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INTRA AND INTER SECTORAL RISK SPREAD AND PORTFOLIO RISK MANAGEMENT: CASE OF S&P 500

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A critical issue of diversification in portfolio management is the intra and inter-sectoral spread of risk. The aim of this study is to capture potential intra and inter sectoral risk spread. In this regard, the Bayesian Neural Networks (BNN) model was involved, the method being applied for a portfolio of 12 shares from the American index S&P 500, on the period January 1st, 2011 – January 28th, 2023. The expected shortfall was involved as a risk estimation measure and the Tabu Search learning algorithm of BNN was employed. The robustness of the results was tested at three significance thresholds namely, 0.85, 0.90 and 0.95. The differences of the results were highlighted on two subsamples, from January 1st, 2011 – December 31st, 2019, and January 1st, 2020 – January 28th, 2023. Evidence of intra and inter sectoral contagion was found on the full sample period, however during the financial turmoil period represented by the last sub-sample, the results display that the linkages between different sectors weakened to certain extents. The key contribution stands in the significant implications for portfolio risk management. The results highlight and strengthen the importance of building a portfolio based on an accurate selection of assets that are not inter-linked.

Keywords: **Financial contagion, financial markets, pandemic crisis, Ukrainian war crisis, S&P 500, Shares**

JEL Classification: **C11, D81, G10, G11**

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1. Introduction

The long-time interest in studying financial market co-movements and financial contagion can be justified by various reasons, especially in a globalized financial world. Understanding how shocks can transfer in-between markets is a key in identifying and developing measures to avoid the transmission of crises. Also, understanding contagion and risk spread is instrumental for investors, fund managers and policymakers in developing portfolio diversification strategies.

So far, the wide literature mainly focused on finding empirical evidence of contagion effects across global financial markets (for instance, Shinagawa (2014), Ouyang et al. (2020), and so on). The issue addressed by these papers refers to the way idiosyncratic shocks originating in one market can transfer to international markets especially in times of financial turmoil. However, as Phylaktis & Xia (2009) argued, studying the effects of contagion only at the market level "could mask the sectors heterogeneous performances". So, in spite of the limited research the literature, sectoral contagion is also of great importance for investors and policymakers. As Phylaktis & Xia (2009) argued, sector contagion is asymmetric due to the fact that external shocks can impact sectors within one market to different extents. By leaning on Forbes (2002) perspective that trade and financial linkages are important drivers for risk transmission in-between markets, it can also be considered that at the sectoral level these linkages play the same role. In other words, sectors that share trade and financial linkages tend to be more vulnerable to risk transmission. From the viewpoint of portfolio risk management, as Phylaktis and Xia (2009) argued, the sector heterogeneity of contagion implies that some sectors within the same market may still provide opportunities for portfolio diversification, regardless the potential contagion effects at the market level.

The recent events have shown that exogenous shocks, such as the COVID-19 pandemic or the Ukrainian war, can lead to financial crises. As Bouri et al. (2021) argued, investors, policymakers and other stakeholders can enhance portfolio decisions based on the direction and size of the spillovers in times of turmoil, as well as formulate proper policies to maintain financial stability. The risk propagation from one sector to another within one market can be the effect of sectoral connectedness. Mensi et al. (2020) and Costa, Matos and da Silva (2021) argued that, although not very much researched, sectoral connectedness is of great importance as it could provide certain internal dynamic that is country specific. Therefore, it could provide insight to investors and asset managers in relation to the management of portfolio risk.

Baruník et al. (2016) analyzed sectoral connectedness in the US. They analyzed the volatility spillovers asymmetries of seven sectors during periods of turmoil and tranquility given by the global financial crisis in 2007-2010. They found evidence of spillovers that in certain sectors were transmitted at various magnitudes that changed over time and they also found a

considerable increase in terms of connectedness during the period of turmoil. On the same direction, Mensi et al. (2020) examined the volatility connectedness between several sectors within the US financial market. They found evidence of inter and intra sectoral risk spread and stronger linkages during turmoil periods and events of great impact, such as energy or geopolitical ones. Costa, Matos and da Silva (2021) studied the way in which the sectoral indices' network within the US was impacted by the pandemic crises. They used a sample of eleven US sectors and found a significant increase of connectedness and volatility among the sectoral indices during the pandemic crisis. At the same time, they found that certain pairs of sectors were more linked in relation to others, for instance the sectors of Energy and Financials.

Considering the literature, intra and inter sectoral risk spread and sectoral contagion are issues of great importance that require more examination. Therefore, this paper aims to explore sectoral contagion from a different perspective by addressing two research questions:

RQ1: Are shocks on one sector transferred to other sectors within a financial market?

