Measuring financial system stability – analysis and application for Poland

Dissertation summary

Marta Karaś, dissertation supervised by Prof. dr hab. Krzysztof Jajuga;
Co-supervisor: Dr Witold Szczepaniak

Introduction

Financial system is stable when it "performs all its functions in a continuous and effective way, even when unexpected and adverse disturbances occur on a significant scale" (NBP 2018[1]). This being said, the experience of the last decades shows that there are many reasons for which the disruptions to financial system stability are an undesirable phenomenon. Among the most obvious ones, one may count the disruption to financial intermediation and the spill-over of financial crises to the real economy. In order to improve the system's resilience to such disruptions, reliable information on the current state of its stability must be available.

Financial system stability is driven by systemic risk which is a very complex characteristic to measure and "one of the most elusive concepts in finance" (Benoit et al. 2013, p. 22). The researchers keep looking for measurement methods which are supplementary to the ones already used by the regulators and which would allow them to obtain as much non-replicated information, as possible. So far there is no golden standard on how exactly systemic risk should be measured.

In the light of the above, the goal of the PhD-related research project became a search for a good method of measuring financial system stability. Poland was selected for the thematic scope of the empirical application of the research, while the selected study horizon was set to the years between 2006 and 2016, a period encompassing two major crises in the financial environment: the global financial crisis and the European sovereign debt crisis.

[1] https://www.nbp.pl/homen.aspx?f=/en/systemfinansowy/stabilnosc.html

The choice was motivated, inter alia, by the fact that there exists a vast group of very different systemic risk measures, but most of them were never actually used in relation to the Polish financial system. At the same time scientific studies of systemic risk in Poland, remain very few. To make matters worse, these studies do not seem to give unequivocal information about the levels of systemic risk or financial stability in Poland for the aforementioned turbulent study period. At the same time, own research carried out prior to this thesis also provided much evidence for the need of a study focused on where the identified discrepancies in empirical results come from. This conclusion served as a starting point for the dissertation.

Chapter One: Definitions and drivers of stability of the financial system and systemic risk

There is an ongoing research in the area of systemic risk and financial stability, which includes the theoretical dispute related to various relevant definitions. In the light of the above, the research objective executed in Chapter one is defined as the critical review and systematization of terminology related to the stability of the financial system and directly linked issues.

The studies of the vast literature in this topic points to identifiable inconsistencies in terminology related to financial stability. Many authors define financial stability through the referral to financial instability, while the list of elements that build up towards the definition of financial system stability entails different elements depending on the author that provides it. Therefore, the systematization of definitions was a necessary first step of the study.

The first part of the chapter presents the major point of this dispute, concentrating on these definitions which are most relevant for the literature review and empirical studies presented in the later parts of this work. Over the course of this discussion, the understanding of risk applied in the dissertation is outlined. Furthermore, the approach to identifying and modelling the financial system is selected and explained. Next, the definitions of systemic risk and financial stability, over-viewing the existing literature is search of the definitions to be followed in the empirical part of the study. The first part of the chapter concludes with an explanation about how financial system stability is understood in the literature and how this information is applied in this dissertation.

The second part of the chapter is focused on systemic risk and how the phenomena related to it affect financial stability. For this purpose, the author introduces her own classification of these phenomena, basing on a vast literature review. She indicates three areas of systemic risk. Specifically, first the first one relates to how the changes in available liquidity in a given system may affect its stability. The next identified area of systemic risk considers the accumulation of fragility, especially in relation to excessive risk taking and behavioural biases, with special attention paid to the occurrence of bubbles. Finally, the interconnectedness of elements in the financial system is in focus, as the contagion effects are discussed, depicting how risk spill-over effect drives accumulation and translation of smaller risks into a systemic scale.

The classification proposed in this part of the chapter is applied in the further parts of this study, especially in Chapter Two where the measures of systemic risk are overviewed and in Chapter Five which presents the empirical part of the study. The discussion is fundamentally based on multiple literature sources, while all the classifications which are not directly concurrent with a source, are the author's own conclusions based on the study of literature and multiple financial stability reports.

Chapter Two: Overview of existing methods of financial system stability analysis and measurement

Over the last years, the issue of the financial system stability has gathered heated attention due to the global financial crisis. Central banks have turned their interest towards improving their measurements of the state of financial stability and analysis of financial system resilience to internal and external shocks. As a result, a number of various approaches towards the measurement of financial stability emerged. The abundance of methods pointed to the necessity of their classification with relation to various criteria, such as for instance applicability, complexity or precision of measurement.

Many authors indicate at least one of the three systemic risk areas. However, there are only a few proposals to use these areas as a means of classifying financial stability measures from the recent literature. These proposals were used as a guide for the structure proposed in the dissertation. Let it be noticed, nevertheless, that these various publications tend to classify same methods into different groups (sometimes partially overlapping) and the discussion regarding the shape of financial stability measures classification is ongoing. Ultimately, the systematisations proposed in each paper serve a slightly different purpose and none of them could be directly applied in this work.

