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Analysis and dynamics of the international coffee trade network

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Abstract. We employ network theory to study the structure, topology, and spectral properties of the coffee trade network. Data from the world trade organization is used to create a year-wise network of coffee trade from 1996 to 2017. More than 82% of world countries participate in the coffee trade network but only 3% of countries control more than 90% of international trade. The networks are very sparse operating at less than 10% of its efficiency. The coffee network shows scale-free behavior. Spectral analysis on the network is performed which shows that the eigenvalue dynamics of adjacency and Laplacian matrices can capture the crisis and stress period of the global economy

1. Introduction

The past two decades have experienced a high interest of physicists in financial and economic systems that led to the development of various techniques to model and explain phenomena like a market crash, portfolio optimization, and the correlation between various financial commodities [1, 2]. In the current globalization era, international trade not only implies the exchange of goods but also affects a country's policies, its economic, social, and political health [1, 2]. The financial systems are highly complex in nature and can be modeled efficiently as a complex network that is extensively studied in the literature [3–5]. Complex network theory has been efficiently used in many interdisciplinary studies including technological [6], ecological [7], social, and financial systems [1, 2]. In this work, we use the network theory to create, and study the global international trade network of coffee from a topological point of view. Coffee is the world's most favorite beverage and second most traded commodity after crude oil. The coffee industry is estimated to be over 100 billion dollars worldwide with an average consumption of 500 billion cups every year. It is mostly consumed by the developed nations while produced by the undeveloped or developing nations being a big source of their economy. We study and compare the structure, dynamics, and evolution of the trade networks, with a future prospect to plan the import-export strategy for an efficient trade network design.

2. Data and methodology

We use the bilateral trade data provided by the World Trade Organization (WTO) from 1996 to 2017 for a period of 22 years. The data consists of the report of import and export values of coffee in US dollars. The year-wise trade data for coffee is downloaded and manually filtered for each country. The data is used to create a directed weighted network representing the trade relationship between countries. In the network, nodes (N) represent the countries and the trade



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value between two countries represents the connection (edge) between them. Given a network, the elements b_{ij} of unweighted adjacency matrix B , is defined as $b_{ij} = 1$ if there is a export from country i to j and zero otherwise. We can also define the weighted adjacency matrix W , the elements w_{ij} is the export value of trade from country i to j and $w_{ij} = 0$, if there is no trade from country i to j . The link in the network starts from the exporter and ends with the importer. The strength of the link is given by the export value in US dollars. The coffee trade network is created and analyzed for each year. Figure 1 shows the coffee trade network of top 6 importers and top 6 exporters for year 1996 and 2017.

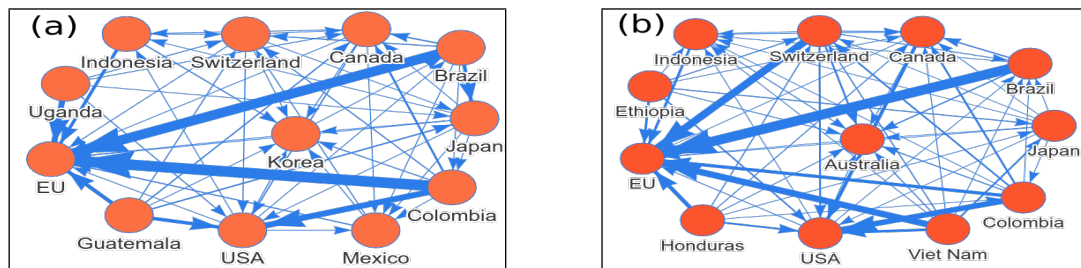


Figure 1. Network of top 6 importers & top 6 exporters for (a) 1996 & (b) 2017.

Table 1. Statistics of coffee trade network from 1996 to 2017.