RQ2: Does the intra and inter sectoral spread of risk represent an issue in portfolio risk management diversification?

By answering these questions, the contribution to the literature is given by the examination of intra and inter linkages between different sectors, based on a sample consisting of twelve shares within four different sectors of the US financial market S&P 500. At the same time, the study highlights the importance of this issue for different stakeholders such as investors, companies and policymakers, in building and optimizing portfolios and managing risk.

For analyzing the potential connection between intra and inter sectoral risk spread and portfolio risk management, it is important to understand the notion of "sectors". Numerous companies are trading on financial stock markets and the firms that operate akin business activities are considered to be part of the same sector. In this regard, financial markets contain various sectors that classify companies' assets based on their field of activity. As Gupta and Basu, (2009) argued, the sectors within a financial market do not evolve with the same rate. In this regard, sectors' performance could significantly impact portfolio selection and management (for instance, investing in stocks of a market's leading sectors could imply various opportunities for earning profits). As Costa, Matos and da Silva (2021) considered, the sector-based approach of portfolio construction is one of the most diversified methods for investment because the risk of targeting a single company can be avoided and the unsystematic risk can be mitigated.

According to the literature (i.e. Ranjeeni (2014), Wu et al. (2020), and so on), a shock on one sector could transfer to other sectors within the same market. However, due to the market particularities, risk characteristics and sectoral heterogeneities, each sector within a market could differently react towards risk. In order to have a strategic portfolio risk management and diversification, investors should identify the leading sectors, the connections between the sectors within one market and the systemic risk transmission between them. Saeed et al.

(2021) and many other researchers carried out studies on the subject of spillovers in-between sectors of leading financial markets. These studies provided significant support for market participants in taking decisions by giving insights about the inter-sectoral behaviour. However, according to Costa, Matos and da Silva (2021), there is a gap in literature in what regards the existence of a comprehensive and accurate model for constructing a portfolio of assets based on inter-sectorial examination.

This study aims to capture evidence of intra and inter sectoral risk spread in-between twelve selected shares within four sectors from the S&P 500 US financial market, during a full sample period, January 1st, 2011 – January 28th, 2023. For testing the results' robustness, the full sample period was split in two sub-samples, namely January 1st, 2011 – December 31st, 2019, and January 1st, 2020 – January 28th, 2023.

Therefore, the paper proposes a three-fold contribution:

- After computing the shares closing prices logarithm, the Expected Shortfall (ES) measure was involved in order to estimate risk. The Expected Shortfall measure represents a coherent risk measure because it implies four main properties, namely monotonicity, translation invariance, homogeneity and subadditivity. As Acerbi & Tasche (2002) argued, the last property can be assured only by the Expected Shortfall measure).
- In order to capture the direct and indirect linkages and correlations between the twelve shares, Bayesian Neural Networks (BNN) model was performed. The BNN score-based structure learning algorithm Tabu Search was applied, and the robustness of the results was tested at three significance thresholds, 0.85, 0.90 and 0.95. The same steps were performed for each sub-sample periods.
- The main features of the obtained linkages between the shares were examined and detailed. The key point of the study is given by the captured evidence of risk spread at the sectoral level which further highlights the importance of this subject in portfolio risk management.

The paper is structured as follows. Section 2 describes the motivation for using the involved methodology and dataset. Section 3 describes the empirical results and comments, while Section 4 describes the conclusions.

2. Methodology and data

Considering the literature, due to stock markets' dynamics, more and more scholars developed various methodologies for building effective portfolios in times of globalization when financial markets are vulnerable and exposed to contagion. In this regard, the recent literature displays a shift towards soft computing techniques and artificial intelligence for portfolio selection and management (Calvo et al. (2015), Pareek & Thakkar (2015), so on). At the same time, still for portfolio selection many researchers tend to use artificial neural

networks while for portfolio optimization genetic algorithms usage became quite notorious (Bavarsad Salehpoor & Molla-Alizadeh-Zavardehi (2019), so on). Also recently in the literature, the interest for using deep learning approaches for both optimizing portfolios and finding evidence of risk spread keeps growing significantly because they ensure better and more robust results in relation to traditional approaches (Zhang et al. (2020a), Ma et al. (2021), so on).

Studies that focus on contagion are becoming more and more innovative in terms of methodology due to the recently developed techniques of computation (i.e. neural networks and machine learning). For instance, the Bayesian Neural Networks model represents a technique of artificial intelligence. It can be expressed based on a graphic statistical model which, according to Fonseca & Carvalho (2021), "maps the joint distribution function of a set of random variables". The interest for selecting such a method in studying risk spread and contagion is given by its ability to identify and illustrate not only the correlations and linkages between variables, but also the causality's direction which shows which are the variables that generate, spread and/or receive contagion.

