Bachelor Degree Project

Artificial Intelligence Applications in Financial Markets Forecasting

- A Systematic Mapping

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Abstract

This bachelor thesis aims to give an overview of the last ten years research on financial market forecasting with Artificial Intelligence techniques. Reviews of this topic have been made earlier, but it can be hard to get a sense to what degree this type of research have been made and to what extent specific topics have been covered. To answer this and also what research type and how these topics have changed over time, a systematic mapping is performed with backward snowballing as literature search method. The results show that various hybrids and Artificial Neural Networks applied to the stock market are the most common combinations and most research is new attempts at trying to predict future market movements and values.

Keywords: Artificial Intelligence, AI, Financial Markets, Stock Market, FOREX, Artificial Neural Networks, Fuzzy Logic, Genetic Algorithms, Machine Learning, Computational Intelligence, Soft Computing, Systematic Map, Review, Finance

Contents

1 Introduction

This bachelor thesis aims to give a broad overview of the research that has been made on Artificial Intelligence (AI) applications for financial market forecasting. The primary motivation for this is self-experienced difficulties of getting an overview of this topic when reading about it. Many questions arise when reading an article about a self-evolving and self-improving program that predicts, for example, future oil prices. For instance, how does this work to begin with and why have humans not been replaced by this technology yet? How could people possibly compete with AI, which consistently makes more and more progress, expanding the boundary of which problems that were thought to be too hard for a computer to solve? This is not any of the research questions for this thesis, but it is the ideas that inspired this paper. Instead, in this thesis, the focus is on giving an overview as clear as possible about AI techniques that have been used for financial market forecasting without getting too technical and by doing so, maybe answer some of the thoughts which spawned this fascination, to begin with.

1.1 Background

This thesis aims to give an overview of the topic described in the section above. Since it is an overview which is intended to be provided, this paper will not delve deep into the underlying theory, neither on financial markets nor AI. The reason for this is because this is a field which has been extensively covered by more technically competent writers before so instead, a rather coarse-grained overview of this topic is intended to be given to the reader, not assuming that technical expertise in this field is present.

The rest of this section contains the general frame of ideas which this type of research commonly is performed within. This gives a sense of the mindset of people trying to solve similar problems. One idea which is present in almost all research that was found when creating this thesis was the *Efficient Market Hypothesis* (EMH) [1]. The Efficient Market Hypothesis is the idea that all relevant information on a financial asset always is incorporated into its price. The only thing that can change the price is new information which is unpredictable by its nature. A consequence, assuming EMH is true, is that it should be impossible to beat the market. There are different flavors on the theory on whether insider information is incorporated into the price or not but they are similar in the sense that at least public information is considered to be incorporated into the current price. Anomalies have been found but also evidence that supports the theory. One type of evidence as such was that it turned out that getting extreme returns from a US mutual fund is very close to what is expected from professional fund managers to what is the expected return if these managers would have no relevant knowledge at all. Even though this question is still active, many researchers believe that for most individuals, the market is practically efficient.

Two other ideas which are in some way present in all attempts for market forecasting are the ideas on Fundamental Analysis (FA) and Technical Analysis (TA) [2, 3]. The names are, at least partly, descriptive of their philosophies and tools for market forecasting. Fundamental analysts try to examine companies, analyzing its financial statements and evaluate it, investing if it seems to be wrongly priced, assuming it will be correctly valued in the future. Technical Analysis tries to look for patterns using charts and TA variables for patterns that could be exploited for profits. For instance, a technical analyst might aim at predicting investors emotional response from negative news on a specific stock, trying to make a profit from predictable patterns.

This thesis will not delve any deeper into any of the topics above, simply state that the ideas above were the most dominant in the problem of market forecasting with AI techniques for the papers included in this thesis.

1.1.1 Artificial Intelligence

Artificial Intelligence is a cross-disciplinary field which has seen media hype and progress in recent years [4]. Examples of the public perception of Artificial Intelligence vary from Elon Musk who, among other things, is one of the co-creator of the research company OpenAI which is partly motivated by safety concerns of creating a general AI [5]. Elon Musk has publicly voiced his opinion, expressing caution since he thinks it might be humanities greatest existential threat [6]. Other voices are more optimistic, one of those is the co-founder and CEO of Facebook, Mark Zuckerberg. In a live-feed on July 23, 2017, he expressed that public worries might be exaggerated and obstruct the development of technology [7].

One problem when dealing with AI is how it should be defined. To begin with, *intelligence* itself is not exactly defined [8], naturally making the definition of AI hard. One point that sometimes is brought up when researchers in the field discuss AI is the history of aviation. That is, by trial and error in combination with people trying to distill the theoretical laws governing aerodynamics, we eventually understood the laws of aerodynamics and were able to create flying machines of our own that were heavier than air [9, 10]. Instead

of starting with defining AI, maybe it is possible to create machines that can accomplish as complicated goals as humans, and in this process also be able to define what intelligence is. One project that is partially motivated by similar reasons is the Human Brain Project (HBP) [11]. It is a long project stretching over ten years (2013-2023) with the goal of trying to recreate, initially simpler brains (such as a mouse's) with supercomputers and eventually simulate a human brain to understand it better. On the HBP website [12], they write the following on their page for their goal of understanding cognition:

> "How does the brain create a representation of an object, like an apple, from multisensory information? This question is crucial since these representations are the basis for higher cognitive processes such as category formation, reasoning and language. One of our goals is to develop a "deep learning" neuronal network that learns to recognize objects and functions in a way similar to real neurobiological systems."

To summarize: the human brain is complicated, and we do not fully understand it. Although when speaking about AI, according to Stuart Russell and Peter Norvig, four main approaches have been attempted [10]. They can be described as four combinations of four components which are thinking or acting in a way that is human-like or rational. In this context rational means making the correct decision, given the information at the time. All these approaches have been used for attempts to achieve AI with various success. As described, one of the methods is to *think human-like*. This is sometimes desirable and sometimes not. For instance, one way humans might think which is not desirable when attempting to achieve AI is what is known as the *gambler's fallacy* [13]. The gambler's fallacy is a fallacy where a person persuade itself that independent events probability will be affected by previous events. One example of this is when an individual flips a coin. Imagine a scenario where a person flips a fair coin seven times and that the first six lands head, many people would say that the probability is higher that the next flip will land tails, but it is not. Even though the likelihood of getting seven heads in a row is $1/2^7 \approx 0.8\%$, when those six heads already have been flipped, the probability of the next flip landing tails is still $0.5 = 50\%$. That is an example of human thinking many wishes to avoid instead when creating AI.

In this thesis, a broad definition will be used for what is considered AI. Generally, techniques which might be classified such as machine learning, soft computing or computational intelligence (CI), will for the intents of this paper, be considered AI.

Although all the specialized techniques encountered when performing the systematic mapping were far too many to enumerate, below is a list of a few of the broader categories and a brief description of the ideas behind them and how they work.

