0.237	0.207	0.39	0.258	0.435	0.253	0.381	0.406	0.385	0.364	0.156	0.423	0.459	1	0.287
ARG	0.067	0.155	0.124	0.118	0.128	0.212	0.174	0.356	0.152	0.268	0.262	0.237	0.234	0.084	0.298	0.372	0.287	1

Appendix 3 The correlation of each group of data in 1/1/2020-8/14/2020(coronavirus period)

	CHN	KOR	JPN	IND	IDN	ZAF	RUS	BRA	TUR	GBR	FRA	DEU	ITA	AUS	USA	CAN	MEX	ARG
CHN	1	0.579	0.468	0.408	0.474	0.465	0.273	0.36	0.33	0.388	0.391	0.397	0.301	0.393	0.29	0.348	0.267	0.265
KOR	0.579	1	0.666	0.619	0.615	0.622	0.331	0.406	0.407	0.528	0.545	0.56	0.414	0.523	0.257	0.414	0.408	0.258
JPN	0.468	0.666	1	0.337	0.386	0.441	0.283	0.336	0.321	0.485	0.525	0.554	0.44	0.391	0.257	0.373	0.344	0.302
IND	0.408	0.619	0.337	1	0.636	0.627	0.482	0.531	0.526	0.555	0.595	0.554	0.52	0.551	0.367	0.555	0.426	0.255
IDN	0.474	0.615	0.386	0.636	1	0.484	0.269	0.395	0.4	0.397	0.448	0.436	0.412	0.427	0.28	0.377	0.396	0.296
ZAF	0.465	0.622	0.441	0.627	0.484	1	0.611	0.655	0.613	0.811	0.826	0.807	0.744	0.686	0.557	0.731	0.586	0.405
RUS	0.273	0.331	0.283	0.482	0.269	0.611	1	0.412	0.53	0.682	0.705	0.71	0.652	0.336	0.361	0.57	0.463	0.237
BRA	0.36	0.406	0.336	0.531	0.395	0.655	0.412	1	0.508	0.71	0.711	0.672	0.698	0.685	0.767	0.871	0.652	0.516
TUR	0.33	0.407	0.321	0.526	0.4	0.613	0.53	0.508	1	0.69	0.687	0.694	0.708	0.497	0.484	0.6	0.435	0.307
GBR	0.388	0.528	0.485	0.555	0.397	0.811	0.682	0.71	0.69	1	0.947	0.93	0.898	0.648	0.645	0.835	0.728	0.424
FRA	0.391	0.545	0.525	0.595	0.448	0.826	0.705	0.711	0.687	0.947	1	0.968	0.916	0.646	0.625	0.8	0.684	0.429
DEU	0.397	0.56	0.554	0.554	0.436	0.807	0.71	0.672	0.694	0.93	0.968	1	0.909	0.622	0.628	0.782	0.664	0.425
ITA	0.301	0.414	0.44	0.52	0.412	0.744	0.652	0.698	0.708	0.898	0.916	0.909	1	0.604	0.659	0.799	0.636	0.39
AUS	0.393	0.523	0.391	0.551	0.427	0.686	0.336	0.685	0.497	0.648	0.646	0.622	0.604	1	0.604	0.708	0.511	0.403
USA	0.29	0.257	0.257	0.367	0.28	0.557	0.361	0.767	0.484	0.645	0.625	0.628	0.659	0.604	1	0.831	0.56	0.406
CAN	0.348	0.414	0.373	0.555	0.377	0.731	0.57	0.871	0.6	0.835	0.8	0.782	0.799	0.708	0.831	1	0.732	0.522
MEX	0.267	0.408	0.344	0.426	0.396	0.586	0.463	0.652	0.435	0.728	0.684	0.664	0.636	0.511	0.56	0.732	1	0.447
ARG	0.265	0.258	0.302	0.255	0.296	0.405	0.237	0.516	0.307	0.424	0.429	0.425	0.39	0.403	0.406	0.522	0.447	1

References

Brockmann, D., & Helbing, D. (2013). The Hidden Geometry of Complex, Network-Driven Contagion Phenomena. Science, 342, 1337-1342.

Bu, H., Tang, W., & Wu, J. (2019). Time-varying comovement and changes of comovement structure in the Chinese stock market: A causal network method. Economic Modelling, 81, 181-204.

