"The impact of COVID-19 on the topological properties of the Moroccan stock market network"

| AUTHORS | Fadwa Bouhlal (iD) |
| | Moulay Brahim Sedra (iD) |

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BUSINESS PERSPECTIVES

Fadwa Bouhlal, Ph.D, Material
and Subatomic Physics Laboratory
(LPMS) Faculty of Sciences, Ibn Tofaïl
University, Morocco. (Corresponding
author)

Moulay Brahim Sedra, Professor,
Material and Subatomic Physics
Laboratory (LPMS) Faculty of Sciences,
Ibn Tofaïl University, Morocco.

Fadwa Bouhlal (Morocco), **Moulay Brahim Sedra** (Morocco)

THE IMPACT OF COVID-19 ON THE TOPOLOGICAL PROPERTIES OF THE MOROCCAN STOCK MARKET NETWORK

Abstract

This paper investigates the topological evolution of the Casablanca Stock Exchange (CSE) from the perspective of the Coronavirus 2019 (COVID-19) pandemic. Cross-correlations between the daily closing prices of the Moroccan most active shares (MADEX) index stocks from March 1, 2016 to February 18, 2022 were used to compute the minimum spanning tree (MST) maps. In addition to the whole sample, the analysis also uses three sub-periods to investigate the topological evolution before, during, and after the first year of the COVID-19 pandemic in Morocco. The findings show that, compared to other periods, the mean correlation coefficient increased remarkably through the crisis period; inversely, the mean distance decreased in the same period. The MST and its related tree length support the evidence of the star-like structure, the shrinkage of the MST in times of market turbulence, and an expansion in the recovery period. Besides, the CSE network was less clustered and homogeneous before and after the crisis than in the crisis period, where the banking sector held a key role. The degree and betweenness centrality analysis showed that Itissalat Al-Maghrib and Auto Hall were the most prominent stocks before the crisis. On the other hand, Attijariwafa Bank, Banque Populaire, and Cosumar were the leading stocks during and after the crisis. Indeed, the results of this study can be used to assist policymakers and investors in incorporating subjective judgment into the portfolio optimization problem during extreme events.

Keywords   econophysics, minimum spanning tree, stock returns, cross-correlation, centrality measures

JEL Classification   D53 , G11, G14

INTRODUCTION

The COVID-19 pandemic disrupted the global economy, suspending many economic activities and creating a dramatic and abrupt decline in demand and employment. As a result, global stock market prices experienced the worst slump since the global financial crisis (GFC). In Morocco, severely affected by the COVID-19 pandemic, the Casablanca Stock Exchange slumped during the year's first quarter. Indeed, according to the electronic magazine "MapNews" (MapNews | Actualité marocaine et internationale, n.d.), the Casablanca Stock Exchange (CSE) positively started the year; its leading index, the MASI, achieved on January 22 a high of 12,633.57 points and ended the first month of 2020 with a net gain of 2.96%. However, in March 2020, the CSE crashed due to coronavirus-associated psychosis. MASI and MADEX, the two main indices of the CSE dropped to 9,704.85 and 7,876.80 points, recording declines of 20.85% and 21.26%, respectively. These two indicators showed negative performances of -20.27% and -20.59%, respectively. In just three months, the capitalization of 123.67 billion dirhams vanished.

With the advent of econophysics, different patterns, methods and theoretical approaches that combine physics and statistical theories have

been used to describe features of financial dynamics (Mantegna & Stanley, 1999). Indeed, the classical theories of rational agents and efficient markets proved insufficient, especially during times of crisis. Network theory provides an unusual tool for investigating stock market network and recognizing trends in a graphical tree topology (Chakrabarti et al., 2006). The interaction and evolution of stock markets are studied using a traditional network approach, which is the minimum spanning tree (MST) method. The main idea is to decrease the complexity of the system by filtering the main information included in the topological structure of the stock market, at the same time, retain the markets' core information.

The COVID-19 pandemic created an entirely new economic environment; the implemented restrictions have significantly influenced the stock markets. Therefore, the present work could help asset managers diversify their portfolios by recognizing the reaction of the network topology of the CSE to extreme events and identifying the essential stocks and companies that influence each other. Although the COVID-19 pandemic caused the crash of many economies around the world, it is not the main threat. Instead, its effects on vital sectors are the most important. Thus, studying the topological evolution of finance, telecommunication, foods, distributors, and the real estate participation stocks is a central focus that provides more insight into the effect of the pandemic.

1. LITERATURE REVIEW

Thanks to financial globalization, stock markets around the world are highly intertwined. In a local stock market, the spread of risks and the complicated character of internal and external events require an extensive study of the dynamics of the stock market networks. In the financial network literature, researchers have most often deployed correlation-based networks to examine the effect of various events (Mantegna, 1999). Indeed, the concept of networks has proven to be a valuable tool for analyzing the static and dynamic characteristics of the stock market.

