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„Innowacyjna Gospodarka Otwarta”

Abstract of the doctoral thesis

„The neural-fuzzy method in predicting the direction of changes in selected exchange rates.”

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Motivation and aim of the thesis

The motivation for writing this thesis is the problem of finding an optimal method of forecasting price changes in the financial markets. Classically, econometric methods, such as linear ARMA models, are used for this purpose. Recently, neural networks [Alakhras, 2005, Strader et al., 2020] and hybrid neural networks [Hao, Gao, 2020] (which are a synthesis of neural networks with another method, for example econometric) have become popular [Zhang, Wan, 2007, Henrique et al., 2019].

The purpose of making predictions is to try to achieve an above-average return on investment. In order to increase such profit and at the same time reduce risk, investors use derivatives. They are both a tool for speculation as well as for hedging investments. One of the most commonly used derivative instruments are options, with the use of which investors can build various strategies depending on whether they expect the price of the base instrument to increase, decrease or stabilize in the future. Such base instruments used in options may be shares, stock indices, and foreign exchange rates.

Exchange rates and their fluctuations have a key role in the economy in times of globalization [Schrimpf, Sushko, 2020]. They have a real and significant impact on the current situation of a country's economy. The use of exchange rate derivatives by traders provides an opportunity not only to make additional profits, but also to hedge against unfavorable changes in exchange rates.

To conclude, the purpose of this thesis is to propose the author's neural-fuzzy approach to forecasting the direction of price changes on the example of selected exchange rates and to assess its usefulness in investing using derivatives.

The structure of the PhD thesis

The thesis is divided into five chapters. The first three provide a substantive introduction to the areas that form the basis of this study, while the last two chapters present the results of empirical research.

The first chapter introduces issues related to the FOREX market and investment opportunities. The chapter presents the beginnings of the FOREX market, its structure and mode of operation. Next, the concept and characteristics of derivatives are presented, together with an indication of investment (or hedging) opportunities resulting from the use of various types of derivatives and option strategies built on their basis. Chapter one concludes by

presenting methods for valuing derivatives. Therefore, the first chapter presents the investment methods used in the empirical study.

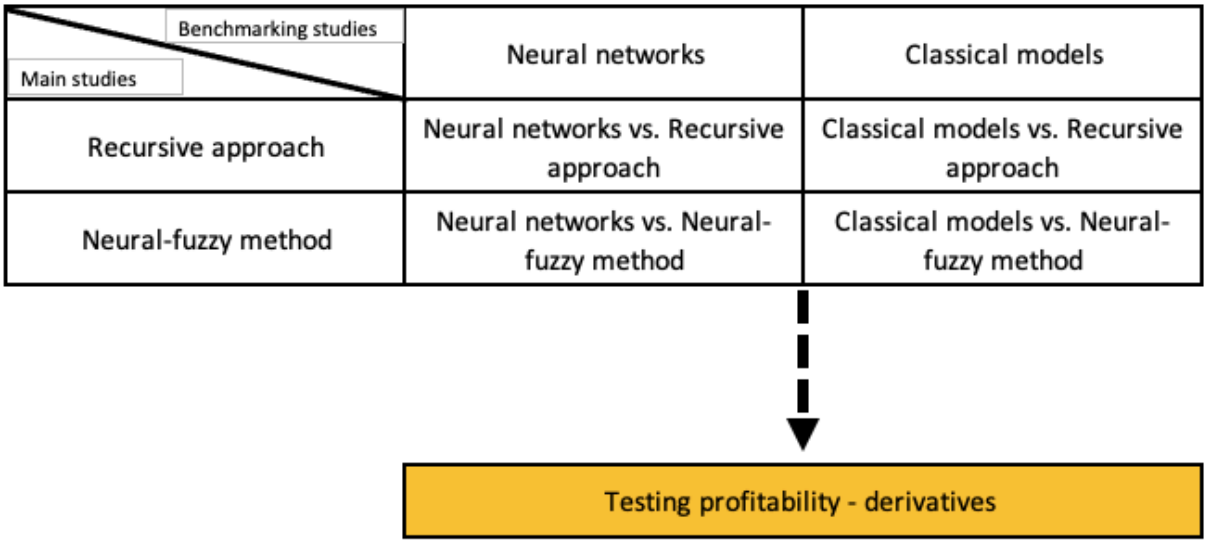
The second chapter describes the methods used in the empirical study to forecast the direction of price changes, which then become the basis for making investments. The introduction to this chapter is a presentation of the classical statistical models, that is, naive forecasting and the ARMA method. These methods will provide a benchmark for the accuracy of forecasting the direction of price changes with the methods used later in this work. The second part of the chapter focuses on neural networks. I describe different types of neural networks and present a literature review on networks used in forecasting. This review forms the ground for selecting the types of neural networks used in empirical studies. The final element of this chapter is a description of selected neural networks used in empirical studies.

