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dr hab. Jacek Jaworski, prof. WSB

WSB University in Gdańsk

Faculty of Business

REVIEW OF THE DOCTORAL DISSERTATION

entitled: ***On a Comparative Analysis of Industrial Credit Portfolio Risk Models Versus a New Support Vector Machine - Based Approach,***

written by MA. Raphael Reinwald

The basis of this review is the resolution of the Economics and Finance Discipline Council of the University of Gdańsk of July 28, 2022. entrusting me with the duties of a reviewer and a member of the doctoral committee in the procedure of awarding the doctoral degree to MA. Raphael Reinwald. The purpose of the review is to answer whether the dissertation submitted for review meets the criteria set out in article 187 of the Act of July 20, 2018 Law on Higher Education and Science (Journal of Laws 2018, item 1668, as amended), and in particular whether:

- 1) the dissertation presents the candidate's general theoretical knowledge in the field of economics and finance and the ability to independently conduct scientific research,
- 2) the subject of the dissertation is an original solution to a scientific problem or an original application of own research results.

A manuscript of 373 pages has been submitted to me for review, consisting of: introduction, five chapters and conclusions, a list of references, lists of diagrams and tables, and appendices. The dissertation has been prepared in English under the scientific supervision of dr. hab. Michał Suchanek, prof. UG. I have assessed the submitted dissertation according to the following agenda:

- A. General evaluation of the topic undertaken and its importance for scientific knowledge
- B. Assessment of the layout, structure and contents of the dissertation
- C. Analysis of the designed research process and the scientific methods used
- D. Other comments on the contents of the dissertation,
- E. Concluding sentence.

A. General assessment of the topic undertaken and its importance for scientific knowledge

Credit risk analysis is one of the key and the most frequently conducted analyses in financial management. Looking for better and more effective methods of the credit risk measurement is also very important from the point of view of economic practice. It is worth mentioning that the topic undertaken does not concern the credit risk of a single borrower, but the entire debt portfolio. In addition, in the reviewed dissertation, the author decided to apply solutions based on artificial intelligence being developed as part of the research of exact and natural sciences in the discipline of Information Technology. In this context, I assess the reviewed dissertation as interdisciplinary, which raises its value as essentially falling within the discipline of Economics and Finance. Summing up, I believe that the subject-matter of the doctoral dissertation is attractive and the most appropriate.

In the Introduction, the author specifies its main goal as "...to introduce a credit portfolio model which is effective (compared to a linear model) and even a better predictor than current credit portfolio models for some common bond portfolios". The context shows that the new model is to be based on artificial intelligence methods. I consider the aim of the dissertation as ambitious and appropriate for research and application works at the level of a doctoral degree in financial management. The implementation of this goal is important from the point of view of the existing knowledge, because it opens up new, interdisciplinary areas of searching for qualitatively better methods of credit risk assessment, which is ultimately also important for business practice. I believe that this goal, despite some shortcomings on the methodological level, has been achieved by the author.

The content of the work shows that the author has embedded the discussion on credit risk in the realities of legal norms and practice of the banking sector. In this context, the title of the dissertation, although correctly worded, seems to be a bit too broadly defined because not only banks are interested in determining the risk of the credit portfolio, and the credit risk itself does not only apply to bonds.

B. Assessment of the layout, structure and contents of the dissertation

The dissertation is divided into five chapters with relatively evenly distributed pages (45-55 pages). The strengths of the dissertation are as follows: an extensive (in some parts even too extensive) presentation of the existing scientific knowledge in the field of credit risk assessment in the context of capital requirements for the banking sector (chapters 1 to 4) and description of the state of research on the use of artificial intelligence in solving analytical

problems (part of the chapter 5.). The small proportion of empirical research in the contents of the dissertation is its weakness. The description of the method used along with the presentation of the research material and results are contained in only two subchapters of Chapter 5.

The substantive content of the dissertation is preceded by Introduction. Justification for the significance of the research problem undertaken by the author has been based mainly on the normative requirements for banks. The necessity to implement risk management methods (including the most important - credit risk) in these banks is a consequence of these requirements. Risk measurement is an inherent element of this management. The lack of references to the current state of research on classic and innovative methods of credit risk assessment in banks is noticeable in this justification. As a consequence the research gap that the author wanted to fulfill is very poorly marked. Subsequently, the author formulated the main purpose of the dissertation and three working research hypotheses. Finally, he briefly described the contents of the dissertation. The methods used in the empirical research are outlined in the summary. Thus, the structure of the Introduction comprises all the required parts and is not particularly objectionable.

Chapter I entitled: *Asset Classes and Investment Portfolio Types* has been divided into three parts and refers to the basic directions of building an investment portfolio by banks. The first part has been devoted to the presentation of capital requirements imposed on banks by the regulators. The basic assets in which the bank can invest its own and entrusted funds have been also indicated. The second subchapter provides information on alternative investment directions in the banking sector. Chapter I ends with the characteristics of investment strategies and methods of measuring their effectiveness. The contents depicted in Chapter I is consistent with the current state of knowledge and presented in an interesting way.