Based on a network approach to analyze developed markets worldwide, Onnela et al. (2003) used the MST approach to examine the impact of the Black Monday on 116 companies from 1982 to 2000. Their results showed that the normalized tree length decreased, and the stock market network rearranged during the downturn. In the same way, between January 2006 and November 2010, MST and HT (hierarchical tree) were applied to the first 40 UK companies listed on the London Stock Exchange (Ulusoy et al., 2012). Again, their findings showed a considerable contribution of the economic factors affecting a specific group of clustered stocks. Bonanno et al. (2001) also analyzed the high-frequency cross-correlation that existed in a group of 100 stocks traded in the US stock exchange using the MST and HT methods from 1995 to

1998. Their finding revealed clustering of stocks according to their sector of activity, an explicit role for the topological properties of the MST in portfolio optimization and risk. Also, Brida and Risso (2010) examined 29 leading German stocks listed in the DAX30 Index from January 2003 to November 2008. Their findings showed clustering of companies from the same economic sector after using MST and HT. In addition, after running bootstrap simulations, they discovered structural changes in the expansion of global distances.

Concerning emerging markets, Lee et al. (2012) reviewed high-frequency intraday level Korean stock market data from January 2009 to December 2009. The results of the MST maps suggested dense structures with high market volatility. Yang et al. (2014) used MST and an HT to define the main nodes that should be observed for the Chinese stock market network to preserve consistency. Their results reveal a little increase in clustering degree for the Chinese stock market network during an economic downturn. Zhang et al. (2010) studied the Shanghai stock exchange time series using the network theory from 5 March 2007 to 16 March 2007. Their results showed a small word property in a scale-free network and revealed that the distribution of time intervals between connected pairs decay exponentially. Bahaludin et al. (2015) recognized the most influential stocks in the Bursa Malaysia stock market using the MST

approach and the centrality measurements on the key 100 stocks between 2011 and 2013. Tabak et al. (2010) assessed the relative importance of several sectors by applying the MST method to the Brazilian stock market for 47 stocks from 2000 to 2008. Majapa and Gossel (2016), exploring the South African stock market, discovered that the normalized tree length contracted during the period of the crisis and expanded after it. Relevantly, Kantar et al. (2012) using MST, demonstrated that the 2008 global financial crisis did not affect Turkish companies.

Regarding network analysis in frontier markets (Market Classification, n.d.), Nguyen et al. (2019) analyzed stocks included in the Vietnam Stock Exchange between 2008 and 2017. The findings revealed a star-like MST in time of the economic crisis in Vietnam between 2011 and 2012. Memon and Yao (2019) investigated the Pakistani stock market by employing the threshold method, MST, and other approaches. They recognize that there were core nodes in different periods, which are fundamental to the stability of the whole stock market and require special focus by the government and other regulators.

The financial consequences of the COVID-19 pandemic on the world's exchange markets are significant because the disease's rapid spread affected almost every economic sector. In this way, network theory provides an innovative and powerful tool to investigate the topological evolution of stock exchanges during the COVID-19 outbreak. Specifically, the MST, as a standard network approach, is widely used to study the complex topology of stock market exchanges. After the COVID-19 pandemic declaration, several scientists used MST to study the complex topology of stock market networks in the context of the pandemic. For example, Kanno (2021) evaluated the impact of the pandemic on Japanese companies between April 7 and May 25, 2020. The author discovered that the TOPIX Index evolved in the opposite sense of COVID-19 measures using correlation analysis. In addition, after analyzing the credit risk, they showed that the COVID-19 policies are approximately the one variable that affects a company's credit risk at this time. Zhang et al. (2020) used the MST approach to examine the impact of the COVID-19 pandemic on financial markets. From their results, the COVID-19 pandemic has important effects on global financial markets, mainly reflected in the considerable increases in volatility. Furthermore, their results revealed an apparent difference between the patterns before and after the pandemic announcement in global stock market linkages. Mbatha and Alovokpinhou (2022) analyzed 134 South African companies listed in the ALSI index between October 2019 and October 2020. Analysis of MST and centrality measurements showed that the consumer services, basic materials, and financial sectors are relatively more influential than the other sectors. Furthermore, the findings reveal that the MST expands during the level 5-lockdown and shrinks after it.

This review reveals several shortcomings in the literature. Indeed, the existing evidence mainly comes from developed and emerging markets; however, very few studies examine the topology of stock market networks in frontier markets from the perspective of the COVID-19 pandemic, e.g. the Moroccan stock market.

