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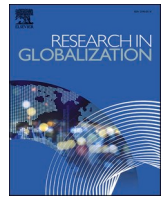
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COVID-19 and cross-border contagion: Trade and financial flows

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ABSTRACT

In this article, we examine the effects of the COVID-19 pandemic on the dynamics of contagion in the economic and financial spheres. The objective of the article is to confirm that the systemic nature of contagion risk is greater in extreme situations than in normal situations. Through this study we want to highlight the nature of contagion and the transmission of shocks in both the economic and financial spheres. Similarly, we have tried to measure the dynamics of contagion processes in normal situations and also those of crises. This work contributes to the current and recent debate on the risk of cross-border contagion and in particular in a health crisis. Using graph theory, information theory and Markov chains, we were able to verify that the systemic risk of contagion was significantly increased during the lockdown and that the commercial and financial dynamics changed during this period (between March 2020 and June 2020). Similarly, our results state that the extreme degree of contagion risk is predictable via Markov chains by pre-emptively using medium-voltage cycles that are precursors of systemic crises.

Introduction

The financial and economic crises that have affected the world have demonstrated the limit of micro-prudential regulation in the sense that systemic risk is even more important to control in all regulatory policies to be considered.

Shocks, economic, financial and even health, can easily spread across all economic and social systems, if the channels of contagion are indeed functional. The importance of contagion lies in its ability to approach the vulnerability of the financial and economic system. Indeed, the more active transmission channels a financial system has, the greater the degree of vulnerability to shocks. As such, macro-prudential regulation is part of the identification of potential contagion channels that can facilitate the spread of shocks (Masson (1998)).

The current health crisis (SARS-COV2) has made it possible to relaunch the debate on the nature of the contagion relations existing between intra- and international economic actors. Indeed, the COVID-19 pandemic has highlighted the value of taking into account other dimensions of systemic risk ranging from the health sphere to the other economic, social and political dimensions.

This research work is part of the developments of post-COVID-19 analysis and aims to identify the contagion caused by this pandemic. The fundamental idea of our research is to verify that the degree of

contagion has increased with the advent of the health crisis (Ahelegbey, Giudici, and Hashem (2021)). Our basic hypothesis is that the channels of contagion are more significant than those identified during the subprime crisis in 2008. Thus, we will examine the contagion effects in the world via both channels; commercial and financial, including the objective of analysing the systemic degree of the actors and the changes affecting them without the knowledge of the health crisis. Thus, our research work aims to set up an analysis of the bifurcations that the financial and commercial spheres may have experienced.

The assessment of contagion through the commercial channel and the financial channel are important at the moment to identify systemic risk and have a pioneering view of the transmission channels and also to be able to detect the fastest path in the spread of the crisis. Similarly, this work is likely to make prevail the most interconnected areas in the world and which can be considered systemic. Our research, like other works, tries to verify these channels (commercial and financial) in the presence of a health crisis that has resulted in an economic and financial crisis. The objective is to demonstrate that this crisis is stronger than that of 2008 and also to present the networks through which it has spread. In terms of results, we have reached some very important conclusions. First, the use of graph theory and information theory has made it possible to affirm that the risk of cross-border contagion has increased during the period of confinement, both via the commercial channel and

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the financial one (Claessens, Dornbusch, and Park (2001)). We have also used Markov chains to identify and quantify the cycles of stress in financial markets and markets for goods and services, and as such we have come to the conclusion that the extreme degree of contagion risk is predictable via Markov chains by pre-emptively using medium-voltage cycles that are precursors of systemic crises.

We specify that the objective of this paper is to arrive at an assessment of the degree of contagion during the health crisis, but also manages to point out the fact that the degree of dependence to increase during this extreme situation. As such, the use of statistical and graphic techniques aims to converge towards a new vision of financial and commercial dependencies in the world.

The rest of this paper is therefore structured as follows: in a first section a literature review is carried out to present the work on the question of contagion as well as the usable approaches. The second section is based on the use of statistical indicators and those derived from graph theory in order to measure dependence on an international scale and identify changes in systemic risk with the advent of the health crisis. The penultimate section is dedicated to the modelling of dependency cycles and the identification of extreme situations in the commercial and financial dimension. The last section will be devoted to discussing the results and concluding the work.

Literature review

Large-scale international crises are recurrent in today's world, prompting economists to pay more attention to the phenomenon of contagion, especially after the Mexican economic crisis of 1994–95, the Asian crisis of 1997, the Russian crisis of 1998 and currently after the two recent subprime crises (2008) and the Covid19 crisis (2020–2022). Some studies have attempted to define the notion of contagion and distinguish it from the notion of interdependence, while others have analysed the contagion effect by dissecting its transmission channels and amplification factors.

Contagion is defined as leaps between equilibria, where the market moves from a “good” to a “bad” equilibrium, which cannot be identified by the observed changes in macroeconomic fundamentals (Masson (1998)). Indeed, it is a largely unpredictable correlation and higher in times of crisis than in normal times. This contagion can take two forms. The first concerns the theory of “monsoon effects”, defined as major economic changes in industrialized countries that trigger crises in emerging markets. Thus, this theory suggests that financial crises appear contagious because the underlying macroeconomic variables are correlated. The second interdependence implies that financial crises can be transmitted between countries through “spill overs”. A crisis affects another country through external links such as trade and the international financialization of markets. Therefore, as Pesaran and Pick (2007) point out, crises resulting from interdependence could, in principle, be predictable using macroeconomic fundamentals.