Numerous scholars used BNN models in order to examine different forms of contagion between financial markets. In what concerns sectoral contagion and intra and inter sectoral risk spread, there is a gap in literature as the topic was not very much researched. However, Fonseca & Carvalho (2021) used Dynamic BNN on a sample of nine Sow Jones' indices for the period 2000-2020. They found that the periods of financial turmoil are the main contagious periods and that during the pandemic crisis, the main spreaders were Oil & Gas, Pharmaceuticals and Real Estate sectors.

Nguyen (2013) argued that the BNN model is widely used by researchers because it involves "a strong-based interference" that can be associated to human intuition to a certain extent. The BNN model captures and illustrates the linkages, the inter-relationships in-between random variables in the shape of conditional distributions. Considering that the model implies random variables, the only information upon the variables' behaviour stands in historical data.

The motivation to build this study based on a model in the framework of BNN stands in the fact that it represents a probabilistic model that provides the possibility to visually depict uncertainty and risk. At the same time, BNN model conditional dependence which generates both direct and indirect linkages between variables. From the linkages it can be seen how risk transfers in-between variables.

Data

This study proposes a sector-based portfolio construction based on twelve shares from the US financial market S&P 500. The S&P 500 consists of various sectors but for this study four major sectors were selected, namely Information Technology – Application Software,

Financials, Health Care – Pharmaceuticals and Consumer Discretionary – Automobile Manufacturers. For each sector, three securities were selected, data being downloaded from Yahoo Finance (https://finance.yahoo.com/): Adobe Inc. (ADBE), Autodesk Inc. (ADSK) and Salesforce Inc. (CRM) for Information Technology – Application Software, Ameriprise Financial Inc. (AMP), Bank of America Corporation (BAC) and State Street Corporation (STT) for Financials, Merck & Co. Inc. (MRK), Johnson & Johnson (JNJ) and Pfizer Inc. (PFE) for Health Care – Pharmaceuticals, and Ford Motor Company (F), Tesla, Inc. (TSLA) and General Motors Company (GM) for Consumer Discretionary – Automobile Manufacturers.

The study aims to find evidence of intra and inter sectoral risk transmission in-between the selected shares and sectors during a full sample period, January 1st, 2011 – January 28th, 2023. The robustness of the results was tested by making a split of the full sample time span in two sub-samples, namely January 1st, 2011 – December 31st, 2019 and January 1st, 2020 – January 28th, 2023. The first sub-sample corresponds to the business-as-usual period right after the 2007-2010 financial crisis. The second sub-sample encompasses a turmoil period triggered by two major exogenous shocks, namely the COVID-19 pandemic and the occurrence of the Ukrainian war.

The analysis starts by calculating the closing prices logarithm and continues by estimating risk through the ES method. The Bayesian Neural Networks (BNN) model was performed by applying the Tabu Search score-based structure learning algorithm. For testing the results' robustness, the Tabu Search algorithm was performed at three significance thresholds, namely 0.85, 0.90 and 0.95. The same analysis was performed for each sub-sample. Before applying the model in the framework of BNN, the database was synchronized by cutting off the non-available information and 3037 observations were obtained for the full sample period (2011-2023), 2262 and respectively 773 for the sub-samples periods of 2011-2019, respectively 2020-2023.

3. Empirical results

The obtained generated acyclic graphs (DAGs) depicted in Figures no 1-3 show that during the full and sub-sample periods, the S&P 500 indices are causally interdependent. However, these results were obtained before applying the bootstrap procedure for the Tabu Serach score-based structure learning algorithm. For illustrating the causality given by the strongest potential direct and indirect connections in-between the indices, the bootstrap procedure was further involved.