2. AIMS

Using the MST and other centrality measurements, this study aims to examine the effect of the COVID-19 pandemic on the CSE network topology and compare the Moroccan market topology before, during, and after the first year of the COVID-19 pandemic. To grasp the stock market's reactions to the COVID-19 outbreak, in addition to the full sample (March 1, 2016 to February 18, 2022), the data (March 1 2019, to February 18, 2022) were split into three periods of equal length. The first one starts on March 1, 2019, and ends on February 28, 2020. The second sub-period is from March 2, 2020, which coincides with the announcement date of the first case of COVID-19 in Morocco, until February 16, 2021. Finally, the third sub-period runs from March 1, 2021 to February 18, 2022. The study tests the following hypothesis:

H1: *The Moroccan stock market network has reacted to the COVID-19 pandemic.*

3. METHODOLOGY

3.1. Data

L = 1,486 observations of N = 49 stocks were evaluated using daily closing prices from March 1, 2016 to February 18, 2022. The analyzed stocks are included in the MADEX index, consisting of the most active stocks listed on the Casablanca Stock Exchange. Among the 53 listed stocks in the MADEX index, only those were selected whose data were available during the analyzed period. Two computer programs were used to process the data; firstly, the time series data were collected from the Casablanca Stock Exchange's official website and saved in a Microsoft excel file (Bourse de Casablanca, n.d.). Secondly, the files were transferred to the R-Studio software to apply the Prim algorithm (Prim, 1957) and generate the MST. The variable sector assumed twenty-one values determined according to the Casablanca Stock Exchange. The company's tick symbols, names, and corresponding sectors are listed in Table A1 of the appendix.

3.2. Minimum spanning tree

By considering companies as nodes and the distance separating them (edges) as a unique function of the correlation coefficient, the MST was created using the methodological approach described by Mantegna and Stanley (Mantegna & Stanley, 1999). First, the following equation is used to calculate the log returns of MSE stock prices:

$$r_i(t) = \ln P_i(t) - \ln P_i(t-1), \qquad (1)$$

where, $P_i(t)$ is the stock price of company $i(i = 1, \ldots N)$ at time t.

Second, to obtain standardized data, the daily price returns are log-transformed. Following that, the cross-correlation coefficient was calculated using the equation:

$$\rho_{i,j}^t = \frac{r_i^t r_j^t - \overline{r_i^t}\,\overline{r_j^t}}{\sqrt{\left[\overline{r_i^{t2}} - \overline{r_i^t}^2\right]\left[\overline{r_j^{t2}} - \overline{r_j^t}^2\right]}}. \qquad (2)$$

In equation 2, the correlation coefficient $\rho_{i,j}^t$ represents the weight allocated to the edge connecting the vertices i and j, and $\overline{r_i^t}$ signifies the statistical mean of r_i^t during the study. The correlation coefficients range between –1 and 1, i.e. $-1 \le \rho_{i,j} \le 1$.

To create the MST, the distance between nodes must meet the following three pre-requisite conditions, which are:

- $d_{i,j} = 0$ if and only if $i = j$
- $d_{i,j} = d_{ji};$
- $d_{i,j} \le d_{i,k} + d_{k,j}.$

$$(3)$$

Third, the metric distance, $d_{ij} = \sqrt{2(1-\rho_{ij})}$, is used to construct the stock price network, where ρ_{ij} represents the correlation between the log-returns of stocks i and j. The MST, designated as T, is finally obtained from an $N \cdot (N-1)/2$ -links data metric to a minimized total weight of $V-1$ isolated edges using Prim's algorithm (Prim, 1957), and the distances d_{ij} between stocks i and j.

3.3. Weighted network measures

Normalized tree lengths, degree centrality, and betweenness centrality are three sub-metrics used to examine the MADEX index stocks' importance changes. The normalized tree length is used to evaluate MST tree length over the study period. Its formula is:

$$L(t) = \frac{1}{N-1} \sum_{(i,j) \in T^t} d_{ij}. \qquad (4)$$

The degree centrality of a node refers to the number of its neighbors (Freeman, 1978), and is used to determine a stock's strength to influence other stocks directly and is given as follows:

$$C_d(k) = \frac{\sum_{h=1}^N A_{kh}}{N-1}, \qquad (5)$$

where $A_{kh} = 1$ if the stock i and stock j are linked, and 0 otherwise, and N is the total number of stocks. Betweenness centrality is the ability of a node to control other nodes by regulating information flows between them (Freeman, 1977). The greater the node's impact on the network, the higher its value. It is calculated as:

$$C_b(k) = \sum_{s \ne k \ne t \in V} \frac{\sigma_{st}(k)}{\sigma_{st}}, \qquad (6)$$

where $\sigma_{st}(k)$ denotes the number of shortest paths that cross stock k from stock s to stock t. While σ_{st} is the total number of shortest links between s and t, such that $s \ne k$ and $t \ne k$.

4. RESULTS AND DISCUSSION

This section synthesizes the findings obtained from the correlation matrix of MADEX stocks by using the log return of the daily closing price from March 1, 2016 to February 18, 2022. The analysis and discussion concern the correlation coefficients, distances and tree lengths, minimum spanning trees, degree centrality and betweenness centrality measures.

4.1. Correlation coefficient and distance

Table 1 shows the correlation coefficients and distance values between the MADEX stocks during the three periods.