The chapter presents and discusses more than 50 approaches to measuring risks which affect financial stability and provides a clear-cut systematisation of these methods, one which allows to classify them with respect to applicability for empirical purposes of the study at hand, following the second research objective, which is the classification of the financial system stability measurement methods.

In the course of the discussion a comprehensive review of studies related to financial stability and systemic risk is carried out. In particular, relevant theoretical studies are systematised and related empirical results are briefly discussed, while the overviewed methods are divided between three sets – each focused on a different area relevant for systemic risk – based on the discussion from Chapter One.

This division is significant for the empirical analysis, as one method from each group is later on selected for the empirical study. The assertion made here is that the proposed systematization allows to distinguish between the methods which are sensitive to different information (and thus give an insight into various characteristics of the financial system condition). This follows from the discussion provided in Chapter One, where it is argued that financial system stability should not be measured with one method, but it should rather draw from a set of them. Consequently, the measures which are pursued empirically in this dissertation include:

- Interbank-market-based Systemic Liquidity Measure based on RMSE,
- SRISK, for fragility accumulation,
- Conditional Value at Risk (specifically: cumulative Delta CoVaR), for spill-over of risk.

Chapter Three: Overview of existing studies of the Polish financial system stability

The chapter gathers the information on the outline of financial stability in Poland based on the existing literature. Two main types of analyses are overviewed. The stability measurements carried out by the National Bank of Poland, the main entity dealing with this area of analysis in Poland, are described first. Next, results published by other regulatory entities, including national ones, such as the national Financial Supervision Authority (KNF), and international ones are discussed. In the second part of the chapter, the empirical results of the analyses carried out by other authors in their scientific work are presented, including the research carried out in accord with the central bank, as well as independent studies.

The main focus of this chapter is to analyse the level of stability in Poland, as measured – for various study horizons and various financial sector segments – in other studies. This information is used in the final part of this dissertation as a point of reference for the proposed measurements. It also facilitates one of the research objectives, which is the analysis of systemic risk measures for their applicability for Poland, that is finalized in Chapter Four.

It is worth mentioning at this point, that a particular challenge for this study is the fact that over the last twenty years, there were no clear-cut episodes of financial instability in Poland, and therefore it is currently very difficult to create a quantitative stability threshold or benchmark based on historical data. Regardless, various methods of analysis reviewed in this chapter point to similar periods of increased systemic risk in Poland.

There are several conclusions that can be drawn to synthesize the observations summarised in Chapter Three. First of all, both types of studies – the ones carried out by the regulators, as well as these conducted by academics, encompass either the whole financial system or just a sample of banks. Interestingly, the differences in the number of institutions covered by each of the studies do not seem to affect the results, suggesting that as long as a reasonably large sample of institutions is selected (e.g. by the size of assets) systemic risk measurements remain generally conclusive. This suggests that modelling the financial system with a smaller sample of biggest banks gives a similar result for systemic risk estimation as fully-ranged studies of large numbers of institutions.

The periods of identified substantially increased systemic risk differ between the measures. All of them unequivocally identify the period of years 2008 to 2009, as well as the year 2011. However, some of the most recent measures identify also year 2012 and 2015, while others do not. Finally, the financial system conditions barometer developed by the NBP points to the worst conditions of the system in 2016 (with constant deterioration since the beginning of the crisis). As this type of a prognosis heavily relies on the economic outlook, while the economic conditions worsen with a significant lag, relative to the reaction of the financial markets, this is not surprising. On the positive side, all other observations point to a significant resilience of the Polish financial system to shocks and indicate high levels of financial stability.

There is an interesting observation related to the measures which are liquidity based. In one of the studies, when the author focuses on the liquidity position of banks treated individually, he notices no deterioration of the sector's liquidity position in 2011. Once a potential risk spill-over effect is considered, the result changes drastically. Also, for the stress testing procedures focused on internal liquidity of individual banks carried out by the regulator, the most vulnerable period is cumulatively identified in 2011 (and not between 2008 and 2009). This shows that such a type of measure responds to the effects of the crisis rather than to its appearance.

In contrast, the systemic liquidity measure, although it identifies the 2008-2009 period as most volatile, it also identifies a peak which significantly proceeds that period – in the beginning of 2008. This suggests that this measure also captures some more/other signals than the others. These discrepancies clearly show that liquidity of the financial system is a crucial element of systemic risk and that diminished liquidity is a prerequisite for crisis development and it is also a crisis consequence.

All the differences identified in this comparison point to the necessity to further investigate systemic risk for the historical period of the last 20 years in Poland, but also – maybe even predominantly – they suggest that the estimation of systemic risk should be a multispectral procedure that captures more than just one facet of risk. Thus, it stays in concurrence with the conclusions from the literature analysis presented in the two previous chapters.