Feng, Y., & Zhao, J. (2020). Comparative study on the linkage of stock markets between china and developed countries and BRICS countries. Journal of Human University of Finance and Economics. 2020(2) 13-23.

Fryzlewicz, P., & Oh, H. S. (2011). Thick pen transformation for time series. Journal of the Royal Statistical Society Series B-Statistical Methodology, 73, 499-529.

Gjika, D., & Horváth, R. (2013). Stock market comovements in Central Europe: Evidence from the asymmetric DCC model. Economic Modelling, 33, 55-64.

Gower, J. C. (1966). Some distance properties of latent root and vector methods used in multivariate analysis. Biometrika, 53, 325-338.

Graham, M., Kiviaho, J., Nikkinen, J., & Omran, M. (2013). Global and regional co-movement of the MENA stock markets. Journal of Economics and Business, 65, 86–100.

Huang, W., Yan, J., & Deng, T. (2017). An empirical study of contagion effect from American and European stock markets to Chinese stock markets based on the subprime crisis and the European debt crisis. Systems Engineering-Theory & Practice, 37, 1982-1991.

Jach, A. (2017). International stock market comovement in time and scale outlined with a thick pen. Journal of Empirical Finance, 43, 115-129.

Ji, Q., & Fan, Y. (2016). Evolution of the world crude oil market integration: A graph theory analysis. Energy Economics, 53, 90-100.

Johnson, R., & Soenen, L. (2003). Economic integration and stock market comovement in the Americas. Journal of Multinational Financial Management, 13, 85-100.

Lee, H., & Cho, S. M. (2017). What drives dynamic comovements of stock markets in the Pacific Basin region?: A quantile regression approach. International Review of Economics & Finance, 51, 314-327.

Lehkonen, H., & Heimonen, K. (2014). Timescale-dependent stock market comovement: BRICs vs. developed markets. Journal of Empirical Finance, 28, 90-103.

Li, H., & He, M. (2017). The spillover effect and international influence of china's stock

market: Based on the Copula-DCC-GARCH model. Journal of Systems Science and Mathematical Sciences, 37, 1790-1806.

Lucey, B. M., & Zhang, Q. (2010). Does cultural distance matter in international stock market comovement? Evidence from emerging economies around the world. Emerging Markets Review, 11, 62-78.

Mantegna, R. N. (1999). Hierarchical structure in financial markets. European Physical Journal B, 11, 193-197.

Prim, R. C. (1957). Shortest connection networks and some generalizations. Bell System Technical Journal, 36, 1389-1401.

Rao, J., Wang B., & Tang M. (2019). Research on the co-movement of chinese and american stock markets before and after the trade war. Journal of Quantitative Economics. 36(4), 8-13.

Rua, A., & Nunes, L. C. (2009). International comovement of stock market returns: A wavelet analysis. Journal of Empirical Finance, 16, 632-639.

Schweitzer, F., Fagiolo, G., Sornette, D., Vega-Redondo, F., Vespignani, A., & White, D. R. (2009). Economic networks: the new challenges. Science, 325, 422-425.

Xu, Q., Wang, X., Jiang, C., & Xiong, X. (2018). Investigating risk spillover effects among stock markets: A vine copula-CAViaR approach. Systems Engineering-Theory & Practice, 38, 2738-2749.

RUIYAN (VIVI) MA

maruiyan20021122@126.com **+ 86-18210181368**

EDUCATION

Beijing No.4 High School International Campus (BHSFIC) Sep. 2018 - Present

Beijing No.8 Middle School Sep. 2017 – Jun. 2018

Online course on edX of "From Poverty to Prosperity: Understanding Economic Development" 2020

Learned and visited the United States 2019

- Had classes in Shady Side Academy, Pittsburgh, Pennsylvania, the United States
- Lived in an American family for three weeks
- Visited universities and colleges in California for one week

AWARDS AND HONORS

Seventh place (National) in Future Business Leader of America Cyber Security 2019 - 2020

Eighth place (National) in Future Business Leader of America Entrepreneurship **2019 - 2020**

1st Prize (National (Preliminary Round)) in Future Business Leader of America Global Business **2018 - 2019**

