A dynamic MST-deltaCoVaR model of systemic risk in the European insurance sector

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ABSTRACT

This work is a response to the EIOPA paper entitled 'Systemic risk and macroprudential policy in insurance', which asserts that in order to evaluate the potential systemic risk (SR), the build-up of risk, especially risk arising over time, should be taken into account, as well as the interlinkages occurring in the financial sector and the whole economy. The topological indices of minimum spanning trees (MST) and the deltaCoVaR measure are the main tools used to analyse the systemic risk dynamics in the European insurance sector in the years 2005-2019. The article analyses the contribution of each of the 28 largest European insurance companies, including those appearing on the G-SIIs list, to systemic risk. Moreover, the paper aims to determine whether the most important contribution to systemic risk is made by companies with the highest betweenness centrality or the highest degree in the obtained MST.

Key words: systemic risk, minimum spanning trees, deltaCoVaR, insurance sector.

1. Introduction

The subject of this work is part of the current research on the interlinkages of large insurance companies and their contribution to systemic risk (SR) in the insurance sector. In the international literature we find many studies related to the systemic risk analysis in the banking sector but little is done regarding systemic risk in the insurance sector. The novelty we bring to the literature is to identify the relationship between the contribution to systemic risk and the structure of the minimum spanning tree (MST) described by topological network indicators, which can be used in further research to construct models whose task is to predict the possibility of systemic risk. The use of a hybrid approach, combining statistical and econometric tools with network modelling and predictive analysis tools, improves both the explanatory and predictive

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power of models used to assess the impact of global system disturbances on the development of the insurance sector.

Our work constitutes an answer to the recommendations contained in the 2017 report of the European Insurance and Occupational Pensions Authority (EIOPA), an independent EU advisory body to the European Parliament, the Council of Europe and the European Commission, which shows that when analyzing systemic risk in the insurance sector one should take into account the dynamics of interconnectedness between institutions, among other things. The present article is another study of the authors in this subject. In a previous paper (Wanat and Denkowska, 2019), selected topological indicators of Minimum Spanning Trees were analysed and interrelationships between major European insurance institutions were examined.

The purpose of this work is to confront the contribution to the systemic risk of each of the 28 insurance institutions analysed with the results of the previous study. We examine whether interlinkages between insurers, and thus the level of possibility of contagion with a potential crisis, is related to the creation of systemic risk by individual insurance companies. Therefore, we examine whether insurance companies, which in MST play a significant role in the structure of the entire network (they are the so-called HUBs) and would pose a threat to the linked companies in the event of bankruptcy, have an equally significant contribution to SR.

The global economic crisis on financial markets, the peak of which was in the years 2008-2009, initiated on the market of high-risk mortgage loans in the USA as a result, among other things, of the deregulation of the financial market in 1999, when the ban on combining two types of banking: investment (high risk) and deposit-credit banking, which had been in force since 1929 and was to protect citizens in the event of losses in investment banking, ceased to apply. On September 15th 2008 Lehman Brothers – the fourth largest investment bank, after a fruitless attempt to obtain help from the US central bank, declared bankruptcy. A week earlier, the Fed took over two insurance and loan companies with huge debts: Fannie Mae and Freddie Mac. The Fed and the Ministry of the Treasury have recapitalized the largest insurance and financial holding company AIG in the amount of USD 85bn, as the loss of liquidity and, consequently, its collapse would mean a rapid spread of the crisis. The American International Group (AIG) is the first example of an insurance company that required (and received) funding because it was considered systemically important. When dividing financial institutions into three groups according to their activity, i.e. investment, depository and risk-dissipating institutions, insurance companies should be in the third group. Therefore, they should not generate systemic risk as long as they deal with taking over, dispersing and redistributing the financial effects of risk. But if they take over credit risk, e.g. financial insurance, insurance guarantees, derivative trading, in particular like AIG Credit Default swap (CDS) involved in trading financial instruments given as

collateral in case of default on repayment obligations, they generate systemic risk (see William and Sjostrum, 2009)

After the subprime crisis, all financial supervising authorities drew attention to the need for macro-prudential policy, which would take into account the dynamics of structure changes and linkages between financial institutions. The situation of AIG in 2008 was surprising, when it was announced in February that in 2007 it achieved profits of USD 6.20 billion (USD 2.39 per share). The stock was closed on that day at USD 50.15 per share. Less than seven months later, the company was on the verge of bankruptcy and had to be funded by the US government. This is the first and very important event that indicates that the insurance sector plays a large role when assessing systemic risk.