The overall sample average correlation between MADEX stocks is 0.077, which is less than the whole sample mean correlation of 0.128 for the Pakistan stock market (Memon & Yao, 2019) and is lower than the mean correlation of 0.145 for the South African stock market (Majapa & Gossel, 2016) during the GFC. As a result, the CSE network seems less clustered and homogeneous than the South African stock market and the Pakistan stock market. Furthermore, the findings suggest a decreased mean correlation before the crisis period, indicating weaker clusters. However, the mean stock correlation increased by nearly seven times during the crisis period compared to before the crisis, stabilizing at 0.048 after the crisis period, which is somewhat higher than the mean correlation of 0.031 before the crisis. Therefore, although the CSE showed a low correlation during the overall period, its response to the COVID-19 crisis was rather impressive.

The highest correlation and shortest distance are found between Attijariwafa Bank (ATW) and Banque Populaire (BCP) in the crisis period. Both companies operate in the banking sector with a correlation coefficient of 0.739 and an associated smaller distance metric of 0.722. Showing a correlation coefficient of 0.352 and an associated distance metric of 1.138, Itissalat Al-Maghrib (IAM) and Attijariwafa Bank (ATW) have the highest correlation and the minimum distance before the crisis period. The Real estate participation and promotion sector, including Douja Prom Addoha (ADH) and Alliances (ADI) companies, has the highest correlated pair after the crisis period, with a correlation value of 0.653 and a minimum distance of 0.833.

4.2. Dynamic evolution of correlations and distances

Table 2. Partition of the data sets into six windows

Window	Start period	End period	Trading days
W1	01/03/2016	28/02/2017	251
W2	01/03/2017	28/02/2018	250
W3	01/03/2018	28/02/2019	247
W4	01/03/2019	28/02/2020	247
W5	02/03/2020	26/02/2021	247
W6	01/03/2021	18/02/2022	247

The data sets were equally partitioned into windows (W) of 247 trading days approximately across the total period to explore the dynamic evolution of the correlations and distances among the stocks included on the MADEX index, as proposed by Situngkir and Surya (2005) (Table 2).

Table 3. Dynamic variation of the mean correlation and distances

Window	Average correlation	Average distance
W1	0.053	1.374
W2	0.046	1.378
W3	0.038	1.385
W4	0.03	1.39
W5	0.213	1.246
W6	0.048	1.378

Table 1. Summary observations before, during, and after the first year of the COVID-19 pandemic in Morocco and the overall period

Period	Time Period	Correlation Coefficient			Distance		
		Average	Minimum	Maximum	Average	Minimum	Maximum
Before crisis	01/03/2019 to 28/02/2020	0.031	−0.195	0.352	1.391	1.138	1.546
During Crisis	02/03/2020 to 26/02/2021	0.213	−0.136	0.739	1.246	0.722	1.507
After crisis	01/03/2021 to 18/02/2022	0.048	−0.17	0.653	1.378	0.833	1.53
overall period	01/03/2019 to 18/02/2022	0.077	−0.06	0.481	1.357	1.018	1.456

Table 4. Topological characteristics of the MST corresponding to the six equal windows

Window	Hub	Vertex Degree	Hub's Sector	Total distance	Normalized tree length
W1	ADH & LYD	6	Real Estate & Utilities	59.545	1.24
W2	ADI	6	Real Estate	59.927	1.248
W3	ATH	7	Distributors	60.8	1.266
W4	ATH	6	Distributors	60.67	1.264
W5	ATW	10	Banks	50.747	1.057
W6	ATW	5	Banks	58.9	1.227

Table 3 shows the six windows with the corresponding average correlation and distances during the total studied period. The findings indicate that the mean correlation in W1, W2, W3, and W4 (the post-crisis period) is extremely low and peaks in W5, which matches the crisis period, and decrease dramatically in W6, which was the start of recovery proceedings in Morocco. The highest tree distance is observed in W4 just before the downturn. The smaller distance values during the first year of COVID-19 pandemic resulted in the shrinkage of the tree, whereas it was more extended before the crisis in W4.

The dynamic evolution of the normalized tree length, total distance, and hub adjustment is shown in Table 4. The results highlight the impact of three major sectors in the MST: real estate, distributors, and banking, where companies from these sectors occupy a central posi-

tion in the MST. The findings imply that during the W5, the normalized tree length decreases considerably. Increasing correlation during the W5 crisis stretches the node and compresses the MST. It expands at W6, justified by the declined correlation coefficient and causing the most significant distances. This expansion means that the Moroccan economy has entered the recovery period.