The third chapter describes fuzzy sets and focuses on the necessary elements of this concept that will be useful in the method used in the following chapters. This subsection will also present the different forms of membership functions and how to create them.

Chapters four and five present the results of the study. Chapter four shows the concept of the presented method and compares the results of the accuracy of the direction of price changes with classical benchmarks, the method of following the majority of networks and the method of recursive selection of networks that best predict the direction of price changes. The fifth chapter focuses on the possibility of generating profits from the investments made, consistent with the forecasts obtained in the fourth chapter.

The concept of the study and research steps

The research structure can be represented by a matrix including all the research steps carried out. As the main research, I include the recursive approach and the neural-fuzzy method. The comparative methods include neural models and classical models, which are the benchmarks for all studies. The internal matrix, contains comparative analyses of the results obtained in each step of the study. Eventually, I examine the profitability of investment in derivatives, using forecasts obtained from all the methods.



The empirical study can be divided into the following stages:

Stage 1 - making predictions about the direction of exchange rates using three types of neural networks: ELM, MLP, and LSTM. For each of the neural networks, several different hyper-parameters were used (number of hidden layers and number of delays used in a given network). Forecasts using neural networks are made using data with an interval of one day, and the forecast horizon ranges from 1 to 10 days. The final result of this stage is a comparison and evaluation of the forecast quality - this comparison is made on the basis of different network hyper-parameters, network types, and forecast horizons.

Stage 2 - construction of forecasts using a recursive approach and selecting only the best forecasting networks. This study provides an introduction to the method used in Stage 3. This stage aims to determine whether it is possible to improve the accuracy of forecasts by using an approach that eliminates networks with certain hyper-parameters depending on the forecast currency and forecast horizon.

Stage 3 - is the main stage of research in this dissertation. In this stage that the original fuzzy neural method is constructed. Using the neural-fuzzy approach, forecasts are made. This approach is an attempt to use the concept of fuzzy sets to make a single forecast using all forecasts made by three different types of neural networks and different hyper-parameters (there are 140 of them).

Stage 4 - presented in the last chapter, involves using the forecasts from the previous stages to invest in derivatives.

The empirical data used

In the empirical study, I analyze three different currency pairs. The reference currency is the euro (EUR), while the quoted currencies are the Swiss franc (CHF), the British pound (GBP) and the US dollar (USD). The time span of the study is 1.01.2014-31.12.2019 and the data are quoted at a daily frequency, resulting in a total of 1440 observations per currency pair. The choice of a six-year study period serves to indicate a method that is resilient, effectively forecasting across different states in the financial markets. The period of analysis chosen in this way ensures that the periods studied include periods of increase, decrease and those featuring relative stability. In the study using derivatives, the dataset was extended by one year due to the need to determine the volatility based on historical data necessary in the Black-Scholes model.

Research questions

The aim of the thesis is to construct an author's neural-fuzzy approach for generating above-average returns on investments in derivatives.

The thesis of the dissertation is: fuzzy forecasts of the direction of changes in the currency exchange rate from the author's neural-fuzzy approach make it possible to generate higher returns on investments in option strategies for growth, decline and stabilization than the use of neural network forecasts.