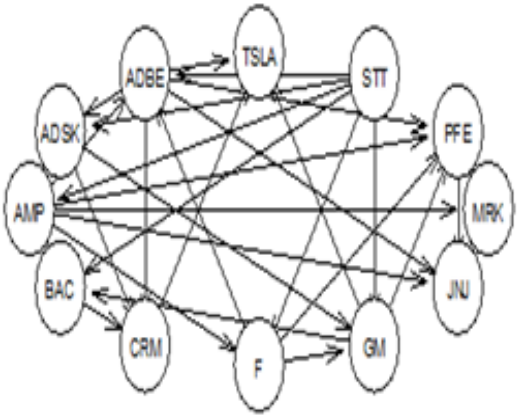

Figure 1. Tabu-Search for 2011-2023

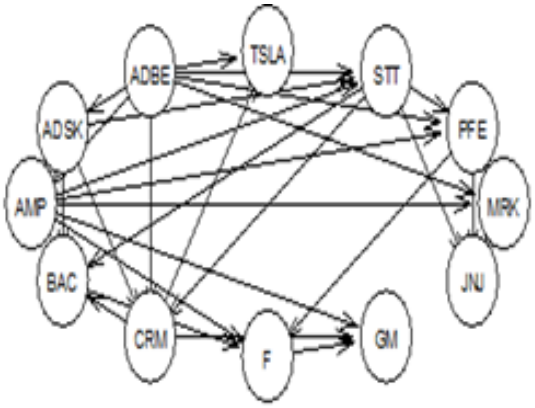

Figure 2. Tabu-Search for 2011-2019

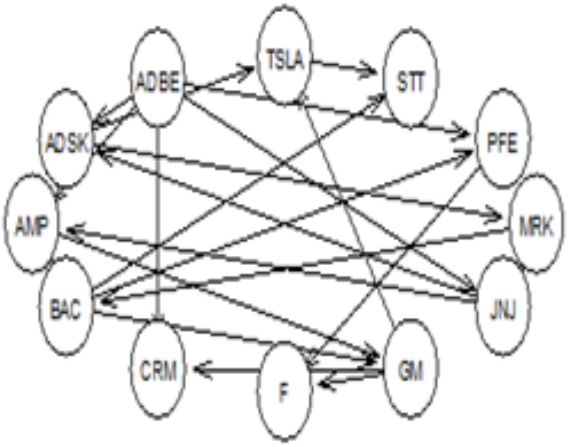

Figure 3. Tabu-Search for 2020-2023

Full sample period January 1st, 2011 – January 28th, 2023:

In order to capture the strongest direct and indirect linkages between the 12 shares from the US financial market S&P 500, the bootstrap procedure was applied for the full data sample (January 1st, 2011 – January 28th, 2023). The results of the Tabu Search score-based structure learning algorithm were tested for three significance thresholds, namely 0.85, 0.90 and 0.95.

For the thresholds of 0.85 and 0.90, the results displayed in Figures no 4-5 show that intra and inter sectoral risk spread exists and evidence of sectoral contagion is found. As illustrated by the DAGs, the causality is running from the STT component within the Financials sector to the

other sectors, except JNJ component within the Pharmaceuticals sector. In this sense, certain remarks can be withdrawn:

- sectoral contagion is sensed in-between 11 shares within the portfolio of 12 components within the US financial market S&P 500;
- S&P 500 market components are causally interdependent in both turmoil and business-as-usual periods (as the analyzed full sample encompasses the business-as-usual period after the 2007-2010 financial crisis and the turmoil periods that were induced by occurrence of the COVID-19 pandemic and the Ukrainian war);
- evidence of intra sectoral risk spread is found for each single sector within the analysis, even in the Pharmaceuticals sector where risk spreads both directly from JNJ to MRK (intra sectoral contagion), and indirectly from the Financials sector (inter sectoral contagion);
- within the Pharmaceuticals sector, causality is running only in-between the components of the respective sector, risk not being transmitted to the others; however, biunivocal linkages are noticed, where risk coming from Financials sector impacts PFE through the Automobile Manufactures sector.

