Contributions and Applications in Loan Loss Provisioning, Stress Testing, and Visual Analytics

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Abstract

This cumulative dissertation summarizes and discusses six research articles that are either published in academic journals and conference proceedings or submitted for review. The topics described are cross-disciplinary and can be allocated to Accounting, Finance, and Information Systems Research. In Accounting, we analyze the methodological differences between ratings and lifetime default risk to develop a proof for the use of rating changes for the determination of significant increases in credit risk in accordance to the impairment requirements of the International Financial Reporting Standards. Our results and findings contribute to more transparency with regard to decision-relevant information for stakeholders of financial statements. In Finance, we combine machine learning techniques with cointegration analysis to produce adequate projections of macroeconomic variables for stress testing exercises. Our results and findings have practical relevance for risk managers in the financial services industry and help to validate the execution of stress tests and to ensure compliance. In Information Systems Research, we develop a general process model and visualization framework to identify and highlight unusual data in subsets for further investigation. Our process model and visualization framework empower domain experts and data analysts to jointly gain and discuss insights from underlying data. Our results and findings show that both our process model and visualization framework contribute to interactive visual analytics, storytelling, and well-founded decision support.

Zusammenfassung

Diese kumulative Dissertation diskutiert und fasst sechs Forschungsartikel zusammen, die entweder in wissenschaftlichen Zeitschriften und Tagungsbänden veröffentlicht oder eingereicht wurden. Die beschriebenen Themen sind fächerübergreifend und lassen sich den Bereichen Rechnungslegung, Finanzierung und Wirtschaftsinformatik zuordnen. Im Bereich Rechnungslegung analysieren wir die methodischen Unterschiede zwischen Ratings und Restlaufzeit-Ausfallrisiko, um einen Nachweis für die Verwendung von Ratingänderungen zur Bestimmung signifikanter Erhöhungen des Kreditrisikos gemäß den Impairment-Anforderungen der International Financial Reporting Standards zu erarbeiten. Unsere Ergebnisse und Erkenntnisse tragen zu mehr Transparenz hinsichtlich entscheidungsrelevanter Informationen für Stakeholder von Jahresabschlüssen bei. Im Bereich Finanzierung kombinieren wir Techniken des maschinellen Lernens mit Kointegrationsanalysen, um angemessene Projektionen makroökonomischer Variablen für Stresstests zu erstellen. Unsere Ergebnisse und Erkenntnisse haben praktische Relevanz für Risikomanager in der Finanzdienstleistungsbranche und helfen, die Durchführung von Stresstests zu validieren und deren Compliance sicherzustellen. Im Bereich Wirtschaftsinformatik entwickeln wir ein allgemeines Prozessmodell sowie ein Visualisierungsverfahren, um ungewöhnliche Daten in Teilmengen für weitere Untersuchungen zu identifizieren und hervorzuheben. Unser Prozessmodell und unser Visualisierungsverfahren versetzen Fachexperten und Datenanalysten in die Lage, gemeinsam Erkenntnisse aus den zugrundeliegenden Daten zu gewinnen und zu diskutieren. Unsere Ergebnisse und Erkenntnisse zeigen, dass sowohl unser Prozess als auch unser Visualisierungsverfahren zu interaktiver visueller Analyse, Storytelling und fundierter Entscheidungsunterstützung beitragen.

Management Summary

In this cumulative dissertation, research questions arising from real-world problems in different domains are presented and discussed. Information Systems Research (ISR) "embraces researchers and research from a wide array of fields under the umbrella of analytics [...] without compromising on the quality of research" (Gupta, 2017). Accordingly, this dissertation contributes to the three domains Accounting, Finance, and ISR. The topics described are all based on articles either published in academic journals and conference proceedings or currently under review. The overarching research motivation is to find new and innovative data-driven applications that are practical, relevant, and meaningful. Chronologically, the conducted research and related publications can be allocated to the following three topics:

I Determining Significant Increases in Credit Risk to Ensure Adequate Recognition of Loan Loss Provisions

II Applying Artificial Neural Networks in Stress Testing to Ensure Compatibility with Provided Scenarios by Regulators

III Visualizing Unusual Data in Subsets to Highlight Potential Areas for Further Investigation

For consistency and comparability, the same structure is used throughout the dissertation to summarize each topic. The chapters all start with a theoretical background of the problem, the derivation of research questions, and a summary of our main contributions. Then, the underlying methodology is described in a process-oriented manner. Following the approach of Rosemann and Vessey (2008), applicability checks are conducted to demonstrate the practical relevance of our research. Based on the results and findings, the main implications, recommendations, and limitations are discussed. Each chapter concludes with an overview of further research opportunities.