Chapter Four: Study scope, hypotheses and selection of measures for the empirical study

The chapter is devoted to the discussion the methodological aspects of the dissertation, placing the current study among the broader research carried out by the author individually and in research teams. It familiarizes the reader with the research scope of the dissertation, as well guides through the process of selection of the measures chosen for the empirical part of the study. Specifically, the discussion entails firstly the motivation for the empirical study, then the research objectives and investigated hypotheses next. Afterwards the method of selection of the measures to be used in the final chapter are presented in detail. In the final section, the scope and type of data to be used in the empirical analysis is presented and the study horizon is selected.

Each of the mentioned aspects are discussed from the perspective of a longer-term research carried out by the author in various works that took place in the course of the PhD studies. This includes especially the major study carried out with other authors under the research grant by the National Bank of Poland – a study which laid ground for the empirical analysis presented in the final chapter of this dissertation.

The proposed hypotheses, as well as all research objectives, are supported by the literature findings presented in Chapters One and Two and the overview of empirical studies presented in Chapter Three. Most importantly, they are also strongly motivated by the previous results obtained prior to this dissertation by the author (and co-authors).

A major part of the chapter is devoted to the realisation of the third research objective which consists in the analysis of systemic risk measures for their applicability for Poland. This entails the discussion of how the measures of three aspects of financial stability, i.e. systemic liquidity, systemic fragility and risk spill-over, were selected. Thus, also means that the applicability and characteristics of each of the measures, which were presented in Chapter Two, are briefly discussed and the logic of the measure selection is outlined.

Overall, the choice of the measures comes down to four aspects: whether their application is at all possible (data limitations); whether contemporaneous measurement is possible with such measures (issues of lags and frequency); how different the information they provide is (potential value added of joint data analysis) and whether their application is theoretically justified in case of Poland (e.g. is the market developed enough). Finally, we consider the specific characteristics of the measurement output for potential aggregation.

In relation to the abovementioned objectives and findings, a set of complementary hypotheses was formulated in Chapter Four. The empirical study, presented in Chapter Five, encompassing the period of 2006 to 2016 was used to verify these hypotheses. In the final part of the chapter the selection of the data sample and the study horizon is described.

Chapter Five: Empirical analysis of the Polish financial system stability

The final chapter of the dissertation is fully devoted to the analysis of the empirical results and to the conclusive discussion of the postulated research hypotheses. It also serves the realisation of the last and most crucial research objective: a proposition of the author's own measurement method for the stability of the Polish financial system.

More specifically, the chapter is devoted to four main parts. The first, second and third section discusses the three measures which are applied in the study, presenting their technical description and the procedures which were followed when the methods were applied. Next, the results obtained with the use of each of the measures are presented. The final part of the dissertation is devoted to a joint analysis of the results given by each of the measures, arguing that such an approach allows obtaining a more complete picture of levels of financial stability.

As it is described in Chapter Four, the methods selected for the empirical part of the study were either validated (used) by other authors either for countries other than Poland or/and for Poland, including the author's research carried out together with the supervisor and the supporting supervisor in the past years. Building on the conclusions formulated in previous studies, here the proposal is explored according to which the selected measures are effectively applicable to Poland (after some technical modifications developed by the author in her previous research, as well as some initially proposed hereof). The point of focus is the joint interpretation of the results, which allows for simultaneous analysis of the three systemic risk characteristics: systemic liquidity, fragility of the financial system and the spill-over of risk.

As argued in Chapters One and Two, and to some extent concurred in Chapter Three, these three aspects of systemic risk should be monitored (included in the measurements) if one wants to diagnose financial system stability accurately. This point is further argued in this chapter, while the hypotheses presented in Chapter Four are verified in the empirical study.

Data and study horizon

The systemic risk of the Polish financial system was estimated on the basis of 12 institutions, including non-banking entities:

- PKO Bank Polski S.A.,
- Bank Pekao S.A.,
- Bank Zachodni WBK S.A,
- mBank S.A.,
- ING Bank Śląski S.A.,
- Bank Handlowy w Warszawie S.A.,
- Bank Millennium S.A.,
- Bank BPH S.A.,
- Getin Holding S.A,
- Globe Trade Centre S.A.,
- Echo Investment S.A.,
- PZU S.A.

The empirical analysis was carried out on the basis of the data corresponding to the balance sheets of financial institutions (the level of debt and financial leverage of a given institution - using *quasi assets*), the market data in the form of WIBOIR rate and return rates from stock quotes of share prices and capitalization of institutions included in the examined financial system, all in accordance with the technical requirements for the measures chosen. In total, daily observations for a period of 11 years were used: roughly 2750 daily observations per institution, per measure. Data was collected from the Thomson Reuters Database (University access).

The choice of the time horizon for the study was dictated by the requirement for the sample to be long enough the effectively estimate static and econometric models used, as well as by the previous studies' results which point to the impact of the global financial crisis, the European debt crisis and the prolonging economic downfall on the stability of the Polish financial system. More specifically, the period includes the years 2006 to 2016.

Including different types of global financial turbulence (banking sector crisis; stock-market runs; public debt crisis; interbank market freezes) and the prolonging economic downturn of the biggest economies in the world in the time span of the study, gives a unique opportunity to study Polish financial system stability facing such unprecedented and significant instability in the global financial system. This is especially noteworthy given the lack of actual full destabilisation of the Polish financial system in its history as such.