The second chapter (*Investment and Credit Risk Management: Definitions and Terminology*) has also been divided into three sections. The first subchapter creates the context for further considerations by defining risk in the banking activity. Subsequently, the basic risk measures have been characterized. Theories of investment portfolios (MPT, CAPM and APT) have been presented in the third part. The content of Chapter II is also consistent with the current knowledge, presented in a very broad way.

Chapters III and IV are crucial in describing the current state of knowledge in the field of achieving the purpose of the dissertation. Chapter III deals with the risk associated with a single loan. It describes the main principles of the rating systems conducted by external institutions, identifies the necessity and methodologies for internal rating, and discusses the

main models for assessing various types of risk associated with business activities. Chapter IV is devoted to the characteristics of credit risk assessment models for a portfolio consisting of multiple financial instruments (obligors). Three classic, widely used in practice models were discussed: i) CreditRisk + ® based on actuarial mathematics, ii) CreditMetrics® focused on the analysis of internal risk factors and iii) CreditPortfolioView® taking into account primarily external factors. All three models are used not only to measure the risk of current loan portfolios, but also to predict measures of this risk in the event of changes in the investment environment. I assess the content of these chapters very highly. In particular, I consider the fragment that compares the features of individual models of portfolio risk analysis based on a detailed literature review and the author's own observations to be very important for the purpose of the study (pp. 202-204).

In Chapter V, the author described the main methodological assumptions of predictive and analytical solutions based on artificial intelligence (Artificial Neural Networks and Support Vector Machine). It is beyond my competence to evaluate this content, but I have read it with great interest. The description is communicative, straightforward and clear. It is only puzzling that the dissertation contains a lot of information about neural networks that has not been used by the author in his own research.

Chapter V also includes an empirical study. The author has attempted to show that the credit risk assessment, and above all its prediction, based on the Support Vector Machine (SVM) is more effective and more accurate than the assessment based on the classic models. I assess this part of the work as the weakest. It is only 18 pages long and it is based on a limited review of the literature, a modest presentation of material and research methods, focusing only on discussing the results of the study. However, the analysis of the essence of the research, its results and the author's comment lead me to the conclusion that the author has largely achieved the aim of the dissertation.

C. Analysis of the designed research process and the scientific methods used

Nowadays, the structure of the scientific process is defined as:

- 1) consciously defining the state of dissatisfaction due to gaps in knowledge about a selected fragment of reality,
- 2) formulation of a non-trivial research problem containing and describing the state of scientific ignorance or existing uncertainty with the current scientific achievements,
- 3) formulation of test statements (hypotheses), i.e. assumptions, statements formulated in front of a scientific proof,



- 4) collecting adequate research material using methods of its collection recognized in the doctrine of a given discipline,
- 5) performing internal verification or falsification of each of the hypotheses put forward through appropriately selected methods of analyzing the collected research material,
- 6) formulation of scientific theses, i.e. confirmed hypotheses that are assigned to the gaps existing in scientific knowledge.

The first stage of the scientific process requires the researcher to establish the current state of knowledge on the subject of interest to him. This is done using a specific method of literature review. Collecting and commenting on scientific achievements to date allow the researcher to isolate the so-called a research gap, i.e. a missing area of knowledge or doubt as to the reliability of the existing knowledge. The author of the dissertation has coped with the first part of this stage of research very well, namely he has presented the current state of knowledge in the field of credit risk analysis and assessment in a broad and correct manner. The second part, i.e. the definition of the research gap, is poorly visible in the work. Attempts to justify the importance of searching for risk assessment methods based on artificial intelligence can be found only in the Introduction and partially in Chapter 5.2. They cover a dozen sentences with reference to undescribed research by other authors. Reading these fragments of the work, one can feel the diagnosed research gap intuitively. However, it is not precisely delineated.

A properly diagnosed research gap usually allows for the formulation of the main research question (problem). The author formulated it as the main research goal, which is: "...to introduce a credit portfolio model which is effective (compared to a linear model) and even a better predictor than current credit portfolio models for some common bond portfolios". I assess this goal positively.

The author has conditioned the realization of the aim of the dissertation by the verification of three research hypotheses: (i) the SVM (Support Vector Machine) regression model is an effective model for credit portfolio risk measurement of typical bond portfolios, (ii) the root mean square of errors (RMSE) for the SVM-based model is lower than for the classic models, and (iii) the SVM-based method may outperform even the classical models for a majority of selected standard bond portfolios. These hypotheses are consistent with the stated aim of the dissertation and sufficiently operationalize the planned research. However, as in the case of the research gap, the author has poorly justified these hypotheses with a literature review.