4.3. Minimum spanning tree

To investigate the dynamics and the efficiency of nodes, three MSTs of the CSE network were plotted for three periods around the first year of COVID-19 in Morocco, nodes are colored based on their respective sector (due to a large number of sectors, only nodes which sector include two or more companies are colored). Figure 1 illustrates the MST in the period before the
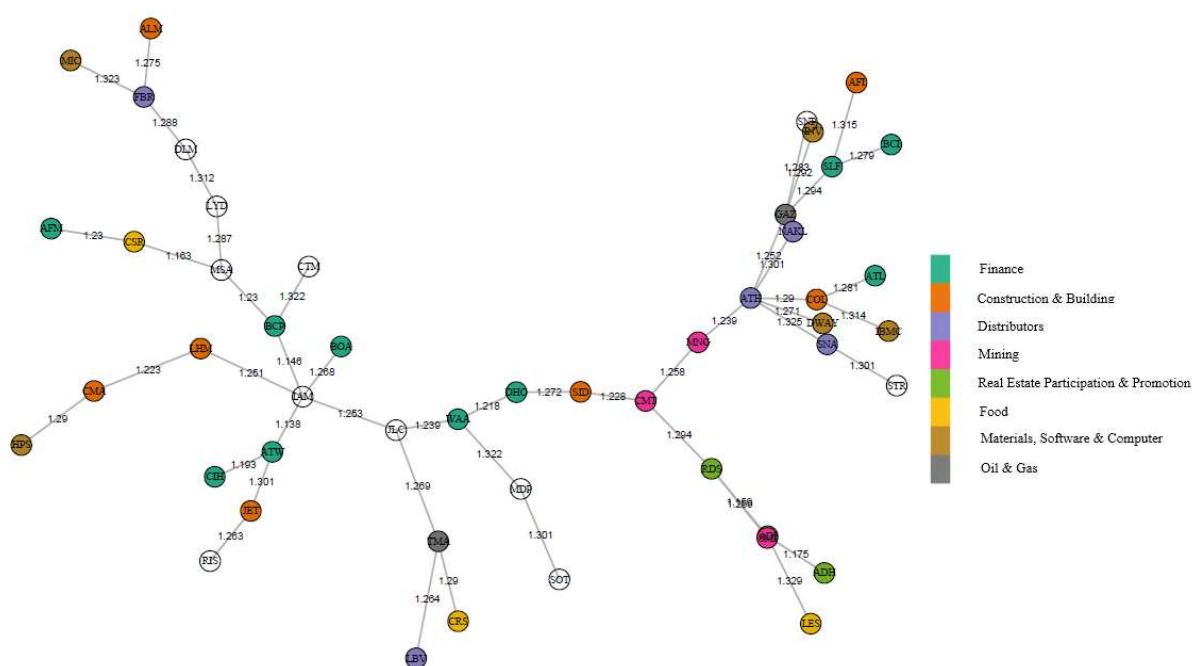

Figure 1. Before crisis minimum spanning tree
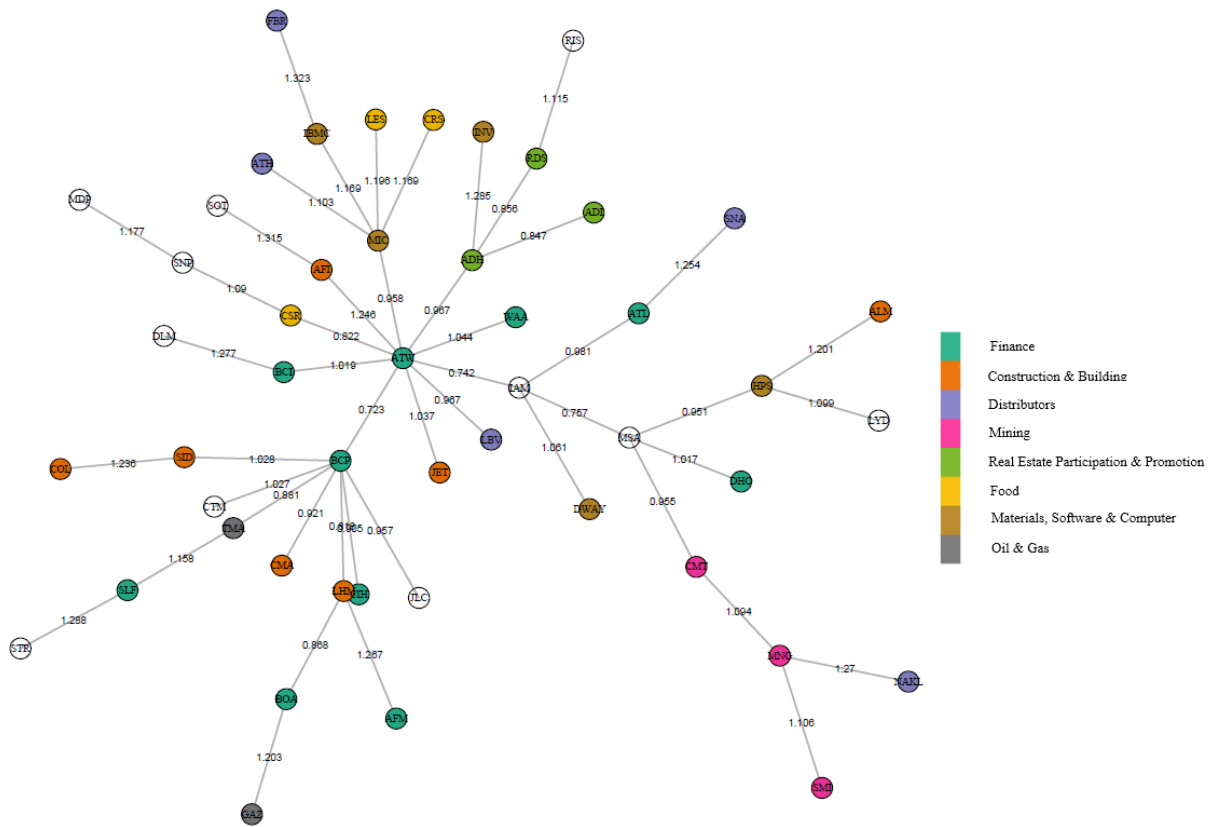of the MSE network (March 1, 2019 to February 28, 2020)

