Correlation Analysis of International Debt Based on Complex Networks

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Abstract: The scale of national debts is closely related to the country's economic development and people's living standards. A proper debt scale can promote a country's economic development, but a high debt level will also lead a country in trouble, even affecting other regions. After the subprime crisis and the European debt crisis, the debt scale of many countries has greatly expanded, and the severity of the debt problem became prominent in one crisis after another. As economic globalization is becoming an inevitable trend in today's world, the national debt and financial conditions of various countries are becoming more closely related. Therefore, this paper adopts the method of complex networks, calculates the rate of change and correlation through the annual total debt of each country from the macro perspective, studies the mutual influence of the total debt level of each country and region.   We have finally drawn the following main conclusions: the countries within the euro area have strong interconnection, and the euro area as a whole has significant impacts on other countries/regions in the national debt market.

1. Introduction

During the subprime crisis in 2008, in order to deal with the huge economic shock and stabilize the domestic economic situation, governments of various countries implemented proactive fiscal policies, which led to higher debt levels. According to data released by the International Monetary Fund, after the subprime crisis, the debt level of developed economies increased by 17.00%, the debt level of EU countries increased by 15.47%, the debt of European developing countries increased by 23.35%, and the total debt level of G7 countries increased by 16.79%. The debt scale of some European countries/regions is far beyond their ability to repay, leading to the occurrence of debt failure or delay, especially for Greece and Ireland. The debt level of Greece has increased by more than 15% for two consecutive years since 2008, and reached a growth rate of 24.66% in the third year (2011). Ireland's debt growth rate was at 45.08% in 2009, followed by 39.53% and 29.18% in the next two years, which topped the euro area. Debt levels in eurozone countries have remained high since 2011, affected by Greece and Ireland. Since 2020, the COVID-19 pandemic has severely impacted the real economy of various countries. In order to maintain the stability of the economy, countries/regions have issued a large number of national debts. The global debt scale is expected to increase by 16.33%. Individual developing countries/regions, such as the Russian Federation and Saudi Arabia, even more than 40%, developed economies, 15.75%, and oil producers, 29.28%. Rising debt levels will inevitably lead to higher debt risks, once again exacerbating the countries' debt problems. Under the circumstance of cultural and economic diversification, economic globalization has become an inevitable trend. As a community with a shared future, different countries/regions in the world interact with each other. The prosperity of one country/region will bring positive impetus to other regions, and the economic crisis of one country/region will inevitably affect other countries/regions. For example, during the subprime crisis in 2008, the economic impact of the US stock market also spread to the Asia-pacific stock market and even the global financial market. During the European debt crisis in 2011, the debt problem of one country escalated into the debt crisis of the entire European Union, which led to the biggest dilemma in the history of the eurozone economy. Therefore, it is of great academic and practical significance to

study the debt level and risk level of countries in the COVID-19 aftermath, as well as the correlation between debt problems among countries/regions, in the context of the increasingly close economic situation of countries around the world.