The Refinitiv® database has been a source of the research material, from where the author downloaded data on bonds listed on the US and EU markets. The criteria that limited the scope of the collected data has been as follows: (i) volatility of the bonds quotation, (ii) the period 2009-2019 and (iii) issuers from the developed markets. The issues with incomplete and unreliable data have been rejected and four portfolios of bonds have been created:

- 1) low volatility bonds listed in the US, issuers of which operated in manufacturing industries (food and beverages, tobacco, household chemicals, energy, etc.) - 27 issues in total,
- 2) low volatility bonds listed in the EU, the issuers of which operated in service industries (mainly for the public) - 28 issues in total,
- 3) high volatility bonds listed in the US, with a predominant share of issuers from the transportation, transportation and financial industries - 27 issues in total,
- 4) high volatility bonds listed in the EU, highly diversified by sectors - 25 issues in total.

While I assess the technical structure of the research sample correctly, I have not found any justification in the dissertation why the author limited his research to only one financial instrument, and also what the purpose of the division of portfolios in terms of volatility was. A significant fault of the empirical study is also the lack of a broader characteristic (even in the form of descriptive statistics) of the analyzed portfolios.

At particular moment of quotation, each bond was assigned a rating standardized by the author for comparative purposes. Subsequently, all portfolios were divided into two sub-portfolios. Randomly selected 20% of bonds formed a training sub-portfolio and 80% formed a test sub-portfolio. Next, on the basis of the training sub-portfolios, two predictive models developed (the first – a classic linear and the second - using the Support Vector Machine). The predictive quality of both models was verified on the test sub-portfolios. The quality of the estimated models was assessed by the Author in three steps:

- 1) applying the Kruskal-Wallis test, which determined that in each analyzed portfolio the risk distribution predicted by the models differed in a statistically significant manner; thus, the author denied the null hypothesis that there were no differences between the risk models predicted; it means that one of the models must predict risk better,
- 2) the identification of a more effective model was based on the RMSE test (the root mean square of errors between the prediction and the real risk level in a given test sub-portfolio); for the SVM-based model, this average turned out to be lower in all 4



portfolios, which justified the author's claim that this model qualitatively exceeded the linear model,

- 3) the SVM-based model was also compared with the CreditMetrics® model for the estimation of Value at Risk (VaR); the comparison of the forecasted VaR with the actual value from the test sub-portfolios showed that the CreditMetrics® model, in line with its previously mentioned feature, underestimated the VaR value; for the SVM-based model, three portfolios projected VaR close to the real one; the results of this test also led the author to conclude that the second model more effectively predicts the credit risk of the bond portfolio.

The research technique adopted by the author does not raise significant objections. The formulated conclusions have been properly based on the obtained results. However, my doubts related to the logic of the dissertation's considerations have been raised by two flaws. The author has not included the structure of the developed models in the dissertation - their parameters are unknown, which makes it impossible to assess the conditions of the results comparability. The author has not attempted to link the obtained results with the three hypotheses formulated in the Introduction until the Conclusions. Although the conclusions are based on correctly "read" premises, only hypothesis (ii) can be considered directly verified. Hypothesis (iii) was verified using only one criterion, and the verification of hypothesis (i) was indirect.

In the Conclusions, the author has also made an attempt to embed the obtained results in the existing scientific knowledge. The correctness of the conclusions does not raise any objections in this regard. However, the lack of an exact definition of the research gap raises a certain insufficiency in the reception of the author's statements and regarding them as important for science.

D. Other comments on the contents of the dissertation,

The text of the monograph is prepared carefully and aesthetically. There are slight errors in the construction of the footnotes used. There are also no direct announcements to the graphic elements (tables and figures) included in the dissertation.

To describe the risk and methods of its measurement, the author has used a very extensive mathematical apparatus. In many paragraphs, in my opinion, it is applied in a too detailed manner. In conjunction with the mental leaps used, this causes that in some fragments of the dissertation mathematical formulas obscure the economic content of the described measures and phenomena.



The author has used abbreviations in his work with great passion. Their list is 17.5 typewritten pages long. The frequency and number of abbreviations used make the contents difficult to understand in some paragraphs.

The final part of the Conclusions contains statements regarding the possible application of methods related to artificial intelligence in finance, having no support in the considerations of the work and the conducted research. However, they can be treated as recommendations for further research.

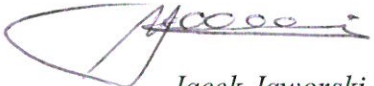
The list of literature used in the work contains 1199 items. Random control of the footnotes did not reveal their inconsistency with the list of references. The number and quality of the items cited are impressive.

E. Concluding sentence

Taking into account the opinions expressed above, I believe that MA Raphael Reinwald demonstrated high knowledge in the field of risk management falling within the discipline of Economics and Finance in the reviewed dissertation. The dissertation is also an original solution to a scientific problem. Thus, most legal and substantive requirements for doctoral dissertations have been met. Some doubts may only be raised by the way of presenting the scientific problem, describing the material and the research method.

Therefore, I am asking the Economics and Finance Discipline Council of the University of Gdańsk to admit the dissertation to public defense. At the same time, I am asking the author to prepare supplements and explanations according to the comments made in the review.

Reviewer



Jacek Jaworski