Therefore, in 2013 and 2016, International Association of Insurance Supervisors (IAIS), when developing a method of identifying insurance institutions of particular importance for financial stability, takes into account the following five dimensions: size of the insurance institution, range of global activity, assessment of the degree of direct and indirect linkages of the institution within the financial system, non-traditional and non-insurance activity of the insurer, product substitutability – the significance of the institution for the financial system increases along with the lack of real substitution possibilities for the services provided by the insurer. In line with the IAIS recommendations, the Financial Stability Board (FSB) announced in 2016 a list of systemically important insurers (G-SIIs): Aegon N.V., Allianz SE, American International Group, Inc. (AIG), Aviva plc, Axa S.A., MetLife, Inc., Ping An Insurance (Group) Company of China, Ltd., Prudential Financial, Inc., Prudential plc.

On the other hand, in 2017, EIOPA publishes the document "Systemic risk and macroprudential policy in insurance", which first analyzes the discussion to date on SR, then gives lessons learned from the financial crisis and the banking sector crisis. It draws attention to the need to complement micro-prudential policy with a macro-prudential approach that requires transnational coordination. EIOPA considers SR in a broader, but not contradictory to IAIS, context. According to EIOPA, system events can be generated in two ways. The first is the "direct" effect, which through a failure is initiated by a systemically important insurer or a collective failure of several insurers generating a cascade effect. The second is the "indirect" effect, which involves behaviour. It is based on the actions and/or responses of insurers to external shocks. Potential externalities generated by direct and indirect sources are transferred to the rest of the financial system and the real economy through dedicated channels (the transmission channel) and can have a significant impact on SR. The transmission channels listed in Table 5, page 29, by EIOPA are: Exposure channel, asset liquidation channel, lack of supply of insurance products, Bank-like channel, Expectations and information asymmetries – 'Soft' or 'indirect contagion' channel, linked to issues such as irrational panics and re-evaluation of expectations. It also includes reputational

issues. One source involving behaviour is the collective actions of insurers, which can influence market prices and excessive risk-taking. In our analysis, we use the weekly logarithmic returns of insurance companies as a reflection of the sentiment in the financial market. They are a response to the behaviour of insurers, thanks to which we catch their reaction to potential shocks. Our emphasis on market returns is motivated by the desire to incorporate the most current information in our measures; market returns reflect information more rapidly than non-market-based measures, such as accounting variables.

Another document where we find the legal definition of SR on the UE level is Regulation (EU) 2019/2176 of the European Parliament and the Council of 18 December 2019 amending Regulation (EU) No 1092/2010 on European Union macro-prudential oversight of the financial system and establishing a European Systemic Risk Board in Article 1, point 1: "Systemic risk means a risk of disruption in the financial system with the potential to have serious negative consequences for the real economy of the Union or of one or more of its Member States and for the functioning of the internal market. All types of financial intermediaries, markets and infrastructure may be potentially systemically important to some degree". According to Article 2, point (b) of Regulation (EU) No 1092/2010 "the financial system means all financial institutions, markets, products and market infrastructures".

Therefore, when analyzing various definitions of SR, we find three common elements in them - namely the fact that SR is associated with an undesirable event that occurs in the financial market, has a systemically important cause and the consequences have an impact on the real economy. The rates of return reflect the condition of insurance companies. In the event of a stock market turmoil, we are able to spot it very quickly. Moreover, these are data that can be seen as a measure of the effects of insurers' activities and policies in the real economy. In the literature, we can find many works in which direct links between insurers and between insurers and other financial institutions, such as banks, are analyzed. One example is Alves (2015). This article explores some direct relationships and recommends that you perform an indirect relationship analysis via *market price channels*.

2. Literature review

Before the subprime (2007–2009) and excessive public debt in the euro area countries (2010–2013) crises, there was a strong belief that the insurance market is systemically insignificant. In the international literature that emerged as a consequence of the crisis, many studies have maintained their previous beliefs, but we also find numerous works confirming the possibility of the insurance sector creating systemic risk. Examples include works in which authors believe that insurance companies have become an unavoidable source of systemic risk (e.g. Billio et al., 2012; Weiß and

Mühlnickel, 2014) and those in which they claim that they can be systematically significant, but this is due to their non-traditional (banking) activities (e.g. Baluch et al., 2011; Cummins and Weiss, 2014) and the overall systemic importance of the insurance sector as a whole is still subordinated to the banking sector (Chen et al., 2013). In turn, in (Bierth et al., 2015), the authors, after examining a very large sample of insurers in the long term, believe that the contribution of the insurance sector to systemic risk is relatively small, however, they claim that it reached its peak during the financial crisis in 2007–2008, which we also confirm in our analysis. Analysts also report that significant factors affecting the insurers' exposure to systemic risk are the strong linkages of large insurance companies, leverage, losses and liquidity (four L's). However, the complete lack of evidence of the systemic importance of the insurance industry is indicated, among others, by the following papers (Harrington, 2009; Bell and Keller, 2009; Geneva Association, 2010).