Artificial Neural Networks

An Artificial Neural Network is a computational structure inspired by neural networks naturally occurring in living organisms [15, 16, 17]. The human brain has many biological neural networks which in themselves consist of connected units called neurons that send electrical impulses to each other, yielding various outputs depending on the input. An ANN tries to mimic this behavior. One property that has been observed in biological neural networks is that they are multi-purpose and seem to learn automatically from experience. Two main fields are dealing with ANNs which have different end goals; there is the AI or machine learning people who want to create practical computing models. The other main area of research is in neuroscience where the aim is to model neural networks as close to naturally occurring ones as possible. The motive for neuroscientists for this replication is to understand biological neural networks better. An ANN consists of a series of input nodes, where the nodes represent neurons (by a mathematical function), a hidden layer of nodes and an output layer or node. The success of ANNs have been significant, but they lack in one key feature, they work as black boxes. When a function has been approximated by an ANN, and a good solution has been solved for, it can be hard to understand how it was derived. A deep neural network is an ANN with more than one hidden layer.

Fuzzy Logic

Fuzzy logic is a form of logic where a truth value x is not binary but continuous in the interval $x \in [0, 1]$, [18, 19]. In many formal logic systems, a statement is either true or false and nothing else. However, it can often be hard for humans to represent their knowledge in such a way that every statement is either 100% true or 100% false. Fuzzy logic is an answer to vagueness naturally occurring for us which makes it easier to represent an expert's knowledge in a computer system. For instance, when asking people about the temperature, one person might answer that it is hot, another that it is very hot. It is not common for a human to answer with an exact number. Such a situation is an example where the relevant information better can be represented with fuzzy logic than two-valued logic.

Genetic Algorithms
Genetic Algorithms (GAs) are a type of algorithms belonging to a larger family of algorithms called Evolutionary Algorithms [15, 20]. The idea is to mimic nature in a simulated evolutionary process for coming up with a suitable solution from a predefined space of solutions. When it comes to Genetic Algorithms, the space of solutions often consists of variations of function parameters. The process is made up of a series of steps where the first step is to randomly create a start population (sometimes this population is consciously chosen in areas where an optimal solution is expected to be, called seeding). The instances in the population are then selected through a stochastic process where their fitness is evaluated and a new generation is generated through crossover and mutation. The process continues until a fixed set of generations have been reached or a particular fitness value has been achieved.

Genetic Programming
Genetic Programming (GP) is also a type of algorithm belonging to the superclass Evolutionary Algorithms [15, 21]. The difference from GAs where (usually) function parameters are optimized is that entire programs are evolved in Genetic Programming. Genetic Programming can, however, be implemented with Genetic Algorithms where the solution space consists of programs relevant to the problem.

1.1.2 Financial markets

A financial market is a market where financial instruments are traded [22, 23]. A financial instrument is a term for any tradable financial contract. For an item to be considered a financial instrument it has to have certain properties. The properties that are required are that the instrument in question has to be assignable, fungible and cost effective. Assignable means that the item has to be able to change owner. Fungible means that the item has to be replaceable by a similar item. For instance, a share in a company is fungible, every stock of the same type in the same company are equivalent. An example of something that in some cases is not fungible is art. An original painting by Vincent Van Gogh is worth a lot more than a copy, even if the difference is impossible to see. The last property is called cost effective, what this means is that if I buy an item X from a person A and resell it to person B, it cannot have a substantial loss in value. For instance, a kebab might cost three dollars buying it new. However, it might even be impossible to resell it even if you try to resell it instantly after purchasing it; therefore it is not cost effective.

When doing this thesis, various financial markets were targeted by researchers trying to forecast them. Below are the three most common (approximately 97 % of the articles included were focused on these markets).

Stock Market
The stock market is a market where shares in corporations are traded [22, 24]. A share is a financial contract representing ownership in a corporation. A corporation is a legal entity which is being run by a board that is elected by the shareholders of the corporation. A share can be traded on a primary or a secondary market. A primary market is a market where a share is being sold for the first time, all other trades are being done on a secondary market where a share change owner instead.

FOREX
FOREX is an abbreviation for the foreign exchange market where currencies are traded [22, 25]. Currencies are a type of financial assets issued by governments. A foreign exchange rate is expressed as the quota between two currencies. For instance, on the 4th of August 2017, the Norwegian VS Swedish exchange rate was expressed as SEK/NOK = 1.0250 according to Avanza Bank [26]. What this means is that every Norwegian crown is worth 1.0250 Swedish crowns. Since many countries do not want their currency regulated by other countries, the foreign exchange rate market is rather deregulated.

Commodities Market
A commodities market is a market where items such as fuel, electricity or metals are being traded [22, 27]. In the case of articles examined in this thesis, the vast majority included in this thesis where the financial market targeted is a commodity market, the property that in most cases is attempted to be forecasted is electricity or oil prices.

1.2 Related work

Reviews similar to this one have been made previously to this one. Below is a summary of similar work found and a brief description of them.

Cavalcante et al. [28] did a recent survey on computational intelligence applications on financial markets published in 2016. It covers research that has been made in the years 2009-2015. Apart from surveying the field and explaining the research that has been made they also propose a methodology for building an intelligent trading system. What differs that review from this is that they include several types of problems that have been attempted to solve regarding AI approaches on financial markets, not only forecasting as this systematic mapping is concentrated towards. They summarize the included work according to what the primary research goal is and to what market the technique was applied (exchange rates, stock indices, etc.). Furthermore, they also include what input variables that were used (technical analysis variables, fundamental analysis variables, etc.), what techniques that were used and whether or not it was a trading system. The result encountered when doing this thesis with regards to questions that could be classified as questions beginning with *what* is identical to this paper, but it is broader and more extensive regarding topics and techniques.

Atsalakis and Valavanis performed a survey called *Surveying stock market forecasting techniques – Part II: Soft computing methods*. It was published in 2009 [29] and was one of the most referenced papers of the articles included in this thesis. More than 28 articles that were included in this work used this document as a source. The survey focuses on stock markets mainly combined with ANNs and neuro-fuzzy approaches.

Bahrammirzaee performed a survey in 2010 on three types of AI techniques used for three categories of financial applications [30]. The three types of economic problems were credit evaluation, portfolio management and financial prediction and planning. The three types of AI techniques that were examined for these financial problems are ANNs, expert systems, and hybrid intelligent systems. Soni did a survey [31] with the descriptive title *Applications of ANNs in Stock Market Prediction: A Survey*, published in 2011 where applications of ANNs to the stock market were described. Li and Ma did a survey one year earlier, 2010, also with a descriptive title *Applications of Artificial Neural Networks in Financial Economics: A Survey* [32]. Two types of markets were examined, the stock market and FOREX. Apart from this, applications to bankruptcy and financial crisis prediction were also examined. Yu et al. surveyed applications of ANNs to foreign exchange rate forecasting in 2007 [33]. Apart from reviewing this topic, the question of whether foreign exchange rates are predictable at all was also looked into, while examining this problem from an ANN perspective.

