# OPPONENT OPINION

Dissertation for acquiring of scientific and educational degree "Philosophy Doctor"

**One candidate:** Ivaylo Vladimirov Boyoukliev

**Topic of the dissertation:** Modeling and Research of Foreign Exchange Financial Markets

**Procedure Notifier**: Department of Mathematical Analysis, FMI, P. Hilendarski University of Plovdiv

**Field of higher equcation:** 4. Natural Sciences, Mathematics, and Informatics

**Professional direction:** 4.5. Mathematics

**Doctoral Program:** Mathematical Modeling and Application of Mathematics

**Opponent**: Prof. Michail Todorov, PhD, Section of Differential Equations and Mathematical Physics, Institute of Mathematics and Informatics – BAS, by RD-21 - 238/29.01.2024 of the Rector of P. Hilendarski University of Plovdiv

### Short biographical record of the applicant

Ivaylo Boyoukliev was born in 1969 in Sofia. In 1987 he finished high school. During the period 1989-1993 he studied and graduated UNWE. Since 1994 the applicant has developed active bank activity: in 1994-98 dealer in board "Money in cash and financial markets" – Bulgarian Post Bank; in 1998-99 г. senior dealer in the same board – Pariba Bank BG; in 1999-2000 head of board "Money in cash and financial markets" – Societe General Bank BG; in 2000-09 head of board "Money in cash and financial markets" – Piraeus Bank BG Plc.; in 2009-19 director of board „Money in cash and financial markets" Piraeus Bank BG Plc.; since November 2019 he has been a director of board "Money in cash and financial markets" – Municipality Bank Plc. In 2020 I. Boyoukliev is taken as a regular postgraduated student in FMI by P. Hilendarski University of Plovdiv and stricken in 2023.

The dissertation is written in Bulgarian, volume of 160 pages, format B5+1/2, including preface, 4 chapters and conclusion, 68 figures, 46 tables and bibliography of 135 items, almost all of them in English.

### 1. General characterization of the dissertation problem

In the dissertation are applied classical methods for statistical modeling and data analysis in the area of currency and financial markets, which are complemented by the modern intelligent methods with machine learning. Together with them there are many problems, which require

further development of the modeling and studying of time series related to the necessity to have predictor values in the future period as well as to identify predicting factors. Combining of these activities requires good knowledge of the real processes on one hand and respective mathematical tools for analytical, computational and software realization of the models and treatments on other hand. The subject-matter has a clear groundwork and indispensability of particular applications, which is a sufficient ground and motivation to conduct the investigations. All that presuppose a high mathematical qualification and practical experience, that the applicant undoubtedly possesses and cleverly executes.

## 2. Current state of the problem

The investigations are based on the real historical data of financial markets and systems. To predict the future dynamics and investment strategy are used new approaches to model the time series based on stochastic and powerful intelligent methods. The goal is an investigation, an analysis and a prediction of the monetary financial markets. The latter requires an elaboration of common frame for modeling of 1d and multidimensional time series by using intelligent methods with machine learning, application of ensemble methods, hybrid approach with ARIMA correction for modeling the variations in bank deposits.

## 3. Methods of investigation

The investigation of the currency financial markets reduces to processing, analysis and modeling of time series. The problem is solved by methods of regression kind. The regression kind aims to describe and predict the observed data as well as to give an opportunity to get predictions for the next moments in the time. The sources usually are the data of central banks and statistical institutes in the investigated countries while the statistical processing is implemented by using of special automated statistical software: Box Jenkins ARIMA, CART Ensembles and Bagging, Adaptively resampling and combine – Arcing, Random Forests, RF, Hibryzed models. All that requires a flexible approach to solve the respective problems. In my opinion, the applicant applied it on a high professional level to the methods and software as well as to the quality and significance of the obtained results.

## 4. Review and evaluation of the scientific achievements

The PhD thesis considers five problems as follows
- Development of common frame of models concerning 1d and multidimensional time series by using of intelligent methods based on machine learning;
- Studying of time series in monetary and financial markets and development of methods how to choice predictors for short-time future forecasts;
- Application of ensemble methods for modeling and predicting of 1d time series for the deposits of Bulgarian citizens in foreign currency;
- Application of ensemble methods for modeling of multidimensional time series to currency courses and macroeconomical indicators;
- Development of hybrid approach with ARIMA correction for modeling the variations in bank deposits of the citizens.

The basic elements and stages of the statistical modeling are presented in **Chapter 1**, the applied domain  is defined, a comprehensive survey of the dissertation topics is accomplished, the methods used and the auxiliary software are announced,  the goals and the problems are formulated.

In **Chapter 2** is described the developed general frame of the investigations, a new approach of modeling and predicting of 1d time series in the financial sector by using formal data of Bulgarian National Bank for the short-time  USD deposits of Bulgarian citizens. By means of the applicants to be predictors models using the ensemble method with ML CART Ensembles and Bagging (EBag) are build. EBag models are evaluated and build in two cases – with a prior data transformation in order to improve the distribution to the normal and without a data transformation. Concerning the CART Ensembles and Bagging modeling are build and analysed great number of models by a calibration of the learning hyperparameters of models.

In **Chapter 3** a new approach to model and short-time prediction of the dynamics of currency course EUR/USD as a function of 8 main macroeconomical indices is developed. The modeling is implemented following the general frame of the study. On the first stage the components of multidimensional time series by 1d ARIMA method, statistical and other tests are analyzed. On the second stage the results of three different ensemble methods with ML are applied and compared: CART-Ensembles and bagging (EBag), Arcing, and Random Forests (RF). Three ensemble methods EBag, Arcing and RF to model and predict the currency course one month ahead are applied. By each of ensemble methods are build and analysed great number of models. From among them are presented four chosen models by using of four groups predictors. The resulted models can be classified as very exact.