2. Literature review

There are many existing research reports on national debts in academia. Bornstein and Dovis [1] (2019) used Eaton and Gers Ovitz's [2] (1981) model's quantitative version to analyze the European debt crisis and showed that matching the periodicity of public debt rather than external debt enables the model to better capture the empirical distribution of interest rate differentials and produce more realistic crisis dynamics. Outmost [3] (2018) analyzed the dynamic interdependence of credit default swap spreads among several EU countries from October 2004 to July 2016, indicating that the interdependence of credit risks among countries was heterogeneous in terms of time, and the credit risk transmission amplitude of some countries/regions is greater than those of others. Chebbi and Naoi [4] (2014) listed the influence of Greece on other countries/regions in the European debt crisis proposed by scholars in the past, studied the infectiousness of debt problems in the European debt crisis by using the method of dynamic conditional correlation, and then explained the extent to which market and macroeconomic indicators would produce contagion. Mutunga[5](2021) utilized employee autoregressive distributed lag model to study the situation of increasing debt scale caused by debt repayment in Kenya, pointed out that external debt had a positive impact on public investment in the short term but then gradually led to a negative impact in the long term, and put forward suggestions on the reorganization of foreign investment in Kenya. Kassouri, Altinatas, Alancioglu and Kacou [6] (2021) used interactive fixed effects and dynamic panel threshold methods to estimate the threshold effect of public debt on economic growth while considering cross-sectional dependence, time-varying unobserved heterogeneity, and feedback effects. An empirical application based on a sample of 62 emerging and developing countries from 2000 to 2018 showed an inverted U-shaped relationship between debt and growth in emerging and developing countries. Arsic, Mladenovic, and Zorica [7] (2019) examined the impact of public debt uncertainty on the economic growth of 10 European emerging economies from 2000 to 2015. Based on quarterly data and using time series and panel data, this paper empirically analyzed the impact of public debt uncertainty on economic growth. The paper's key findings showed that uncertainty over public debt had a significant adverse impact on GDP growth in emerging Europe, particularly during the "Great Recession" that began in 2008. Campos and Cysne[8](2021) pointed out that the relationship between sovereign risk and debt level is an important guide to evaluate the probability of debt default. The study provided debt limits for 18 emerging countries. The study's main conclusion was that countries with debt-to-gross domestic product ratios above their limits either struggled to secure new loans to finance their debt or needed help from international institutions. Conor and Slaymaker [9] (2021) explored the changing relationship between current household solvency and mortgage defaults in Ireland during crisis and non-crisis periods.

To sum up, relevant papers highlighted the urgency and severity of the debt problem and demonstrated the importance of the research on national debts by studying the impact of national debt on national/regional economic development and the correlation of national debt in various countries/regions during the financial crisis. However, most of the existing researches on debt issues are limited to a single country or region, while the impact of COVID-19 is global, and each country is affected and greatly impacted by each other. Therefore, it is of great academic and practical significance to study the correlation and mutual influence of debt problems among countries/regions worldwide.

3. Data

This paper selects samples from some countries/regions of G20, EU, ASEAN and OPEC to analyze the correlation between debt scale of each country. Among them, the debt scale of sample countries is

represented by the proportion of total national debt to GDP, which is the annual data. The sample interval is from 2001 to 2020, and the data is from the International Monetary Fund.

The debt scale data covers 61 countries/regions. In order to ensure the stability of the data, the rate of change is firstly calculated on the basis of the original data, and the correlation between countries/regions is studied using the rate of change in the following paper. The descriptive statistics of 61 sample data are shown in Table 1.

