Real-time Intraday Option Pricing With Advanced Neurosimulation

Masterarbeit

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1 Introduction

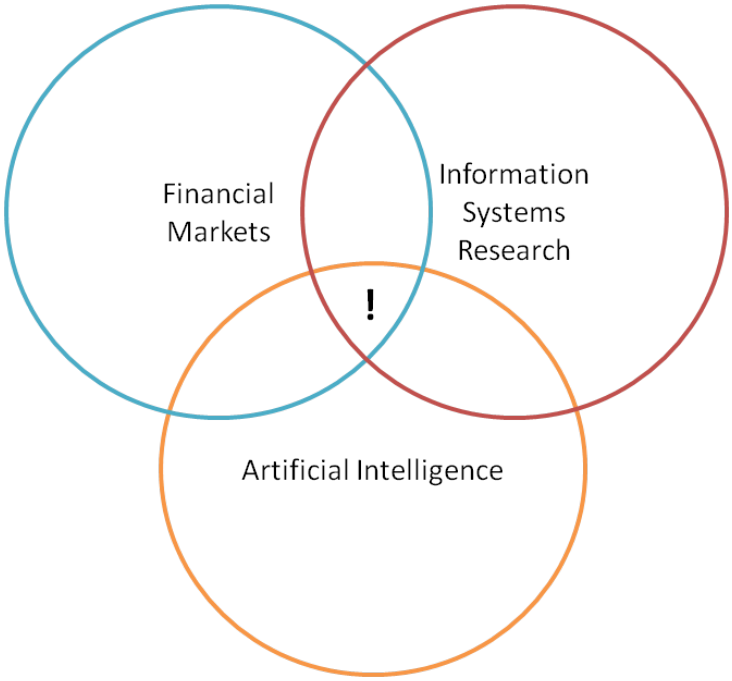
Financial derivatives have become a widely used instrument in the world's financial markets since the inception of the Black-Scholes model in 1973, which is considered the "holy grail" of financial research. This option pricing model has a number of restrictive and unrealistic assumptions, which can lead to an inaccurate valuation of derivatives.[1] Although there exists an increasing amount of parametric models, that move in the footsteps of Black, Scholes and Merton, no model succeeds to solve the underlying problems.[2]

The global financial crisis of 2007 and the Euro crisis of 2009 show, that losses are more common than the model by Black and Scholes insinuates. One of the assumptions of the model is the log-normal distribution of the returns of the underlying. This can not be upheld under real world conditions. Other assumption are also not realistic. Nevertheless, the Black-Scholes formula and its adjustments remain on the most widely-used option pricing models. The foreign exchange money market has an average daily turnover of $ 4 trillion and a variety of actors, which are actively trading with a plethora of instruments, including derivatives. The scale and scope of this global market that operates 24 hours on nearly every day of the week, and the complexity of relationships in the interbanking market make it an interesting field for the application of option pricing with neural networks. Nowadays, it is not important if a trader operates in London, Chicago, Tokyo, Singapore or Sidney. Transactions can be done with a rapid frequency and a huge volume. Furthermore, this market is considered to have near perfect conditions, with near to zero arbitrage opportunities. The risk in the international efforts of institutions has to be actively managed in order to be competitive in an ever increasingly difficult market.[3] Moreover, the market has a variety of different institutions, from central banks to hedge funds and multi-national corporations. This fact highlights the complexity of relations. As such, the problem of accurately pricing a non-linear derivative is of a significant importance. All parties on the foreign exchange derivatives market have the need to accurately price the option premium. Having a superior model on even the smallest scale could prove to be a big comparative advantage in this harsh environment.

For this problem artificial neural networks may be an interesting approach to non-linear regression, based on biological neural networks. This approach has proven itself useful in financial applications, such as interest rate forecasting, credit rating and option pricing. The main strength of neural networks is the greater flexibility, because neurosi-

[1] cf. Lajbcygier (2004), p. 465.
[2] cf. Rubinstein (1986), p. 478.
[3] cf. Brown (2001), p. 417-418.