Bronze Award in Canadian Open Mathematics Challenge **2018**

Best Marketing Manager (School) in MicroBiz! Business Simulation Campus Challenge **2018**

Excellent Student Leader of Beijing No.4 High School International Campus **2018 – 2019**

Excellent Volunteer of Beijing No.8 Middle School **2017**

LEADERSHIP EXPERIENCE

Future Business Leader of America (FBLA)

Function Leader of Beijing Aug, 2020 - Present

- Design activities and contribute great ideas
- Assist President and Vice President and work together with the other two Function Leader of Beijing

President of BHSFIC Chapter Sep. 2019 – Sep. 2020

- Organized activities for the meeting of each week
- Organized commune members to actively participate in the national competition of FBLA in Shanghai by giving guidance and help and our school have won many awards

Member of BHSFIC Chapter Sep. 2018 – Sep. 2019

- Actively participated in activities in every meeting

the Student Union

Member of the Study Department of BHSFIC Sep. 2018 – Sep. 2020

- Designed and organized activities with other members
- Provided platform for students to seek help from senior students academically

President of Beijing No.8 Middle School Sep. 2017 – Jun. 2018

- Organized activities such as a bazaar and donated the money that was earned to a poor school
- Assisted teachers to finish various work

Editorial Office

Team Leader of Beijing No.8 Middle School Sep. 2015 – Jun. 2018

- Led a team of three students and assigned things that team members needed to do
- Wrote articles, edited, and composed for the school newspaper and made it popular again

RESEARCH

Shing-Tung Yau High School Science Award of Mathematics 2020

- Write an essay about information spillover of stock returns across G20 countries: evidence from a novel directional tree approach

A research project about statistics and probability 2019

- Listened to lectures of Professor Jiangang Ying from Fudan University online for two months
- Wrote two papers, one was a brief introduction about mathematical expectation and variance, the other was about application in competition design

EXTRACURRICULAR ACTIVITIES

Capital Museum

Commentator Sep. 2016 - Present

- Serve as a commentator of Dayuan Three Capital and Old Beijing Folk Custom Exhibition

Basketball Varsity

Member of BHSFIC Sep. 2019 - Present

- Have basketball classes for one and a half hour every week
- Practice with the varsity
- Represent our school to compete with other schools

The 38th Beijing Marathon

Volunteer 16th Sep., 2018

- Helped participants who were in need and cheered for them

INTERNSHIP

Industrial and Commercial Bank of China (ICBC) Credit Suisse Investment Management Co., Ltd 2019

- Collated documents and collected typical cases
- Learned knowledge about Asset Backed Securitization, company related Law, human resource...

SKILLS AND INTERESTS

Language: Fluent in Mandarin and English

Interests: Watching films, Travelling

Sports: Basketball, Badminton, Table Tennis, Tennis, Squash, Running (Fifth Place in the 100 meters competition of Beijing No.8 Middle School sports meet)

Arts:

Piano:

- Passed Level 9 of Chinese Musicians' Association
- Hosted a warm-up piano show which was the opening ceremony of a 4-day cultural exchange activity between Chinese and European artists, called "The Road of The Masters" in the Forbidden City Concert Hall

Drama:

- Joined the Drama Club in Beijing No.8 Middle School and practiced every week
- Performed in a play in the graduation ceremony

QI QI

15711196233@163.com

ACADEMY

Beijing No.2 Railway middle school **Grade 9**

Beijing No.4 High School International Campus **Grade 10-12**

Ross Mathematics Camp **Online Summer School in 2020**

RESEARCH

Research and development on a new medium ratio for tissue culture of succulents

Nov. 2018-Jun. 2019

LEADERSHIP

Contact person between school and Zhixing Foundation Apr. 2019-present

VOLUNTEER

Mentorship program, BHSFIC Sept. 2019-Dec. 2019

Investigation on Distribution of Common Swift (Apus apus pekinensis) over Beijing city

Mar. 2019- Jul. 2019

INTERNSHIP

Beijing University School of Medicine, properties of nucleoside

20th Aug., 2019-24th Aug., 2019

Complete six basic experiment under instructions of the professor.