Kumar and Rav performed a survey published in 2007 focused on statistical and soft computing methods for bankruptcy prediction [34]. Various methods and techniques were examined and described as to how they have been applied to the referred problem. The review had a large time horizon, including work in the years 1968-2005.

Rada did an experimental literature review published in 2008 on what the most common themes were for certain time periods where the focus is not only on getting an overview but also on testing a new survey method [35]. Krollner et al. performed a survey on machine learning techniques that had been applied to stock market movements [36]. Apart from which technique, the literature is also sorted according to the time horizon of predictions.

Aguilar-Rivera et al. published a survey in 2015 focusing on Genetic Algorithms and Darwinian approaches to financial applications [37]. Several problems are examined, and the paper includes topics such as cash management, credit scoring and abnormal noise and fraud detection. P. Yoo et al. surveyed the use of machine learning techniques for stock market prediction [38]. It was published in 2005, and one feature of this work is that event information which might affect the market is also examined.

Mochón et al. did a general survey of soft computing techniques in finance published in 2008 which covered several topics [39]. Li et al. performed a study published in 2016 on machine learning combined with quantitative trading [40].

This topic has previously been covered although there are some problems which have not been dealt with that will be covered by this thesis. One problem is to what extent this topic has been covered. Another issue is that several of these reviews are broad as to what types of financial applications that were studied or specific to certain AI techniques. Many of these articles were published in 2011 or earlier and research on this topic is ongoing so an update can be relevant. Several of these papers are technical, and this thesis does not have only tech professionals as target group but anybody interested in this topic.

1.3 Problem formulation

Market forecasting with AI techniques is something that has been extensively researched [40, 39, 38, 37, 36, 35, 34, 33, 32, 31, 29, 28]. The problem that is intended to be solved is to give a broad overview of the last ten years of the type of research being made in this field as well as what topics that have been explored. Furthermore, the intention is also to examine how these topics have changed with regards to time. The ambition is to give the most useful overview possible while not limiting the contents utility to academics

and tech professionals.

1.4 Motivation

Financial markets play a role in different countries economical development [28]. Being able to predict trends of financial markets may not only be considered something positive due to economic revenue and mitigating financial losses, but it might also be helpful in forecasting coming trends for a country or region.

Knowing what type of research that has been done and what topics that have been covered and to which extent will give future researchers and students an idea of where a gap might be filled or where to find an entry point for future research within the field of AI and financial market forecasting. Since much research has been made on this topic, one problem is to find a new angle. If it is hard getting an overview, this might a time-consuming problem.

A broad overview might also be of interest to people outside the discipline of computer science. For people belonging to this category, getting into all various soft computing techniques might be unnecessary, and a broad overview might be more than sufficient.

Systematic mappings are used in various research fields and are increasing within software engineering [41]. Since applications of AI for market forecasting is common but reviews are less common [28] and no systematic map for this scope and aim exists (as far as could be found), this thesis will make a small but important contribution to this topic.

1.5 Scope/Limitation

In the project plan for this degree project [42], two research questions specified and they can be seen in table 1.1.

RQ1	What are the most frequently used research methods for research on financial market forecasting with AI techniques?
RQ2	What topics have been researched in the field of AI applications of financial market forecasting and how have they changed over time?

Table 1.1: The research questions specified for this thesis

To make sure this is achievable, the limitations on how this will be achieved will be that only articles that have been published in peer-reviewed journals or conference proceedings will be included where the **main** focus is on AI applications for financial markets forecasting. All specific restrictions will be thoroughly described in the method section.

1.6 Target group

For this thesis, the target group is anyone interested in this domain. Experts already working in this field will also benefit from this paper. For the latter mentioned group, it is helpful since it summarizes all work that could be found using this research method. Instead of needing to perform a time-exhaustive search for relevant literature, one could use this thesis and find much material to start from. For people doing a thesis of their own, implementing some soft computing technique for market forecasting, it might be interesting to see which topics that already have been extensively covered. After reading this thesis, maybe some time could be saved for actually solving the problem at hand rather than trying to solve a similar problem to what this thesis does.

This thesis also aims to reach people who do not have a degree in computer science nor knows how to program or perform similar tasks. Delving into technical reports might be an endeavor with a too high threshold leading to disproportionally much time spent just trying to understand the basic abbreviations used or decipher formulas used to describe the optimization of an ANN. It is the intention that people avoiding this topic due to these reasons will find this paper useful.

1.7 Outline

The rest of the paper is organized the following way: Section 2 describes the method used for this thesis and how the research was being performed. Section 3 summarizes the results that came from performing the literature review. Section 4 analyzes the findings from the result section. Section 5 discusses the results, and finally, section 6 summarizes the conclusions made from the data and discuss possible future work.

2 Method

The method for answering the research questions in this thesis will be a type of literature review called *systematic mapping*. According to Petersen et al. [41], a software engineering systematic mapping is defined in the following way:

> "A software engineering systematic map is a defined method to build a classification scheme and structure a software engineering field of interest. The analysis of results focuses on frequencies of publications for categories within the scheme. Thereby, the coverage of the research field can be determined."

The primary goal of the method is to give an overview of a research field without evaluating the research that has been made. For this thesis, these guidelines along with an update on how to perform systematic mapping studies from the same institute will be used [41, 43].

Although systematic mapping studies in software engineering are continuously increasing, the type study is relatively new in software engineering [43]. For clarity, the method will be described below according to above-specified guidelines. The process consists of five different phases which are performed chronologically. The steps are:

1. Definiton of Research Question
    - The main goal of a systematic mapping study is to give an overview, so suitable research questions are formulated in this phase in order to successfully perform the study.
2. Conduct Search
    - In this phase, all relevant literature is collected, according to the constraints of the study.
3. Screening of Papers
    - A subset of the papers that were selected from the previous step, which were deemed relevant gets chosen to represent the field examined.
4. Keywording using Abstracts
    - Keywords are collected and extracted, mainly from the abstracts.
5. Data Extraction and Mapping Process
    - The information collected get organized and summarized in a way deemed suitable by the researchers performing the mapping.

In the guidelines described that will be used in this paper [41, 43], the authors specify search strings and which databases that were used to find the primary studies to include in the literature review. For this thesis, that process is replaced by a literature acquiring process called *backward snowballing* [44]. Backward snowballing is a process in which a start set of articles are chosen, and from these articles, the reference lists are used for finding additional literature. After this, work is being made in iterations where all relevant literature from reference parts are being collected into the next iteration until no more is found using this method.

When doing a literature search with snowballing, it is important get a good start set, mainly with diversity to increase chances that as much as possible of the field gets captured. Some properties that are desirable for the start set are to have different publication venues and topics. Before this is made, the inclusion and exclusion should also be formulated, if not the study will start off with literature that is not relevant and likely pick up a lot of unnecessary articles along the way.

The inclusion criteria for literature that will be included in the systematic mapping are the following:

- The articles that will be included must be written in English and been published in peer-reviewed journals or conference proceedings during 2007-2016.
    - No books or other formats will be included.
    - Articles that are published where the conference or the journal does not explicitly say that the material is peer-reviewed will get excluded.
    - Articles have to be accessible online.

