SCIENTIFIC REVIEW

by Prof. D.Sc. Rositsa Rangelova Pavlova, Institute for Economic Research at the BAS,
of a dissertation for the award of the educational and scientific degree "doctor"
in Higher Education Area 3. Social, Economic and Legal Sciences, Professional Direction 3.8.
Economics, doctoral program "Economics and Management (Industry)" at the Department
"Economics and Management by Sectors", Faculty of Economics and Business Administration at
Sofia University "St. Kliment Ohridski"
on the basis of the provision of art. 4, para. 5, 6 and 7 of the Law on the Development of the
Academic Staff in the Republic of Bulgaria (ZRASRB), decision of the Faculty Council Protocol
No. 14 of 11.07.2023 and Order No. RD 38-454/19.07.2023 of the Rector of the Sofia University
" St. Kliment Ohridski"

Author: Mihail Veselinov Yanchev

Topic: Modeling economic uncertainty: methods, evaluation, and applications of probabilistic
forecasting

1. **Brief biographical data for the doctoral student**

Mikhail Yanchev received his undergraduate education at the District of Columbia, United
States of America, Adelphi University, Honors College and Institute of Business in 2010. The study
focused on economic theory, mathematics and humanities. Later (2012) again in the District of
Columbia, he completed a master's degree in studies focusing on economic theory, mathematics,
statistics and econometrics. In recent years, he has been a full-time doctoral student at the Faculty
of Economics and Business Administration at the University of St. Kliment Ohridski" on the topic
discussed today. Research supervisor: Associate Professor, D.Sc. Anton Antonov Gerunov.

Meanwhile, Mihail Yanchev exercises his knowledge and skills in an expert activity as:
technical team leader of a first-class experts of data, data engineers and developers, consulting
corporate clients on data analysis and design and implementation of predictive models, design,
review and applying the Basel and IFRS 9 credit risk models, portfolio and macroeconomic
environment analysis, macroeconomic modeling and forecasting, etc. Participated in the
preparation of periodic and non-periodic analyses, including several scientific articles. (I have a
small quibble with his presented CV in terms of clarity, and recommend to follow the EU format)

These biographical data show a consistently acquired high professional training, active
implementation, and then dissertation orientation to a topic that is in his field of expertise -
perspective and complex.

2. Assessment of the fulfillment of the minimum national requirements

According to the report attached by Mihail Yanchev on the fulfillment of the minimum national requirements for obtaining the educational and scientific degree "doctor" in the professional direction 3.8. Economics, he has a total of 90 points - development of a dissertation for the award of the ONS "doctor" - 50 points and two scientific publications, one of which is published in a scientific publication, referenced and indexed in world-famous databases and brings him 30 points, and the other, published in non-refereed peer-reviewed journals and earns him 10 points. I accept that Mihail Yanchev meets the minimum national requirements for admission to the defense of his doctoral dissertation.

3. General characteristics of the dissertation work

The dissertation has a total volume of 152 pages in English, including 15 tables and 33 figures. It consists of an introduction, three chapters and a conclusion, and four appendices, which actually contain sequentially figures 30 and 31 in the first appendix, figure 32 – in the second, table 17 in the third and figure 33 in the fourth. Obviously, the author understands their nature more as evidential or illustrative. There is attached a rich list of used literature in English (about 350 in number), which are serious scientific studies mainly on the researched econometric toolkit. My note here is that there are too many - they could be at least half that number.

The introduction introduces the upcoming research very well by presenting clearly and comprehensively the necessary components in it: relevance and significance of the research, object and subject of the research, aims and scientific objectives, hypotheses, scope of the research, research methodology, data sources, limitations in the study, and directions for future research.
The *main objective* of the dissertation is (I quote) "to define the state-of-the-art methods for probabilistic forecasting in the fields of economics, statistics, and machine learning, and to propose new improvements that may have practical utility for the purpose of the economic forecasting." To achieve this goal, a multidisciplinary study has been carried out and a new approach to probabilistic forecasting has been proposed, which has been applied to several economic cases of interest among economists.' The characteristic here is that the purpose of the dissertation is formulated at a close distance in the text four more times, which, in my opinion, obey the main purpose and are in the context of the considered thought, but it is a little superfluous.

The object of research is economic uncertainty. It includes measurable degrees of uncertainty that relate to economic conditions in a particular region or globally as measured by various economic indicators. *The subject* of the study is the forecasting of economic uncertainty (I would add the word modeling before forecasting, because forecasting is always based on a model, in this case the DQPR model). Furthermore, the focus of the research is the development of a new neural network architecture for probabilistic prediction, which is based on the concept of quantile regression and the use of artificial neural networks. The research methodology is based on (I quote) "established procedures in economic forecasting, as well as drawing on established and novel approaches from the fields of machine learning and deep learning." The time span of the empirical analysis is the period after 2000 to the present. A strong positive impression is made by the doctoral

student's in-depth reflections on the limitations of the research, which show his broad knowledge in this matter and the outlined possibilities for future research.