The problem of the insurance sector's ability to create systemic risk has also been the subject of consideration in Polish scientific literature in recent years. In general, as above, two main positions are represented. In (Czerwińska, 2014), based on research of the insurance sector in European Union countries covering the period 2005–2012, it was found that along with the increase in the level of linkages between insurers and various financial system segments, mainly the capital market and the banking sector, the importance of insurance institutions for the stability of the entire system increases. In turn, in (Bednarczyk, 2013), the author, assessing insurance institutions as a potential creator of systemic risk, concluded that dispersing and taking over insurance risk ultimately does not create systemic risk. It indicates a relatively low level of interconnectedness and draws attention to the fact that insurers are not highly dependent on external financing, so they should not be included in the group of systemically important institutions. At the same time, it was mentioned that insurers engaged in non-insurance activities pose a threat to the system by taking over credit risk. Measures of the impact (contribution) of an individual financial institution on the systemic risk of a given market and measures of the institution's sensitivity to this risk are CoVaR (Acharya et al., 2010; Bierth et al., 2015; Jobst, 2014) and deltaCoVaR (Adrian and Brunnermeier, 2011)

3. Methodology

In order to identify the possible relationship linking the structure of the interconnections between insurance companies to the creation of systemic risk by these companies, we proceed in two steps. In the first one, we analyze the dynamics of the structure of interlinkages between insurers. For this purpose, we use the time series of the following selected topological network indicators (Wang et al., 2014):

– Average Path Length (APL);

– Maximum Degree - Max.Degree;
– parameters α of the power distribution of vertex degrees: $P(s) = C \cdot s^{-\alpha}$, $\alpha > 0$;
– betweenness centrality (BC).

The Average Path Length (APL) is defined as the average number of steps taken along all the shortest paths connecting all possible pairs of network nodes.

The Maximum Degree: in graph theory it is defined as the maximal number of edges coming out from a vertex (where each loop counts for two). In other words, it measures the number of connections to the central vertex.

The Betweenness Centrality (BC) measures the centrality of a vertex: we consider the ratio between the number of shortest paths connecting two vertices and passing through the given one, and the number of all the shortest paths between pairs of distinct vertices. It indicates thus the most important nodes of a network based on shortest paths (e.g. the most influential insurer).

We obtain these series based on the determined minimum spanning trees MST_t for each period studied. We construct the MST_t trees using conditional correlations between each pair of analysed insurance companies determined using the copula-DCC-GARCH model, using Kruskal's algorithm. Details of the construction are presented in the work (Wanat and Denkowska, 2019).

In the second step, we examine the contribution of a single insurer to the systemic risk of the European insurance sector using the deltaCoVaR model. In this model, the basis for measuring risk is the CoVaR measure. Formally, $CoVaR_{\beta,t}^{j|i}$ is defined as the value at risk (VaR) of an institution *j* under the condition that another institution *i* is at risk of crisis in a given period *t*, i.e. its rate of return is less than its value at risk:

$$P(r_{j,t} \leq CoVaR_{\beta,t}^{j|i} \mid r_{i,t} \leq VaR_{\alpha,t}^i) = \beta \qquad (1)$$

Using the formula for the conditional probability we have:

$$\frac{P(r_{j,t} \leq CoVaR_{\beta,t}^{j|i}, r_{i,t} \leq VaR_{\alpha,t}^i)}{P(r_{i,t} \leq VaR_{\alpha,t}^i)} = \beta \qquad (2)$$

In addition, the definition of value-at-risk for institutions implies that

$$P(r_{i,t} \leq VaR_{\alpha,t}^i) = \alpha \qquad (3)$$

From equations (2) and (3) we get:

$$P(r_{j,t} \leq CoVaR_{\beta,t}^{j|i}, r_{i,t} \leq VaR_{\alpha,t}^i) = \alpha\beta \qquad (4)$$

From the relationship (4) we can estimate $CoVaR_{\beta,t}^{j|i}$, but first we need to determine the two-dimensional distribution F_t of the rate of return vector $(r_{j,t}, r_{i,t})$. This distribution can be represented using the copula in the following way:

$$F_t(r_{j,t}, r_{i,t}) = C_t(F(r_{j,t}), F(r_{i,t})) \qquad (5)$$

From formula (5) we can numerically calculate $CoVaR_{\beta,t}^{j|i}$ by solving the equation:

$$C_t\left(F_t\left(CoVaR_{\beta,t}^{j|i}\right),\alpha\right) = \alpha\beta \tag{6}$$

Then, knowing the value of the measure $CoVaR_{\beta,t}^{j|i}$, we can calculate the measure deltaCoVaR ($\Delta CoVaR_{\beta}^{j|i}$). The value of this measure is the difference between the value at risk of the insurance sector (institution j), provided that the insurer (institution i) is in a state of financial crisis and the value at risk of the insurance sector in the event that the financial standing of the entity i is normal (average), i.e.

$$\Delta CoVaR_{\beta}^{j|i} = CoVaR_{\beta}^{j|X^i \leq VaR_{\alpha}^i} - CoVaR_{\beta}^{j|X^i \leq Median^i}. \tag{7}$$

The value of this measure represents the contribution of the institution i to systemic risk. The lower this value, the greater the institution's share in generating systemic risk. In our analysis we estimate the distributions F_t of the vectors $(r_{j,t}, r_{i,t})$ and determine $CoVaR_{\beta,t}^{j|i}$ using the two-dimensional copula-DCC-GARCH models with the t-Student copula.