Applied measures

Systemic Liquidity Measure (SLM) uses the model proposed by Nelson and Siegel (1987), which expresses the instantaneous forward rate$f(s)$, for $s \in [0\,;t]$ as a function of four parameters:

$$f(s) = \beta_0 + \beta_1 \cdot e^{-\frac{s}{v}} + \beta_2 \cdot \frac{s}{v} \cdot e^{-\frac{s}{v}}$$

In the model, β_0 relates to the longest maturity forward rate, the sum of the parameters $\beta_0 + \beta_1$ relates to the instantaneous spot rate, $\beta_2$determines the shape of the slope of the curve and v determines its peak. Then, it is possible to express the theoretical prices and the vector of the discount factors as:

$$\overline{\delta}(t_j) = \exp\left[-\left(\beta_0 + (\beta_1 + \beta_2) \cdot \frac{1 - e^{-\frac{t_j}{v}}}{\frac{t_j}{v}} - \beta_2 \cdot e^{-\frac{t_j}{v}}\right) \cdot t_j\right]$$

Finding the values of the parameters which would allow to best fit the theoretical curve to real market data has no single analytical solution. The function to minimise the distance between the estimated curve and the real data is selected following the proposal of Dziwok from 2017 – the nonlinear method of mean-root-square error is used:

$$\Psi(P) = \sum_{l=1}^{k} (P_l - \overline{P_l})^2 \rightarrow \min$$

In effect of the minimization procedure a set of model residuals are detected, which then are plotted into a time series to obtain the SLM measurement results.

The fragility measure, SRISK, is based on the concept of the Expected Shortfall (ES):

$$ES_{Mt}(u) = E_{t-1}(R_{Mt}|R_{Mt} < u) = \sum_{i=1}^{N} w_{it} E_{t-1}(R_{it}|R_{Mt} < u).$$

Marginal Expected Shortfall (MES) which indicates the institution's extreme contribution to systemic risk, i.e. whether the expected shortfall of the system changes if the entity's share in it changes in the extreme, is given as the partial derivative of ES:

$$MES_{it}(u) = \frac{\partial ES_{Mt}(u)}{\partial w_{it}} = E_{t-1}(R_{it}|R_{Mt} < u),$$

Of we assume a decline in equity conditional on the equity of the system falling below the assumed marginal threshold within the next 6 months, then we define the Long Run Expected Shortfall (LRMESS):

$$LRMES_{i,t}(C) = 1 + \exp\left(\gamma \cdot MES_{i,t}(C)\right).$$

The SRISK measure determines the expected shortage of equity (increased quasi-leverage - $[D_{it}; W_{it}]$) in the event of a systemic crisis and is based on the long-term marginal shortfall expected, calculated using the aforementioned Long Run Marginal Expected Shortfall (LRMES). SRISK is thus defined as:

$$SRISK_{it} = \max[\,0\,; k\,(D_{it} + (1 - LRMES_{it})W_{it}) - (1 - LRMES_{it})W_{it}].$$

System-level SRISK is obtained by the aggregation of individual institutions" SRISKS.

The third measure used in the study is based on CoVaR, i.e. the Conditional Value at Risk of the system, provided that there is a threat to the financial condition in the analysed institution. This measure is defined by the equation:

$$\mathrm{P}(\mathrm{R}_{\mathrm{Mt}} \leq \mathrm{CoVaR}_{\mathrm{it}|} | \mathrm{C}(\mathrm{R}_{\mathrm{it}})) = \alpha.$$

In the study, the measure derived from CoVaR, i.e. Delta CoVaR is used. It is the difference between the system's Value at Risk if the given financial institution is financially at risk and the system's value at risk if the financial position of the given entity is normal (median). This is illustrated by the following formula:

$$\Delta\mathrm{CoVaR}_{\mathrm{it}}^{\mathrm{q}} = (\mathrm{CoVaR}_{\mathrm{it}}^{\mathrm{q}} | \mathrm{R}_{\mathrm{it}} = \mathrm{VaR}_{\mathrm{it}}^{\mathrm{q}}) - (\mathrm{CoVaR}_{\mathrm{it}}^{\mathrm{q}} | \mathrm{R}_{\mathrm{it}} = \mathrm{VaR}_{\mathrm{it}}^{0.5}).$$

We obtain the system-wide Delta CoVaR by aggregating the individual Delta CoVaRs of all analysed financial institutions.