QIUWAN ZHAO (BRENA)

Zhaoqiuwan2003@163.com **+86 18010156963**

EDUCATION

BEIJING NO.4 HIGH SCHOOL (INTERNATIONAL CAMPUS) Sept. 2019-Present

BEIJING NO.4 HIGH SCHOOL (MAIN CAMPUS) Sept. 2018-Jun. 2019

BEIJING SANFAN MIDDLE SCHOOL Sept. 2015-Jun. 2018

COURSERA: SOCIAL PSYCHOLOGY Aug. 2020-Sept. 2020

RESEARCH

PIONEER RESEARCH (MUSIC): author Feb. 2020-Jul.2020

- Compared different performances, did the harmonic analysis, and wrote an analytical paper on Carl Czerny's Variations on a Theme by Rode, Op.33.
- Taught by Prof. Lubben from Oberlin College Conservatory, earned an A on the final report, and gained two college credits.

INFORMATION SPILLOVER OF STOCK RETURNS: Co-author

Aug. 2020-Oct. 2020

- Proposed a novel directional minimum spanning tree approach to comprehensively analyze the relationship between the stock markets of G20 countries from 2007 to 2020, especially during the coronavirus outbreak.
- Coordinated between the team members, did data analysis, and wrote a significant part of the paper to compete for S. -T. Yau High school Science Award.

THE EFFECT OF EATING IN STRESS ALLEVIATION: Author

Mar. 2020-Jul. 2020

- Contrived a case study to examine the factors conducive to stress alleviation in eating.
- Collected data from 24 subjects, did the fundamental analysis and drew correlative conclusions.

HOBBY AND INTEREST

FIGURE SKATING: Single and synchronized skater Aug. 2016-Present

- Receive professional single skating training and reach Advanced Novice level in the moves test.
- Skate as a key member in the Golden Flowers Synchronized Skating Team.
- Won the first place in Juvenile in 2018 and the second place in junior in 2019 in Chinese Figure Skating Interclub League.

CHORUS: Piano accompanist and alto voice singer Sept. 2015-Present

- Represented the school's chorus to attend significant school ceremonies and flash mobs.
- Recomposed several songs and led the members to do vocal exercises before rehearsals.
- Earned the Best Instrumental Accompanist Award in BHSF Choral Festival.

PIANO: Solo pianist Nov. 2007-Present

- Hold concerts every year to show progress and achievements.
- Passed the highest level of the Central Conservatory of Music's piano grade examination in primary school.
- Earned the first prize in 2017 Asia International Arts Competition (Taiwan)

FLUTE: The chief flutist Sept. 2009-Jun. 2018

- Played the national anthem and school song on the flag raising ceremony every week.
- Represented the school's symphonic band to attend Beijing Arts Festival and earned the second prize.

EXTRA-CURRICULUM

WE-MEDIA ON FIGURE SKATING: Founder and editor Mar. 2020-Present

- Set up the official account "Devotees" on WeChat Media and write articles about personal training experiences and skating fundamentals to promote figure skating.

BHSF PHYSICS TEAM: Devoted member Sept. 2018-Jun. 2019

- Joined the school team as one of the top students in physics. (40 out of 490)
- Prepared for the Chinese Physics Olympiad and represented the school to attend two major competitions.

USAD: Key member Sept. 2019-May. 2020

- Ranged online meetings and assigned weekly tasks for team members.
- Designed numerous study guides and introduced knowledge in Mathematics, Music, and Economics to the team.

A CUP OF COFFEE: Star translator Feb. 2020-Present

- Selected, translated, and publicized seven articles related to psychology.
- Engage in discussions about the translated articles and gave suggestions to the translator.

JINFAN DAY: Prominent Singer Sept. 2018-Present

- Visited multiple communities and sang for the inhabitants.
- Taught the local students to sing traditional Chinese songs.

PUBLIC SHOW: Lead Dancer Dec. 2010-Dec. 2016

- Danced with members of the JZS dance club for the public twice a year.
- Raised money from the tickets to help the disadvantaged children in villages in Hebei Province.

HONOR

Excellent League Member Award May. 2019

- Given to the top 5% League members who are academically and morally outstanding.

Model in Academics, Sports, and Volunteering May. 2019

- Award students who showed extraordinary achievement in academics, sports, and volunteering.