In these models, the average rate of return was modelled using the following ARIMA process:

$$r_{i,t} = \mu_{i,t} + y_{i,t} \tag{8}$$

$$\mu_{i,t} = E(r_{i,t}|\Omega_{t-1}) \tag{9}$$

$$\mu_{i,t} = \mu_{i,0} + \sum_{j=1}^{p} \varphi_{ij} r_{i,t-j} + \sum_{j=1}^{q} \theta_{ij} y_{i,t-j} \tag{10}$$

$$y_{i,t} = \sqrt{h_{i,t}} \varepsilon_{i,t}, \tag{11}$$

where Ω_{t-1} denotes the collection of information available until the moment $t-1$, while $\varepsilon_{i,t}$ are independent random variables with identical distributions. We model the conditional variance $h_{i,t}$ using the exponential GARCH (eGARCH) model:

$$\log(h_{i,t}) = \omega_i + \sum_{j=1}^{p}\left(\alpha_{ij}\varepsilon_{i,t-j} + \gamma_{ij}\left(|\varepsilon_{i,t-j}| - E|\varepsilon_{i,t-j}|\right)\right) + \sum_{j=1}^{q} \beta_{ij} \log(h_{i,t-j}) \tag{12}$$

where $\varepsilon_{i,t} = \frac{y_{i,t}}{\sqrt{h_{i,t}}}$ stands for the standardized errors.

To model the relationship between the rates of return we use Student's t-copula, whose parameters are the conditional correlations R_t, obtained using the DCC(m, n) model:

$$H_t = D_t R_t D_t \tag{13}$$

$$D_t = diag(\sqrt{h_{1,t}}, ..., \sqrt{h_{k,t}}) \tag{14}$$

$$R_t = (diag(Q_t))^{-\frac{1}{2}} Q_t (diag(Q_t))^{-\frac{1}{2}} \tag{15}$$

$$Q_t = (1 - \sum_{j=1}^{m} c_j - \sum_{j=1}^{n} d_j)\bar{Q} + \sum_{k=1}^{m} c_j \left(\varepsilon_{t-j}\varepsilon'_{t-j}\right) + \sum_{k=1}^{n} d_j Q_{t-j} \tag{16}$$

$\bar{Q}$ is the unconditional covariance matrix for standardized errors ε_t; c_j, d_j, $j = 1, …,$ are scalar values, with c_j describing the impact on current correlations of earlier shocks, and d_j, takes into account the impact on current correlations of earlier conditional correlations. We estimate the parameters of the above copula-DCC-GARCH model using the inference function for the margins method.

4. Data and results of empirical analysis

The basis of the analysis are stock quotes of 28 European insurance institutions selected from among the 50 largest companies, for which quotations are available in Thomson Reuters database, in the period adopted for the analysis, according to https://www.relbanks.com/top-insurance-companies/europe, all those that were listed in the period studied, namely: AXA, Allianz, Prudential plc, Legal & General, Generali, Aviva, Aegon, CNP Assurances, Zurich Insurance, Munich Re, Old Mutual, Swiss Life, Chubb Ltd, Ageas, Phoenix, Unipol Gruppo, Mapfre, Hannover Re, Storebrand, XL.Group, Helvetia Holding, Vienna Insurance, SCOR SE, Mediolanum, Sampo Oyj, RSA Insurance Group, Società Cattolica di Assicurazione, Topdanmark A/S. Five of them, AXA, Allianz, Prudential plc, Aviva, Aegon appear as systemically relevant on the current list of G-SIIs published by the FSB in 2016. We estimate the deltaCoVaR measure assuming that the European insurance sector is represented by the STOXX 600 Europe Insurance index. We analyse weekly logarithmic rates of return from 07.01.2005 to 26.04 2019.