Table 1. Descriptive statistics of 61 sample data

	Average	Median	Variable Coefficient	Standard Deviation	Minimum	Maximum	Sample Size
AGO	0.0569	0.1236	0.1130	0.3361	-0.4403	0.7943	19
ARE	0.1900	0.1165	0.1291	0.3593	-0.2449	1.3618	19
ARG	0.1041	0.0276	0.2571	0.5071	-0.3189	2.0663	19
AUS	0.0810	0.1075	0.0236	0.1535	-0.1235	0.4170	19
AUT	0.0153	-0.0029	0.0047	0.0689	-0.0581	0.2086	19
BEL	0.0045	-0.0170	0.0028	0.0532	-0.0456	0.1727	19
BRA	0.0204	0.0162	0.0045	0.0670	-0.0631	0.1647	19
CAN	0.0233	-0.0001	0.0090	0.0949	-0.0530	0.3573	19
CHE	-0.0076	0.0010	0.0029	0.0538	-0.1170	0.1289	19
CHN	0.0570	0.0408	0.0068	0.0826	-0.0687	0.2728	19
COD	-0.0964	-0.1211	0.0371	0.1926	-0.6650	0.2385	19
COG	0.0077	-0.0102	0.0782	0.2796	-0.4813	0.7529	19
CYP	0.0461	0.0327	0.0169	0.1300	-0.1698	0.2965	19
DEU	0.0111	-0.0095	0.0042	0.0645	-0.0603	0.1556	19
DZA	0.0519	0.0078	0.1487	0.3856	-0.4286	1.3382	19
ECU	0.0167	-0.0470	0.0293	0.1711	-0.2336	0.3517	19
EGY	0.0103	0.0181	0.0071	0.0844	-0.1256	0.1385	19
ESP	0.0481	-0.0061	0.0154	0.1239	-0.0845	0.3412	19
EST	0.1106	-0.0106	0.1147	0.3386	-0.1870	1.1920	19
FIN	0.0299	-0.0027	0.0079	0.0889	-0.1077	0.2755	19
FRA	0.0370	0.0249	0.0033	0.0572	-0.0411	0.2074	19
GAB	0.0215	-0.0091	0.0561	0.2369	-0.4889	0.4510	19
GBR	0.0635	0.0254	0.0074	0.0862	-0.0062	0.2811	19
GNQ	0.4560	-0.0917	3.5415	1.8819	-0.6548	7.8873	19
GRC	0.0399	0.0143	0.0078	0.0882	-0.1191	0.2466	19
HKG	0.0857	-0.0665	1.0284	1.0141	-0.8743	4.1731	19
IDN	-0.0315	-0.0579	0.0097	0.0985	-0.1698	0.1982	19
IND	0.0083	-0.0041	0.0035	0.0589	-0.0711	0.2121	19
IRL	0.0546	-0.0313	0.0629	0.2508	-0.2661	0.7751	19
IRN	0.1133	-0.0061	0.2803	0.5295	-0.2223	2.1998	19
ITA	0.0198	0.0020	0.0019	0.0441	-0.0267	0.1561	19
JPN	0.0309	0.0283	0.0011	0.0332	-0.0220	0.0995	19
KHM	-0.0023	0.0063	0.0059	0.0767	-0.1672	0.1399	19
KOR	0.0582	0.0555	0.0044	0.0665	-0.0283	0.1621	19
KWT	0.0041	-0.1472	0.1821	0.4268	-0.3177	1.1530	19
LAO	-0.0142	0.0019	0.0064	0.0797	-0.1803	0.1028	19
LTU	0.0578	-0.0218	0.0575	0.2398	-0.1438	0.9196	19
LUX	0.0801	0.0345	0.0444	0.2107	-0.0861	0.8726	19
LVA	0.0961	-0.0338	0.1439	0.3793	-0.1849	1.2188	19

MEX	0.0249	0.0214	0.0040	0.0632	-0.0784	0.1421	19
MLT	-0.0081	-0.0284	0.0091	0.0955	-0.1064	0.3201	19
MMR	-0.0868	-0.0567	0.0120	0.1096	-0.2723	0.0539	19
MYS	0.0330	0.0159	0.0057	0.0755	-0.0282	0.2807	19
NGA	0.0158	0.0405	0.0800	0.2829	-0.5035	0.8557	19
NLD	0.0096	0.0026	0.0081	0.0899	-0.0921	0.2815	19
NZL	0.0285	-0.0250	0.0187	0.1366	-0.1146	0.2894	19
PAK	0.0062	-0.0033	0.0053	0.0728	-0.1018	0.1870	19
PHL	-0.0087	-0.0149	0.0081	0.0898	-0.1228	0.2733	19
PRT	0.0505	0.0440	0.0042	0.0647	-0.0408	0.1607	19
RUS	-0.0236	-0.0286	0.0403	0.2008	-0.3398	0.4018	19
SAU	0.0903	-0.2285	0.5732	0.7571	-0.4360	2.7132	19
SGP	0.0178	0.0184	0.0035	0.0589	-0.0802	0.1755	19
SVK	0.0153	-0.0282	0.0141	0.1188	-0.1674	0.2714	19
SVN	0.0733	0.0045	0.0294	0.1715	-0.1233	0.5848	19
THA	-0.0040	-0.0180	0.0082	0.0905	-0.1382	0.2122	19
TUR	-0.0334	-0.0528	0.0080	0.0892	-0.1459	0.1507	19
TWN	0.0066	-0.0079	0.0016	0.0404	-0.0413	0.1007	19
USA	0.0487	0.0187	0.0040	0.0636	-0.0194	0.1770	19
VEN	0.5519	0.1036	2.7396	1.6552	-0.5607	5.9524	19
VNM	0.0340	0.0538	0.0034	0.0579	-0.0589	0.1708	19
ZAF	0.0363	0.0499	0.0094	0.0971	-0.1617	0.2399	19