To achieve the set goals, *six tasks* are defined following the research logic, namely: a literature review on the topics of uncertainty in economics and machine self-learning, economic forecasting, and probabilistic forecasting in statistics and deep self-learning, through the development of a neural network architecture for economic modeling and forecasting that allows uncertainty to be quantified and be used in various economic contexts and for time series forecasting, applying the proposed neural network architecture to three economic processes.

The main research hypothesis (in my opinion, this is a thesis) is that a general architecture for modeling and forecasting economic uncertainty can be formulated that would outperform a set of reference models, especially in situations involving rare events and unexpected shocks. In connection with it, *four working hypotheses* are formulated, and the commendable thing is that in the course of the research they were empirically verified.

The dissertation as a whole is precisely laid out. The style is clear, which with the adopted structure facilitates the difficult econometric matter, as well as the description of the results in the empirical applications.

The structure of the dissertation thesis is logical and scientifically sound. *The first chapter*, "Economic Forecasting and Uncertainty", is introductory, descriptive and consists of two parts dealing respectively with the concept of uncertainty and the development of economic forecasting in the last century. This is necessary to reduce semantic ambiguity and define a clear distinction when it comes to quantifying the uncertainty of the prediction. The first part focuses on the definition and classification of economic uncertainty for the purposes of economic forecasting. The parallel examination of two fundamental sources of uncertainty connected with the names of Frank H. Knight and John M. Keynes through the lens of dividing uncertainty into aleatory (related to the inherent stochasticity in the environment or its measurement) and epistemic (related to the limitations of the observer's knowledge) is original. In the second part, a comprehensive review of the literature on economic forecasting and its development is made. The chapter concludes with an overview of various methods used to generate, calibrate, and evaluate probabilistic forecasts. Finally, a comprehensive review of interval, quantile, and density forecasting methods is performed with methods spanning the fields of econometrics, statistics, and machine learning.

The second chapter contains the theoretical part of the research: probabilistic forecasting using artificial neural networks and a technique from the economics literature - deep quantile-based probabilistic regression (DQPR). The essence of this approach is that it builds on an established two-step statistical method, but recast it in an integrated model using artificial neural networks, allowing for the quantification of both aleatory (aleatoric) and epistemic uncertainty. Simulations are conducted to verify how cost optimization of the model improves the performance of point forecast and density forecast. A discussion of the literature on Bayesian inference for artificial neural networks is briefly conducted *Chapter three* contains applications of deep quantile probabilistic regression (DQPR) in three separate case studies. The first two case studies focus on modeling aleatory uncertainty, while the third considers both aleatory and epistemic uncertainty. The first case study consides current forecasting of pandemic-related recessions in four countries in Eastern Europe: Bulgaria, Lithuania, Estonia and Romania. The second case study demonstrates how the proposed framework can be applied to predict natural gas prices in a Balkan gas hub based

on data from the leading European TTF gas hub in the Netherlands. The performance of the proposed framework is compared with several statistical and machine learning methods and is shown that it outperforms the benchmarks. The third case study uses the DQPR model to construct a fan-shaped inflation chart for Bulgaria and quantify both aleatory and epistemic uncertainty.

The decision to structure the individual chapters deserves admiration – the first begins with an introduction and ends with conclusions, the second begins with motivation and ends with explanations, and the third begins with an introduction and ends with a discussion, with the same structure applied to the three points in it.

4. Evaluation of the scientific and practical results and contributions of the presented dissertation work

1. I highly appreciate the choice of such a perspective and complex topic as modeling and forecasting of economic uncertainty, as well as the very serious professional work. The aim of the dissertation has been achieved.

2. The dissertation is subject to a logical and consistently developing research structure. It is developed in detail and with deep knowledge, which Mihail Yanchev undoubtedly has.

3. As a result of the research, the doctoral student reaches important conclusions, which he reflects in the text or finally in the conclusion. More important of them are the following:

- Probabilistic forecasting has clear advantages over the more commonly used point forecasting that is still prevalent in economics. In the context of rare events of a global or national scale (such as extreme shocks, economic crises and natural disasters) and the resulting extreme economic instability, probabilistic forecasting becomes indispensable.