  - Much research has been made on this, hence the time limit of publication years 2007-2016 (inclusive).
  - All articles have to have been written in English as well so the research could be reproduced.

- The primary theme of the article has to be on AI applications for financial market forecasting.
  - The word *applications* do not refer to software applications in this context, for which another synonym is *program*. It refers to techniques used for achieving Artificial Intelligence *applied to* the problem of forecasting financial markets.
  - The **main** theme has to be on the combination of the two and that this is the explicit goal of the research.
  - It is stressed that AI techniques (such as ANNs and GAs) have to be used to achieve the sought-after goal of financial market forecasting. In cases where it is not apparent how to classify the technique used, the instances will be discarded.
  - No too specialized applications will be included.

Since backward snowballing was used when performing this study, the process is mixed when compared to the above-described steps to searching for primary studies for this paper. This is due to the reason that if the inclusion/exclusion criteria are not applied during this process, articles that are irrelevant to the thesis would have to be snowballed, leading to unmanageable quantities. Therefore the modified process looks the following way:

1. Definiton of Research Questions
2. Conduct Backward snowballing
   - Apply screening, so only relevant papers get snowballed.
3. Keywording using Abstracts
4. Data Extraction and Mapping Process

2.1 Performing Backward Snowballing

A LibreOffice Calc document was created with the following headers for every entry:

1. **Title**
   (a) The title of the entry evaluated.
2. **Id**
   (a) An integer for identification of every article, making the backward snowballing traceable. The first entry got id 1 and increased by 1 for every new entry in the document.
3. **Journal name/conference name**
   (a) The name of the journal or conference in which the article was published.
4. **Peer reviewed**
   (a) Yes or no to whether the conference or journal explicitly say that peer review is applied to **all** articles published in proceedings or journal.
5. **Year published**
6. **Month published**
7. **Included (yes/no)**
   (a) All entries from the references which were not obviously in the exclusion criteria (such as a website) were entered into the document and evaluated to whether they should be included in the study or not.
8. **Iteration number**

(a) The iteration the article was **first** found.

9. **Snowballed**

   (a) A yes/no/- column for keeping track on which articles that had been snowballed.

10. **Derived from / referenced by**

    (a) A list of all ids that refer to the article in question.

11. **Motivation for inclusion/exclusion**

    (a) All entries had to have a short motivation for why they were included or excluded.

12. **# of articles excluded because of published outside publication years**

    (a) The number of articles that were published outside of the publication years relevant to this thesis that this article refers to.

The start set used for the backward snowballing was found using various search strings inspired by the topics covered by Cavalcante et al. [28]. To avoid publisher bias, the Linnaeus University's library search engine, called OneSearch, and Google Scholar was used. OneSearch uses various databases such as IEEExplore, SpringerLink and ScienceDirect. The search strings were several different combinations of the keywords listed below:

- Artificial Intelligence
- Artificial Neural Networks
- Fuzzy Logic
- Natural Language Processing
- Genetic Algorithms
- Support Vector Machine
- Finance
- Financial Markets
- Stock Market
- Electricity Price
- Oil Price
- Forecasting
- Prediction
- Nasdaq
- Financial News
- Economy

A preliminary start set consisting of 25 papers was initially chosen. After several iterations and refinements, only 14 were deemed relevant, and they are listed below. The articles listed are what is considered iteration 1.

1. The relationship between model complexity and forecasting performance for computer intelligence optimization in finance

   - Author(s): Adam Ghandar, Zbigniew Michalewicz, Ralf Zurbruegg
   - Publication Venue: International Journal of Forecasting
   - Publication Year: 2016

- Description: Examining whether complex models necessarily perform better than simple in financial forecasting.

2. Predicting Market Impact Costs Using Nonparametric Machine Learning Models
    - Author(s): Saerom Park, Jaewook Lee, Youngdoo Son
    - Publication Venue: PLOS ONE
    - Publication Year: 2016
    - Description: Using machine learning for predicting market impact cost using three different input variables.
3. Learning on High Frequency Stock Market Data Using Misclassified Instances in Ensemble
    - Author(s): Meenakshi A.Thalor, Dr. S.T.Patil
    - Publication Venue: International Journal of Advanced Computer Science and Applications
    - Publication Year: 2016
    - Description: Ensemble for stock market prediction.
4. Cognitive Intelligence based Expert System for Predicting Stock Markets using Prospect Theory
    - Author(s): D. Velumoni, S. S. Rau
    - Publication Venue: Indian Journal of Science and Technology
    - Publication Year: 2016
    - Description: Using behavioral economics to predicting stock markets.
5. A Stock Market Prediction Method Based on Support Vector Machines (SVM) and Independent Component Analysis (ICA)
    - Author(s): Hakob Grigoryan
    - Publication Venue: Database Systems Journal
    - Publication Year: 2016
    - Description: Extracting important features for stock market prediction using Independent Component Analysis (ICA) and Support Vector Machines (SVM).
6. An adaptive stock index trading decision support system
    - Author(s): Wen-Chyuan Chiang, David Enke, Tong Wu, Renzhong Wang
    - Publication Venue: Expert Systems With Applications
    - Publication Year: 2016
    - Description: Different AI techniques for recognizing stock trading signals.
7. A hybrid stock trading framework integrating technical analysis with machine learning techniques
    - Author(s): Rajashree Dash, Pradipta Kishore Dash
    - Publication Venue: Journal of Finance and Data Science
    - Publication Year: 2016
    - Description: A system with three different signals for stock trading is devised with different machine learning techniques.
8. Extended forecast methods for day-ahead electricity spot prices applying artificial neural networks
    - Author(s): Dogan Keles, Jonathan Scelle, Florentina Paraschiv, Wolf Fichtner
    - Publication Venue: Applied Energy
    - Publication Year: 2016
    - Description: Authors use ANNs for forecasting electricity prices.
9. Empirical analysis: stock market prediction via extreme learning machine

- Author(s): Xiaodong Li, Haoran Xie, Ran Wang, Yi Cai, Jingjing Cao, Feng Wang, Huaqing Min, Xiaotie Deng
- Publication Venue: Neural Computing and Applications
- Publication Year: 2016
- Description: Extreme learning machine for using news and stock price for stock market prediction.