Figure 1 shows the total debt level of some European countries/regions in a specific year. It can be found that Greece had a high debt level in the past 20 years. In addition, the debt levels of some countries such as Greece, Cyprus, Spain and Ireland increased significantly in 2014. More-developed European countries had higher and more significant debt levels than less-developed European countries. In most European countries, except for Switzerland and Malta, debt levels increased gradually over time.
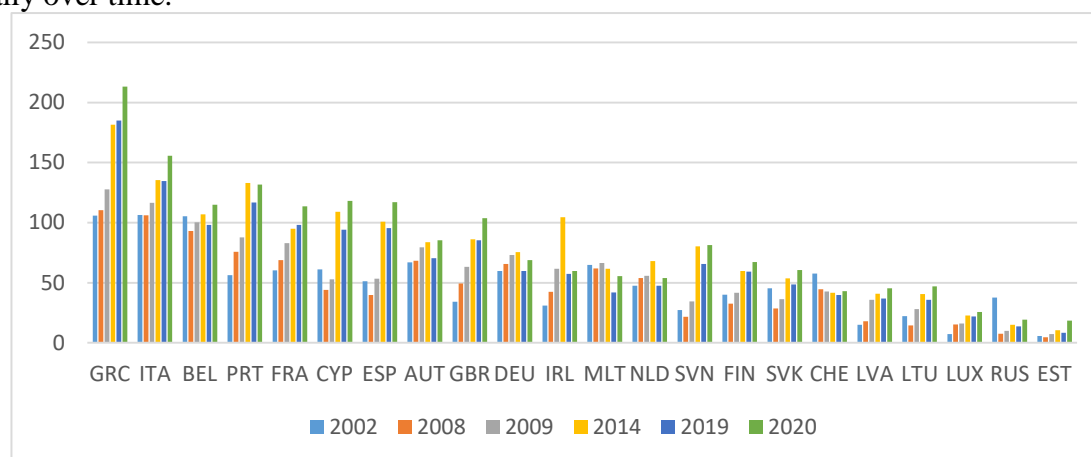

Figure 1. Total debt levels of some European countries in given years

Figure 2 shows the total debt level of Greece and Ireland from 2001 to 2019 (in the percentage of GDP). It can be found that Greece's total debt level remained high for nearly two decades, always higher than its GDP. Greece's national debt scale expanded significantly during the European debt crisis, and then the debt level was slowly rising. Ireland's debt level declined year by year in the early period (from 2001 to 2007) and remained at a low level, but since the subprime crisis in 2008, its debt level began to soar. Between 2011 and 2014, Ireland's total debt was higher than its GDP. The upward trend in its national debt levels did not begin to slow down until 2013.
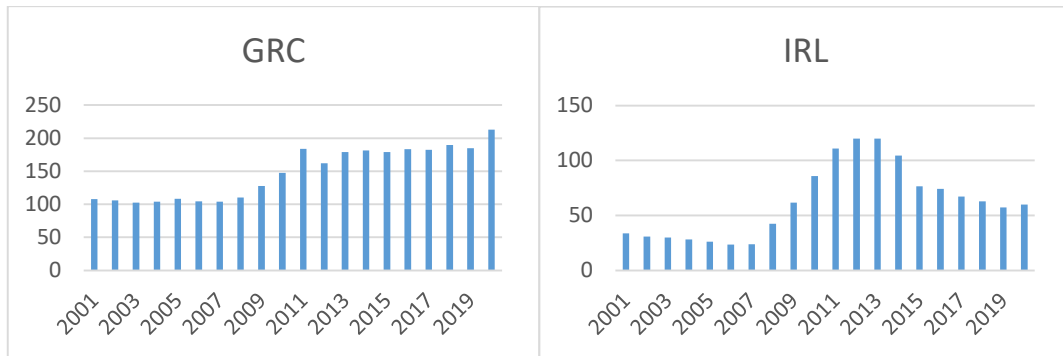
Figure 2. Total debt levels for Greece and Ireland in some years