The main conclusion from the results of the first case study discussed in chapter three is that artificial neural networks with a sufficient level of complexity outperform linear models of the same type in predicting of sudden recessionary events. The second case study compared DQPR with several statistical and machine learning approaches, and the results demonstrated the far superior performance of DQPR. The same conclusions are found for the third case study, which is a demonstration of DQPR to construct a fan-shaped inflation chart for Bulgaria and to quantify both aleatory and epistemic uncertainty. It is shown that the proposed DQPR model can be used to generate specific diagrams.

I accept the contributions defined by the doctoral student Mihail Yanchev, which he divides into three main groups - scientific, scientific-applied and methodological. According to him, the main areas of contributions are economics, econometrics and machine learning. The contributions lead to new results in the researched areas and to clear practical applications of the proposed methodology.

Scientific contributions include a proposed new method to improve economic forecasting that uses a neural network architecture for probabilistic time series forecasting, called deep quantile probabilistic regression (DQPR).

Among the *methodological contributions* are as follows: a Bayesian version of the DQPR model was developed, which was applied in the construction of fan-shaped graphs of inflation in Bulgaria, as well as in the quantitative assessment and decomposition of aleatory and epistemic uncertainty; the LIME interpretable machine self-learning algorithm is applied to the DQPR model to perform a sensitivity analysis and gain insight into the global and local explainability of the

model. The proposed DQPR model outperforms both statistical reference models and those based on deep self-learning.

Scientific and applied contributions are related to the application of deep quantile probabilistic regression (the DQPR model) in three economic case studies described above. To the contributions of an applied nature, the doctoral student justifiably points to the fact that the analyzes and proposals made can be used in making management decisions, as well as in the legal framework governing individual economic cases in order to increase the efficiency of the economy as a whole. In addition, in my view the research in the dissertation can serve as educational material for students and doctoral students and anyone interested in the issues under consideration.

Assessment of dissertation publications

The doctoral student has submitted two independent publications on the dissertation, which correspond to the requirements of art. 12 of ZRASRB, and the Regulations for its implementation. Both articles are in English. The subject matter of the publications covers the subject matter of the dissertation work and reflects parts of it. The publications are sufficient in volume and content to conduct the present defense. The first article was published in an edition of SU "St. Clement of Ohrid". It has a theoretical character, dealing with the definition and classification of the uncertainty of the economic forecasting task. The other article was published in the journal "Economic Studies" of the Economic Research Institute at the BAS. It proposes an improvement to the established two-step procedure for empirical estimation of the future growth distribution, which involves directly modeling the parameters of the conditional distribution in one step within an artificial neural network. The proposed procedure is tested on macroeconomic data from four small European open economies covering the coronavirus pandemic lockdown period and the associated recession. The model achieves better performance in all four countries than the established two-step procedure.

The abstract of the Dissertation Thesis is 66 pages in Bulgarian and 56 in English. It is developed according to the requirements, reflecting the main results achieved in the dissertation work. The abstract is well structured and reflects the main points and contributions of the dissertation work, as is its purpose.

Critical notes and questions

I have no fundamental criticisms of the PhD student.

Questions:

1. How would Mihail Yanchev relate Nasim Nicholas Taleb Black Swan phenomenon to the definition of uncertainty and probabilistic forecasting?

2. In the dissertation, the concept of machine self-learning and deep self-learning is often used, but the definition of them is not well explained. It is generally believed to be related to AI. What more would the author say about this?

Personal impressions

I don't know Mohail Yanchev personally and I don't have personal impressions, but what I got in absentia is very good.

Recommendations for future use of dissertation contributions and results

I would recommend the PhD student to continue his research in the field of his dissertation, deepening and expanding it. He has invested a lot in this matter, he has a clear vision for it, pointing

out the features and limitations of the tools he uses. With this degree of thoroughness on his part and high level of expertise, I believe he will continue to work in this field.

CONCLUSION

According to the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria (Article 5, Paragraph 3), I believe, that the presented dissertation work on the topic "Modeling economic uncertainty: methods, assessment and applications of probabilistic forecasts" possesses the necessary qualities and contains scientific, methodological and scientific-applied results that represent a contribution to science. The presented materials and the quality of the dissertation fully correspond to the specific requirements of the Regulations for the admission and training of doctoral students at SU "St. Kliment Ohridski".

Bearing in mind the above, I give my positive assessment of the research carried out in the dissertation work and confidently propose to the honorable scientific jury to award the educational and scientific degree "doctor" to Mihail Veselinov Yanchev in Professional direction 3. 8. Economics; doctoral program "Economics and Management (Industry)" at the Department of "Economics and Management by Industry" of the Faculty of Economics and Business Administration at SU "St. Kliment Ohridski".

27 September 2023   Reviewer:
                                               (Prof. Rositsa Rangelova Pavlova, D.Sc.)