10. Gold price volatility: A forecasting approach using the Artificial Neural Network–GARCH model
    - Author(s): Werner Kristjanpoller, Marcel C. Minutolo
    - Publication Venue: Expert Systems with Applications
    - Publication Year: 2015
    - Description: Combination of generalized autoregressive conditional heteroskedasticity (GARCH) model with ANNs for forecasting the price volatility of gold price.
11. Modeling and Trading the EUR/USD Exchange Rate Using Machine Learning Techniques
    - Author(s): Konstantinos Theofilatos, Spiros Likothanassis, Andreas Karathanasopoulos
    - Publication Venue: ETASR - Engineering, Technology & Applied Science Research
    - Publication Year: 2012
    - Description: EUR/USD exchange rate forecasting using various machine learning techniques.
12. Twitter mood predicts the stock market
    - Author(s): Johan Bollen, Huina Mao, Xiaojun Zeng
    - Publication Venue: Journal of Computational Science
    - Publication Year: 2011
    - Description: Natural language processing combined with six different classified moods (Calm, Alert, Sure, Vital, Kind and Happy) used along with artificial neural networks for stock market predictions.
13. Textual Analysis of Stock Market Prediction Using Breaking Financial News: The AZFinText System
    - Author(s): Robert P. Schumaker, Hsinchun Chen
    - Publication Venue: ACM Transactions on Information Systems
    - Publication Year: 2009
    - Description: Natural language processing for predicting stock market impacts from financial news.
14. Forecasting stock market short-term trends using a neuro-fuzzy based methodology
    - Author(s): George S. Atsalakis, Kimon P. Valavanis
    - Publication Venue: Expert Systems with Applications
    - Publication Year: 2009
    - Description: An Adaptive Neuro Fuzzy Inference System (ANFIS) is devised to model the stock market for forecasting.

The most common financial market that is being examined is the stock market in the start set. Efforts were made for trying to include other financial markets. The energy market and precious metals market is also in the above-listed articles as well as foreign exchange rates. Besides from having different financial markets, different entry angles was also prioritized. Natural language processing is being examined as well as various machine learning approaches and also incorporating behavioral economics with AI techniques for financial market forecasting.

The most common year of the articles chosen for the start set is 2016. This is because the literature search used for this thesis was backward snowballing, so once an iteration had moved back an entire year, we would theoretically only continue in this direction. In practice, it was discovered that it is not entirely uncommon to refer to articles in press which can mean that the publication year actually is several years in the future.

The six iterations following the start set all looked the same. Going through the reference list of the articles that were included in the current iteration, including relevant entries, excluding nonrelevant and when all had been snowballed in one iteration, move to the next. In figure 2.1, a summary of all iterations where new literature was snowballed can be observed.

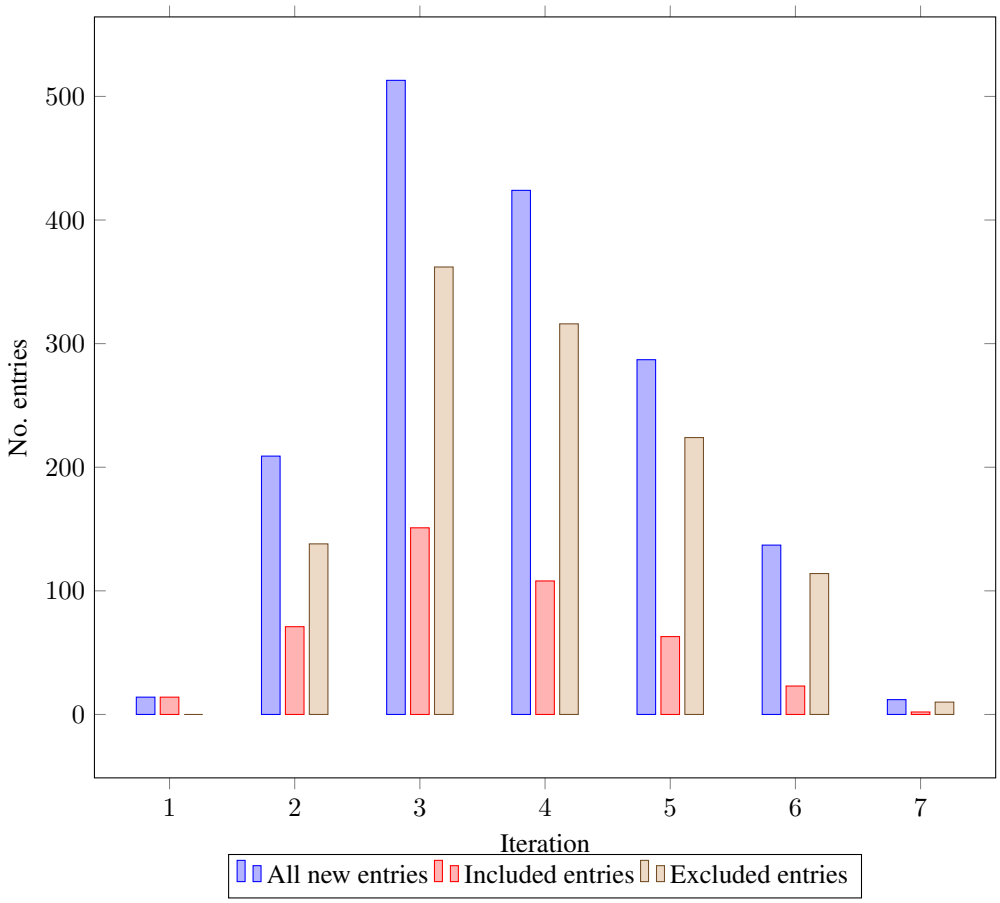

Figure 2.1: A bar chart displaying the number of new entries in each iteration

When the backward snowballing was being performed, it was realized that parts of the literature examined had very specific applications. Some were so specific that it led to the conclusion that some slightly modified guidelines were needed when performing the backward snowballing:

1. Do not check for peer-review
    - In several publications and conference proceedings, it was hard to find explicit information on whether they performed peer-review or not. Hence it was more practical to not look for that during the backward snowballing and assume that entires examined are peer-reviewed, and remove the ones that are not later.
2. If not sure on whether to include or exclude - include
    - The main goal of this thesis is to give an overview of the research field. Some specializations in this research area are so specific that it was more practical to build an understanding of the research field and remove entries that were too hard to decide on whether to include or exclude after the snowballing had been performed.

2.2 Refining accumulated articles

After the backward snowballing had been performed, all articles were controlled for explicit statements that the conferences or journal they were published in were peer-reviewed. Before removing articles where information on explicit statements for peer-review was lacking, there were 432 unique articles. After doing the control, 12 articles were removed for not explicitly stating that all articles in the journal or conference proceeding were peer-reviewed.

2.3 Keywording using abstracts

In this phase the document of all accumulated articles was modified to a document with the following columns:

- Title
- Id
- Journal name/conference name
- Year published in journal/conference proceedings
- Iteration number
- Derived from/referenced by
- Keywords
- Type of research

In the **keywords** section, keywords for every article was entered. In **type of research** the type of research was entered according to one of the six categories suggested by Wieringa et al [45] and summarized by Petersen et al [41], which can be observed in table 2.1.

Validation Research	Techniques investigated are novel and have not yet been implemented in practice. Techniques used are for example experiments, i.e., work done in the lab.
Evaluation Research	Techniques are implemented in practice and an evaluation of the technique is conducted. That means, it is shown how the technique is implemented in practice (solution implementation) and what are the consequences of the implementation in terms of benefits and drawbacks (implementation evaluation). This also includes to identify problems in industry.
Solution Proposal	A solution for a problem is proposed, the solution can be either novel or a significant extension of an existing technique. The potential benefits and the applicability of the solution is shown by a small example or a good line of argumentation.
Philosophical Papers	These papers sketch a new way of looking at existing things by structuring the field in form of a taxonomy or conceptual framework.
Opinion Papers	These papers express the personal opinion of somebody whether a certain technique is good or bad, or how things should been done. They do not rely on related work and research methodologies.
Experience Papers	Experience papers explain on what and how something has been done in practice. It has to be the personal experience of the author.