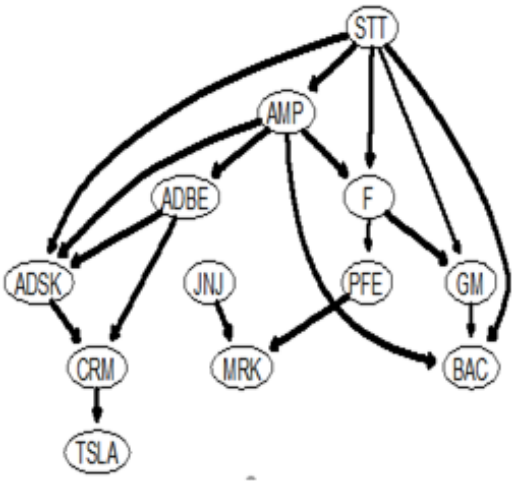

Figure 4. Bootstrapped Tabu Search at 0.85 threshold for 2011-2023

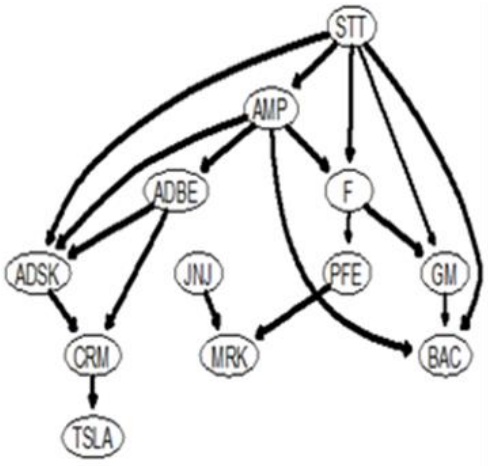

Figure 5. Bootstrapped Tabu Search at 0.90 threshold for 2011-2023

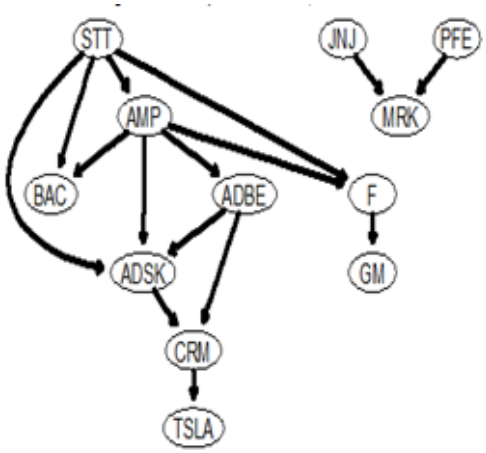

Figure 6. Bootstrapped Tabu Search at 0.95 threshold for 2011-2023

Having increased the threshold to 0.95, it can be noticed in Figure no 6 that the causality between the 12 market components changed for the full sample. The main risk driver in-between the components of the S&P 500 is still STT within the Financials sector. The most important observations to be withdrawn from the results are given by the linkages within the Pharmaceuticals sector. The sector became isolated from the others, which shows that risk running from the other sectors does not impact the Pharmaceuticals one. Also, even within the sector, JNJ and PFE components are not assimilating any shock coming from the other ones, however any shock at the level of these shares directly impacts MRK.

Sub-sample period January 1st, 2011 – December 31st, 2019:

The bootstrapped Tabu Search score-based structure learning algorithm was employed for the sub-sample corresponding to the business-as-usual period after the 2007-2010 financial crisis and the DAGs from Figures no 7-9 were obtained. It can be noticed that for all the three significance thresholds, the causality runs from the Financials sector, from the AMP component of the S&P 500 financial market.

For a threshold of 0.85, all the shares are correlated, so evidence of intra and inter sectoral contagion is sensed. It is interesting to notice that a shock at the level of the Financials sector, can spread to the Information Technology sector and further to Pharmaceuticals and Automobile Manufacturers (Figure no 7).

After increasing the threshold to 0.90, it can be seen in Figure no 8 that the results slightly changed, even though the risk driver remained the AMP component of the Financials sector. For this case, evidence of inter sectoral contagion was sensed from the Financials sector to the others, while intra sectoral risk spread was sensed in all the four sectors within the analysis. It is also important to highlight that the TSLA component was not impacted by other shares within its corresponding sector, but rather by the Information Technology sector. This is mainly due to the fact that Tesla is a company that grew based on its technological innovations; so the trading linkages between the company and the Information Technology sector are very strong. Tesla is classified as part of the Automobile Manufacturers sector due its activity of producing cars that requires huge capital infusions for financing production costs. Firms within the Information Technology sector usually have low scaling costs; so, in spite of its advanced technology, Tesla does not fit into this market sector.