To estimate the quantile-based systemic risk measures, a two-dimensional process for the rates of return of the system *s* and institution *i* is adopted:

$$\mathrm{r}_{\mathrm{t}} = \sqrt{\mathrm{H}_{\mathrm{t}}}\upsilon_{\mathrm{t}},$$

where R_t is a vector (R_{st}, R_{it}) and H_t is a conditional variance-covariance matrix of the form:

$$\mathrm{H}_{\mathrm{t}} = \begin{pmatrix} \sigma_{\mathrm{st}}^2 & \sigma_{\mathrm{it}}\sigma_{\mathrm{st}}\rho_{\mathrm{it}} \\ \sigma_{\mathrm{it}}\sigma_{\mathrm{st}}\rho_{\mathrm{it}} & \sigma_{\mathrm{it}}^2 \end{pmatrix},$$

with a conditional standard deviation of the rate of return of the system σ_{st} and institution σ_{it}, and conditional correlation ρ_{it}. υ_t is a vector (ε_{it}, ε_{st}) of independent equally distributed random variables, such that E (υ_t) = 0 and $\mathrm{E}(\upsilon_{\mathrm{t}}\upsilon_{\mathrm{t}}') = \mathrm{I}_2$ is a 2 by 2 units matrix (cf. Benoit et al. 2011). Conditional volatility of the rates of return of the system σ_{st} and institution σ_{it} was estimated on the basis of the GJR-GARCH model, while the conditional correlation of the institution and the system ρ_{it} was based on the GJR-GARCH DCC model, whereas the individual conditional expected value for each institution is determined on the basis of the estimator:

$$\mathrm{VaR}_{\mathrm{it}}^{\mathrm{q}} = \sigma_{\mathrm{it}}\mathrm{F}_{\mathrm{i}}^{-1}(\mathrm{q})$$

For the institution’s contribution to the conditional VaR of the system, is estimated as:

$$\Delta \mathrm{CoVaR}_{it}^{q} = \hat{\gamma}\left(\mathrm{VaR}_{it}^{q} - \mathrm{VaR}_{it}^{0.5}\right),$$

where: $\hat{\gamma} = \frac{\hat{\rho}_{i,t}\hat{\sigma}_{s,t}}{\hat{\sigma}_{i,t}}$. The marginal expected shortfall is estimated as:

$$\mathrm{MES}_{i,t}\left(\mathrm{VaR}_{s,t}^{q}\right) = \hat{\sigma}_{i,t}\hat{\rho}_{i,t}\hat{\mathrm{E}}_{t-1}\left(\varepsilon_{s,t}|\varepsilon_{s,t} < \kappa\right) + \hat{\sigma}_{i,t}\sqrt{1-\hat{\rho}_{i,t}^{2}}\hat{\mathrm{E}}_{t-1}\left(\varepsilon_{i,t}|\varepsilon_{s,t} < \kappa\right),$$

where:

$$\hat{\mathrm{E}}_{t-1}\left(\varepsilon_{s,t}|\varepsilon_{s,t} < \kappa\right) = \frac{\sum_{t=1}^{T} \mathrm{K}\left(\frac{\kappa - \varepsilon_{s,t}}{h}\right)\varepsilon_{s,t}}{\sum_{t=1}^{T} \mathrm{K}\left(\frac{\kappa - \varepsilon_{s,t}}{h}\right)}$$

and

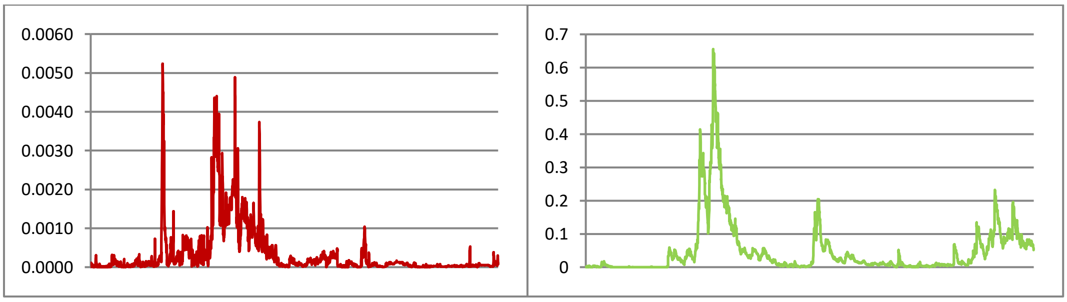
$$\hat{\mathrm{E}}_{t-1}\left(\varepsilon_{i,t}|\varepsilon_{s,t} < \kappa\right) = \frac{\sum_{t=1}^{T} \mathrm{K}\left(\frac{\kappa - \varepsilon_{s,t}}{h}\right)\varepsilon_{i,t}}{\sum_{t=1}^{T} \mathrm{K}\left(\frac{\kappa - \varepsilon_{s,t}}{h}\right)},$$

for $\kappa = \frac{\mathrm{VaR}_{s,t}^{q}}{\sigma_{s,t}}$, $\mathrm{K}(x) = \int_{-\infty}^{\frac{x}{h}} k(u)du$ for the normal distribution density function $k(u)$ and $h = T^{\frac{-1}{5}}$. In turn, the LRMESS is determined on the basis of the following estimator, as proposed by Brownlees and Engle (2017):

$$\mathrm{LRMES}_{i,t}(C) \simeq 1 + \exp\left(18 \cdot \mathrm{MES}_{i,t}(C)\right).$$

Empirical results – brief presentation and discussion

In order to facilitate the comparison of the time series obtained by applying the three afore-discussed measures, they were plotted into one graph, following standardization, to obtain a comparable scale for the analysis:



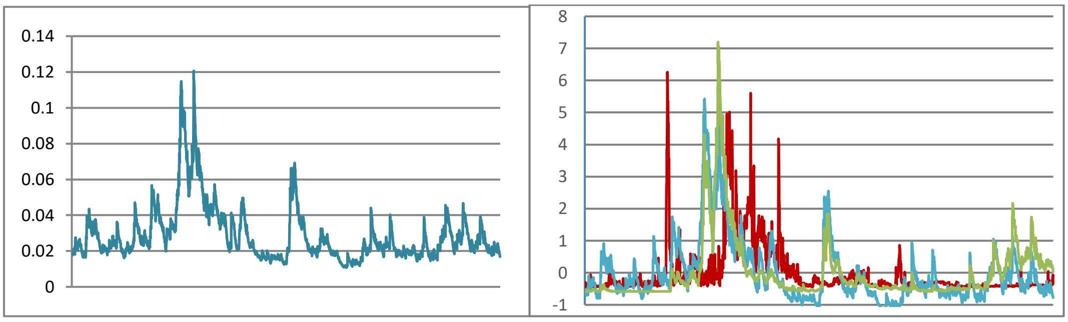


Figure 1 Comparative view on the three systemic risk characteristics
Note: Upper left panel – Systemic Liquidity Measure; upper-right panel – SRISK; lower left panel – Delta CoVaR; lower right panel – comparative view on the three risk characteristics.
Source: PhD dissertation, Figure 42, p. 255.

As it can be noticed in the graph, the three measures actually show different information. For instance, each measure peaks at different moments in time (CoVaR peaks actually follow the SRISK and the SLM measures' peaks), which is consistent with the expectations – the three measures are sensitive to three different characteristics of systemic risk. Also, Delta CoVaR for most periods shows higher risk than the other two measures, demonstrating how risk spill-over effect increases the scale of the other systemic risk aspects. These observations are confirmed by statistical properties of the analysed time series. Furthermore, if the first differences for each of the characteristic are plotted, the different signalling properties of the three measures are visible.

Table 1 Descriptive statistics regarding the systemic risk characteristics' time series

Risk characteristic	Mean	Standard deviation	Kurtosis	Skewness
Liquidity (L)	0.000354	0.000809	15.8319	3.632549
Fragility (F)	0.029058	0.084278	13.7175	3.320987
Spill-Over (S)	0.049081	0.015787	6.8649	2.312402

Source: PhD dissertation, Table 24, p. 256.

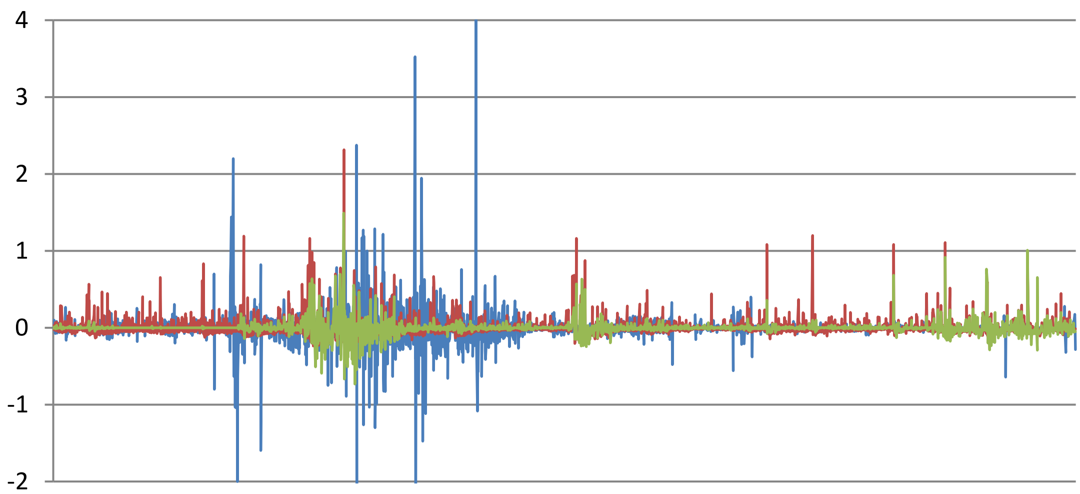


Figure 2 Volatility clustering in the systemic risk characteristics' time series
Note: liquidity – blue; fragility – green; risk spill-over – red.
Source: PhD dissertation, Figure 43, p. 256.

The next step of the study is the proposal of the author’s own financial stability measure. This proposal consists in using the concept of Mahalanobis distance to create an aggregate Index of Financial System Stability:

$$\mathrm{IFSS_t} = (\mathrm{y_t} - \mu)\sum -1(\mathrm{y_t} - \mu)'$$

The figure below presents the result of the Mahalanobis-Distance-based index calculation.