Table 2.1: Petersen et als summary of research classification according to Wieringa et al

During this process, more articles were removed. During the backward snowballing, the policy of ”if in doubt - include” was used so that a final decision could be reached during this final iteration. During this process, there were 420 articles when the process started and when all articles had been processed, there were 392 left. The most common reason for removing an article was that they were too specific in some sense or the financial market forecasting was more a byproduct of the research.

After performing this activity, the scheme got updated. The scheme for each entry got changed to the headers described below:

- Title

- Id
- Journal name/conference name
- Year published in journal/conference proceedings
- Iteration number
- Derived from/referenced by
- Type of research
- Technique(s) for solving problem – (ANN, Fuzzy logic, ANFIS, other hybrid etc)
- What is mainly being forecasted/produced? (Price, price direction, demand etc)
- Which financial market primarily? (Stock Market, Foreign Exchange etc)
- Other keywords

This scheme was deemed sufficient to describe the research field to answer the research questions for this thesis. This update led to having to redo the entire classification one more time to classify all research into the revised scheme. When the classification scheme got even more specific, it got apparent that even more papers had to be removed and the numbers were further reduced from 392 to 362 articles.

The types of research specified in table 2.1 needed small adjustments on the interpretations of these classifications. This was necessary since people working on this topic sometimes do not reveal the progress they have made [28] nor how their implementations look. Because of this, the class *Evaluation Research* was given a slightly different meaning. Rather than how things look in the industry, it is more interpreted as how well-known techniques and previously suggested methods perform when being evaluated without adding anything seemingly new.

In the guidelines for making a systematic mapping [41], the authors describe the process of keywording slightly different to the approach that was used for this thesis. In the guidelines, a classification scheme is supposed to be developed by examining abstracts, but in this thesis, this was replaced by mainly taking the authors own keywords. Other keywords were only entered when the original keywords seemed insufficient or misguiding for this degree project. When doing the keywording, obvious synonyms were also replaced with one chosen representation to make the result more unified. For example the terms ”Neural Networks”, ”Neural Network”, ”Artificial Neural Network”, ”Artificial Neural Networks”, ”ANNs” or ”ANN” all refer to the same thing and were replaced to ”ANN”. All terms that were written in plural were replaced to their singular form, and if a well-established abbreviation for the term existed, it was replaced by that form. For instance ”Support Vector Machine”, ”SVMs” and ”Support Vector Machines” would all be replaced by ”SVM”. However, if specific types of neural networks were used as keywords, they would be replaced by an abbreviation if one existed but not be lumped into the supercategory of ”ANN”.

2.4 Reliability and Validity

When this degree project was performed, the ambition was to follow best practices and guidelines that were mentioned earlier. Even though this was the aim, reliability issues and validity threats are still present and the ones identified are described below.

2.4.1 Reliability

One threat to the reliability of this thesis is the project guidelines created by the author for this thesis that was used during the backward snowballing process. The guidelines referred to in this context are the ones regarding not controlling for peer-reviewed and to include articles when it was not apparent on whether to include or exclude. Since articles were included when it was hard to decide whether or not to include or exclude, articles got snowballed which later got discarded. There is no downside to this when it comes to the overview of the field, but if the main concern is to get the same result if the study were to be reproduced, it would mean that this thesis might contain more articles than a duplicate study.

Apart from this, the reliability threats can be summarized with one word: *bias*. This systematic mapping was performed by one single individual which means that only one person’s classification and judgment used for all decisions. When examining systematic mappings, it was found that one of the most common ways to try to solve disagreements was with having a consensus meeting [43]. Since this was not possible when only one individual was involved in this thesis, that might be a reliability issue. There have been

other documented cases of threats to reliability in systematic mappings, which was discovered by Wohlin et al. [46]. The authors examined two systematic maps that were made on software product line testing independent of each other at the same time. Even though the two teams used the same classification scheme for classifying the research type, the same that is used in this paper, the two systematic maps only agreed on 11 out of 33 articles with regards to research type.

When classifying the research for this thesis, the same problem was present. In general, most research was such that it was not easy to categorize. For instance, several articles seemed to be touching upon both the categories of solution proposals as well as validation research. In the end, they were categorized as the category they appeared to belong to the most. This was also the case during the inclusion and exclusion process. When deciding whether to include or exclude an article, many articles were perceived as a case could be made for both cases. Kitchenham et al. described problems when performing a systematic mapping in 2012 [47]. In that paper, the authors express that there was a problem concerning ambiguity with abstracts. Sometimes authors would describe a slightly different type of research to what was performed. This problem was present when classifying the research for this thesis. When reading an abstract and then look further in the paper for more information, one might become confused since the perception was that there, in some cases, was a dissonance between what was being described in the abstract, to what the paper dealt with. One reoccurring example was when an author would describe a paper as if the stock price was being forecasted, something which at least by this paper's author, was interpreted as the future price of a specific stock. What was meant in many of those cases was sometimes a composite index, some other times just the direction of the price the following days and not the price of the stock itself. For obvious reasons, this was dealt with whenever discovered, but since some of these differences were difficult to spot, it is likely that some errors such as these got incorrectly classified.

If an estimation would be made on the reliability, then a personal guess would be that the papers included of a replicated study would be roughly the same. The classification scheme might differ, but a rough estimation of that would be that a similar classification scheme would emerge. Research classification is one key point where it is estimated that the result might differ the most, although it is hypothesized that it might not be a large difference. The conflict would most likely be between what should be classified as validation research or solution proposal.

2.4.2 Validity

This thesis suffers likely from less risk of validity problems than reliability problems. The main validity threats are due to bias. As stated in the section on reliability there is a certain likelihood that papers have been misclassified, the remedy of this is the large selection of articles. Assuming there is a 10% chance of misclassification, it still means the expected value is that 90% of included papers (appr. 326) are correctly classified and the ones which are wrongly classified of the included, are likely not misclassified in a major way.

3 Results

The results from the summary of results from the systematic mapping will be shown in this section.

3.1 Type of Research

In table 3.1 the type of research encountered of the articles included are summarized.

Type of Research	No. articles	Percentage
Solution Proposal	275	76.0 %
Validation Research	65	18.0 %
Evaluation Research	21	5.8 %
Philosophical Papers	1	0.3 %
Opinion Papers	0	0 %
Experience Papers	0	0 %

Table 3.1: Type of research

3.2 Time Distribution of Articles

The distribution per year on the articles included can be seen in figure 3.1 below.