Contagion can also be defined as a significant increase in market linkages after a shock (Forbes and Rigobon (2001)). The links between markets can be measured by any means; the correlation of asset returns to the likelihood of a speculative attack, the transmission of shocks or volatility. This definition implies that if two markets are highly correlated after a shock, it is not necessarily a contagion. This is contagion only if the correlation between the two markets increases significantly during the crisis. The authors argue that the change in transmission mechanisms during a crisis and the cause of increased market linkages after a shock are explained by contingent crisis theories. These are in fact multiple equilibria, based on the psychology of the investor, endogenous liquidity shocks leading to a recompositing of the portfolio and political economy affecting exchange rate regimes.

This vision was also supported by Claessens et al. (2001) where they stress the importance of other linkages through which crises are normally transmitted, including trade and finance. They show that the root causes of contagion include macroeconomic shocks that have

international repercussions and local shocks transmitted through trade links, competitive devaluations and financial linkages. Furthermore, Calvo and Reinhart (1996) distinguished between fundamental contagion, which occurs when the infected country is linked to others through trade or finance, and contagion due to herd behaviour, which occurs when common shocks and all potential interconnection channels are not present or have been controlled. Similarly, other authors have arrived at the same results by confirming that macroeconomic rebalancing policies, such as exchange rate policies and monetary policies, can lead to cross-border contagion phenomena (Calvo (2004), Calvo and Mendoza (2000), Caramazza, Ricci, and Salgado (2004), Çevis, Ceylan, and Yayla (2018) and Chevapatrakul and Tee (2014)).

Beyond the controversial definition of contagion, factors are also to be taken into account in the analysis of the dynamics of contagion. For Calvo and Mendoza (1998), the globalization of securities markets exacerbates the volatility of capital flows by strengthening incentives for speculation. This behaviour can lead to significant capital outflows from emerging markets. This globalization of financial markets and the existence of global interdependencies led Kaminsky and Reinhart (2000) to consider contagion to be more regional than global, and it is difficult to stick this regional character to trade links rather than financial ties, since most countries linked by trade are also linked by finance. Indeed, several studies have made it possible to affirm these results. For example, the work of Billio and Caporin (2010) modelled contemporary relationships between Asian and American stock markets by introducing a system of simultaneous equations with GARCH-type errors. In the estimated residues, the correlation matrix is analysed on rolling windows and using a distance correlation matrix, which allows graphical analysis and the development of a statistical test of correlation movements. The authors proposed and calculated a concordance index and a strength (or severity) index for contagion occurrences, mimicking similar amounts available in the business cycle literature. These agreement and strength indices indicate a relevant change in the correlation structure after taking into account both mean dynamics and variance. The results reveal signs of contagion and the proposed statistics identify, on the basis of the data, periods of turbulence consistent with those currently assumed in the literature. Mensah and Premaratne (2017) also examined the potential for systemic risk for banking institutions in Asia, drawing on recent analyses of systemic risk. The authors used the risky conditional value method to measure the systemic contribution of institutions and the Granger causal network approach to determine their degree of interconnection. The analysis shows that the degree of interconnection has generally increased between Asian banks. Nevertheless, the causal network between banks has become less dense since the 2008 financial crisis. As a result, banks in developed Asian economies generally have a higher potential for systemic risk than those in other emerging markets, as well as a positive relationship between bank size and contribution to systemic risk.

Ahelegbey et al. (2021) used an econometric network approach to study the ripple effect between countries, over the period 2006–2015, which may come from financial markets, bank loans or both. They chose the VAR-type network model, which combines market-based links estimated from national stock market indices, with bilateral links estimated from direct financial flows between countries' banking systems. Empirical results have shown that bilateral exposures and financial markets act as channels of contagion in the transmission of shocks from one country to the global system. If the impact of the former is more stable over time, the latter is more volatile. In addition, changes in the volume of interbank lending in one country can have an impact on the financial markets of other countries. However, analysis of the correlation between the Asian crisis of 1997, the Mexican crisis of 1994 and the US stock market crash of 1987 indicates that there has been virtually no increase in unconditional correlation coefficients (i.e., no contagion), but there is a high level of competition in the market at all times, what they called interdependence (Forbes and Rigobon (2002)). This result obviously indicates that the debate on the measures of interdependence

and also on the definition of contagion is still relevant.

Other factors other than economic and financial factors are also to be remembered, namely political factors. Indeed, some authors suggest that crises can spread through a particular institutional, developmental and legal structure (Rigobon (1998) and Goldstein (1998)). Indeed, if a country belongs to a group with a standard exchange rate arrangement, the political cost of depreciating their currency in the face of external crises is much lower than for a country without organizational affiliation; such affiliations lead to the aggregation of crises (Hernández and Valdés (2001) and Drazen (1999)). Similarly, another view of contagion management assumes that actions in countries with similar financial structure and policies tend to have similar responses facilitating contagion (Hausken and Plümper (2002)). In addition, Kaufmann, Kraay, and Mastruzzi (2009) suggest that corruption, regulatory quality and law are three policy variables that influence the contagion of the crisis. This political channel describing the institutional factors has indeed been tested by several authors such as Novo (2003) who was able to verify the relevance of the political channel in parallel with the other channels discussed below. Additional support has been provided by the work of Chakrabarti, Dhar, and Dasgupta (2015) and the work of Bertin, Ohana, and Strauss-Kahn (2016) which suggest that political unrest has relatively limited predictive power regarding financial crisis outbreaks in Africa.