The following is a brief summary of our addressed research questions, proposed solutions, main contributions, and related publications.

I. Determining significant increases in credit risk

»Too little, too late« is the popular term used to summarize the weakness of existing accounting standards with regard to the recognition of credit losses of loans and other financial instruments in the time of the 2008 global financial crisis, see Brixner, Schaber, and Bosse (2013). To counteract the weakness, a new forward-looking expected credit loss (ECL) model was developed and published in the International Financial Reporting Standards (IFRS) 9, set effective in 2018, see EY Global CRS (2018). Following, the amount of ECL recognized as loan loss provision for a financial instrument depends on whether there is a significant increase in credit risk (SICR) since its initial recognition. If there is SICR, an amount equal to lifetime ECL must be recognized as loan loss provision. As long as there is no SICR or default, an amount equal to 12-month ECLs, i.e. only a portion of lifetime ECLs, must be recognized. The determination of SICR is one of the key elements of the IFRS 9 ECL model. To determine SICR, entities, i.e. banks, shall compare the lifetime default risk at the reporting date with the lifetime default risk at the date of initial recognition. Because ratings or credit scores are much more common measures in practice than lifetime default risk, the use of rating or credit score changes rather than lifetime default risk changes for the determination of SICR is easier to communicate and more transparent for stakeholders of financial statements. We analyze the methodological differences between changes of ratings and lifetime default risk for determining SICR (Bosse, Stege, & Hita Hochgesand, 2017a) and develop a proof for the use of rating changes for SICR in accordance with the impairment regulations in IFRS 9 (Bosse, Stege, & Hita Hochgesand, 2017b). We address the following research questions:

RQ1 Under what conditions can ratings be used for the determination of SICR in the IFRS 9 ECL model?

RQ2 How to demonstrate that rating changes are a reasonable approximation of lifetime default risk changes for the determination of SICR in the IFRS 9 ECL model?

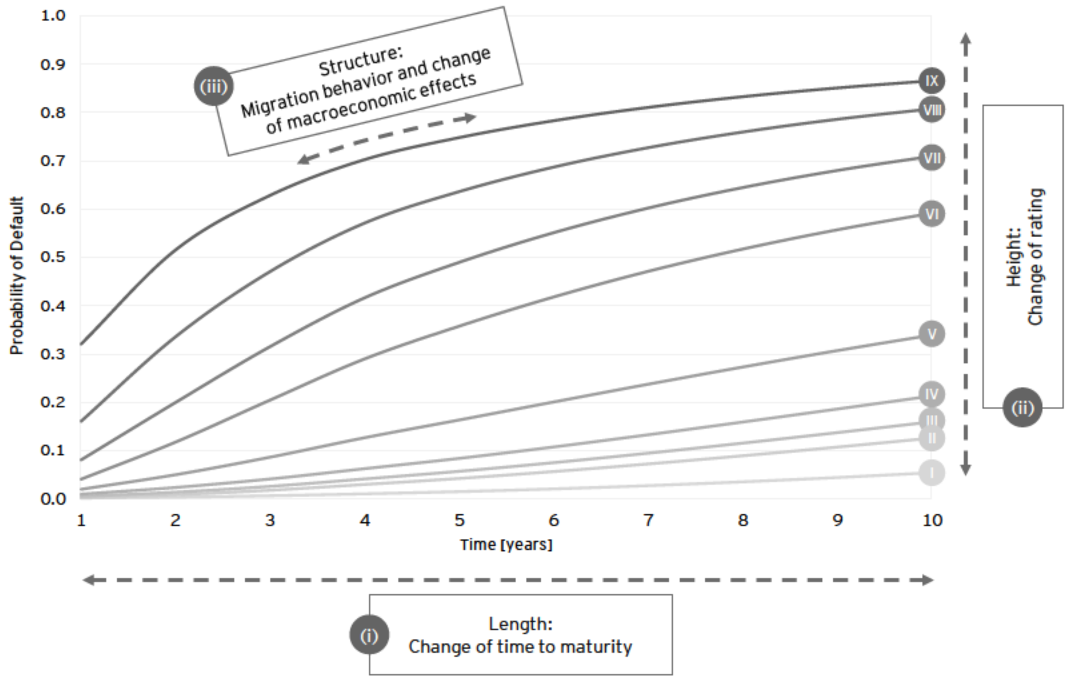

Figure 1: Factors of Lifetime Default Risk Changes (adaption of Bosse et al., 2017b, p. 439).