Figure 1: The context of financial neural network research.



Source: Own illustration.

mulation is not bound to any assumption about the underlying price process. Neural networks can approximate multivariate and non-linear relationships. This makes them attractive for the valuation of options.[4]

This study has the main goal to develop an option pricing model with the use of neural networks. The contribution can be explained as follows: The foreign exchange OTC market is a fast-moving market with a substantial volume and likewise this thesis will develop an option pricing model, which can be used to price options with readily available intraday data in real-time. Such a model would prove invaluable for any financial institution with exposure in the FX markets, if the model could outperform existing parametric and market-driven alternatives. The characteristics of the global money market need to be considered in order to successfully build such an artifact. Furthermore, the resulting model should be able to provide the framework for a concept of a decision support system, without relying on many input factors. With the goal of an easy implementation in mind, the model will be designed in a way that maximizes the applicability to financial institutions.

Figure one highlights the relationship between the three main fields of research that will be bridged in this thesis, with the help of a simple Venn diagram. Information systems research is a research field in itself, which joins a number of other disciplines, such as

[4] cf. Chen and Sutcliffe (2011), p. 1.

mathematics, computer science, and business and organization, but also in a broader sense psychology. Artificial could be considered a part of information systems research but is considered its own field for the time being. Financial markets are the main fields of application for the findings of this thesis. Stock markets have different characteristics from other markets. In this thesis, the foreign exchange market will be the object of study. The third field of research highlighted in figure one, is at the same time a topic of controversy. Artificial intelligence aims to produce human-like machines, which are capable of solving complex problems. Neurosimulation through the use of artificial neural networks is one example of artificial intelligence. The intersection of the three shapes in figure one is the topic at hand, which bridges these three fields.[5]

The following subpart will introduce the structure of this thesis to the reader. Then, the underlying research methodology known as "design science" will be explained.

[5] cf. Hesse (1999), p. 126-127.

1.1 Structure of the Thesis

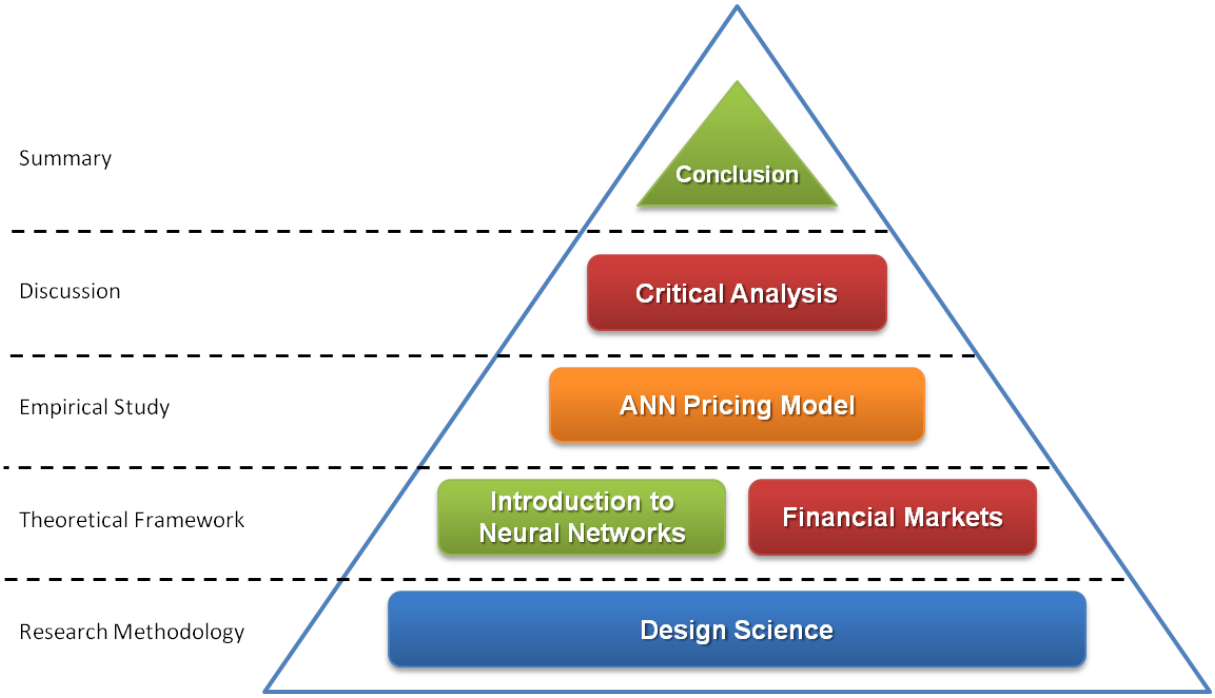
This part will introduce the reader to the overarching structure of this thesis. Figure one shows the structure in the form of a pyramid, with five layers representing the five basic segments of the thesis. This shape indicates, that the different parts build upon one another to make up the whole thesis. In particular the theoretical framework together with the next part ought to be considered as the foundation of the empirical study. The introduction will be concluded by the following part. The topic of design science is an necessary introduction to the methodology behind the research conducted for this thesis. Part 1.2 will present a set of guidelines for the development of artifacts to be used in the design of information systems. This is very much applicable to the problem at hand, because the model should be implementable in such a system.