It is added in this literature review that the macroeconomic channel is also important in explaining contagion phenomena. The similarity between countries in macroeconomic conditions creates behavioural mimicry among investors and thus facilitates contagion (Eichengreen, Rose, and Wyplosz (1996) and Van Rijckeghem and Weder (2001)). Also, the leverage effects of the financial system, the development of credit and the level of corporate debt are also factors that help the spread of crises and thus facilitate contagion (Berkmen, Gelos, Rennhack, and Walsh (2012) and Luchtenberg and Vu (2015)). Other studies on the macroeconomic channel have argued that macroeconomic similarities and trade links are relevant in the contagion (De Gregorio and Valdes (2001)). In parallel, the macroeconomic channel plays a role in the spread of crises. The data show that when a country is subject to external shocks (e.g., shocks from the European debt crisis), its macroeconomic fundamentals can influence financial markets elsewhere, particularly in a highly interconnected environment (see Adrian and Brunnermeier (2016), Giglio, Kelly, and Pruitt (2016), Silva, Kimura, and Sobreiro (2017), Gkillas, Tsagkanos, and Vortelinos (2019) and Davidson (2020)).

Currently, with the Covid19 crisis this debate has grown and the international crisis caused by the COVID-19 pandemic has had a significant impact on foreign trade and international financial transactions. The interconnection between different businesses and financial markets has played a very important role in spreading the effects of COVID-19 on the economy and household well-being. To measure the impact of COVID-19 on international trade and stock markets, the authors studied the intra-firm relationship between suppliers and customers and the variables of financial companies (Zhang (2021)). Several studies have focused on the issue. For example, Papadamou, Fassas, Kenourgios, and Dimitriou (2021) analysed the impact of the COVID-19 pandemic on the time-varying correlation between equity and bond yields. Based on daily data on bond and stock market yields from ten countries, covering the regions of Europe, Asia, the United States and Australia, the authors attempted to identify episodes of flight to quality during the global crisis of the COVID-19 pandemic using both a panel data specification and wavelet analysis. Their result reveals that quality leaks occur simultaneously between countries and are not country-specific events. In the same vein as an impact assessment on the stock market, Aslam et al. (2020) analysed the effects of COVID-19 on 56 global stock market indices from 15 October 2019 to 7 August 2020 using the complex network method. After an in-depth study of the structure of the network, dividing stock markets into developed, emerging and frontier markets, the authors discovered a significant impact of COVID-19 on financial networks through structural changes in the form of node changes,

reduced connectivity and significant differences in the topological characteristics of the network.

Also, the work of Firano and Filali Adib (2017) converged towards the same results where the risk of contagion can have financial transmission channels during fairly important interconnections between the actors of the financial system and in particular banking. The purpose of this study is to assess the risk of cross-border contagion of the Moroccan banking system through the data of the "BIS". The methodology is to first approximate the gross bilateral exposures using data from the banks' financial statements. Then simulations based on contagion algorithm integrating counterparty risk are conducted to assess the risk of contagion. Also, centrality of indicators and measurement of systemic importance are presented. The results were synthesized in indicators to assess the systemic importance of the French banking system internationally to Morocco; the fall of the latter is a significant risk of contagion.

In addition, the impact of COVID-19 varies depending on the level of development of the stock market, a contagion effect has been identified in the structure of the emerging markets network, as the nodes behave synchronously. Their results also show, on the basis of geographical positioning, a substantial grouping and homogeneity of the global stock exchange network. In addition, the number of positive correlations between stock market indices has increased during the pandemic and the Community structure reveals that the crucial stock markets for developed countries are those of France and Germany, for emerging markets that of Taiwan and for border markets that of Slovenia.

Moreover, in their work Guo, Zhao, Yu, and Zhang (2021) studied the interconnection between international stock markets during international financial crises or disasters, from 1995 to 2020, with a focus on the crisis related to the Covid-19 pandemic. The authors chose 7 American countries, 19 European countries, 1 African country, 2 Oceania countries and 11 Asian countries/regions. By building six corresponding networks of 40 stock indices, they explored their topological properties and calculated the correlation coefficients and distances between each pair of indices with a sliding window. The results showed that the links between markets have become even closer as COVID-19 has spread around the world than those of any other risk. The same applies to the work of Guidolin and Pedio (2017), Guo, Chen, and Huang (2011), Haidar (2012), Haile and Pozo (2008), Hansen (2021), Wu, Ji, and Su (2011) and Ying (2005) who proved that the intense links between financial markets and also the degree of financialization and opening of the capital account are factors that amplify the relationships between financial markets and can facilitate the occurrence of contagion shocks.

Lai and Hu (2021) studied the complex web of international financial markets by estimating the granger causalities of 20 stock markets between August 2019 and March 2020. They noticed that COVID-19 leads to a close relationship of financial connections between different countries and that its impact extends over a shorter distance, as well as the transmission of the crisis is faster. For these authors, financial crises can be identified using the topological structure of the network and centralized analysis based on measures of network connectivity. In addition, Granger's complex network can be used to measure and warn of systemic risk.