In **Chapter 4** are developed and studied hybrid methods. One-dimensional dynamical series containing month data for periodic USD deposits of Bulgarian citizen for 227 months. The modelled data are divided into two parts. The bigger parts of observations are used to build the models, while the last three values  serve as test and verification of the correctness of models to predict "new data". Firstly hybrid Arcing-ARIMA models with transformed data separately for 2 extracts of data are build – an extract containing all the available data (A) and a reduced extract (B) including 70% of the initial data. After the data transformation are constructed ARIMA models for comparison. In order to eliminate the series correlation the model errors are modified additionally by using of 1d ARIMA model and are constructed hybrid Arcing-ARIMA models. Arcing- ARIMA hybrid models with untransformed data are developed. At last by using Random Forests are built models, that are compared with the untransformed data.

The main contributions can be generalized in four items:

1. A general frame of the investigations related to statistical modeling of 1d and multidimensional time series in the field of monetary and financial markets. The frame includes an approach for predictor identification and application of low-proficient intelligent methods by using ML to prediction and short-time prognostication.

2. Efficient predicting models of 1d time series for the deposits in foreign currency of Bulgarian citizens are built and analyzed. To this end for first time in this field the ensemble method CART Ensembles and Bagging (EBag) is applied and investigated.

3. High-effective predicting models of multidimensional time series about the currency course EUR/USD depending on macroeconomics with three methods - EBag, Arcing and Random Forests are built and analyzed.

4. An approach to hybrid Arcing-ARIMA data modeling about the deposits of Bulgarian citizens both with transformed and untransformed data is developed and applied. It is demonstrated that these results exceed the predicting capacities of the standard ARIMA and Random Forests methods.

## 5. Opinion of the author contributions

The author information correctly tells on the achievements and accents of the dissertation thesis. In my opinion, the achievements are joint and I evaluate the role of the scientific supervisors. However, the applicant takes leading role. The achievements belong to the directions "Adding to existing knowledge" and "Applications in practice". The investigation of such kind of problems needs a bilateral relation between the theory and experiment – mutual complement and adding to knowledge. Undoubtedly the applicant is expert in both.

## 6. Critical remarks and recommendations. Literary knowledge

My impression from the dissertation thesis is excellent. Written in Bulgarian, the statement is concise and clear. I have not any remarks and criticisms. The literary knowledge is based on contemporary sources. Also, there is an excellent symbiosis and complement of practical experience and theoretical base.

## 7. Publications

The results are presented and verified on few conferences and seminars in BG and abroad. They are published in *AIP Conference Proceedings, Cybernetics &Information Technologies, Proceedings of ICoMS, Sciences of Europe*. All of them are co-authored by the scientific supervisors. *AIP CP has SJR, Cybernetics &Information Technologies* possesses IF = 1.2 and belongs to Q3, *Proceedings of ICoMS* is visible in SCOPUS, *Sciences of Europe* – in Index *C*opernicus.

More details one can find in the table below

| | Abroad - 4 numbers |
|---|---|
| Papers – 4 numbers | *AIP Conference Proceedings, Cybernetics &Information Technologies, Proceedings of ICoM , Sciences of Europe* |
| Conference reports and presentations – 5 | *AMiTaNS'21, ICoM'23, 3 seminars in Dept of Math. Analysis, PU* |

The applicant took part in 2 scientific projects – one, financed by PU, and one more – financed by the National Scientific Foundation by the Ministry of Education and Science. The presented information for the implementation of minimal requirements for gaining of ESD Philosophy Doctor are executed and the index G is exceeded triply.

Having in mind the said above and according with the Regulations in the P. Hilendarski University of Plovdiv I can conclude that the applicant covers the requirements to hold the educational and scientific degree Philosophy Doctor in the professional subject 4.5 Mathematics. Also, he covers and exceeds the minimal national regulations of LDASRB and has not any plagiarism in his works.

### 8. Importance and contribution to the practice

As I mentioned above there is an excellent symbiosis and complement of practical skills and theoretical schooling. The results obtained in the dissertation contribute to the bank activities. General frame of investigations of statistical modeling of 1d and multidimensional time series concerning the monetary and financial markets with machine learning to predict and short-time forecast is created. The successful realization and building presume the solving of new interesting problems. I totally support and encourage the intention of the applicant to prepare a monograph.

### 9. Opinion of the abstract of the dissertation

The abstract corresponds to the matter of the dissertation completely.

### 10. Personal impression

I do not know personally Ivaylo Boyoukliev.

## Conclusion

Gaining an impression for the doctoral thesis (dissertation) of the applicant and having in mind the legal rules and criteria (LDASRB, and specific requirements in PU) I **rate positively** the dissertation. On the strength of virtue of the law **I propose Ivaylo Vladimirov Boyoukliev** for scientific and educational degree Philosophy Doctor (PhD) in Field of Higher Education: 4. Natural Sciences, Mathematics and Informatics, Professional Direction 4.5 Mathematics, Doctoral Program: Mathematical Modeling and Application of Mathematics.

Opponent

Prof. Michail Todorov

Section of Differential Equations and Mathematical Physics, Institute of Mathematics and Informatics – BAS

Sofia, March 19th 2024