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Review on doctoral dissertation*

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The title of the Ph.D. dissertation:	Neural Network Structure Identification in Measurement of Expected Inflation
Committee in charge:	Zdravka Aljinović (chair); Josip Arnerić (mentor); Mario Pečarić
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The doctoral dissertation, successfully defended by Tea Poklepović, consists of 6 chapters (237 pages), a list of 227 references (18 pages), a list of abbreviations and notations (4 pages), a list of 25 pictures and 60 tables (5 pages), an appendix (2 pages) and CV (4 pages). The acknowledgements and the abstracts in Croatian and English are given before the table of contents in the first few pages. The dissertation is written in Croatian.

The main issue of the dissertation is of a methodological character, referring to different approaches and econometric models in the analysis of time series that have so far been most frequently used in the measurement and forecasting of the expected inflation. In this dissertation, by systematizing the advantages and disadvantages of traditional econometric models, including different parametric and nonparametric models, and linear and nonlinear models, the author comes to the conclusion of the necessity of application of a semi-parametric approach for measurement and forecasting of the expected inflation, i.e. neural networks.

Neural networks are appropriate to use in time series analysis under conditions of the unfulfilled assumptions, i.e. under conditions of non-normality and nonlinearity. The purpose of the paper was to investigate the disadvantaged of neural networks and to propose ways to address these shortcomings with the aim of identifying the neural network structure that will best adapt to inflation expectations. Namely, from the econometric perspective, the most commonly used models in the estimation of expected inflation are linear ARIMA, VAR and VEC models, while nonlinear time series models are rarely taken into account. Linear models are limited in the presence of nonlinearity, which causes errors in predictions and wrong conclusions that can be derived from such models. Moreover, nonlinear models require that a nonlinear functional form is defined in advance. For this reason, and because of the

aforementioned disadvantages of linear and nonlinear models, neural networks are proposed for modelling and forecasting the expected inflation. In addition to relying on historical inflation data and econometric models, central banks use inflation expectations measures for inflation analysis and forecasting. They can be market-based or survey-based measures. Based on the limitations of these measures, the necessity for the use of neural networks in modelling and forecasting inflation expectations becomes apparent. Therefore, using an optimal neural network, a time series of inflation expectations are generated. The inflation expectations are then used as an input in the reformulated Taylor rule to test the inflation expectations obtained from the neural network model with expectations obtained from survey of professional forecasters in examining the interest rate convergence to its long-term trend value.

This research is based on a theoretical model that includes characteristics of demand-pull and cost-push inflation, i.e. it uses labour market variable, financial variable, external factor and lagged inflation. The research is conducted at the aggregate level of euro area countries in the period from January 1999 to January 2017. For each variable used in the empirical research, descriptive statistics is calculated. Moreover, normality, stationarity, independence and linearity is tested. The results of the tests indicate that the underlying assumptions of traditionally used econometric models are disrupted, leading to the necessity of the use of neural networks. Based on the estimated 90 feedforward and 450 Jordan neural networks, which differ in variable parameters (number of iterations, learning rate, initial weight value intervals, number of hidden neurons, weight value of the context unit), the model adequacy indicators for each neural network (Mean Squared Error - MSE and Akaike Information Criterion – AIC) are calculated for two periods: "in-the-sample" and "out-of-sample". Simultaneously ranking of the neural networks on the "in-the-sample" and "out-of-sample" subsamples either according to MSE or AIC does not lead to the matching of rankings and the selection of a suitable neural network because the "best" neural network in the "in-the-sample", based on MSE and/or AIC criteria, often has high "out-of-sample" values of both indicators, and vice versa.

Therefore, in order to achieve the best compromise solution, a PROMETHEE method is used to select a suitable neural network. By comparing the "best" feedforward neural network – FNN (4,5,1) and the "best" Jordan neural network – JNN (4,3,1), it is concluded that under approximately equal conditions less neurons in the hidden layer of Jordan neural network (3) is required than in feedforward neural network (5), confirming that Jordan neural network is parsimonious compared to feedforward neural network, without the existence of the overfitting problem. Thus, the first auxiliary hypothesis is proved.

Moreover, Diebold-Mariano (DM) test assumes the equality in predictive performances of two models. Using DM test, the second auxiliary hypothesis of the

research is confirmed, i.e. the selected Jordan neural network has a better predictive ability than the feedforward neural network. Finally, interest rate convergence is analysed, by incorporating inflation expectations estimated by Jordan neural network into the reformulated Taylor rule. Based on the results obtained, it is not possible to confirm the functioning of the Taylor rule at euro zone level in the observed period. Nevertheless, the convergence of interest rates can be confirmed, especially in the period from 1999 to 2009. The results are robust on both the use of various interest rates, including the EURIBOR and the ECB refinancing rate, and the use of the expected inflation obtained through a survey of professional forecasters in the reformulated Taylor rule. Therefore, the estimated value of output from the appropriate Jordan neural network can be used as inflation expectations in the modified Taylor rule with the aim of examining the euro zone interest rate convergence, particularly as a complementary method in terms of missing data and expressed shortcomings in other inflation expectations measures. This confirms the main hypothesis.

Through its content and structure, the dissertation is a peculiar, original and useful scientific work and as such it represents a significant and high quality contribution to domestic and wider economic science. In this dissertation, the author has thoroughly and methodically studied and critically weighted the scientific achievements in the field of measurement and forecasting of the expected inflation as well as in the domain of identification of the structure of the neural networks and thus gave its undisputable contribution to this problem. So far, neither in domestic nor foreign scientific and professional literature has the topic of this dissertation been the subject of research. The issues that are explored from the aspect of neural networks are extremely important. In addition, the empirical results of the application of the improved methodological approach in measurement and prediction of the expected inflation contribute to the development of scientific thinking in this area.

By solving the overfitting problem in the model and the divergence of the learning algorithm, methodological contribution to the development of neural networks is realized. This dissertation explains how neural networks can be improved from an econometric perspective and it encourages other researchers to apply them in time series analysis, especially under the conditions of the unfulfilled assumptions, i.e. in terms of nonlinearity and non-normality. The scientific contributions of this dissertation are primarily aimed at dissemination of existing knowledge about neural networks and on improving the methodology for measurement of the expected inflation using semi-parametric approach. Moreover, this paper has a number of practical applications that economic and monetary policy holders have the most benefit from. Namely, the author explains in detail the use of neural networks as a semi-parametric approach in the analysis of time series under the conditions of the unfulfilled assumptions. This dissertation proposes a way to solve

these problems, and in the context of the application of neural networks provides a methodological contribution to the measurement and forecasting of the expected inflation.

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