So, Chu, and Chan (2021) investigated the impact of the COVID-19 pandemic on the connectivity of Hong Kong's financial markets from 3 January 2006 to 30 October 2020, comparing the yield connectivity of 100 stocks with the highest market capitalization on the Hong Kong Stock Exchange, with a total of 3663 trading days. Indeed, they have built dynamic financial networks based on correlations and partial correlations (Wang, Iglesias, and Wooldridge (2013)) of equity returns to assess the impact of COVID-19 and compare the impacts of previous financial crises over the past 15 years. Their result shows that market factors cannot adequately explain the co-movement of equity returns during the COVID-19 outbreak, which led to a substantial increase in network connectivity in financial networks in March and April 2020. In addition, network density and aggregation are higher in partially

correlated networks during the COVID-19 outbreak, implying a sharp increase in systemic risk during this period of the financial system.

Our evaluation approach is able to present the dynamics of contagion during the covid-19 crisis. To achieve this, we will use several mathematical and statistical tools capable of verifying the relevance of our hypothesis of the supremacy of contagion during the existence of health frictions that can amplify economic and financial shocks.

Statistical analysis of contagion

The recent health crisis has led to a halt in transactions in most economic sectors and in several countries. It is true that economic activities have not been stopped, especially basic activities such as the consumption and production of essential products. However, the advent of this crisis has increased the degree of risk contagion and in particular systemic risk. Indeed, the channels of the latter have been activated significantly because of the financial fragilities felt.

Research in finance and economics has tried to respond to this problem of the link between the different sectors or economies in the world, in order to measure the effects of contagion and measure the systemic effects of size (too big to fail) and interconnection (too interconnected to fail).

In this perspective, our approach is based on three levels namely: the quantification of dependencies via graph theory, the development of networks before and after the COVID-19 crisis and finally measuring the similarity between this crisis and previous crises via the analysis of transition regimes. Several authors have used quantitative techniques based on graph theory and also advanced statistical methods to quantify dependency relationships between investments, exchange rates, industrial sectors or geographical regions.

We begin our analysis by presenting data from trade and financial dynamics around the world. The trade database consists of trade (export and import) between the countries of the world, taking into account their geographical position and also their level of development. As for the financial data, they are composed of the stock market indices of the twenty most important markets in the world, taking into account regional diversification.

Fig. 1 shows the evolution of stock indices and trade between countries before and after the COVID-19 crisis. We note from a simple visual analysis that the two shocks: the subprime crisis of 2008 and the COVID-19 crisis in 2020 stand out significantly indicating a break in the long-term dynamics of the commercial and financial markets.

It is quite clear that the events of 2008 and 2020 had the same effects on trade between countries. Admittedly, the decline is less drastic in 2020 than during the Subprime crisis in 2008.

Similarly, the analysis of the contagion network on the trade front indicates a great transformation between the regions of the world,

indicating consequently the advent of a large-scale shock that is COVID-19 and especially the containment policy that has had a significant effect on bilateral relations (see Fig. 2). The shutdown during the period of the COVID-19 crisis due to the lockdown has led to an offshoot of the structure of international trade. We note, in this sense, that the areas of concentration of commercial activities have changed between the ex-ante and ex-post situation of the pandemic crisis. As such, developed countries continue to concentrate trade activities and share this systemic dominance with the euro area. Whereas after the crisis we have the rise in force of the emerging and developing countries of the Asian zone.

A review of potential dependencies between countries and regions was conducted using the data correlation matrix. This analysis makes it possible to note that the dependency structure between the different types of countries is quite large. The level of correlation remains more or less the same over the entire period of analysis from 1990 to 2020 in monthly frequency for both spheres; commercial and financial (see Fig. 3).

We also introduced dependency analysis in a probabilistic way by referring to distance analysis in order to corroborate the correlation results. From this perspective, it emerges that the distances indicate the systemic importance of emerging Asian countries, whose driving force in the world is quite important, followed in second place by countries in the MENA region.

The development of dependencies in terms of distance can facilitate the construction of networks of relationships between countries. We put into perspective the network of minimum distances, a subgraph connecting all the nodes in which the total length of the edges is minimized. These networks will allow us to measure the systemic nature of global areas. Especially since we know that, according to the theory of financial stability and systemic risk, systemic importance is of several forms namely: interconnection, size and similar exposure. In our context, the impact of a country or agglomeration of countries depends on its adjacent character (importance by interconnection).

In addition, proximity is measured by the distance of the components between them. Thus, a high proximity value implies that the node is central or large (by size). Similarly, the interval of a node measures how often that node appears on the shortest path between two other nodes in the graph. A high interval value implies that the node is large (by similar exposure or frequency).

The calculation of these measurements in our relational network produces the results presented in Fig. 4. We note that MENA, Asia and Europe have the highest values for all centrality measures. The most systemic areas are in red.

The analysis of the figure above indicates that the interconnection of MENA countries and Centre Asia are the most interconnected in the world in terms of trade and the same is true in the financial sector. While, in terms of importance by size and frequency, we find the