Figure 2. Crisis minimum spanning tree
of the MSE network (March 2, 2020 to February 16, 2021)

COVID-19 announcement in Morocco. The tree nodes with the most connections pre-crisis are Auto Hall (ATH, 6), Itisalat Al-Maghrib (IAM, 5), and Afriquia Gaz (GAZ, 4) (the number next to a stock symbol indicates the number of the node's neighbors). At the same time, the other nodes have three, two or one connection each. Therefore, the MST emphasizes that the distributors, the telecommunications, and the oil and gas sectors play a major role in the Moroccan economy before the crisis period. The MST shows a lower clustering and homogeneity compared to other stock markets. However, to some extent stocks belonging to the financial, construction and building, distributors, mining, and real estate sectors are linked, forming groups of stocks. The other stocks are dispersed through the tree. Financial companies operating in the banking sector are placed in the middle of the MST, while the insurance companies are scattered on the outskirts.

The MST corresponding to the crisis period is given in Figure 2. As can be observed,

Attijariwafa Bank (ATW) and La Banque Populaire (BCP) are the two key nodes with the most connections. Their degrees climbed from tree connections before the crisis to ten and eight respectively in the crisis period. Due to the COVID-19 crisis, these companies represent the central nodes of the MST. Therefore, they are directly exposed to any network shock. Indeed, compared to the MST before the crisis, the crisis MST displays an increase in connections. Microdata (MIC) is another key node with five links. Effectively, despite the COVID-19 pandemic, the Microdata's net income increased in 2020 by 8.9% compared to 2019. This can be explained by the fact that banks, which are the most resilient companies to the impact of a financial crisis, are the main customers of Microdata. It is evident that during the downturn, the financial sector played a crucial role. The MST confirms the research conclusions on the UK stock market conducted by Coelho et al. (2007) and Coronnello et al. (2005), which found that the financial sector was the tree's backbone. Compared to the period before the crisis, sev-
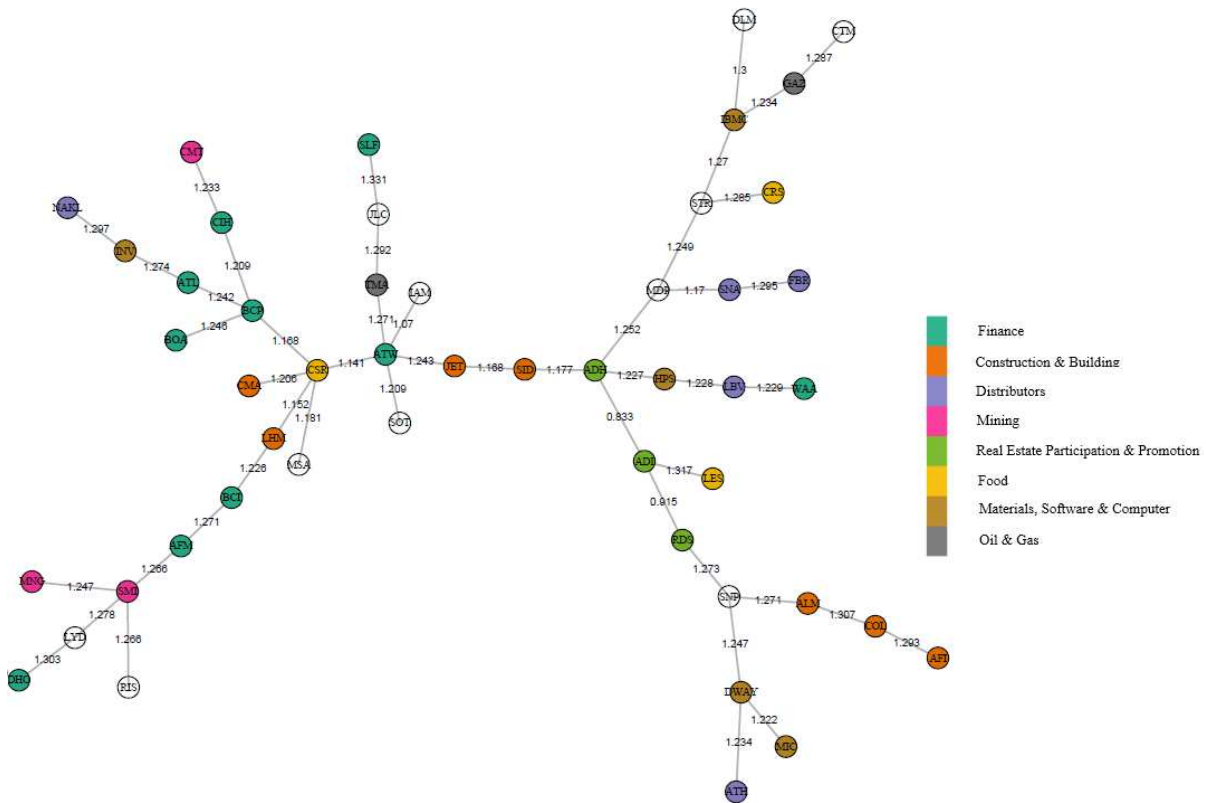
Figure 3. After crisis minimum spanning tree
of the MSE network (March 1, 2021 to February 18, 2022)