The research questions in the thesis are directly assigned to the different stages.

Stage 1:

The questions in this stage relate directly to the quality of predictions made using different types and hyper-parameters of neural networks and are as follows:

1.1. Does the accuracy of forecasting the direction of exchange rate changes depend on the forecast horizon?

1.2. Does the accuracy of forecasting the direction of exchange rate changes depend on the hyper-parameters of neural networks?

1.3. Does the accuracy of forecasting the direction of changes depend on the type of network?

1.4. Is the accuracy of forecasting the direction of change using neural networks higher than econometric models?

Stage 2:

This stage attempts to answer the question of whether the recursive method will allow the selection of hyper-parameters and neural network types characterized by a higher level of

accuracy for a given currency and forecast horizon. The recursive method consists in making forecasts with all 140 networks with different hyper-parameters, selected for the study in stage 1, during the test period, and then making forecasts using only the 20 networks with specific hyper-parameters that proved to be the best during the test period. The research questions assigned to this stage are:

2.1. Does the recursive method obtain higher forecast accuracy than the forecast accuracy obtained with the naive forecast or the ARMA model?

2.2. Does the recursive method obtain more accurate forecasts than average forecasts for individual networks?

Stage 3:

Stage three is crucial for this thesis as it presents the main method used in this thesis. The research questions concern the differences between the results obtained by using different types of membership functions in the neural-fuzzy approach and the comparison of this method to the methods of the previous stages:

3.1. Does the type of membership function affect the accuracy of forecasts in the neural-fuzzy approach?

3.2. Does forecasting using the neural-fuzzy approach show higher performance than forecasting based on neural networks only?

3.3. Does the neural-fuzzy approach have better forecasting accuracy than forecasting based on majority within the network and naive and ARMA forecasting?

3.4. Does combining a recursive approach with a neural-fuzzy approach improve forecast accuracy?

Stage 4:

The research questions in stage four explore issues related to the possibility of generating profits by investing in derivatives based on indications of price direction changes obtained in stages 1-3:

4.1. Does the use of fuzzy forecasts of price directional changes allow for higher returns on investment in contracts and options than the use of indications obtained from neuron network forecasts and the recursive method?

4.2. Does the use of fuzzy forecasts in the stabilization option strategy allow for limiting potential losses or generating higher profits than using only the upside or downside game?

Main conclusions

The answers to the research questions are summarized in a table together with the answers.

Question ID	Research question	The answer
1.1.	Does the accuracy of forecasting the direction of exchange rate changes depend on the forecast horizon?	The answer to this question depends on the type of neural network. LSTM achieved higher accuracy for forecasts with a longer horizon, while for the other networks no clear dependencies exist. For example, for the ELM network forecasting the CHF/EUR currency pair, the accuracy decreases as the horizon increases, and for the same network forecasting the GBP/EUR pair, the accuracy increases as the forecast horizon increases.
1.2.	Does the accuracy of forecasting the direction of exchange rate changes depend on the hyper-parameters of neural networks?	The conclusions depend on the type of network. For LSTM and MLP networks, the prediction accuracy depends on the network parameters. The LSTM network obtained the highest accuracy in settings with two hidden nodes. The MLP network in many cases obtained more accurate forecasts when the number of delays in the network was equal to the length of the forecast horizon. For the ELM network, no clear patterns were found.
1.3.	Does the accuracy of forecasting the direction of changes depend on the type of network?	The LSTM network showed the highest accuracy in forecasting directions of change, especially for settings with two hidden nodes. The conclusion of research question 1.3. is a result that is consistent with the result expected from the selection of neural network