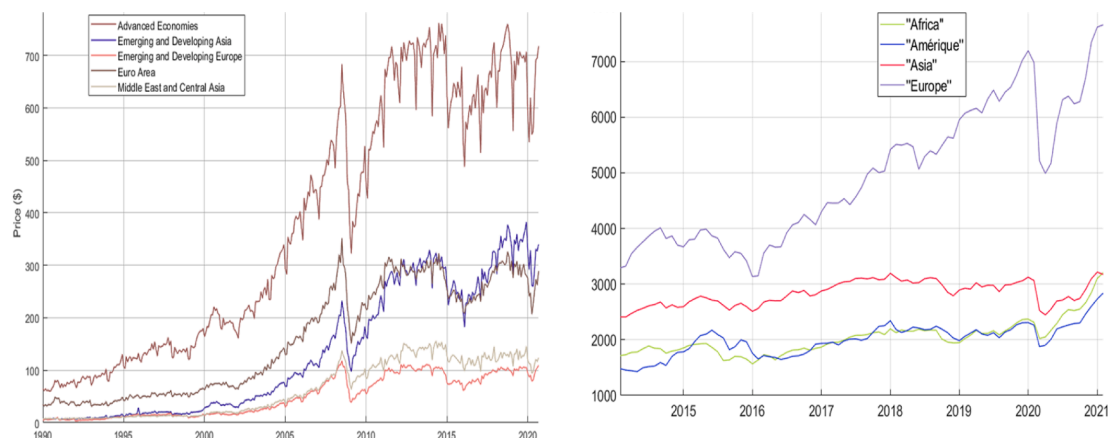


Fig. 1. Evolution of commercial transactions (export and import, left) and stock market indices (right). Source: IMF and World Bank Data (by author).

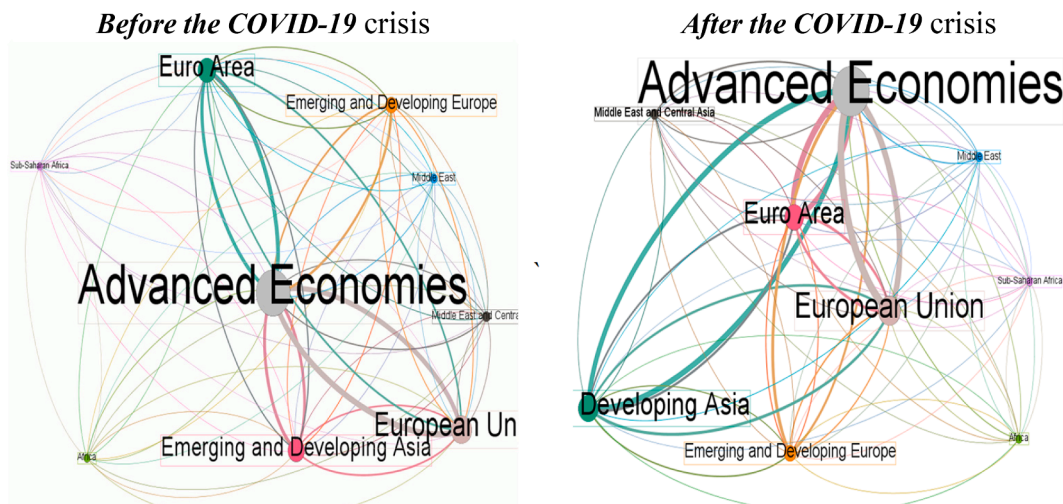


Fig. 2. International Trade Network before and after the COVID-19 crisis (using the RAS algorithm to approximate the bilateral exposure matrix). *Source:* IMF and World Bank Data (by author).

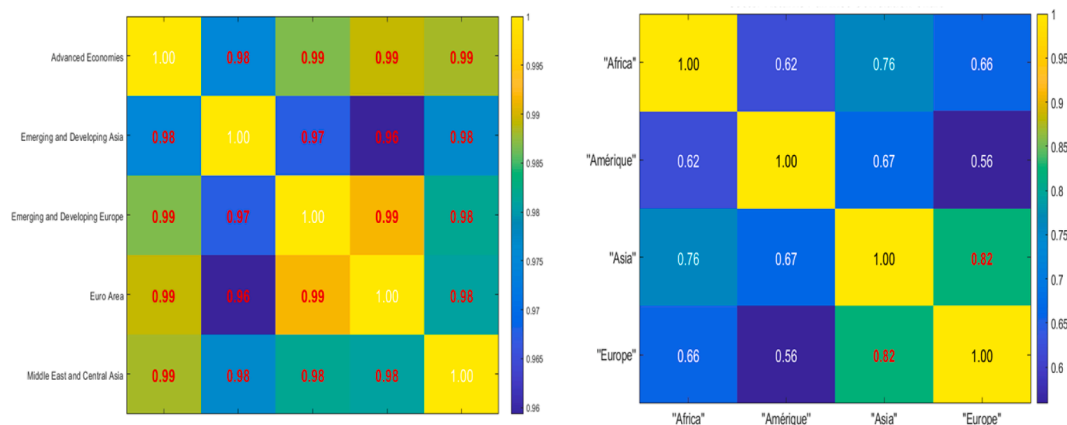


Fig. 3. Trade (left) and financial (right) correlation matrix. *Source:* IMF and World Bank Data (by author).

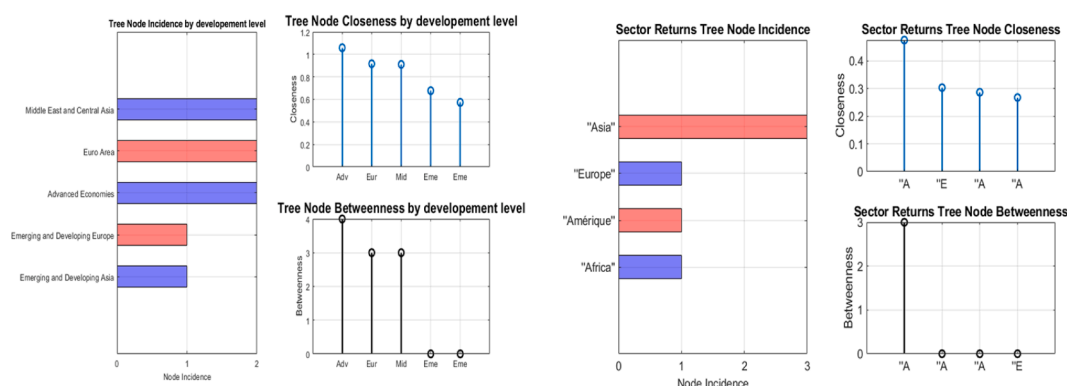


Fig. 4. Measure of commercial (left) and financial (right) centrality. *Source:* IMF and World Bank Data (by author).

advanced countries (including the Euro countries) and the MENA countries.