Time series of topological network indicators, determined according to the first stage of the presented empirical strategy, are presented in Figure 1 and 2. The first figure (Figure 1) shows the average path length (APL), average maximum degree (Max.Degree) and estimated parameters α of the power distribution for minimum spanning trees from 07/01/2005 to 26/04/2019. The analysis of the charts shows that in the periods of June 2nd, 2006 – August 17th, 2007 and December 5th, 2008 – September 17th, 2010, APL decreases while Max.Degree increases, the α index is close to 2, which means that the network is shrinking and its structure is "scale-free", that is, it takes a form in which there are few vertices with numerous edges (hubs) and many vertices with a low degree (betweenness centrality). In turn, Figure 2 shows BC for AXA, Allianz and Phoenix. The first two companies have the highest average values of this measure in the examined period (see Figure 3), while the third one (Phoenix) is one of the five insurers for which BC is equal to zero in each of the examined weeks. Considering the fact that BC is an indicator on the basis of which we assess the importance of a given insurer in the context of the possibility of risk contagion, we note that the time series for these companies are "complementary" behaving graphs. During the entire analysed period, if BC for AXA increases, BC for Allianz decreases and vice

versa. If BC for AXA remains stable, the BC level for Allianz does not change either. Figure 3 shows that in the subprime crisis state the French AXA company was clearly the dominant one on the European insurance market, while the German Allianz took over during the phase of excessive public debt.
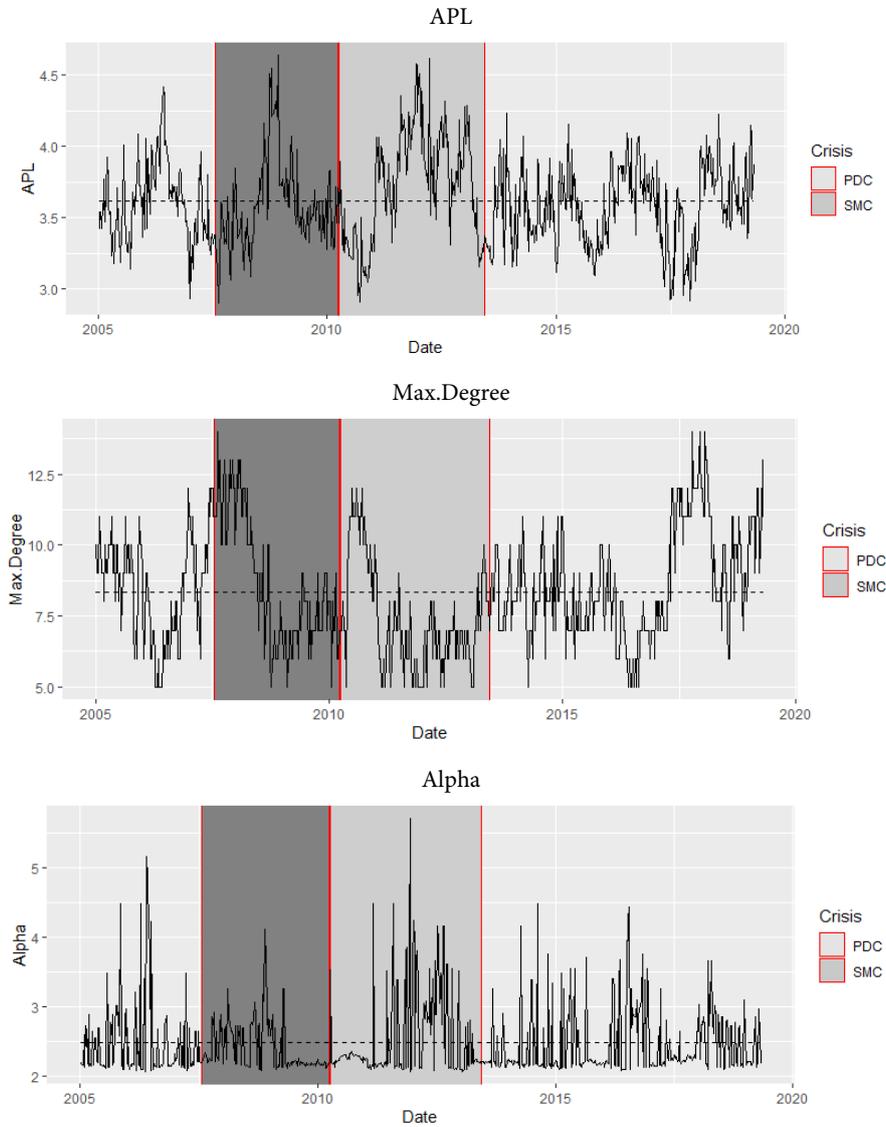