eral stocks form homogeneous groups of companies belonging to same sectors. These sectors are the real estate participation and promotion, the mining, the material software and computer, and the construction and building sectors. Concerning the other sectors, the stocks are dispersed throughout the tree.

Figure 3 shows the MST after the crisis period. Similar to the downturn period, the results show the emergence of the Attijariwafa Bank (ATW, 5) as a critical node. This finding is eventual, since the Moroccan economy has not recovered from the COVID-19 crisis yet. The most significant exception is the Banque Populaire (BCP) node, which connection was reduced from eight to four connections and replaced by Cosumar (CSR,5), a food sector stock. As a result, the MST after the crisis shows a decrease in links number (node's degrees) compared to the crisis period. Again, this behavior is similar to what has been observed in the South African stock exchange network after the crisis (Mbatha & Alovokpinhou, 2022).

4.4. Degree and betweenness centrality

Based on two measures of centrality, which are the degree and betweenness centrality, the relativistic strength of every node in the MSE network is calculated.

Table 5. The five highest values of degree centrality for the three periods

Degree centrality					
Pre-crisis		Crisis		Post-crisis	
Code	C_d	Code	C_d	Code	C_d
ATH	0,125	ATW	0,208	ATW	0,104
IAM	0,104	BCP	0,167	CSR	0,104
GAZ	0,083	MIC	0,104	BCP	0,083
ATW	0,063	ADH	0,083	ADH	0,083
BCP	0,063	IAM	0,083	SMI	0,083

Table 5 shows the first five nodes with the highest degree of centrality for each period. Due to the smaller number of edges connected to nodes during the three periods, the MST presents a decline in the average degree of centrality. Indeed,

Attijariwafa Bank (ATW) has a lower degree value of 0,063 before the crisis period. However, it achieves the top values during and after the crisis with a degree value of 0,208 and 0,104, respectively. Similarly, Banque Populaire (BCP) degree centrality increased from 0,063 before the crisis to 0,167 and 0,104 in the period of crisis and after it, respectively.

Moreover, CSR (Cosumar) suddenly appeared in the first three stocks after the crisis. Besides, apart from Attijariwafa Bank (ATW) and Banque Populaire (BCP), there are no long-term stocks in the ten most important degree centrality values during the three periods. This classification signifies a reorganization of the network to adapt during challenging times. Indeed, companies from the distributors and telecommunications sectors were the strongest before the crisis. However, the banking and food companies replaced them during and after this downturn.

Table 6. The five highest values of betweenness centrality for the three periods

Betweenness centrality					
Pre-crisis		Crisis		Post-crisis	
Code	C_b	Code	C_b	Code	C_b
IAM	0,566	ATW	0,824	ADH	0,637
CMT	0,563	BCP	0,464	ATW	0,596
JLC	0,558	IAM	0,409	CSR	0,544
WAA	0,551	MSA	0,301	JET	0,511
DHO	0,507	MIC	0,199	SID	0,51

The analysis of the betweenness centrality during the three periods (Table 6) shows that Itissalat Al-Maghrib (IAM) had the most significant score in the pre-crisis period, with betweenness centrality values of 0.566, but dropped significantly in the crisis period, a score of 0.409. However, during the financial crisis, Attijariwafa Bank (ATW) replaced Itissalat Al-Maghrib (IAM) and received the highest score in betweenness centrality of 0.824. The post-crisis period shows an enhanced mediating effect of DHA and an increased intermediary role of Attijariwafa Bank (ATW). Douja Prom Addoha (ADH)'s betweenness value entered the top five and achieved the highest betweenness centrality of 0.637, while Attijariwafa Bank's (ATW) score has risen from 0.824 to 0.596.

According to the results, there are no constant stocks included in the top five throughout the three periods. However, before and during the crisis period, Itissalat Al-Maghrib (IAM) was in the top five, while Attijariwafa Bank (ATW) was in the top five during the crisis and after it. Indeed, Itissalat Al-Maghrib (IAM), which belongs to the telecommunications sector, was a good mediator before the crisis. But then, companies from the banking sector replaced it during and after the crisis. Besides, Douja prom addoha (ADH), which belongs to the real estate participation and promotion sector, was influential after the crisis.