The results obtained use all the data from 1990 until the end of 2020. But, the objective of our research is to analyse the structure of dependency before and after the pandemic crisis and especially after the end of the confinement.

The need to assess the shock of the pandemic is a sliding window risk analysis to assess dynamic changes in the variables of interest. To

achieve this, we created sequential six-month sliding windows. This will provide a better understanding of how risk associations vary over time and particularly during global crises.

It is clear from the analysis of minimum distances and also indicators of centrality that the COVID-19 crisis to drastically transform the systemic character of geographical areas and consequently the risk of contagion to change the transmission channel (see Fig. 5). With regard to the commercial sphere, the health shock and the lockdown have led to

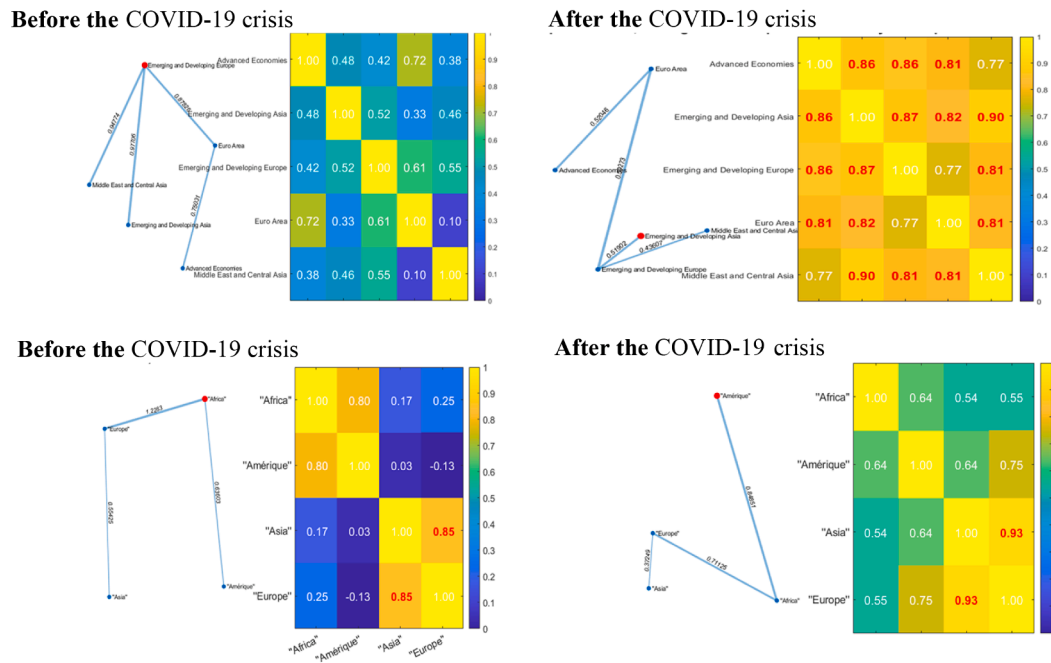


Fig. 5. Systemic components before and after the pandemic crisis (Commercial in high and financial at the bottom). *Source:* IMF and World Bank Data (by author).

a high concentration of activities in the Asian zone and especially in the emerging and developing countries of this agglomeration. Similarly, the correlation structure has increased compared to the situation before the COVID-19 crisis. The situation is different with regard to the financial markets, where the shutdown of the markets has led to a reduction in dependency and a concentration of systemic effects on the American markets. This can be explained, for the United States, by the refusal of the containment policy during the beginning of 2020 and by the choice of continuity of economic activities.

In order to corroborate our results, we calculated the degree of systemic centrality and character of the geographical areas over time. The analysis of this dynamic indicates that the systemic nature of emerging developing countries in the Asian zone has increased over the last decade to take a major turn without the knowledge of the 2020 health

crisis (see Fig. 6).

Before the subprime crisis, systemic dominance was in favour of developed countries and the eurozone in particular. This affirms our basic assumption that; the advent of structural shock makes it possible to transform the trajectory of systemic risk and in particular the active contagion channels.

Dependency modelling

The results of graph theory indicate the effectivity of the pandemic shock on global systemic dynamics. In order to confirm this result, we proceeded to the examination of other modelling approaches namely: the analysis of entropy and also mutual information.