To address RQ1, we identify three factors that affect lifetime default risk changes. Figure 1 illustrates the three factors and their effect on lifetime default risk changes. The horizontal axis describes time in years, the vertical axis describes default risk, i.e. the probability of default (PD). If it can be shown that rating changes are the key factor for lifetime default risk changes, then rating changes can be used to determine SICR in accordance with the impairment requirements in IFRS 9.

To address RQ2, we develop a test that can be used to continuously monitor the adequacy of rating changes for SICR determination. The test is based on the interdependency between ratings and corresponding PD values that is usually described by »master scales«, a typical tool in credit risk modeling. We use the PD ranges from master scales to derive PD corridors that describe the PD ranges over time. This allows to evaluate the impact of factor changes to lifetime default risk changes. We find that leaving a PD corridor is equivalent to a rating change. Following, rating changes are the key factor for lifetime default risk changes, as long as changes caused by other factors stay within the corresponding corridor.

To demonstrate how our test can be applied in practice, we perform an applicability check and describe all necessary steps and data for replication. Our results and findings contribute to more transparency with regard to decision-relevant information for stakeholders of financial statements. An important limitation is that the application of our test is only meaningful in combination with a general validity of ratings, i.e. subject to the quality of information captured by ratings.

II. Applying artificial neural networks in stress testing

In risk management, stress testing is one of the most important tools. It describes a special form of scenario analysis to estimate losses in certain environments and has evolved considerably since the global financial crisis, see Aragonés, Blanco, and Dowd (2001) and Kohn and Liang (2019). In 2016, the European Banking Authority and European Central Bank required all major banks in the European Union to participate in a stress test specifically designed with a baseline and an adverse scenario, see European Systemic Risk Board (2016). The regulators provided official scenario estimates for a number of relevant macroeconomic factors. Estimates for other relevant factors not provided had to be generated in a way that ensured compatibility with the official scenario estimates. We demonstrate how innovative techniques from machine learning and time series analysis can be employed to map macroeconomic variables provided by regulators to relevant variables that were not provided, see Stege, Wegener, Basse, and Kunze (2021). We address the following research question:

RQ3 How can Artifical Neural Networks (ANNs) be used to produce adequate projections of macroeconomic factors consistent with regulatory guidelines on stress testing?

To address RQ3 we develop a step-by-step process with the objective to model the relationship between provided scenario variables and relevant variables that were not provided by regulators. For this, we use a basic ANN

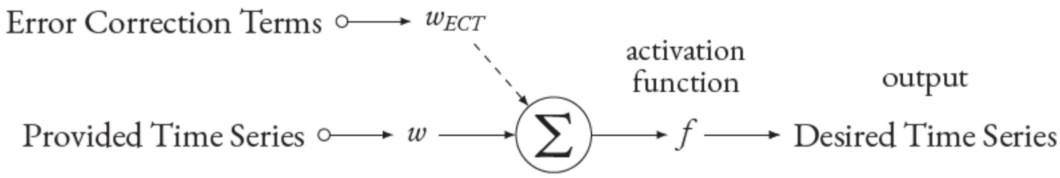

Figure 2: ANN Design of Model Types A and B (adaption of Stege et al., 2021, p.316).

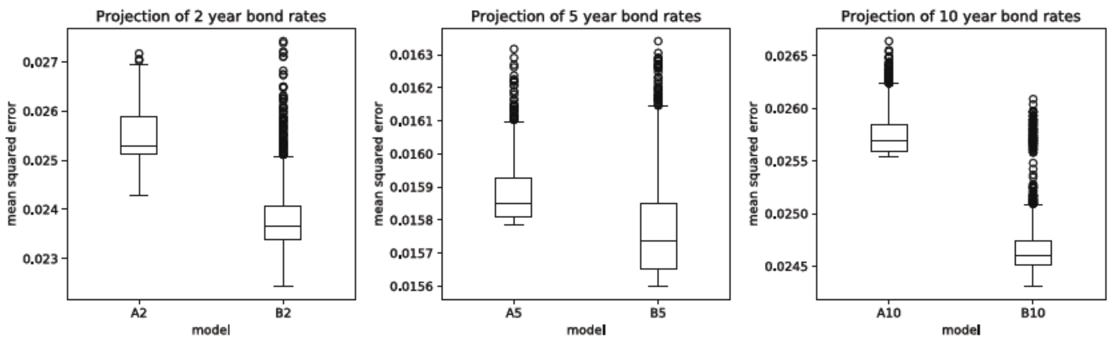

Figure 3: Comparison of Model Accuracy (Stege et al., 2021, p. 318).