China Daily "21st Century Saixue Cup" High School English Writing Conference Beijing Regional Final 1st Prize Dec. 2019

FLTRP Cup National English Competition for Schools Beijing Regional 2nd Prize Jun. 2019

AP Scholar with Distinction Award May. 2020

USAD North China Regional Award in Music and Team Score Apr. 2020

KUN GUO

Associate Professor
Research Center on Fictitious Economy & Data Science,
Chinese Academy of Sciences

86-010-82680927, 86-13810439286
guokun@ucas.ac.cn
No.80 ZhongGuanCun East Road,
Haidian District, Beijing, 100190, China

RESEARCH INTRESETS

Financial market,
Agent-based model,
Complex science,
Big data analysis.

ACADEMIC EMPLOYMENT

2017.12–present: Associate Professor, Research Center on Fictitious Economy & Data Science, Chinese Academy of Sciences
2013.12–2017.11: Assistant Professor, Research Center on Fictitious Economy & Data Science, Chinese Academy of Sciences
2011.11–2013.11: Post Doctor, University of Chinese Academy of Sciences.

OTHER EMPLOYMENT

2016-present: Secretary General, Business Intelligence Society, Chinese Academy of Management
2017-present: Secretary General, Cheng Siwei Fund, University of Chinese Academy of Sciences Education Foundation

EDUCATION

2006.09–2011.7: Ph.D., University of Chinese Academy of Sciences, China, majoring in Management Science and Engineering
2002.09–2006.06: B.S., Beijing Normal University, China, majoring in Management Science

AWARDS & HONORS

2019: Best Paper Award, rewarded by 7th International Conference on Information Technology and Quantitative Management

2017: Best Paper Award, rewarded by 7th International Conference on Information Technology and Quantitative Management

2013: Best Paper Award, rewarded by 2013 International Conference on Computational Science

MAJOR RESEARCH PROJECTS

Analysis of China Stock Market Evolution based on Dissipative Stock System Theory Model. **National Natural Science Foundation of China**, 2016-2018, PI.

Research on Performance Evaluation of NSFC in Program Level. **National Natural Science Foundation of China**, 2011-2012, PI.

The dynamic correlation between stock market and monetary policy based on TEI@I methodology. **Special Support from the National Postdoctoral Fund**, 2013-2014, PI.

Financial Risk Management & Performance Evaluation. **Beijing Shixin Holdings**, 2016-2017, PI.

Research on construction of economic index. **China Economic Information Service**, 2017-2020, PI.

Xinhua Silk Road National Data Platform consulting project. **China Economic Information Service**, 2018-2020, PI.

MAJOR REFEREED ARTICLES

(IN ENGLISH, * CORRESPONDING AUTHOR)

[1]. Guo Kun, Zhou Weixing*, Cheng Siwei, Sornette Diddier, The US Stock Market Leads the Federal Funds Rate and Treasury Bond Yield s, PLoS ONE, 2011, 6(8): e22794. doi:10.1371/journal.pone.0022794

[2]. Wang Xuan, Guo Kun*, Lu Xiaolin, The long-run dynamic relationship between exchange rate and its attention index: Based on DCCA and TOP method, Physica A: Statistical Mechanics and its Applications, 2016, 453: 108-115

[3]. Lu Xiaolin, Tian Xin, Guo Kun. Study on the interactive mechanism of economic growth, inflation and capital markets using dynamic Bayesian factor graph. African Journal of Business Management, 2016, 10(12): 298~307.

[4]. Lu Xiaolin*, Guo Kun, Dong Zhi, Wang Xuan, Financial development and relationship evolvement among money supply, economic growth and inflation: a comparative study from the US and China, Applied Economics, 2017, 49(10): 1032-1045

[5]. Lai Lin, Guo Kun*, The performance of one belt and one road exchange rate: Based on improved singular spectrum analysis, Physica A: Statistical Mechanics and its Applications, 2017, 483: 299-308

[6]. Guo Kun, Yi Sun*, Xin Qian. Can investor sentiment be used to predict the stock price? Dynamic analysis based on China stock market, Physica A: Statistical Mechanics and its Applications, 2017, 469: 390-396

[7]. An Na, Wang Baixue, Pan Peilin, Guo Kun*, Sun Yi*, Study on the influence mechanism of air quality on stock market yield and Volatility: Empirical test from China based on GARCH model, Finance Research Letters, 2018, 26, 119-125.