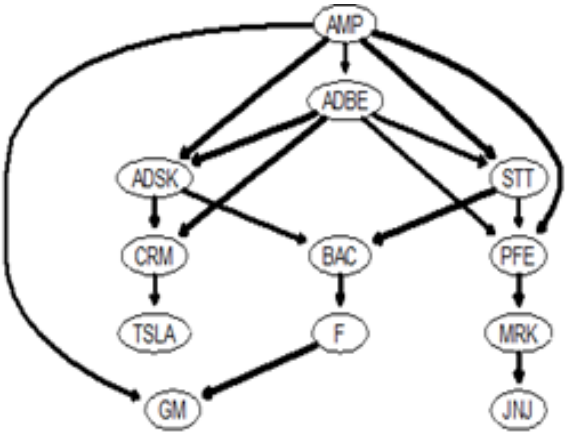

Figure 7. Bootstrapped Tabu Search at 0.85 threshold for 2011-2019

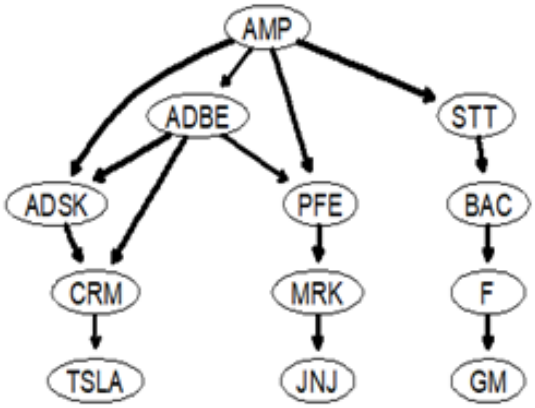

Figure 8. Bootstrapped Tabu Search at 0.90 threshold for 2011-2019

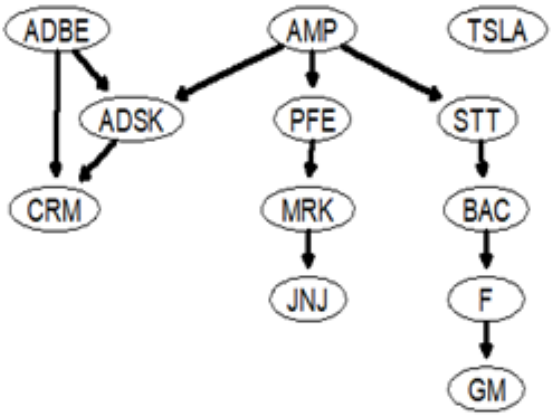

Figure 9. Bootstrapped Tabu Search at 0.95 threshold for 2011-2019

By employing a 0.95 threshold, the results show that risk is directly running from the Financials AMP component to the Pharmaceuticals and Information Technology sectors (Figure no 9). The linkages between AMP and the shares within the Automobile Manufacturers sector are biunivocal linkages as risk is running indirectly through the STT Financials component. It is important to highlight that the ADBE shares do not assimilate any shock that could happen at the level of the other sectors. An even more interesting result is that TSLA is immune to any shocks that could occur in any of the other sectors, as it neither assimilates, nor spreads any risk to the shares within the analysis.

Sub-sample period January 1st, 2020 – January 28th, 2023:

The last sub-sample that was analyzed encompasses the periods of social, economic and financial turmoil triggered by the two exogenous shocks, namely the COVID-19 pandemic crisis in 2020 and the war in Ukraine in 2022. Compared to the results obtained previously,

the shares within the S&P 500 are not as much correlated. It can be seen that the more the threshold increases, the less linkages are illustrated by the DAGs.

For the 0.85 significance threshold, the linkages between the shares display evidence of intra sectoral contagion, so causality is running in-between the components of the same sector (Figure no 10). However, it can be noticed that Financials and Information Technology sectors do share certain linkages. An important observation stands in the fact that TSLA is no longer impacted by shocks coming from the Information Technology sector, but from the Financials sector.

After increasing the threshold to 0.90, the results did not change very much, however the STT component became immune to shocks at the level of other Financials sector components. It is important to mention that TSLA is still correlated with STT, but not with any other component (Figure no 11).

As depicted in Figure no 12, for a higher threshold of 0.95, the linkages between the shares weakened considerably. There is no evidence of inter sectoral contagion, only some companies that are part of the same sector are correlated (for instance, the causality running from ADBE to CRM, from AMP to BAC and from GM to F). The only exception is given by the correlation between STT and TSLA which is the only sign of inter sectoral risk spread.