»Model A« with the provided scenario variable as input and the desired variable as output. We design a second ANN »Model B« that uses cointegration information, i.e. error correction terms (ECTs), to account for the long-run relationship between both time series, see Figure 2. We then show how to generally configure the ANNs and describe the normalization of inputs, the number of neurons, and our fitting process. In an applicability check, we fit 12000 models in total. We use the mean squared error to evaluate model results. Figure 3 shows our results of both model types A and B for different maturities of the desired time series. Our results show that model B outperforms model A for all maturities. For empirical evidence, we apply non-parametric median tests to the model pairs to show that the medians of model errors differ systematically.

Our results and findings are relevant for risk managers in the financial services industry. From a different perspective, our approach can also be applied by auditors and regulators of financial institutions to validate the execution of stress tests and to ensure compliance. There is great potential for further research, because in its current state the complex configuration requirements most likely limit general applicability and acceptance.

III. Visualizing unusual data in subsets

Visualization methods in an analytics context, i.e. visual analytics, has been an active research field with applications in many sectors, see Sun, Wu, Liang, and Liu (2013). A powerful tool in visual analytics is storytelling, which describes the investigative process of connecting dots between seemingly disconnected information, see Hossain, Andrews, Ramakrishnan, and North (2011). In auditing, for example, accountants and auditors are increasingly using visual analytics and storytelling to analyze and communicate results, see, e.g., Sekar (2022). For complex analytical tasks, auditors are often assisted by specialists who have the required technical qualifications for these tasks. Visual analytics and the competency in storytelling can improve collaboration of auditors and specialists to jointly increase the overall quality of an audit. We develop a visualization framework to identify and assess unusual items in financial data for further investigation, see Stege and Breitner (2020). Because our framework is not limited to auditing, we generalize it for application in many domains where structured data is available, see Stege and Breitner (2023). We address the following research questions:

RQ4 How can visual analytics be embedded into a decision-making process to improve collaboration between data analysts and domain experts?

RQ5 How can the visualization framework be efficiently applied in practice to support anomaly explanation, well-founded decisions, and storytelling?

To address RQ4, we deduce a general process model and embed a visualization framework for the visual analysis of subset-dataset relationships. The process model consists of four main phases that are run through sequentially and cyclically until a well-founded decision is reached. The process is initiated with a problem statement and an underlying dataset that are run through the four phases. Accordingly, in a nutshell, subsets are identified from the dataset which are then visualized and jointly discussed by domain experts and data analysts to utilize insights and draw conclusions for decision support, see Figure 4.