Figure 1. Average distances (APL), maximum degrees (Max.Degree) and estimated parameters α of power distribution α for MST in the period 07.01.2005 – 26.04.2019 with the subprime mortgage crisis (SMC) and the public debt crisis (PDC) highlighted
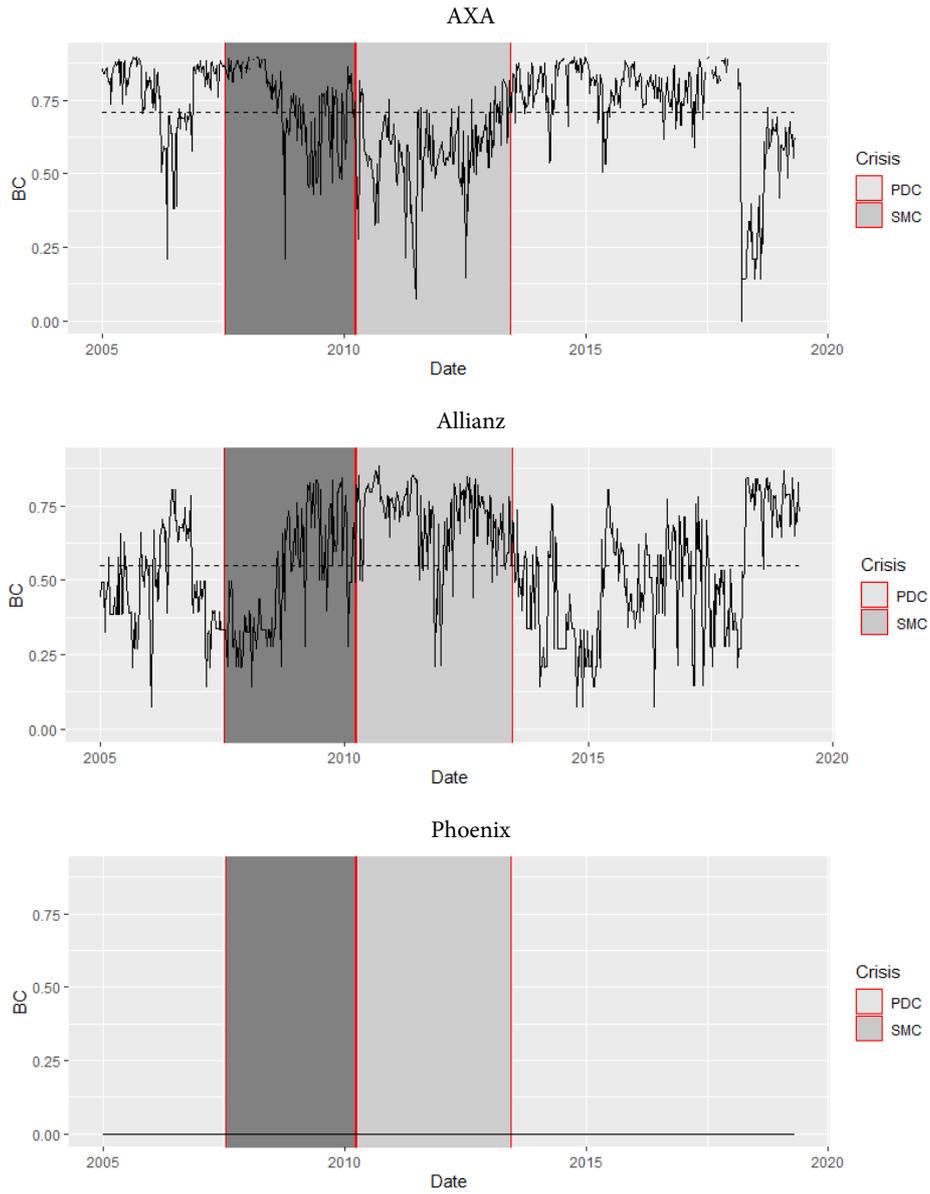
Source: Own study.

Figure 2. BC for selected insurance institutions (AXA, Allianz and Phoenix) during the period
07.01.2005 – 26.04.2019 with the subprime mortgage crisis (SMC) and the public debt crisis
(PDC) highlighted
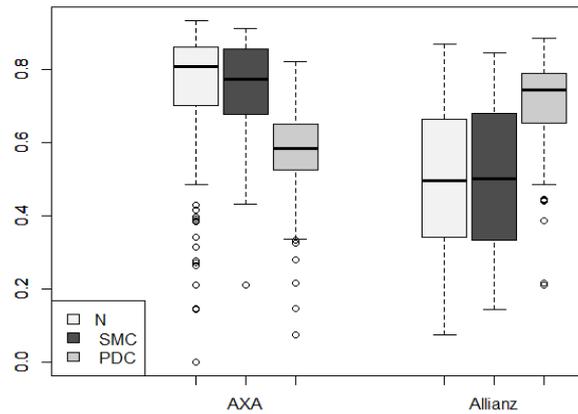
Source: Own study.

Figure 3. BC distribution for AXA and Allianz in the normal state of the market (N), during the subprime mortgage crisis (SMC) and the public debt crisis (PDC)

Source: Own study.