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Nodes	140	146	143	148	158	168	162	161	165	163	173
Edges	1082	1282	1435	1516	1792	2245	2052	1961	1974	2051	2259
Density	0.056	0.061	0.071	0.070	0.072	0.080	0.079	0.076	0.073	0.078	0.076
Clus. Coeff	0.325	0.330	0.356	0.317	0.328	0.303	0.340	0.345	0.314	0.331	0.329
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Nodes	173	173	170	172	172	175	176	175	172	179	171
Edges	2358	2477	2578	2606	2710	2675	2494	2549	2640	2463	2216
Density	0.079	0.083	0.090	0.089	0.092	0.088	0.081	0.084	0.090	0.077	0.076
Clus. Coeff	0.348	0.331	0.371	0.360	0.371	0.354	0.371	0.372	0.406	0.389	0.418

2.1. Topological properties of network

The basic topological properties of the network for each year are shown in table 1. For coffee trade, there were 140 countries with 1082 trade interactions in 1996 which grows to 171 countries with 2216 interactions in 2017. The average number of countries participating in the trade network for the 22 years period is 165 (85% of the world countries) with 2155 interaction. Number of countries participating in the network are high but the trade interactions between them are low as shown by the network density. Network density implies that coffee trade network is very sparse with less than 10% of the total possible trade interactions. The variation of network density and average clustering coefficient is shown in figure 2. There is a decrease in the density of the network in 2002 (dot-com bubble burst) and 2012 (European sovereign debt crisis). These years correspond to two big financial events in world history namely the dot-com bubble burst and European debt crisis. Inter connectivity between group of countries given by average Clustering coefficient [table 1] which increases with time.

Degree of a node is the number of connections of the given node with other nodes in the network. Since the network under consideration is a directed network, out-degree is the total number of outgoing links representing the total number of exports and in-degree is the number of incoming edge or imports of the country. Total degree is the sum of out-degree and in-degree. In terms of the unweighted adjacency matrix B , the out-degree is defined as $k_i^{\text{out}} = \sum_j b_{ij}$, and

in-degree is $k_i^{\text{in}} = \sum_j b_{ji}$. The total degree of the directed network is given by $k_i^{\text{tot}} = k_i^{\text{in}} + k_i^{\text{out}}$. Total degree for every country is calculated for each year from 1996 to 2017 and is shown in figure 3. The high degree nodes in the network are known as hubs. These nodes have many trading partners and are influential in affecting many countries. In the coffee network, Australia, Canada, EU, Korea, Singapore, South Africa, Switzerland, Taiwan, and USA act as hubs. Most of these countries does not have high import and export in terms of value (Korea, Singapore, South Africa, Australia, Taiwan) but they have many trading partners. The presence of hubs is result of scale free property of the network. Hubs in scale-free networks are associated with power-law distribution which has a significant influence on the topological properties of network. To further study the scale free nature of Coffee network, we plot and compare degree distribution of system with the random network (Erdos-Renyi random graph [8]) with nodes and edges are taken as the average of all years) which is shown in figure 2(b) for 1996 and 2017. The coffee trade network shows nearly scale free behavior where the large number of nodes has small degree and only a few nodes have large degree (hubs). Random network does not have hubs and hence are not scale free. Scale free behavior is observed in many real world networks including internet, world wide web, biological (protein interaction, neurons), social network etc.

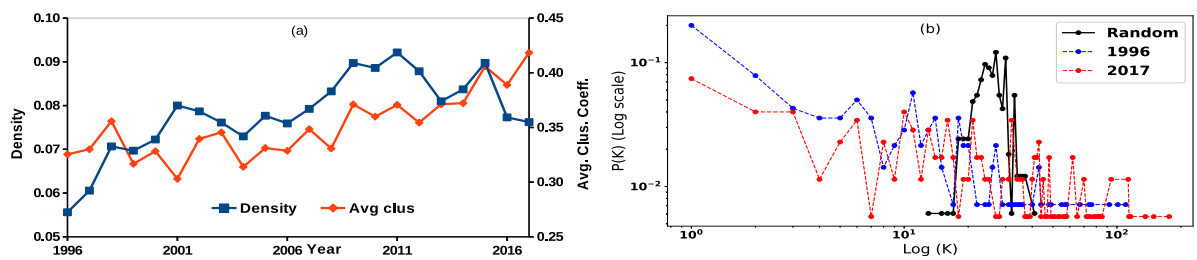


Figure 2. (a) Density (primary y-axis) & average clustering coefficient (secondary y-axis) of coffee network. (b) Comparison of degree distribution of coffee network with random network.