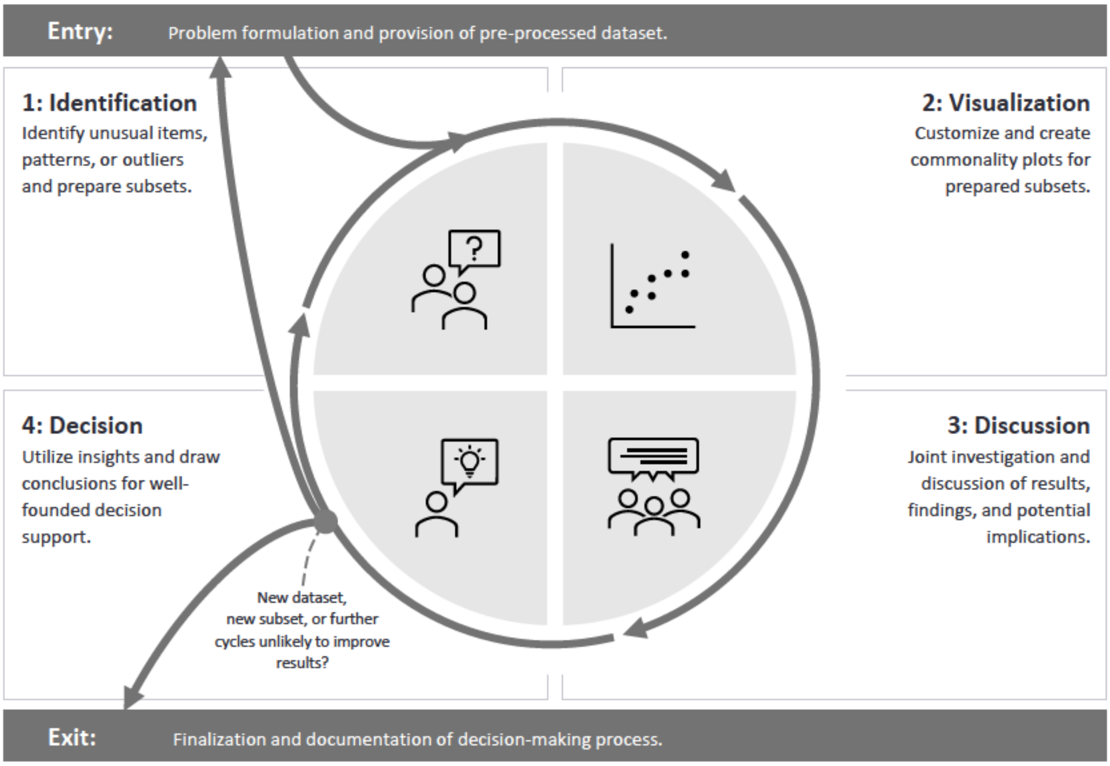

Figure 4: Interactive Process Model for Decision Support (Stege & Breitner, 2023, p. 6).

For the visualization phase, we introduce »commonality plots«, a novel visualization framework specifically designed to visualize commonalities in subsets and highlight items that have a low likelihood of occurrence. We create commonality plots for each feature in a dataset. Our visualization framework is inspired by Zoomable Circle Packing by Bostock (2018), which is closely related to treemaps, but better reveals the underlying hierarchy of data. This is very useful for the visualization of subset-dataset relationships. Figure 5 shows the commonality plots for three features of an arbitrary subset of the well-known Titanic dataset, which is publicly available and contains information about all passengers aboard the famous ship, see Kaggle (2012). The light gray circles show all values of the respective feature. The size of the circles indicates the number of occurrence in the main dataset. The dark gray circles show the values of the subset. We say there is commonality, if a feature of the subset only consists of equal values. Accordingly, the subset for feature »Age« has commonality, because there are only 23-year-old passen-

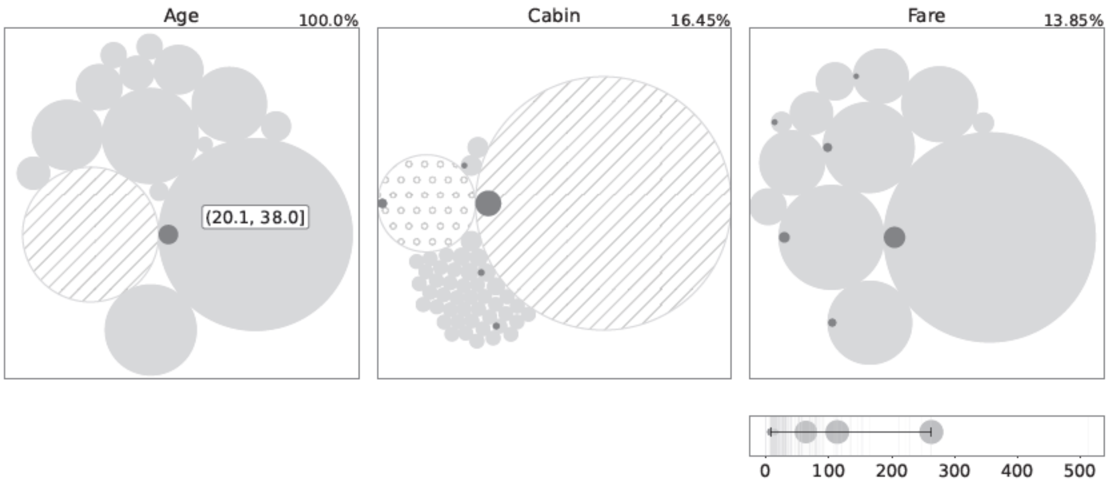

Figure 5: Commonality Plots for Selected Data Fields of the Titanic Dataset.

gers in the subset. The commonality plot for feature »Fare« shows the ticket prices passengers paid to get aboard. Because the feature is numeric, we show the distribution as a one-dimensional rug plot. The line plotted on top of the distribution shows the value range of ticket prices in the subset, i.e. the distribution of ticket prices paid by 23-year-old passengers. The feature »Cabin« describes the cabin labels of the passengers. A striped hatching indicates missing values, a dotted hatching indicates individual values that only appear once in the dataset. Apparently, the cabin label information is missing for the majority of passengers. Also lots of passengers have booked single cabins. Finally, we measure the unlikeliness of occurrence of the observed items in a subset. The results are presented on the top right corner of each visualization.

To address RQ5, we perform an applicability check to demonstrate how our process model and embedded visualization framework are applied in practice for well-founded decision support and storytelling. We show how data analysts and auditors jointly apply our process to analyze risk data from a European bank. Our process is most efficient for the analysis of structured datasets, because all measures necessary for the visualizations need to be calculated only once, regardless of the number of subsets. Our process is least efficient for the analysis of time series data that is constantly updated and where chronological order is of importance.

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