		types for the study and is due to the specific design of the LSTM network showing better accuracy in time series forecasting.
1.4.	Is the accuracy of forecasting the direction of change using neural networks higher than econometric models?	The results of the study confirm that for most of the studied series neural networks obtain higher accuracy than classical models, but this depends on the studied series. **Neural networks vs ARMA model:** For the USD/EUR currency pair, neural networks obtained better forecast accuracy than ARMA models in all cases. For the GBP/EUR pair, neural networks obtained higher accuracy than ARMA in most cases (except for ELM and MLP learning on price levels). For the CHF/EUR pair, forecasts from the ARMA model had higher accuracy than those from the MLP and ELM networks, while the LSTM learning on price levels achieved higher accuracy than ARMA **Neural networks vs naïve forecasting:** For the USD/EUR currency pair, all network types performed better than naive forecasting. For the GBP/EUR currency pair, ELM and MLP networks learning on price levels achieved lower accuracy than naive forecasting. For the CHF/EUR currency pair, only ELM and LSTM learning on price levels achieved higher accuracy than naive forecasting.
2.1.	Does the recursive method obtain higher forecast accuracy than the forecast accuracy obtained with	The naive forecast was worse than the recursive method. ARMA was better only for the CHF/EUR currency pair and forecast horizons of 1,2,3,6 and 7 days.

	the naive forecast or the ARMA model?	In the vast majority of cases, the recursive method improves forecasting results relative to neural network forecasting.
2.2.	Does the recursive method obtain more accurate forecasts than average forecasts for individual networks?	In the vast majority of cases for all neural networks and all forecast horizons, the neural-fuzzy method obtained higher accuracy than the average accuracy results for individual network types.
3.1.	Does the type of membership function affect the accuracy of forecasts in the neural-fuzzy approach?	The selection of an appropriate membership function is more important for the accuracy of the forecasts than modifying the selection of the set kernel. It was not possible to clearly identify the best membership function for all three currency pairs. For the currency pair CHF/EUR the triangular membership function obtained the highest accuracy, while for GBP/EUR and USD/EUR - the trapezoidal membership function
3.2.	Does forecasting using the neural-fuzzy approach show higher performance than forecasting based on neural networks only?	Yes, a significant advantage was shown between forecasting by the neural-fuzzy method and based on neural networks only. The average accuracy of the network was higher than the neural-fuzzy method only in 13 out of 90 cases and in as many as 6 of them the MLP network forecasts for CHF/EUR and forecast horizons of 1-3 and 8-10 days and 5 times for the LSTM network forecast for USD/EUR and forecasts for 1,2,5,7 and 8 than the neural-fuzzy method built on the network forecasts. These results are due to poor accuracy for the MLP network forecasting CHF/EUR and very good

		accuracy for the LSTM network forecasting USD/EUR.
3.3.	Does the neural-fuzzy approach have better forecasting accuracy than forecasting based on majority within the network and naive and ARMA forecasting?	Comparing the accuracy of the neural-fuzzy method with the majority method for 80% of cases higher accuracy was obtained from the neural-fuzzy method (Table 39) and in 69% compared to the naive forecast and ARMA (Table 36)
3.4.	Does combining a recursive approach with a neural-fuzzy approach improve forecast accuracy?	For most of the currency pairs and forecast horizons studied, the method combining the recursive and neural-fuzzy methods achieved higher accuracy than the methods used separately.
4.1.	Does the use of fuzzy forecasts of price directional changes allow for higher returns on investment in contracts and options than the use of indications obtained from neuron network forecasts and the recursive method?	Very low rates of return were obtained when investing in contracts, so the differences between the methods can be considered statistically insignificant. Using the indications of the neural-fuzzy method to invest in options and options with an option strategy in most cases yielded higher returns than following the indications of single neural networks and the recursive method.
4.2.	Does the use of fuzzy forecasts in the stabilization option strategy allow for limiting potential losses or generating higher profits than using only the upside or downside game?	Conclusions depend on the choice of option strategy. It has been shown that with high forecast accuracy, the use of a short-stack strategy and a stabilisation play increases profits, while with low forecast accuracy it can generate higher losses. This is due to the possibility of incurring unlimited losses when investing in the short rack strategy. In contrast, using a stabilisation option strategy based on fuzzy forecasts allows for higher profits than when investing only in call

		and put options. The case of limiting potential losses does not exist for the fuzzy neural method as it achieves high prediction accuracy, and no high losses are recorded.

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