We examine the relationship between the structure of the network of connections (MST) and the contribution to systemic risk based on time series deltaCoVaR measures, determined for individual insurers in accordance with the empirical strategy of the second step of the study. In each analysed period, we determine the deltaCoVaR measure for each insurer, assuming $\alpha = \beta = 0.05$. Figure 4 shows the average BC and Figure 5 shows the average deltaCoVaR over the period under consideration for all 28 companies analysed. Comparison of these diagrams shows that BC and deltaCoVaR levels are related in extreme situations. In clear, for institutions with high BC, the deltaCoVaR value is the smallest, which means the largest contribution to systemic risk, for institutions with BC at zero level, the deltaCoVaR is the highest (i.e. the lowest contribution to systemic risk). So AXA and Allianz contribute to systemic risk to a much greater extent than Phoenix. However, it cannot be argued that companies that have a low BC do not generate systemic risk. The diagram shows that the contribution to the risk of companies with low BC is comparable to that of companies with high BC. Figure 6 shows how the deltaCoVaR depends on the mean BC. It can be seen that with the increase of BC of insurer vertices, the deltaCoVaR decreases (the contribution to systemic risk increases). Figure 7 presents a summary of MST and a diagram of the deltaCoVaR dependence on BC in the period when all analysed companies have the smallest deltaCoVaR, which happens to coincide with the middle of the crisis, that is October 17th, 2008. The tree during this period is such that AXA, Allianz and Aegon,

having the largest BC and the largest contribution to systemic risk are directly related to each other. In Figure 8, we compile the contribution of AXA and Phoenix to systemic risk, i.e. the two companies that have the lowest and highest average deltaCoVaR, respectively. We observe large differences between these companies in the determined market states: the normal one and two crisis states.
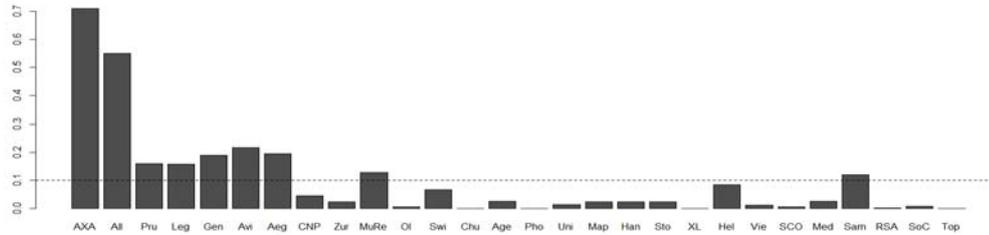

Figure 4. Average value of BC in the period under consideration for individual insurance institutions, the line showing the arithmetic mean of all the average values
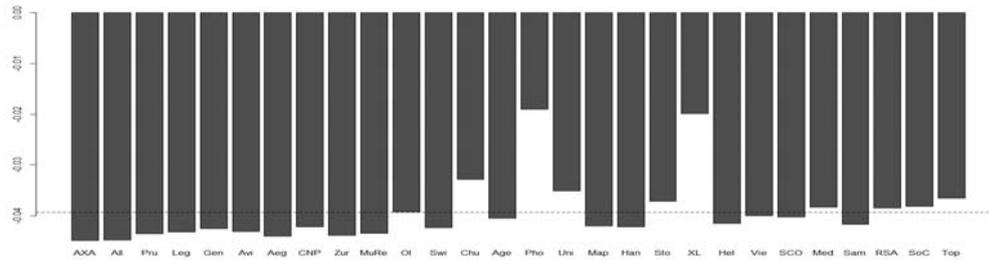
Source: Own study.

Figure 5. The average deltaCoVaR value over the period under consideration for individual insurers, the line showing the arithmetic mean of all the average values
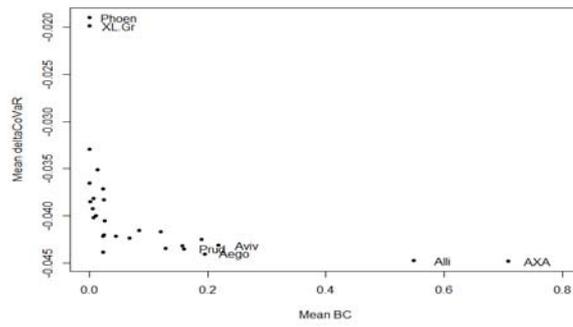
Source: Own study.