Chapter two is the introduction to neural networks. First basic definitions of artificial intelligence and neurosimulation will be explained. Part 2.1 will introduce the neuron, which makes up the different layers of the feedforward neural network. It will explain the underlying mathematics in a simple way. Neural networks learn through the training process. What is this process and how does it work? The following part is called "Advanced Neurosimulation with FAUN" and will deal with the FAUN software suite. Part 2.3 will highlight fields of application of neural networks in general. Some publications will be briefly introduced to focus on the application of neurosimulation and the FAUN software suite.

The **third chapter** will present the vast theoretical framework of financial markets. The goal for this chapter is to provide an understandable overview of the relationships of finance, for an outside reader. The first part presents the definition of risk and risk management, which are the main drivers for financial institutions. Moreover, the motivation behind the use of derivatives, is the main topic of this part. Chapter 3.2 will provide an extensive introduction to derivative instruments, such as forward, futures and options. The basic process of a conditional and unconditional forward will be explained. The formula developed by Black and Scholes will be briefly introduced in this part as well. Part 3.3 will introduce the foreign exchange market with its characteristics.

Chapter four will present the neural network model of the empirical study conducted for this master thesis. The first part of that chapter will give an introduction to the design methodology behind a neural network model according to Kaastra and Boyd. The model will be explained extensively in chapter 4.2 with all the steps taken to ensure the best outcome. Figure one shows a discussion on the fourth step of the pyramid, which is **Chapter five** and is the critical analysis of the findings of the empirical study.

Figure 2: Basic overview of this thesis.



Source: Own illustration.

The results will be reviews and compare to those of other studies. In particular a main topic will be possible problems in the steps followed through to come to the conclusions of the study.

Chapter six is the conclusion of this thesis, which will highlight all findings and problems related to this thesis and present the single conclusion and outlook of this thesis to the reader. A significant number of figures and tables will highlight the different findings of this work. The following chapter will deal with the seven guidelines for design science.