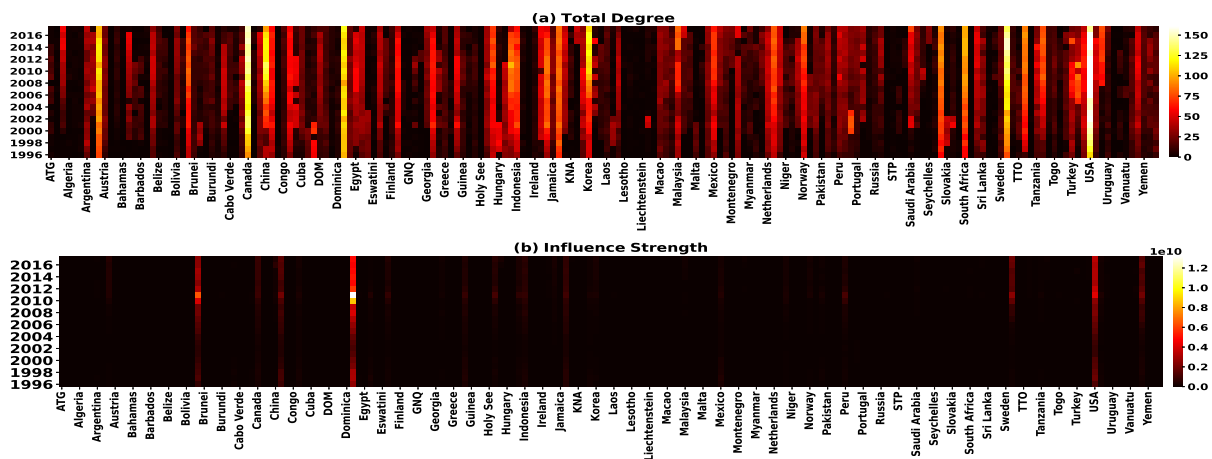


Figure 3. The degree (a) and Influence strength (b) of each country from 1996 to 2017.

3. Importance of countries in trade network

The strength of a country in the trade network is defined as sum of weights of all its links (incoming and outgoing). Mathematically influence strength S_i , of a node i for year (y) is

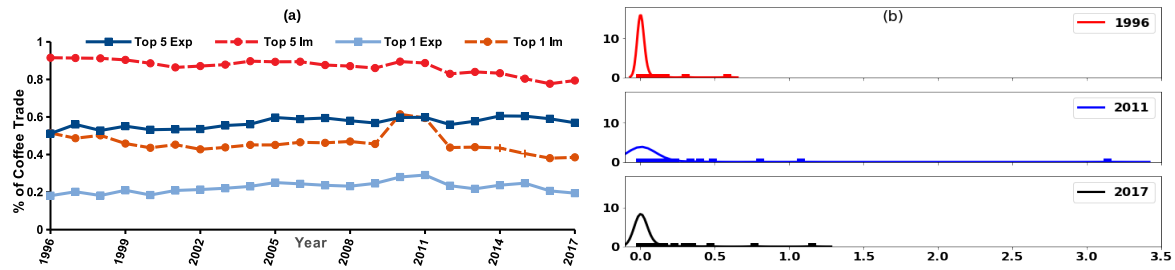


Figure 4. (a) Percentage of the trade controlled by top importers and exporters in coffee trade network (b) Eigenvalue distribution of the Laplacian matrix for different years.

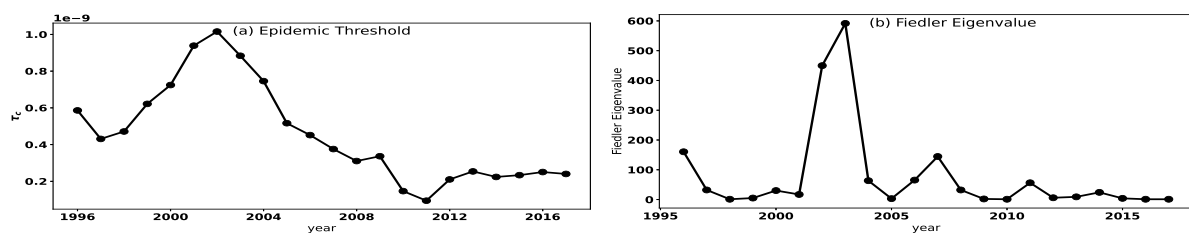


Figure 5. The dynamics of (a) epidemic threshold and (b) Fiedler eigenvalue for coffee network.

$S_i(y) = \sum_j w_{ij}^y + w_{ji}^y$, where w_{ij}^y is element of the weighted adjacency matrix for year y . For the coffee trade network, influence strength of a country represents the total trade (import and export) of a country and is shown in figure 3. A detailed analysis on the network, shows that top importers in terms of the value are European Union with a trade from 5.33 billion US\$ in 1996 to 9.83 billion US\$ in 2017, followed by USA with value of 2.61 in 1996 to 6.23 billion US\$ 2017, and Japan with values ranging from 0.93 to 1.50 billion US\$. In terms of export, Brazil is top exporter with a trade ranging from 2.62 (1996) to 4.96 (2017) billion US\$, followed by Columbia (2.28 – 1.76 billion US\$) and Vietnam (2.69 – 3.48 billion US\$).