[8]. Li Wei, Guo Kun*, Shi Yong*, Zhu Luyao, Zheng Yuanchun, DWWP: Domain-specific new words detection and word propagation system for sentiment analysis in the tourism domain. Knowledge-Based Systems, 2018, 146, 203-214.

[9]. Sun Yi, Jin Quan, Cheng Qing, Guo Kun*, New tool for stock investment risk management: Trend forecasting based on individual investor behavior, Industrial Management & Data Systems, 2019, 120(2): 388-405.

[10]. Liao Zhewen, Wang Zhongxing, Guo Kun*, The dynamic evolution of the characteristics of exchange rate risks in countries along "The Belt and Road" based on network analysis, PloS One, 2019, 14(9) : e0221874.

[11]. Shi Yong, Zhu Luyao, Li Wei*, Guo Kun*, Zheng Yuanchun, Survey on classic and latest textual sentiment analysis articles and techniques, International Journal of Information Technology & Decision Making, 2019, 18(04): 1243-1287.

[12]. Jin Zhenni, Guo Kun*, Sun Yi*, Lai Lin, Liao Zhewen, The Industrial Asymmetry of the Stock Price Prediction with Investor Sentiment: based on the comparison of predictive effects with SVR, Journal of Forecasting, 2020, accepted, DOI: 10.1002/for.2681.

[13]. Shi Yong, Zheng Yuanchun, Guo Kun*, Jin Zhenni, Huang Zili. The Evolution Characteristics of Systemic Risk in China's Stock Market Based on a Dynamic Complex Network, Entropy 2020, 22, 614.

[14]. Li Wei, Zhu Luyao, Shi Yong, Guo Kun, Cambria Erik. User reviews: Sentiment analysis using lexicon integrated two-channel CNN–LSTM family models, Applied Soft Computing, 2020, 94, 106435.

[15]. Zhu Luyao, Li Wei, Shi Yong, Guo Kun, SentiVec: Learning Sentiment-Context Vector via Kernel Optimization Function for Sentiment Analysis, IEEE Transactions on Neural Networks and Learning Systems, 2020, doi: 10.1109/TNNLS.2020.3006531.

XIAOLEI SUN

Professor
Institutes of Science and Development,
Chinese Academy of Sciences

86-010-59358802, 86-18600261924
xlsun@casisd.cn, sxltracy@163.com
No.15 ZhongGuanCunBeiYiTiao Alley,
Haidian District, Beijing, 100190, China

RESEARCH INTRESETS

Energy security, energy finance, energy planning
Country risk, sovereign risk
Risk correlation modelling, risk management
Strategic planning, decision making

ACADEMIC EMPLOYMENT

2019.08–present: Professor, Institutes of Science and Development, Chinese Academy of Sciences
2016.01–2019.07: Associate Professor, Institutes of Science and Development, Chinese Academy of Sciences
2013.11–2015.12: Associate Professor, Institute of Policy and Management, Chinese Academy of Sciences
2010.01–2013.10: Assistant Professor, Institute of Policy and Management, Chinese Academy of Sciences

OTHER EMPLOYMENT

2016-present: Member, Center for Energy and Environmental Policy Research, Institutes of Science and Development, Chinese Academy of Sciences
2016-present;Visiting Professor, University of Chinese Academy of Sciences, China
2013-present: Assistant to the Dean, Institute of Qinghai Innovation and Development
2011-Present: Secretaries-general of Youth Branch, Chinese Society of Optimization, Overall Planning and Economical Mathematics.
2011-Present: Member ,Youth Innovation Promotion Association of the Chinese Academy of Sciences

EDUCATION

2004.09–2009.12: Ph.D., University of Chinese Academy of Sciences, China, majoring in Management Science
2000.09–2004.06: B.S., Hefei University of Technology, China, majoring in Information system

AWARDS & HONORS

2018: China Youth Science and Technology Award on Decision Science, rewarded by Decision Science Branch of Operations Research Society of China

2018: Study on the development strategy of Qinghai's science and technology during the period of the 13th Five-Year Plan, rewarded by Qinghai second-class Provincial scientific awards

2018: Best Paper Award, rewarded by 2018 International Conference on Energy Finance

2013-2016: Youth Innovation Promotion Association Program, sponsored by Chinese Academy of Sciences

2013: Study on major strategic problems of Qinghai's science and technology development, rewarded by Qinghai second-class Provincial scientific awards

2012: Optimization theory and applications in credit scoring, rewarded by Beijing second-class Provincial scientific awards

2009: Prize of President Scholarship of the Chinese Academy of Sciences

MAJOR RESEARCH PROJECTS

Correlation Feature and measurement on country risk. **National Natural Science Foundation of China**, 2018-2021, PI.