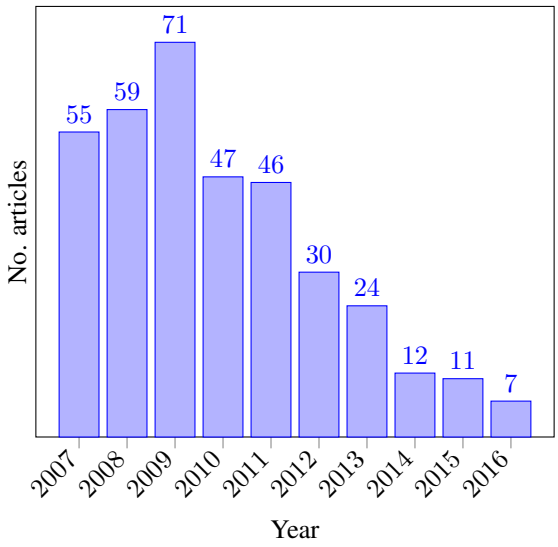

Figure 3.1: Articles per year included

3.3 Market Distribution

In table 3.2 the main financial market(s) that were targeted for the articles included is shown.

Market	**No. articles**	**Percentage**
Stock market	269	74.3 %
Commodity market	46	12.7 %
FOREX	29	8.0 %
Several	8	2.2 %
Other	10	2.8 %

Table 3.2: Number articles per financial market

3.4 Most Common Combinations

In table 3.3 all combinations of what main technique was being used, what was being forecasted and which financial market that was occurring three or more times.

Main Technique /Approach	Property being forecasted/predicted	Financial market	Quantity
Hybrid	Index	Stock Market	52
Hybrid	Price	Stock Market	25
ANN	Price	Stock Market	20
Hybrid	Trading signals	Stock Market	20
ANN	Price	Commodity Market	16
Hybrid	Price	Commodity Market	13
ANN	Exchange rate	FOREX	13
ANN	Index	Stock Market	9
Hybrid	Price direction	Stock Market	8
ANFIS	Index	Stock Market	7
Hybrid	Index direction	Stock Market	7
ANN	Trading signals	Stock Market	7
Fuzzy logic	Index	Stock Market	6
Hybrid	Exchange rate	FOREX	5
Hybrid	Volatility	Stock Market	5
Various	Index	Stock Market	4
Various	Index direction	Stock Market	4
ANN	Return	Stock Market	4
Hybrid	Return	Stock Market	4
Various	Exchange rate	FOREX	3
ANN	Price	Over-the-counter	3
ANN	Index direction	Stock Market	3
ANN	Various	Stock Market	3
Hybrid	Various	Stock Market	3
ANN	Volatility	Stock Market	3
Hybrid	Various	Various	3

Table 3.3: All combinations occurring three or more times

3.5 The 10 Most Common Combinations and their Change Over Time

Figure 3.2 depicts the percentage distribution of the ten most common combinations of all combinations and the change with respect to time.

In figure 3.3 the same result is shown, the difference is that every year the 10 most common combinations are compared to how many percentages in comparison to all articles that were included that year.