We study the fraction of coffee trade controlled by importers and exporters [figure 4(a)]. We find that 90% of coffee trade is controlled by the top 5 importers which includes European Union, USA, Japan, Canada and Switzerland, all of these are the developed countries whereas the top exporters include Brazil, Colombia, Vietnam, Indonesia, and Honduras, (underdeveloped or developing nations) and controls only 40% of the global trade. The top importer, European Union, controls more than 50% of the trade alone, whereas the largest exporter Brazil controls only 20% of the net global coffee trade. There is a huge disparity between the importer and exporter in the trade value and the coffee network is mainly driven by the importers.

4. Spectral analysis of network

Spectral analysis of the Coffee network is done by creating an undirected weighted network from the trade relation. The weighted adjacency matrix A is created by the total of import and exports value between two countries. Mathematically, for a year y an element a_{ij}^y of undirected weighted adjacency matrix $A(y)$ is given by $a_{ij}^y = w_{ij}^y + w_{ji}^y$, which represents the total trade value between country i and j . The adjacency matrix $A(y)$ for a given year (y) is a real symmetric matrix. The weighted Laplacian matrix defined as $L(y) = D(y) - A(y)$ is created for each year, where $D(y)$ is the diagonal matrix, containing degree of nodes at the diagonal. The spectral properties of the adjacency matrix and Laplacian matrix are studied for coffee network. The eigenvalue distribution of Laplacian matrix is given in figure 4(b). The spread of distribution is maximum for 2011, which is time of European debt crisis (2011-2012), showing a significant

change in the structure of the network. The network becomes more connected with higher interactions at the time of crisis and is sparse during the calm period.

Spectral radius: The largest eigenvalue (λ_{max}) of adjacency (weighted) matrix A is known as the spectral radius of the graph and is related to the flow of information or substance in the network. The spectral radius of a graph is proportional to the robustness of the network [9]. A higher λ_{max} implies higher information flow and hence a less robust network. The spectral radius also gives the epidemic threshold rate (τ_c) for the spread of contagion in an epidemic model of infection spread [10], where $\tau_c = (\lambda_{max})^{-1}$. A low value of τ_c indicates a less robust network against the random or targeted attacks. We study the dynamics of epidemic threshold (τ_c) for the coffee network, which is shown in figure 5(a). We find τ_c drops sharply for 2002–2003 (dot-com bubble burst period), and then at 2008–2009 representing the global financial crisis. The lowest value of τ_c is observed in 2011, which is the European sovereign debt crisis where the connectivity (trade relation) and flow of information is maximum. This drop is significant as the top importer in coffee network is European Union and related countries which controls more than 70% of coffee imports.

Fiedler eigenvalue is the second smallest eigenvalue λ_2 of Laplacian matrix which gives the algebraic connectivity in a network. It defines the robustness of the network in terms of the edges. It measures the cost to cut the network into independent components by targeting edges [10]. A network is more stable against the link failure if its algebraic connectivity is higher. The algebraic connectivity figure 5(b) shows a higher value just before or during the crisis but drops just after the crisis. There are four such drops 2003 (after dot-com bubble burst), 2008 (global crisis), 2011 (European debt crisis) and 2014 (Chinese turbulence). Thus, the Fiedler eigenvalue is able to capture the time of financial stress on the network.

5. Conclusion

In this work, we study the topological and spectral property of the coffee trade network. Degree of a node gives the number of trade partners of a given country. The country with high degree tends to be important in the network as they can influence a higher number of trade interactions. Degree does not completely capture the influence of a country, therefore we define the influence strength which gives the total trade value for a given country. Influence strength shows that importers dominate the coffee trade network. The spectral analysis indicates that eigenvalue dynamics is able to capture the major world financial events. The network is highly connected at the time of crisis with a decrease in interactions during the calm period. For the trade network, the spectral radius quantifies the communication and robustness in the network, i.e if we change the trading policies of a given country how fast these changes propagate in trade network to affect the whole system. We find the speed of propagation increase before any global economic event such as 2002 dot com crash or 2008 financial crisis.

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