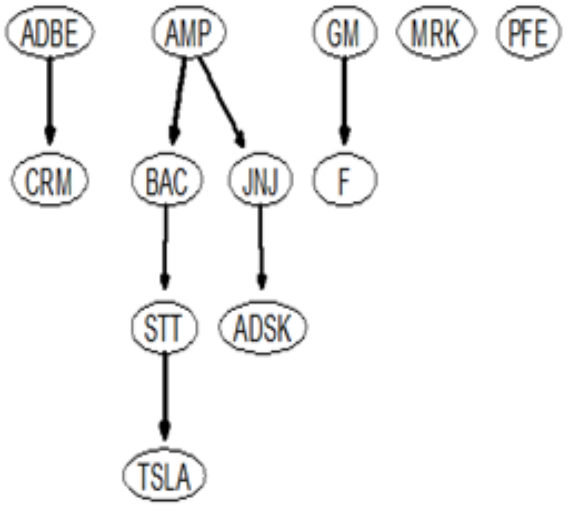

Figure 10. Bootstrapped Tabu Search at 0.85 threshold for 2020-2023

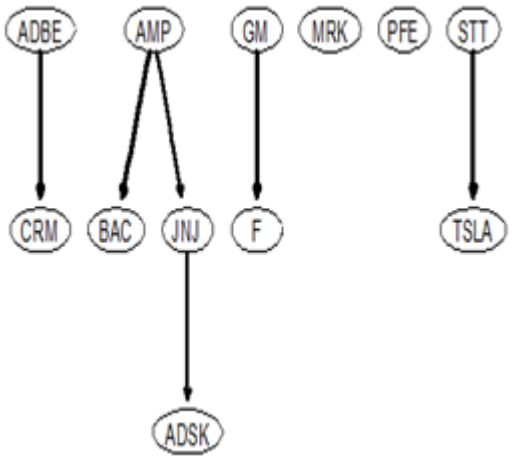

Figure 11. Bootstrapped Tabu Search at 0.90 threshold for 2020-2023

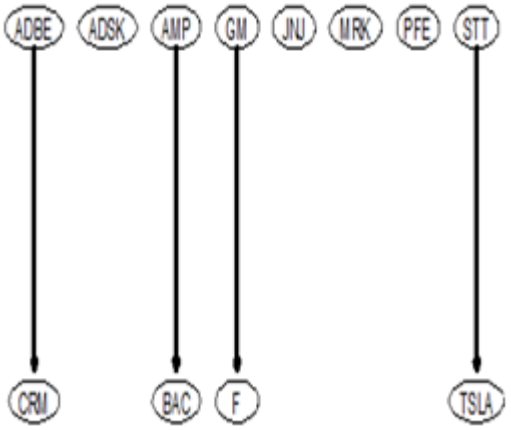

Figure 12. Bootstrapped Tabu Search at 0.95 threshold for 2020-2023

Comments:

The extreme events triggered by exogenous shocks that ended up in financial crises have significantly impacted all sectors within financial markets. Many scholars (such as Zhang et al. (2020b), Wang et al. (2021), so on) argued that risk event shocks on one sector can affect other sectors due to the strong financial and economic linkages. In this way, through the linkages and interconnections, sector-specific shocks could transfer to the economy, further leading to inter sectoral risks of systemic nature. In this regard, understanding how risk spreads and propagates in-between sectors is a key in finding methods to handle financial crises and ensure economic stability.

The results within the study support that shocks at the level of one sector can transfer to other sectors within the same financial market. On the long-run, during the full sample period from January 1st, 2011 – January 28th, 2023, evidence of intra and inter sectoral risk spread was found between 11 shares out of a sample of 12 shares traded on the US S&P 500 financial market. The exception is given by the Pharmaceuticals industry which was not connected with the other sectors at 0.95 significance threshold.

After splitting the full sample in two sample periods, one of tranquility and one of turmoil, the robustness and differences of the results was highlighted. The study shows that during financial turmoil the volatility within the US sectoral stock returns exacerbated, mainly due to uncertainty. As the results confirmed, during the COVID-19 crisis and the war in Ukraine, the relationships, the linkages between S&P 500 sectors' components weakened while the Pharmaceuticals sector was completely isolated from the others. This effect can only trigger even more market volatility and uncertainty. Why? Because a lack of such linkages give space for arbitrageurs and speculators to draw predictions on the short-run upon future prices, profits, returns and most of all, future sectoral co-movements. In this regard, policymakers could consider the design and implementation of effective policies that prevail financial stability.

At 0.95 significance threshold, some of the S&P 500 components are linked two by two, while the others are not correlated. The pairs of components show evidence of intra sectoral risk spread (i.e. ADBE/CRM - Information Technology sector, AMP/BAC - Financials sector, GM/F - Automobile Manufacturers), with the exception of STT/TSLA pair which displays inter sectoral risk spread. The strong correlations between the shares can be explained by trade and financial linkages between de firms, or certain alliances that were built by the firms within the same area of activity. For instance, GM and F components share both trading and financial linkages as they have certain common projects that make them allies on the market. One of their projects, for example, stands in the joint development and implementation of a 10-speed automatic transmission. The two companies designed this project with the main purpose of helping them meet stringent fuel-economic standards. At the same time, both companies invested in creating and expanding their production of electric vehicles (EV). They implemented partnerships with semiconductor groups to increase electronic chip supply while the car manufacturing industry went through a shortage of such components. General Motors Company and Ford Motor Company also collaborate in improving and introducing new safety technologies, especially regarding the automotive safety for children, and in reducing emissions. One of the latest common project of the two firms stands in promoting virtual power plants (VPPs). More precisely, they work together in establishing standards for extending the use of VPPs because these systems help in easing loads on electricity grids when there is a short supply.

The Adobe Inc. (ADBE) and Salesforce Inc. (CRM) also formed an alliance and work jointly in order to find solutions for fine-tuning customer experience. They have jointly developed customer data platforms meant to collect and gather in one place the pieces of information

about customers that could help them in reaching the goal to deliver optimal customer experiences. Another linkage between the two firms is that Adobe Sign and Salesforce implemented an important service through which organizations could close businesses rapidly by using trusted e-signatures. Recently, ADBE introduced "Document Builder" for Acrobat Sign+ Salesforce that gives clients the possibility to standardize on a cost-effective document generation that can be digitally signed through the e-signature platform.