One of the advantages of using information content rather than

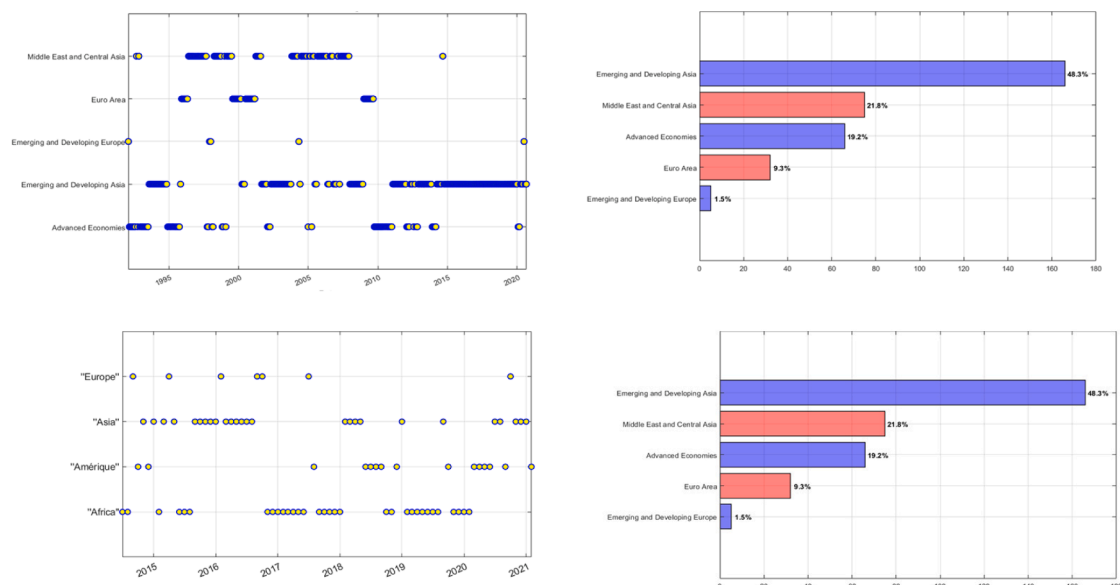


Fig. 6. Evolution of systemic components over time (Commercial at the top and financial at the bottom). *Source:* IMF and World Bank Data (by author).

simple correlation is that covariance matrices are not necessary in this case. In fact, to calculate the content of the information, we just need a sequence of observed values in order to be able to estimate the joint density of the two variables examined.

On this basis we propose the entropy indicator ϵ which is written in the following form:

$$E = - \int f(x) \log(f(x)) dx \quad (1)$$

Where $f(x)$ is the probability density function of the random variable "x".

Entropy by definition is a measure of disorder. High entropy indicates a high degree of disorder. Similarly, we can approximate the joint entropy via the following relationship between two random variables:

$$E_{x,y} = - \int f(x,y) \log(f(x,y)) dx dy \quad (2)$$

This entropy makes it possible to measure an indicator of mutual information between two joint systems, the measure of which is as follows:

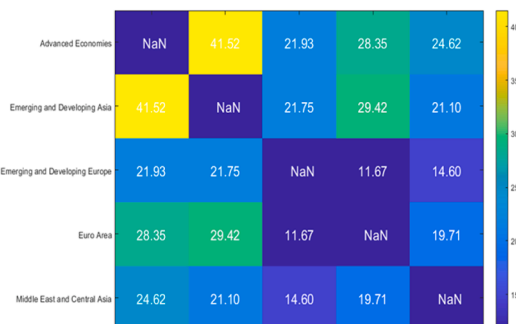
$$I_{x,y} = H_x + H_y + H_{x,y} \quad (3)$$

The maximum value of the distance cannot exceed 1 when the mutual information is 0 and therefore no dependency is to be raised. If they are closely related, then their mutual information content is important and, therefore, the distance is close to zero. In connection with the previous statistical results, the analysis of informational indicators corroborates the fact that the Asian area and developed countries have the highest levels of entropy and mutual information, testifying to their systemic nature especially after the advent of the pandemic in 2020 (see Fig. 7).

Indeed, network analysis and entropy analysis confirm that commercial and financial transactions pass mainly through the Asian zone, which gives this geographical area and the countries of this region a systemic character over two stages: first, a systemic character by size (as indicated by the indicators of centrality) where the volume of transactions is very important. In addition, the character of interconnection (to interconnected to fail) is also very important (entropy measurement) which provides this area with a strong degree of contagion and can jeopardize international transactions.

The existence of a cycle of change in the systemic character of countries in the world, whether commercial or financial, leads us to propose an approach to detecting cycles. As such, Markov's chain-based modelling approach is able to facilitate the dating of cycles and also to confirm the shock effect in 2020 following the COVID-19 crisis.

Thus, we will define three theoretical cycles of contagion and systemic risk: a cycle of low systemic effect, a cycle of medium effect and a cycle of high effect. These cycles will have to constitute the cycles of the Markov chain and will be measured via the matrices of mutual transitions.



Indeed, the results obtained using the Markov chain confirm that there are several periods of strong contagion and that this vigorous contagion seems to dissipate at different rates (see Fig. 8). As the graph shows, the period of the 2008 crisis and the period of the health crisis of 2020 are periods or cycles of amplification of contagion and the emergence of large-scale systemic risks.

Similarly, the transition matrices for business and financial activities were estimated via Markov's hidden process. Thus, matrix analysis asserts the existence of a high probability of staying in a given cycle (low, medium and high) and the probabilities of transition between cycles is low but remains non-zero (see Fig. 9). This asserts that the transition to extreme location is a rare but potentially achievable event. However, the main result affirmed by the transition matrices is that the transition from a low-risk cycle to an extreme situation is of zero probability, stating as such that it is necessary to go through a medium disruption cycle to reach an extreme crisis situation. In this sense, the Markov chain allows us to predict the end of the risk of contagion from the average disturbances in the median cycle, or even the possibility of predicting it in a preventive way.