Figure 6. The relationship between the average BC and deltaCoVaR values over the period under consideration for individual insurers

Source: Own study.
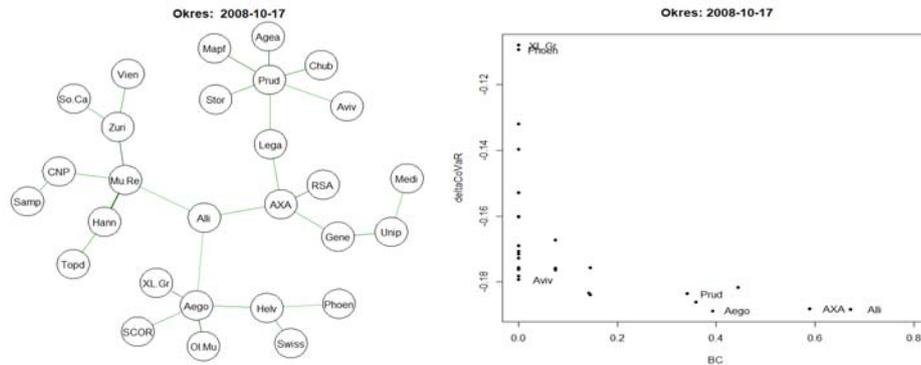
Figure 7. MST[3] and the relationship between BC and deltaCoVaR in the period with the lowest deltaCoVaR for AXA and Allianz

Source: Own study.

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[3] AXA, Allianz (Alli), Prudential plc (Prud), Legal & General (Lega), Generali (Gene), Aviva (Aviv), Aegon (Aego), CNP Assurances (CNP), Zurich Insurance (Zuri), Munich Re (Mu Re), Old Mutual (Ol Mu), Swiss Life (Swiss), Chubb Ltd (Chub), Ageas (Agea), Phoenix (Phoen), Unipol Gruppo (Unip), Mapfre (Mapf), Hannover (Hann) Re, Storebrand (Stor), XL.Group (Xl Gr), Helvetia Holding (Helv), Vienna Insurance (Vien), SCOR SE (SCOR), Mediolanum (Medi), Sampo Oyj (Samp), RSA Insurance Group (RSA), Società Cattolica di Assicurazione (So Ca), Topdanmark A/S (Topd).
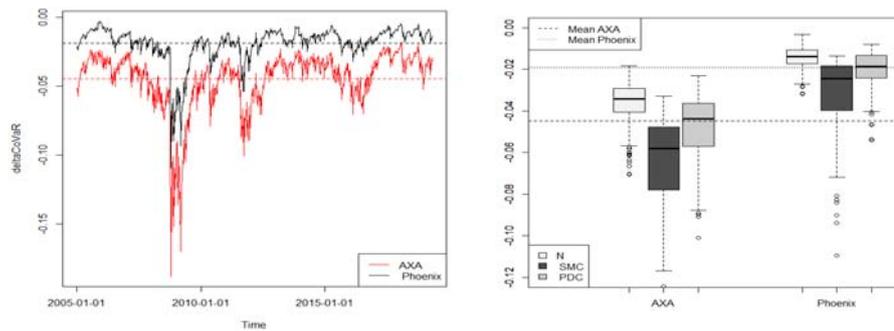
Figure 8. DeltaCoVaR for AXA and Phoenix in the period under consideration (left panel) and its
distribution in the normal state of the market (N), during the subprime mortgage crisis
(SMC) and the public debt crisis (PDC) (right panel)

Source: Own study.

5. Conclusions

Analyzing the time series of topological APL, MD, BC indicators and the MST
alpha indicator and the MST structure (Wanat and Denkowska, 2019), we conclude
that when the market is in a normal state, the series show volatility, but they do not
have a large amplitude. MSTs change their structure and the linkages between the
companies are different depending on time. We also note that to assess the potential
risk of a rapid spread of the crisis, it is necessary to analyze all the four indicators.
Indeed, with high correlation, the tree becomes very dispersed, which means that
assessing the linkages only on the basis of the correlation coefficient could lead to
erroneous conclusions. From the MST analysis, a clear shrinkage of the network can be
seen in the periods of June 2nd, 2006 - August 17th, 2007, i.e. just before the subprime
crisis and during its first phase, and in the period December 5th, 2008 – September
17th, 2010, i.e. before and at the beginning of the European public debt crisis. If MSTs
are shrunk, it promotes potential propagation of financial problems. However, during
the subprime crisis itself, the trees changed their appearance. They were relaxed: APL
increased, MaxDegree decreased.

In this study, we analysed 28 largest insurance companies from the point of view of
the contribution of each institution to systemic risk in accordance with the currently
used deltaCoVaR measure. The analysis of time series shows that in the period from
2005 to 2019 for each of the companies there is an obvious relation between its
contribution to systemic risk and the structure of the network of connections (MST).
During the entire period, the contribution of each company remains at the same level,
save for the clearly apparent period during which the deltaCoVaR decreases and,

consequently, the contribution to the systemic risk increases, and this happens at the very centre of the subprime crisis, October 17th, 2008. As the deltaCoVaR changes, the APL ratio increases. We should emphasize that for the entire analysed period, it reaches its maximum exactly on December 5th, 2008.

The identified relationship between the contribution to systemic risk and the minimum spanning tree structure described by topological network indicators can be used in the construction of models whose task is to predict the possibility of systemic risk. The construction of this type of predictive models is the subject of further research by the authors.

Acknowledgements

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