Ameriprise Financial Inc. (AMP) and Bank of America Corporation (BAC) also shared real and financial linkages across time. For instance, AMP uses BAC's Private Client Advisory as sales channel. Also, Ameriprise Financial Inc. acquired from Bank of America Corporation "the long-term asset management business of Columbia Management Group" (Ameriprise Financial, 2009), which was BAC's mutual fund unit in Boston. BOA needed to shed the massive client in order to raise and consolidate their capital position and to repay its governmental debt. Hence, they reached an agreement with AMP as both firms were pursuing similar goals in offering proper solutions to their customers.

The correlation between the last pair of components, namely State Street Corporation (STT) and Tesla Inc. (TSLA), can be explained by a strong financial linkage. According to Willing (2023), State Street Corporation represents the third largest institutional investor of Tesla Inc., owning a 3.13% stake of 98.99 million shares. Owning such an amount of shares, State Street Corporation can influence the share price on the market by buying or selling massive volumes of stock. In this way, State Street Corporation impacts Tesla Inc., any shock being transmitted directly.

The results also offer significant policy implications to policymakers or investors in what regards the management of portfolio risk. It is crucial for investors to understand and take into account the propagation mechanism and effects of intra and inter sectoral risk spread in order to build asset portfolios and manage their risk. As Zhu et al. (2021) argued, investors should be able to identify the sources of intra and inter sector systematic risk spread of their assets because it gives them the possibility to effectively assess the potential risk associated to their holding assets. In this way, they would be able to rebuild diversified portfolios and to optimize their hedging strategies. For instance, let's consider the portfolio of assets that was selected for this study: if all the components within the portfolio were linked and the shares' prices co-moved, the diversification strategy would not be effective and the portfolio should be rebuilt. By taking into account that the selected sectors and shares are of great interest for investors, in the case of significant price co-movements, the shares should be included not in the same portfolio at once, but in different portfolios, especially in times of financial turmoil. At the same time, investors and policymakers should take into account that a diversified portfolio containing various assets implies that the overall systemic risk tends to be reduced to zero. However, the individual risk of each single asset within the portfolio is not reduced. In this regard, the study has important implications in portfolio risk management in what concerns the necessity of carefully selecting assets that do not share inter-linkages. The study also displays the importance of the heterogeneity in substitutability between the

shares within the portfolio. For instance, considering that on the long-run, the shares would be correlated, it could be difficult to protect the portfolio without having to substitute certain asset holdings.

4. Conclusion

The Bayesian Neural Networks models allowed the study of international contagion and intra and inter sectoral risk spread at the market level. In order to answer the research questions, a selected portfolio containing twelve shares which are traded on the US financial market S&P 500 was assumed, and significant evidence of sectoral contagion was found.

For the full sample period (2011-2023), causality was captured between eleven shares from four different sectors and the obtained causality shows that the leading sectors were mainly the Information Technology and the Financials sectors. The causality obtained within the results could be explained through the trading and financial linkages between various market participants.

For a deeper analysis, the full-time span sample was divided in two sub-samples and the results shown that in times of financial turmoil, more precisely during the COVID-19 crisis and the one triggered by the Russo-Ukrainian war, the linkages in-between the shares significantly weakened. This might have happened due to uncertainty and country-specific regulations imposed by governments.

Therefore, the results lead towards a positive answer to the research question RQ1, proving that shocks can transfer from one sector to others within the same market in both business-as-usual and turmoil periods. At the same time, the results lead to a positive answer to the research question RQ2. The fact that shocks can transfer from one sector to another within the same financial market is instrumental for stakeholders in the area of diversification and portfolio risk management. On one hand, investors and companies should take into account such interdependences between sectors in the decision-making process in order to protect their investments and mitigate risk by adopting accurate hedging strategies. On the other hand, policymakers should also consider the interdependences between sectors in order to implement proactive mechanisms and accurate regulations with the scope of maintaining financial stability.

The study implies several limitations that could be mentioned. First, the dataset could be extended in terms of both sectors and shares in order to obtain clearer insights. Second, the period analyzed can also be extended by including other financial turmoil periods such as the global financial crisis from 2007-2010 and other bubbles. This would allow for a deep comparison between crises triggered by different factors. Third, the robustness of the results

obtained through the used risk estimation measure and methodology could be double checked.

In spite of the mentioned limitations, the study provides considerable implications for stakeholders such as policymakers, companies and investors. The results showed that intra and inter sectoral risk spread exists and represents a critical issue in portfolio risk management. Investors should consider the potential correlations between their portfolio asset holdings in order to take accurate decisions for diversification. At the same time, policymakers should promote corrective mechanisms and prudential supervision measures in order to prevent sectoral contagion in periods of extended turmoil and to preserve financial stability.

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