1.2 Design Science

The overarching methodology of this paper will be introduced in this part. The goal of the thesis is to develop an option price model with neurosimulation, that could be part of a decision support system. This chapter will explain and analyze the design science of this thesis. Design science is a paradigm for problem solving, to develop an information system according to a specific set of guidelines. In other words: Design science can be a starting point of how to conduct research, to measure performance of resulting models and to present the final research. The goal of design science is the development of an artifact, by using methods and tools available to the researcher.[6]

Table 1: Guidelines for design science

Guideline 1:	Design as an Artifact
Guideline 2:	Problem Relevance
Guideline 3:	Design Evaluation
Guideline 4:	Research Contributions
Guideline 5:	Research Rigor
Guideline 6:	Design as a Search Process
Guideline 7:	Communication of Research

Source: Hevner et al. (2004), p. 83.

The first guideline is **"Design as an Artifact"**, which means that research has to develop a model, a method or any other kind of construct. This paper can be described as part of information system research, therefore the results of this paper should be useful for the development of an information system. First, the problem at hand has to be understood and described effectively. The title of the thesis is: "real-time intraday option pricing with advanced neurosimulation". According to this, the problem can be described as follows: The thesis has to develop a construct or model, which enables the pricing of options. The words real-time and intraday mean, that the options have to be priced with a short time frame in mind. This artifact uses intraday data as opposed to end of day values. Furthermore, the result has to be obtained through neurosimulation, which will be described in the following parts.

The second guideline **"Problem Relevance"**, deals with the importance of this problem, which needs to be relevant. Is the topic important and significant? Research needs to address the advantages of such an artifact. The problem posed in this thesis can be described as follows: The difficulty in accurately estimating the premium of an option

[6] cf. for the chapter Hevner, March, Park, and Ram (2004).

has been described in a number of different publications. The current state is, that derivatives are priced using two different approaches. The first approach is embedded in theory. One can show, that models such as the Black-Scholes formula have assumptions, which are not realistic. Furthermore the calculated option price is not accurate. The second approach will be used in the following part. Neurosimulation uses market data to learn underlying connections of the financial markets. It is therefore based in reality. The problem is, that this data is not always readily available. Research publications overwhelmingly use end-of-day data, thus limiting the applicability of artificial neural networks on real-time option pricing. This study will present neurosimulation as a useful and innovative tool. **"Design Evaluation"** is the next guideline and describes, that the model has to be evaluated. This especially applies to neural networks, because they have to be benchmarked against the real world and other widely used models as well. After evaluating the results, feedback can be used to refine the previous approach.

"Research Contributions" is the fourth guideline and is intended to show, that the work has to have a specific contribution to information systems research, which need to be verifiable. The contribution of this thesis aims to be a focus on intraday derivatives trading. It is highly significant, because financial institutions have a high stake in part of business. Later parts will highlight the scope and scale of the market. The fifth guideline is **"Research Rigor"** and describes, how the methods of research need to be applied for the artifact to be successful. The researcher must to be rigorous in her or his work. This further emphasizes the need to evaluate one's results. **"Design as a Search Process"** is the sixth guideline and means that the resulting model or artifact, may not be clear from the start of the process. Information systems need to be redesigned in the process of development. This also applies to the development of any other model. The last guideline **"Communication of Research"** is the need to present results of the information system's research to the general public. More specific to audiences from business management and technology perspectives.

This part dealt with guidelines of research. Design science is the framework upon which this work was conducted. The seven guidelines may assist in the process of research. Information systems research has the goal of developing an artifact, construct, model or any kind of methodology for the development of an information system. This applies to the work at hand, because the model developed in the following chapters, could potentially be used in the development of a decision support system. The applicability will be discussed later. The following chapter will introduce the broad topic of neurosimulation and provide the necessary foundations for artificial neural networks.