Figure 3 shows the total debt levels of countries/regions in particular years in Africa, America and Oceania, respectively. The debt levels of these countries/regions were generally high in 2002. The data of DRC, Brazzaville, Gabon and Argentina was particularly prominent in 2002. Most countries in the America and Oceania showed a general upward trend in debt levels after 2002; in contrast, most African countries experienced a high level of public debt in 2002, which fell sharply after 2008 and then rebounded. For example, Venezuela's debt level remained stable at a low level from 2008 to 2014, but it showed a huge increase after 2017 due to political factors.
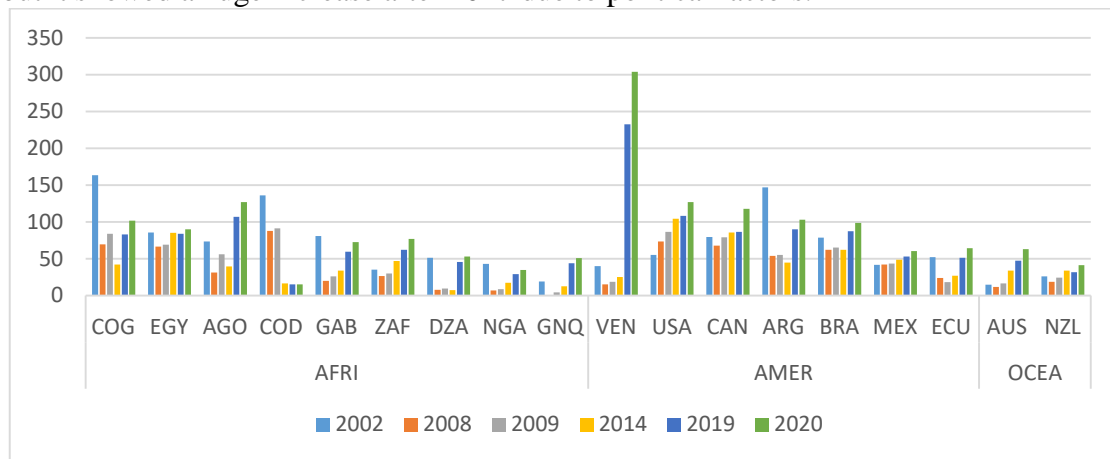

Figure 3. Total debt levels of countries in Africa, America and Oceania in given years

Figure 4 shows total debt levels for some Asian countries. As a developed country, Japan has always had significantly higher debt levels than other Asian countries/regions. Singapore, another developed Asian country, also has a high debt level second only to Japan. However, as an advanced country, Korea has maintained a relatively small debt scale. In some countries, such as Myanmar, Laos, Turkey, Indonesia, Saudi Arabia and Kuwait, debt levels were more significant in 2002 than in subsequent years, and fell sharply after 2008 before slowly rising in 2019. Among them, Saudi Arabia's debt level fell sharply after 2001, but slowly rose again since 2015. Debt levels in the Philippines and Turkey have been generally on a downward trend. Debt levels in Hong Kong have remained low under any economic conditions.
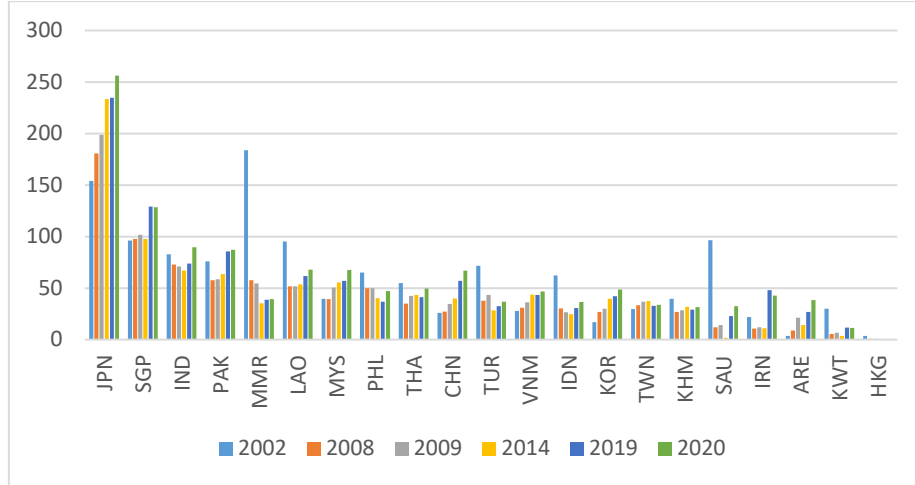
Figure 4. Total debt levels of selected Asian countries in given years