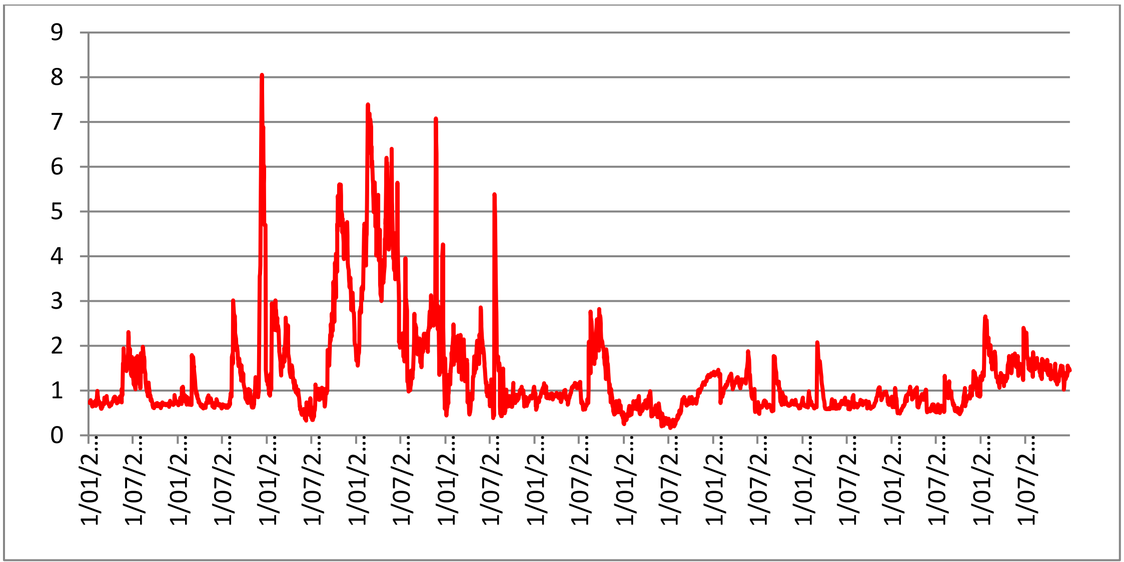


Figure 3 Mahalanobis-distance-based Index of Financial System Stability for Poland for years 2006-2016
Source: PhD dissertation, Figure 44, p. 262.

The figure above illustrates the joint information provided by the three analysed systemic risk characteristics, the table below presents the features of the aggregation outcome.

Table 2 Regression analysis results for the aggregate measure and risk characteristics' time series

Time series	y = Index of financial stability				
	R^2	Standard error	*p*-value		
For x_1 = liquidity	0.366287	0.020292	0.00000		
For x_2 = fragility	0.571414	0.013612	0.00000		
For x_3 = spill-over	0.551374	0.013928	0.00000		
	0.802723	0.490236	x_1	x_2	x_3

Multiple regression (x_1; x_2; x_3)		x_1	x_2	x_3	0.00000	0.00000	0.00000
		0.01167	0.01652	0.01663			

Source: PhD dissertation, Table 25, p.262.

As presented in the table above, each of the three characteristics has a significant impact on the aggregate, and each of them brings new information. Moreover, none of them explains the variability in the Index of financial stability to an extent that would justify using less characteristics for the aggregate. On the other hand, multiple regression analysis shows that the three variables treated together not only are all significant for the total function, but they also explain only about 80% of the total variability of the aggregate. The analysis of the residuals suggests that there is a latent factor in the regression (residuals are not normal, in fact they are scattered around the non-horizontal mean). As the assumed concept of aggregation is based on the Mahalanobis transformation which includes the information about the covariance matrix, it may be speculated that the latent factor is - at least partially - driven by the interconnectedness between the variables.

The Index of Financial System Stability calculated for Poland for the period of 2006 to 2016 allows to distinguish between more turbulent periods when financial system stability is weakened and the calm periods where risk is quantified closer to zero, signifying satisfactory levels of financial stability. The most stable periods are recorded for the year 2006, before the global financial crisis begun and 2014, after the European sovereign debt crisis subsides. In all other periods, the proposed systemic risk measure indicates increased risk in at least one of the three analysed risk aspects. Several peaks are recorded and each of them corresponds to an event that is important for stability of the Polish financial system.

In the final section of the dissertation the results obtained with the Index of Financial System Stability are compared with the results of the other authors, which were presented and discussed in Chapter Three. Recalling Tables 18 and 19, as well as Figure 27, the conclusion should be recapped that these measurements do not uniformly show the same periods of decreased financial system stability. As is argued throughout this dissertation this is due to the relatively narrow focus of all these methods, which impedes the results of the systemic risk analysis. To compare whether the measure proposed here captures the changes in systemic risk differently than the other measures, the results are again plotted on the time-axis.