CONCLUSION

Using the daily closing price of the 49 companies listed in the MADEX from March 1, 2016 to February 18, 2022, this study investigate the effect of the COVID-19 pandemic on the CSE network topology. The data (March 1, 2019 to February 18, 2022) were divided into three periods: before (March 1, 2019 to February 28, 2020), during (March 2, 2020 to February 16, 2021), and after the first year of the COVID-19 in Morocco (March 1, 2021 to February 18, 2022). The relative importance of each stock in the MADEX network is estimated using two centrality measures: degree and betweenness centrality. Roughly, the results reveal that, during the overall period, the correlation coefficients across the MADEX companies are weak. The correlation would be higher if the CSE were more efficient, allowing short selling or developing derivative trading. Furthermore, foreign investors' access to the CSE was liberalized only in the last years.

The study results supported the research hypothesis that suggests a CSE network reaction to the COVID-19 crisis. Indeed, the MST showed a shrinking during the first year of the COVID-19 pandemic in Morocco compared to the MST before and after this year. The topological transformation of the MST in time of crisis represents a specific result of the COVID-19 pandemic. The correlation coefficients rise

during the crisis, resulting in a tree's compression during this period. During a stock market decline, companies act simultaneously, and their correlations are much higher than those of a regular period. Furthermore, centrality measures suggest that hub nodes were moving away from the distributors and telecommunications sectors before the crisis to the banking and food sectors during and after the crisis.

All of these results on the network dynamics and the relative importance of specific stocks could support CSE local and foreign investors in handling their portfolios as well as the regulatory authority in assessing the stock market's stability. Further research could exploit the complexity and self-similarity of the MSE network.

AUTHOR CONTRIBUTIONS

Conceptualization: Fadwa Bouhlal.
Data curation: Moulay Brahim Sedra.
Formal analysis: Fadwa Bouhlal.
Funding acquisition: Moulay Brahim Sedra.
Investigation: Fadwa Bouhlal.
Methodology: Moulay Brahim Sedra.
Project administration: Fadwa Bouhlal.
Resources: Moulay Brahim Sedra.
Software: Moulay Brahim Sedra.
Supervision: Fadwa Bouhlal.
Validation: Fadwa Bouhlal.
Visualization: Moulay Brahim Sedra.
Writing – original draft: Fadwa Bouhlal.
Writing – review & editing: Fadwa Bouhlal.

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APPENDIX A

Table A1. The company's tick symbols, names, and corresponding sectors of the 49 stocks listed on the MADEX index

Symbol	Company	Sector	Symbol	Company	Sector
ADH	Douja Prom Addoha	Real Estate Participation And Promotion	IBMC	Ib Maroc.Com	Materials,Software & Computer Services
ADI	Alliances	Real Estate Participation And Promotion	INV	Involys	Materials,Software & Computer Services
AFI	Afric Industries Sa	Construction & Building Materials	JET	Jet Contractors	Construction & Building Materials
AFM	Afma	Insurance	JLC	Taqa Morocco	Electricity
ALM	Aluminium Du Maroc	Construction & Building Materials	LBV	Label Vie	Distributors
ATH	Auto Hall	Distributors	LES	Lesieur Cristal	Food Producers & Processors
ATL	Atlantasanad	Insurance	LHM	Lafargeholcim Maroc	Construction & Building Materials
ATW	Attijariwafa Bank	Banks	LYD	Lydec	Utilities
BCI	Bmci	Banks	MDP	Med Paper	Forestry & Paper
BCP	Bcp	Banks	MIC	Microdata	Materials,Software & Computer Services
BOA	Bank Of Africa	Banks	MNG	Managem	Mining
CIH	Cih	Banks	MSA	Sodep-Marsa Maroc	Transportation Services
CMA	Ciments Du Maroc	Construction & Building Materials	NAKL	Ennakl	Distributors
CMT	Miniere Touissit	Mining	RDS	Res Dar Saada	Real Estate Participation And Promotion
COL	Colorado	Construction & Building Materials	RIS	Risma	Leisures And Hotels
CRS	Cartier Saada	Food Producers & Processors	SID	Sonasid	Construction & Building Materials
CSR	Cosumar	Food Producers & Processors	SLF	Salafin	Investment Companies & Other Finance
CTM	Ctm	Transport	SMI	Smi	Mining
DHO	Delta Holding	Holding Companies	SNA	Stokvis Nord Afrique	Distributors
DLM	Delattre Levivier Maroc	Engineering & Equipment Industrial Goods	SNP	Snep	Chemicals
DWAY	Disway	Materials,Software & Computer Services	SOT	Sothema	Pharmaceutical Industry
FBR	Fenie Brossette	Distributors	STR	Stroc Industrie	Engineering & Equipment Industrial Goods
GAZ	Afriquia Gaz	Oil & Gas	TMA	Totalenergies Marketing Maroc	Oil & Gas
HPS	Hps	Materials,Software & Computer Services	WAA	Wafa Assurance	Insurance
IAM	Itissalat Al-Maghrib	Telecommunications	–	–	–