Risk Management and Scenario Planning of Key Raw Materials in Strategic Emerging Industries, **National Development and Reform Commission**, 2018-2019, PI.

Monitoring and early warning of country risk along the Belt and Road. Supported by President's Youth Foundation of the Institutes of Science and Development, **Chinese Academy of Sciences.** 2017-2019. PI.

Risk Contagion mechanism in Energy and Resource Security. **National Development and Reform Commission**. 2016-2017, PI.

Systematic risk aggregation and optimization in China's oil importing. **National Natural Science Foundation of China**, 2014-2017, PI.

Oil-importing risk control and optimization strategy: in the paradigm of correlation. **National Natural Science Foundation of China**, 2012-2016, Co-PI.

Study on Risk management and optimization strategy on the utilization of global oil resources. Supported by Key project of Institute of Policy and Management, **Chinese Academy of Sciences**, 2012-2016. PI.

Theory and Method of Risk Management, **National Natural Science Foundation of China**, 2015-2019. Co-investigator.

Research on Management Theory and Implementation Mechanism of Social Credit System Construction, **National Natural Science Foundation of China**, 2012-2016. Co-investigator.

Strategic planning of Characteristic Bio-innovation Clusters in Qinghai Province, **Qinghai Science & Technology Department**, 2017-2018. Co-PI.

Key Issues in Implementing Qinghai Province's Innovation Driven Development Strategy, **Qinghai Science & Technology Department**, 2017-2018. Co-PI.

Planning of Scientific and Technological Development in Qinghai Provence during the 13th Five-year Plan, **Qinghai Science and Technology Department**, 2015. Co-investigator.

Development Strategy of Science and Technology in Qinghai Province during the 13th Five-year Plan, **Qinghai Science and Technology Department**, 2014-2015. Co-investigator.

MAJOR REFEREED ARTICLES

(IN ENGLISH, * CORRESPONDING AUTHOR)

[16]. Jianping Li, Yuyao Feng, Guowen Li, Xiaolei Sun*, 2020. Tourism companies' risk exposures on text disclosure. *Annals of Tourism Research*, 84: 102986.

[17]. Jun Hao., Jianping Li., Dengsheng Wu., Xiaolei Sun*, 2020. Portfolio optimisation of material purchase considering supply risk – A multi-objective programming model. *International Journal of Production Economics*, 230: 107803.

[18]. Jun Wang, Xiaolei Sun*, Jianping Li, 2020. How do sovereign credit default swap spreads behave under extreme oil price movements? Evidence from G7 and BRICS countries. *Finance Research Letters,* 34: 101350.

[19]. Yinhong Yao, Jianping Li, Xiaolei Sun*, 2020. Measuring the risk of Chinese Fintech industry: evidence from the stock index. *Finance Research Letters*, 101564.

[20]. Chang Liu, Jianping Li, Xiaolei Sun*, Jianming Chen, 2020. Multi scale interactions between Turkish lira exchange rates and sovereign CDS in Europe and Asia. *Applied Economics Letters*. https://doi.or/10.1080/13504851.2020.1765961.

[21]. Xiaolei Sun, Jun Wang, Yanzhen Yao, Jingyu Li, Jianping Li*, 2020. Spillovers among Sovereign CDS, Stock and Commodity Markets: A Correlation Network Perspective. *International Review of Financial Analysis*, 68:101271.

[22]. Xiaolei Sun, Chang Liu, Jun Wang, Jianping Li*, 2020. Assessing the extreme risk spillovers of international commodities on maritime markets: A GARCH-Copula-CoVaR approach. *International Review of Financial Analysis*, 68: 101453

[23]. Yao Xiaoyang, Lewei, Sun Xiaolei*, Li Jianping, 2020. Financial stress dynamics in China: An interconnectedness perspective. *International Review of Economics & Finance*, 68: 217-238.