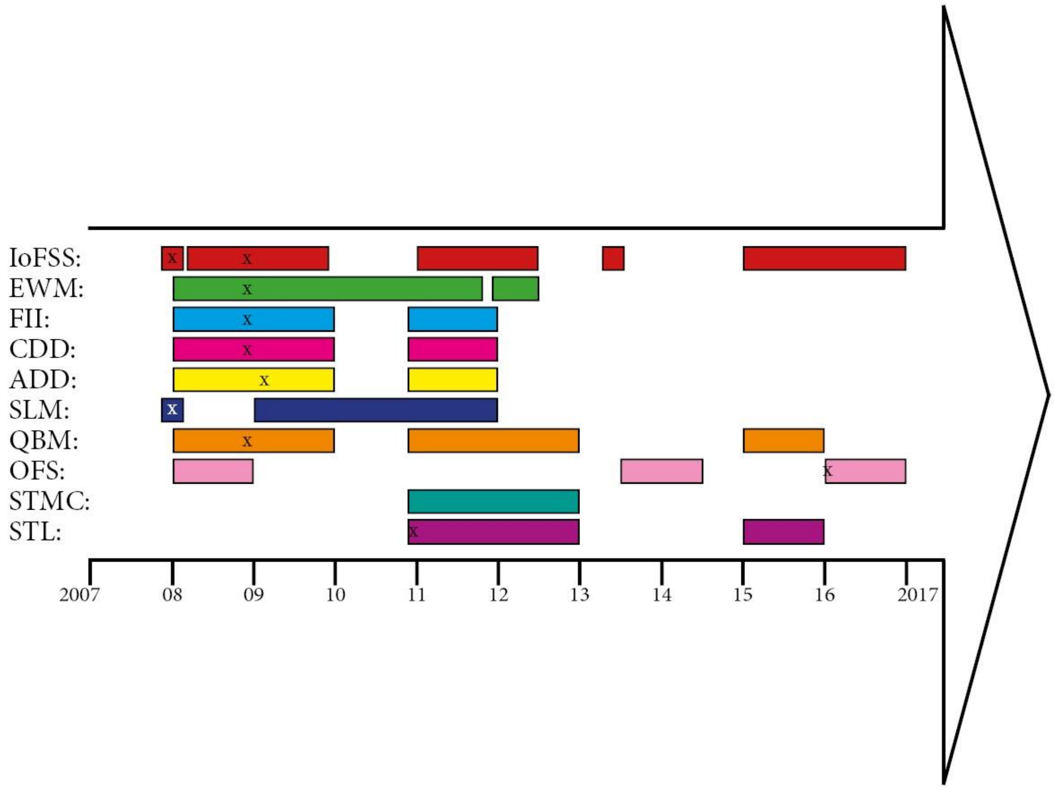


Figure 4 Periods and peaks of increased systemic risk identified in cross-referenced studies and by the proposed Index of Financial System Stability (IoFSS)
Note: for abbreviations explanation, please go to Figure 29.
Source: PhD dissertation, Figure 45, p. 272.

As illustrated by the figure presented above, the proposed measure is more sensitive to risk triggers than the other analysed measures.

Hypotheses positively verified in the dissertation

Major hypothesis of this PhD thesis stipulates that in the analysed period of 2006 to 2016, lowered levels of financial stability were present in the Polish financial system not only around the time of the global financial crisis, but also in various other periods and they were driven by both national and international occurrences. This hypothesis is validated based on the partial results obtained with each of the three selected measures, as well as with the author's own proposal of the Index of Financial System Stability. Identified periods of decreased stability included the years 2007-2010; 2011-2012 and 2015-2016. Based on the qualitative study of the historical events, the first two periods were found to be mostly externally driven, while the third period was found to be typically internal for the Polish financial system.

Additionally, in the course of the study four minor hypotheses were identified. The first one states that successful application of solutions related to the measurement of financial stability proposed in the literature is possible for Poland only after significant technical modifications. This hypothesis is partially verified in the initial and preliminary stages of the study (including former publications of the author), as well as in the empirical research carried out here, since further necessary modifications were made in the course of this study, to enable measurements and the aggregation carried out at the end.

The three remaining minor hypotheses related to the three identified characteristics of systemic risk. Minor hypothesis H2 postulates that systemic risk is driven by three risk characteristics: systemic liquidity risk, fragility of financial institutions and risk spill-over. It is validated by the literature findings in Chapters One and Two, as well as empirically verified in the ex-post event analysis described in Chapter Five.

Minor hypothesis H3 says that the methods focused on a single characteristic of systemic risk, such as liquidity, fragility or contagion, are not universal enough to detect all the increases in risk which are crucial for systemic risk realisation. This became evident from the studies reviewed in Chapter Three, as well as is further proven with the final empirical analysis described in Chapter Five.

The final minor hypothesis postulated in this work refers to the aggregation procedure. In order to accommodate this hypothesis, the author developed an aggregating procedure based on the concept of the Mahalanobis distance and applied it to the empirical data in the scope of the study. The result is analysed and serves the verification of the major hypothesis (as explained before) and minor hypothesis H4, stating that aggregating the three identified risk characteristics (systemic liquidity, fragility and risk spill-over) in one index allows for higher measurement output's sensitivity to systemic risk triggers, if compared with the other currently existing measures of systemic risk applied by others to Poland for the analysed period of 2006 to 2016.