4. Research methods

4.1 Complex networks

The main method used in this paper is complex networks. A complex network consists of several nodes and edges connecting nodes. Nodes are the basic elements of a complex network, and edges are expressions of relations between elements. Weights can be determined according to the degree of relations given. In a complex network, wij represents the weight of the edge connecting node i to node j; i, j = 1,2,3,4..., n; n indicates the number of nodes in an unknown network.

For an undirected network, the weight of the edge satisfies:

$$w_{ij} = w_{ji} \qquad (1)$$

At the same time, the weighted degree can be used to represent the importance of nodes, and the formula is defined as:

$$dw_i = \sum_{j \in v(i)} w_{ij} \qquad (2)$$

In the first part of this article, the total debt of each country is used as the network node, and the second part uses the 10-year national debt yield rate of each country as the node, and the correlation coefficient ρ_{ij} is used as the edge weight to construct the network.

$$w_{ij} = \rho_{ij} = <Y_{it} \cdot Y_{jt}> \qquad (3)$$

4.2 Weighted average degree

This paper also uses the concept of the weighted average degree of the network to calculate the average of all node weights. There are n nodes: x_1, x_2 ..., x_n, and their weights w_1, $w_{2...}$, w_n, $\overline{x}$ Represents the weighted average degree of the network, namely, the sum of all weights/number of nodes:

$$\overline{x} = \frac{x_1 w_1 + x_2 w_2 + x_3 w_3 + \ldots\ldots + x_n w_n}{w_1 + w_2 + w_3 + \ldots\ldots + w_n} \qquad (4)$$

4.3 Module degrees

This paper introduces the concept of modularity to study the structure and quality of communities in the network. The number of network nodes is N, and the number of edges is M. Respectively, i and j represent nodes i and j in the same community. A_{ij} represents the number of edges between node i and node j; $\frac{k_i k_j}{2m}$ is the expected value of the number of edges when edges are randomly placed. Since ij and ji are repeatedly counted, $\sum_{ij} A_{ij}$ and $\sum_{ij} \frac{k_i k_j}{2m}$ respectively represent the double number of

edges in a community and the double expected number of edges in a community when edges are randomly placed. Therefore, as the difference between the proportion of edges in the community and the expected ratio of the number of edges in random placement, the formula of modularity is:

$$Q = \frac{1}{2m}\Sigma_{ij}\left(A_{ij} - \frac{k_i k_j}{2m}\right) \tag{5}$$

5. Network analysis of debt scale correlation

5.1 Overall complex networks analysis

The data of the total national debt scale of 61 countries/regions in the world from 2001 to 2020 are selected to calculate the correlation coefficient between any two, and the absolute value is taken as the weight of the edge. The overall debt correlation is analyzed by drawing an undirected and fully connected complex networks model.
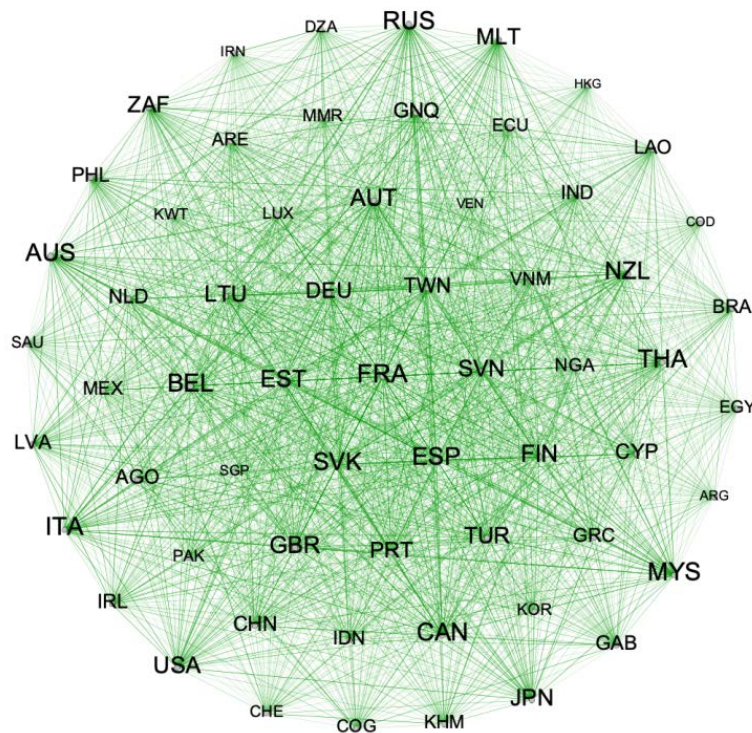

Figure 7. Complex networks of correlation of gross national debt for 61 countries/regions

Figure 7 is a complex network drawn according to the weighted average degree of 61 countries/regions, in which the label size represents the weighted average degree of this node, in other words, the magnitude of its correlation. The color and density of the line indicate the strength of the correlation. The darker the color, the higher the density of the line, the stronger the correlation.

In Figure 7, we rank the weighted average degree of each node from high to low, and we find that half of the top one quarter of countries are European countries, and France, Belgium and Italy are the top three. For the rest, there is no significant difference in the weighted average of influence between developing and developed countries as a whole. As can be seen from Table 3, The weighted average degree of China ranks 27th, and the weighted average degree of the United States ranks 17th, indicating that although the two largest economies in the world have a certain correlation with other countries, their influence is not particularly significant. Despite its large debt scale, Greece ranks 37th on an average weighted scale, indicating that its correlation with other countries is not strong over the long term.

Table 2. Statistical table of total debt size weighting for 61 samples

S/N	Code	Weighted Degree	S/N	Code	Weighted Degree
1	FRA	28.745365	31	PHL	19.773580
2	BEL	28.203623	32	IRL	19.728351
3	ITA	28.087304	33	GAB	19.605429
4	THA	27.946899	34	AGO	19.593393
5	MYS	27.940138	35	IND	18.944382
6	CAN	27.871439	36	LAO	18.866704
7	RUS	27.871249	37	GRC	18.339738
8	AUS	27.395694	38	IDN	18.285156
9	ESP	27.240274	39	BRA	18.073921
10	SVK	27.053744	40	MEX	17.585088
11	NZL	26.577572	41	VNM	17.515350
12	AUT	26.492561	42	KHM	17.174344
13	EST	26.349201	43	NGA	16.617060
14	FIN	26.155541	44	ARE	16.328998
15	GBR	25.881112	45	ECU	15.832754
16	SVN	25.214878	46	COG	15.751407
17	USA	24.933029	47	MMR	15.155157
18	JPN	24.853963	48	EGY	15.125659
19	LTU	24.785824	49	KOR	13.896213
20	TUR	24.201860	50	PAK	13.873630
21	MLT	23.819324	51	LUX	13.798425
22	ZAF	23.756591	52	SAU	13.530002
23	DEU	23.065458	53	DZA	13.469496
24	PRT	22.866317	54	CHE	13.379209
25	CYP	21.487223	55	KWT	12.414234
26	TWN	21.443793	56	SGP	10.466394
27	CHN	21.286629	57	IRN	10.405824
28	GNQ	21.046821	58	VEN	9.315064
29	LVA	20.183074	59	ARG	9.278035
30	NLD	20.024749	60	COD	8.783273
			61	HKG	7.794744