[24]. Xiuwen Chen, Xiaolei Sun*, Jianping Li, 2020. How does economic policy uncertainty react to oil price shocks? A multi-scale perspective. *Applied Economics Letters*, 27(3):188-193.

[25]. Weilan Suo, Jin Zhang, Xiaolei Sun*, 2019. Risk assessment of critical infrastructures in a complex interdependent scenario: A four-stage hybrid decision support approach. *Safety Science*, 120:692-705.

[26]. Xiuwen Chen, Xiaolei Sun*, 2019. Dynamic spillover effect between oil prices and economic policy uncertainty in the BRIC countries: A wavelet-based approach. *Emerging Markets Finance and Trade*, 55:12, 2703-2717.

[27]. Qiang Ji, Jianping Li, Xiaolei Sun*, 2019. Measuring the interdependence between investor sentiment and crude oil returns: New evidence from the CFTC's disaggregated reports. *Finance Research Letters*, 30: 420-425.

[28]. Qiang Ji, Jianping Li, Xiaolei Sun. New Challenge and Research Development in Global Energy Financialization. *Emerging Markets Finance and Trade*, 2019, 55(12): 2669-2672.

[29]. Lu Wei, Guowen Li, Xiaoqian Zhu, Xiaolei Sun, Jianping Li. Developing a hierarchical system for energy corporate risk factors based on textual risk disclosures. *Energy Economics*, 2019, 80: 452-460.

[30]. Xiaoyang Yao, Jianping Li, Xiaolei Sun*, Dengsheng Wu, 2018. Insights into tolerability constraints in multi-criteria decision making: Description and modeling. *Knowledge-Based Systems*, 162:136-146.

[31]. Jianping Li, Xiaoyang Yao, Xiaolei Sun*, Dengsheng Wu, 2018. Determining the fuzzy measures in multiple criteria decision aiding from the tolerance perspective. *European Journal of Operational Research*, 264:428-439.

[32]. Jun Wang, Xiaolei Sun*, Jianping Lib, Jianming Chen, Chang Liu. 2018. Has China's oil-import portfolio been optimized from 2005 to 2014? A perspective of cost-risk tradeoff. *Computers & Industrial Engineering*, 126: 451–464.

[33]. Xiaolei Sun*，Chang Liu，Xiuwen Chen，Jianping Li, 2017. Modeling systemic risk of crude oil imports: Case of China's global oil supply chain. *Energy*, 121: 449-465.

[34]. Xiaolei Sun*，Xiaoyang Yao，Jun Wang, 2017. Dynamic interaction between economic policy uncertainty and financial stress: A multi-scale correlation framework. *Finance Research Letters*, 21: 214-221.

[35]. Chang Liu, Xiaolei Sun*, Jianming Chen, Jianping Li, 2016. Statistical properties of country risk ratings under oil price volatility: Evidence from selected oil-exporting countries. *Energy Policy*, 92: 234-245.

[36]. Yuying Yang, Chang Liu, Xiaolei Sun*, Jianping Li, 2015. Spillover effect of international crude oil market on tanker market. *International Journal of Global Energy Issues*, 38:257-277.

[37]. Jianping Li, Xiaolei Sun*, Fei Wang, Dengsheng Wu, 2015. Risk integration and optimization of oil-importing maritime system: A multi-objective programming approach. *Annals of Operations Research*, 234(1):57-76.

[38]. Xiaolei Sun, Ling Tang, Yuying Yang, Dengsheng Wu, Jianping Li, 2014. Identifying the dynamic relationship between tanker freight rates and oil prices: in the perspective of multiscale relevance. *Economic Modelling*, 42: 287-295.

[39]. Xiaolei Sun, Jianping Li, Yongfeng Wang, Woodrow W. Clark, 2014. China's sovereign wealth fund investments in overseas energy: The energy security perspective. *Energy Policy*, 65: 654-66.

[40]. Jianping Li, Ling Tang, Xiaolei Sun *, Dengsheng Wu, 2014. Oil-importing optimal decision considering country risk with extreme events: A multi-objective programming approach. *Computers & Operations Research*, 42:108-115.

[41]. Yuying Yang, Jianping Li, Xiaolei Sun *, Jianming Chen, 2014. Measuring external oil supply risk: A modified diversification index with country risk and potential oil exports. *Energy*, 68:93-938.