Conclusion and discussion

The advent of the COVID-19 pandemic has had a significant impact on all areas of activity. The entry into confinement as a policy of response to the spread of the crisis has led to a cessation of economic and financial activities that have had an impact on the social and political dimension. The propagation of the crisis and its spread over time evokes the notion of contagion and brings out analyses of the channels of transmission of shocks that have been multiplied to include those of a health and social nature.

With this objective in mind, our paper analyses the dynamics of contagion in the world in two spheres, namely: commercial and financial. Thus, we implemented techniques to quantify the proximity between financial and business variables, including correlation and information distance. We saw how to visualize proximity information using graph theory. Quantifying and visualizing the relationships between variables is important at the exploratory stage of data analysis. Moving on to the modelling stage, we created a simple contagion model by adjusting a hidden Markov model to the observed data.

The results state that systemic risk has increased during the COVID-19 crisis, both commercially and financially. Similarly, the contagion analysis asserts that there has been a change in systemic character after the lockdown indicating a supremacy of the Asian zone. In addition, an examination of the crisis cycles from 1990 to 2021 highlights the existence of a COVID-19 cycle similar to the situation in 2008 relating to the subprime crisis. Similarly, we were able to confirm, in this work, that the possibility of predicting the probability of birth of seizures cannot be estimated during low voltage or normal situations. However, the existence of a situation of medium tension or medium risk makes it possible to identify an early situation of systemic crisis.

The existence of increased contagion during the advent of the Covid-

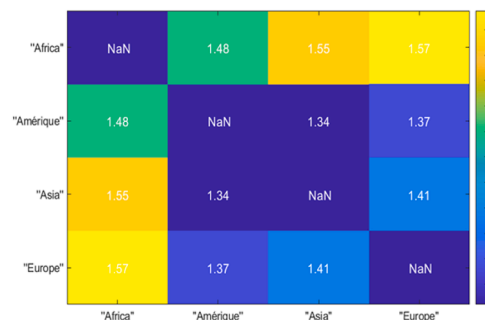


Fig. 7. Mutual Information Matrix for the Trading System (left) and financial (right). Source: by author.

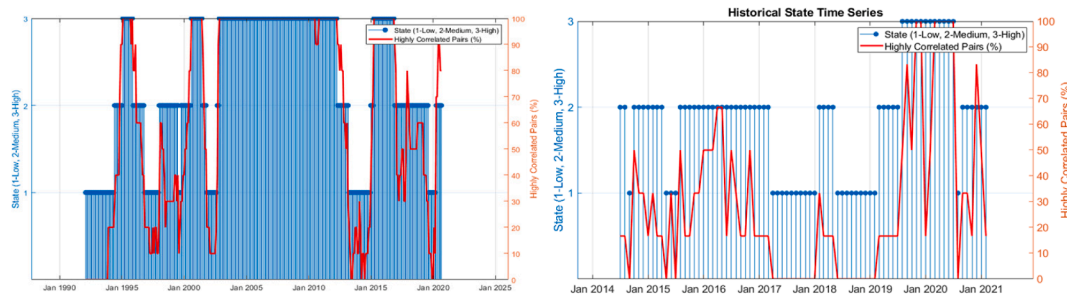


Fig. 8. Markov cycle for the trading (left) and financial (right) system. Source: by author.

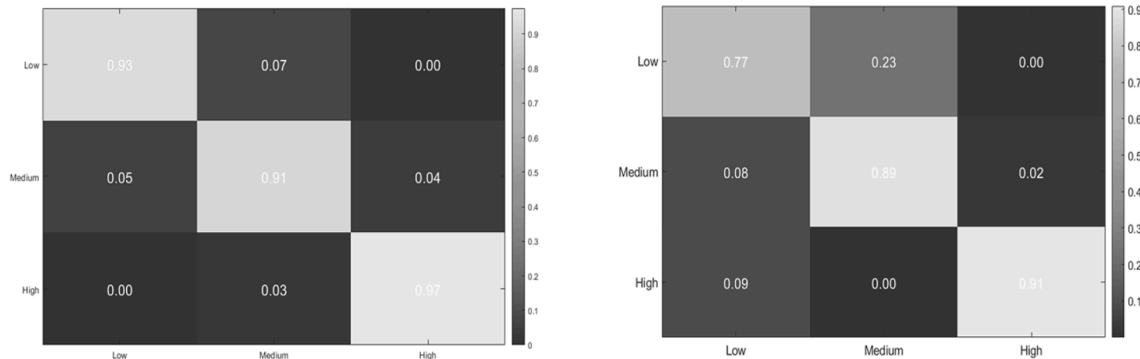


Fig. 9. Transition matrix of the trading system (left) and the financial system (right). Source: by author.

19 crisis, which exceeds the contagion movement during the Subprime crisis (2008), is mainly due to the combined effects between several economic and social factors, in particular: the shutdown of production systems, wait-and-see behaviour and reasoning in relation to distribution issues during decision-making. There is also a very important factor relating to the uncertainty and pandemic duration whose cyclical policies (monetary, fiscal, ...) are unable to rest quickly in the short term.

CRedit authorship contribution statement

Achraf Louati: Conceptualization, Methodology, Investigation, Writing – original draft, Visualization, Writing – review & editing. **Zakaria Firano:** Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Investigation, Writing – original draft, Visualization, Writing – review & editing. **Fatime Filali Adib:** Formal analysis, Data curation, Methodology, Validation, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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