5. Robustness analysis after the replacement of Eurozone

In this part, the Eurozone countries are replaced with the Eurozone as a whole for data analysis. The absolute value of the correlation coefficient is also taken as the weight of the edge, and a new undirected and fully connected complex networks model (Fig. 8) was drawn to calculate and analyze its change rate. As each node represents its weight, it can be found by observing Figure 8 that Russia, Thailand, Turkey, Canada and Malaysia have a large weight, which means they have a great influence on other countries/regions. After replacing the Eurozone countries, Russia's average weighting rises from the seventh to the first; over the past 15 years, Russia's debt level has increased every year, reaching a peak during the COVID-19 pandemic, but it has remained within safe levels. In the Belt and Road region, Russia, Thailand, and Malaysia all have relatively large weights, which may lead to the aggregation of regional debt risks. Singapore, Argentina, DRC, Venezuela and Hong Kong have smaller weights and are not significantly correlated with other countries/regions.
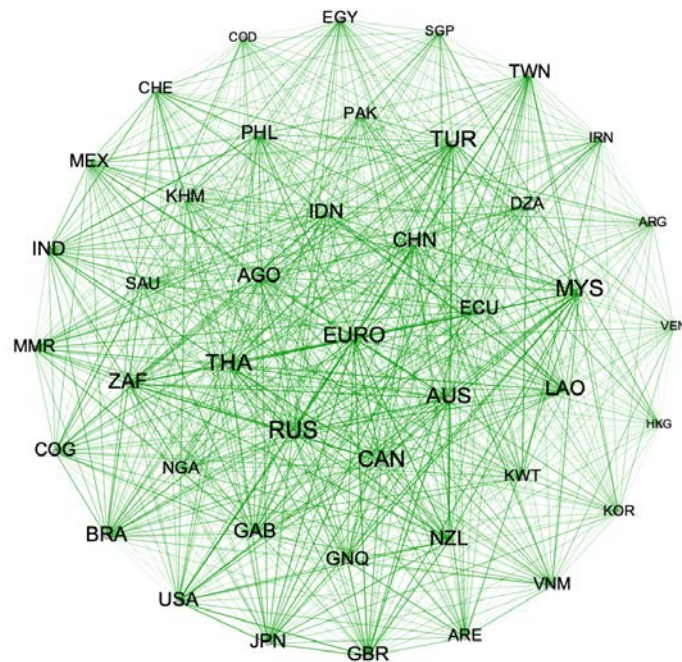
Figure. 8 A complex network of correlations between the total debt scale in 43 samples after the substitution of the Eurozone countries

6. Conclusion

This paper analyzes the correlation of overall debt scale and national debt yield of important countries/regions in the international scope, and builds complex networks for systematic analysis, and draws the following conclusions:

First of all, developed countries have higher debt levels than less-developed countries, but South Korea has maintained a relatively small debt scale. Debt levels in some European countries rose significantly in 2014. Greece has had high debt levels for nearly two decades. Countries in Africa, America and Oceania all had higher debt levels in 2002; most countries in America and Oceania showed a general upward trend in debt levels after 2002; After experiencing a high level of national debts in 2002, most African countries and some Asian countries showed a sharp decline and then a trend of recovery after 2008.

Secondly, from a staged dynamic analysis, the two financial market crises after 2008 increased the correlation of 10-year debt yields among countries around the world, and the European debt crisis had a great impact on the debts of all countries. However, in the recovery period after 2012, the relevance of countries declined. The COVID-19 pandemic impacted the global economy, and the debt levels of all countries increased significantly. Although the correlation between the global 10-year debt yields declined, the modularity increased. During this period, the correlations among some countries increased significantly, which showed that the economic development of these countries had obvious clustering.

Third, from the perspective of regional and national characteristics, 10-year debt yields of some Asian countries/regions will become more correlated with that of other countries/regions in the event of large shocks. The strong interactivity of countries in the Eurozone means that they have a significant influence and correlation with each other. The Eurozone also has a profound influence on other countries and regions in the world, that is, the Eurozone has a significant correlation with the whole world. As the top three economies, the United States, China and Japan have no significant influence on the correlation of the global national debt scale. However, among countries and regions outside the Eurozone, China's influence has significantly increased, exceeding that of the United States and Japan.

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