6 Conclusion and Possible Future Developments

Financial institutions use the market for foreign exchange to manage the risk of their international efforts. One of the main instruments for the hedging of risks are financial derivatives. This thesis presents an alternative market-driven approach to the parametric model by Black and Scholes, which is based around restrictive and unrealistic assumptions. Artificial neural networks try to mimic the structure of the brain. Although the term artificial intelligence is often used to describe such systems, the ANN lacks most of the features, which are considered characteristics of intelligence. However, one characteristic which it does not lack is the learning feature, because neural networks are trained by backpropagation. The main tool used in this thesis is the FAUN neurosimulator. Through its use, it is possible to train three and four layered perceptrons for the approximation of various problems, such as financial applications in the foreign exchange market, which is the biggest OTC market in the world and operates all 24 hours of the day. The FX market, which operates under its current form with floating foreign exchange rates since 1973, is a market with an average daily turnover of $ 3.9 trillion. The big volume of trade in the FX market and the fact, that it is a global market that operates 24 / 7, makes it an interesting field for further research.

The main goal of the thesis was to develop an artificial neural network model, which uses intraday data to estimate the market price of options. This kind of network could then be used for the development of a decision support system. An EUR/USD future-option is used for the empirical study and the data on individual trades are captured and processed. A futures option in this case, is the right, but not the obligation, to buy the underlying future-position, on a specific date and to a specific future-rate. Out of the data, two datasets are created. The first contains all trades on the option and the underlying future rate. Only trades of the option with the corresponding future rates are contained in the second dataset. The two other input variables, besides the underlying future-rate are time to maturity, and the moneyness ratio. Bid and ask midpoint is used as the output factor for the neural network. Two basic three layered perceptrons are used in the process and the dataset is segmented into training, validation and testing sets. The best neural networks are exported and benchmarked against the widely-used Black model for the pricing of options on futures. The results of the model are benchmarked with measures of fit and indicate a good accuracy of the estimated option prices versus observed market price. In specific, the neural network with one inner neuron has a better accuracy for the entire dataset. The model with the best in-sample performance with the reduced dataset proved to be the neural network with two inner neurons. Then, out-of-sample tests are conducted using data, that is not available to the neural networks for training. In both cases, the formulas derived from the use of

neural networks still remain the models with the best generalization ability, while the benchmark model's measure of fit worsens. A second approach tries to combine neural networks with the parametric model by Black and Scholes to make a hybrid approach computing the deviations from the observed market prices. This part of the study is successful to show, how neural networks can improve upon the parametric models and correct possible biased prices. Both methods perform better than the benchmark model and show, that neural networks can successfully synthesize option prices with less data. The hybrid neural network approach has also one significant advantage in that it could possibly be used to compute option prices in areas, that are otherwise difficult to price with the use of neural networks. One financial implication, which is highlighted in this thesis, is the use of the neural network in a decision support system. A concept of this information system highlight the possibility of the collection and preparation of data from online broker's information systems, in order to train and validate neural networks via the FAUN neurosimulator, and then price options for market makers or for other corporations, which need to value options. Such a system could work in real-time, meaning a constant autonomous reevaluation and retraining of networks using more recent intraday data.

A critical analysis shows possible room for improvement. This study uses intraday data of approximately one week to train neural networks. One possible improvement could be the use of data of a longer captured period of time to better capture different maturities. Moreover, a broader range of moneyness ratios could improve upon the generalization ability of the model. The moneyness ratio in the dataset is only at the money or just out of the money. On the one hand, more input factors can be considered, if the Black-Scholes model is used as a template, i.e. volatility or risk-free interest rates. On the other hand, one goal of this study is to create a basic model with only a few variables. Furthermore, the mentioned variables tend to be difficult to estimate in the case of the volatility, and constant in the short-term in the case of interest-rates. Both inputs do not guarantee a better neural network performance. In conclusion, no abstract model can capture all the moving parts of reality. In particular, many fractions of the foreign exchange market and all the underlying relationships are not easy to comprehend. Every model will have some degree of misspecification. Nevertheless, neural networks are indeed an interesting alternative to the widely-used and biased Black-Scholes model and other parametric models in a broader sense. They can also be a tool to supplement the parametric models as shown by the hybrid neural network approach. Both neural network model and hybrid model have a better performance than the benchmark and use less variables to compute a, closer to market, option price.