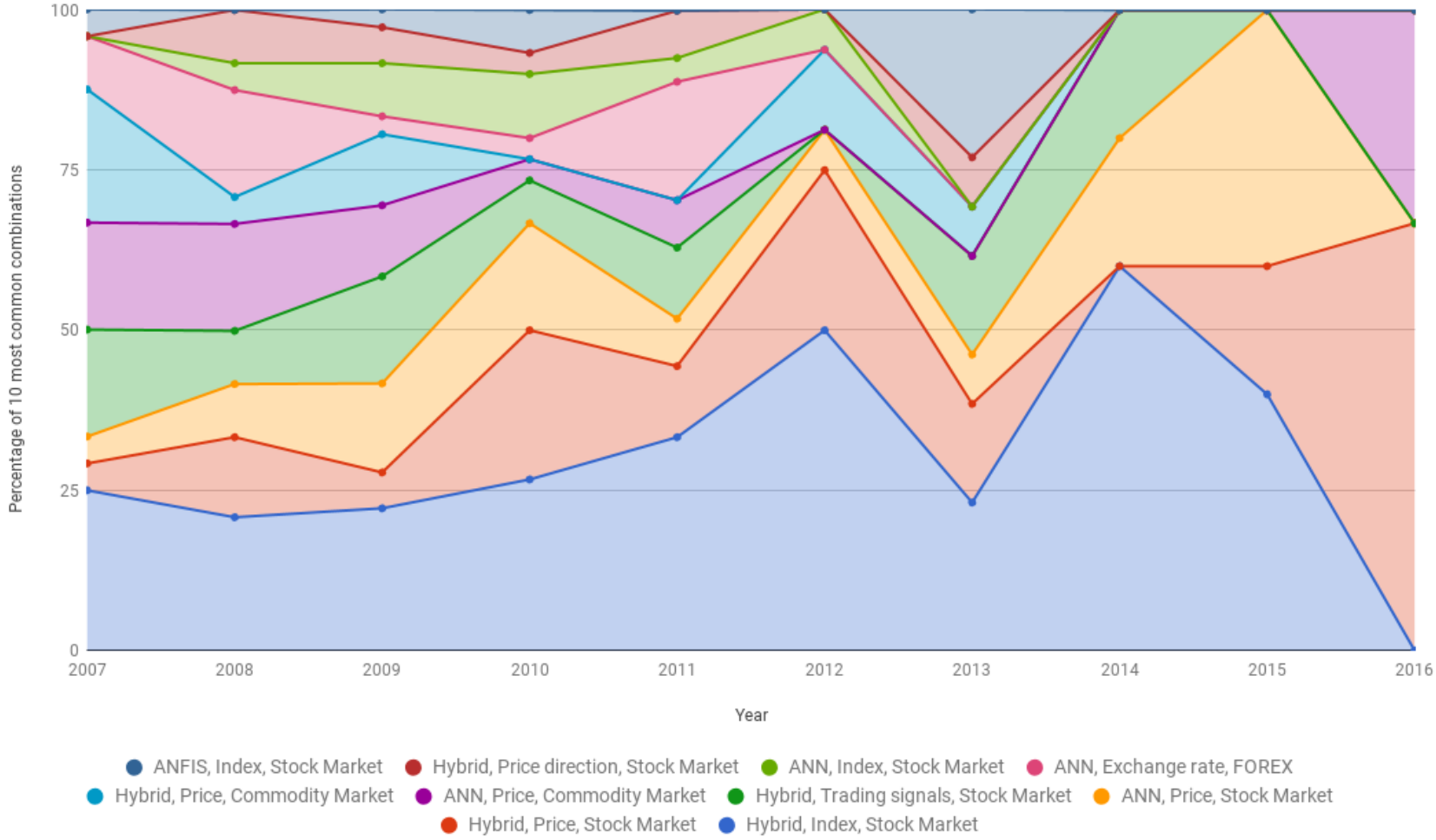

Figure 3.2: 10 most common combinations and their change with respect to time

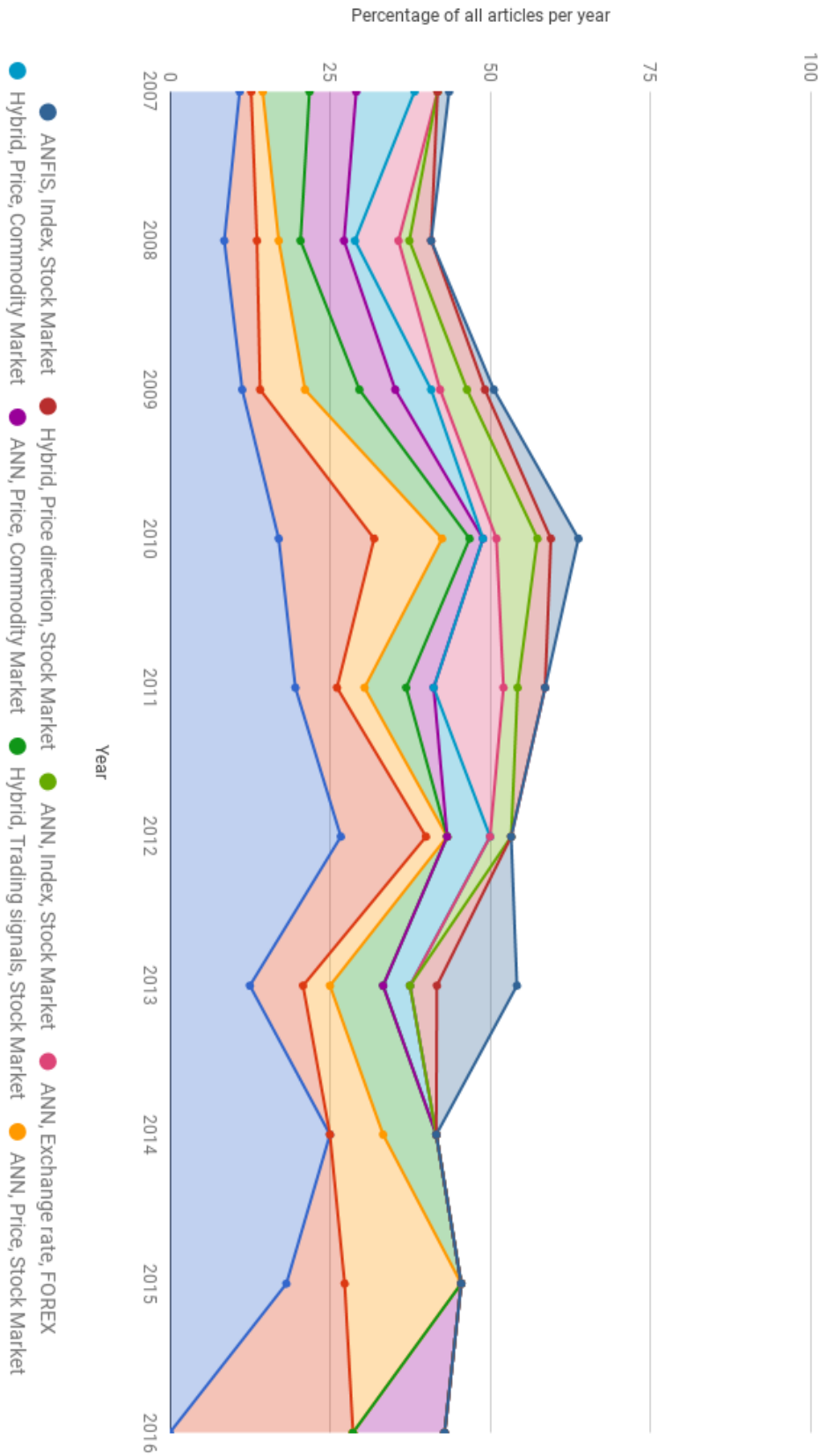

Figure 3.3: 10 most common combinations out of all articles

4 Analysis

Reconnecting to the first section of this thesis, it is worth reminding the reader about the research questions. The first research question was on what type of research that has been performed on this topic. This is answered in table 3.1. The other research question was on what topics that have been researched in this application and how they have changed over time. All results apart from table 3.1 attempt to answer the second research question.

The results in the previous section present some interesting insights into the field examined. One of these is that a vast majority of articles are classified as solution proposals, as can be seen in table 3.1. This was expected since when it comes to AI and financial forecasting, progress is often not communicated to outsiders because a unique, successful solution is many times what gives a competitive advantage [28].

A finding that was unexpected when doing this degree project was that it was the year 2009 that had the most articles that were included in this thesis, as can be seen in figure 3.1. A naive guess would be that the year 2007 should have the most articles since the literature search method was backward snowballing. One thing worth pointing out before continuing on the time distribution is that it was not uncommon for articles included that were published in journals to have been edited and redrafted for 1-2 years before they were published in the journal. Therefore, the time distribution might be misleading since some articles from conference proceedings were published the same year as the first draft was produced while some articles that were published in journals were not published until two years after a first draft was received. This does not explain why the most articles were during 2009 though, but it is still worth pointing out to the reader. One possible explanation might be, assuming that there actually were more research being done on this topic at that time, is due to the financial crisis that recently had shaken the world, leading to further research in that area.

Much of the content that was examined and included in this systematic map was similar to each other. Although it occasionally was hard separating articles due to similar titles and topics, almost half was occurring seven times or less as can be seen in figure 3.3. In general, approximately 50% of research on this topic does not fall into any large category as can be seen in the previously mentioned figure. Even though these categories in themselves are rather broad, five out of ten years drops below the 50% mark.

When viewing the most common techniques, it is striking how dominant various hybrids and ANNs are in this problem, something that can be observed in table 3.3. Another point worth noting is that it is rather common to forecast or predict indexes. This is information which can be hard to find out in this field, this since as earlier mentioned, there was often a discrepancy on what was claimed to be examined and what was actually examined/forecasted.

When further inspecting table 3.3, it is clear that ANNs are the most common single technique that was used for forecasting. Fuzzy logic or Adaptive Neuro-Fuzzy Inference Systems (which could be considered a hybrid) were also used, but not to the same extent. Looking at the financial market column, the results are dominated by applications to the stock market, with some applications to commodity markets or the foreign exchange rates. When looking at what property that is being forecasted, there is a significant diversity of what properties that are being forecasted, including examples such as index directions, indexes, and volatility.

In table 3.2 one can observe that stock markets are the most common markets where forecasting using AI techniques is attempted.

5 Discussion

The aim of this thesis was to answer which topics that have been researched on financial market forecasting with AI and to what extent. Typically when reading reviews, it is hard to find answers to what extent or when something has happened. The answer to the question of to what extent certain applications have been used is easy to see in the result section in this review, where the reoccurring combinations are described and on how many instances of them there are. It is also relevant to see the distribution of the reoccurring themes visualized, such as in figure 3.2 and figure 3.3, a result that can make the decision-making process for future researchers or students venturing into this field more efficient.

When looking at possible trends and future directions in figure 3.2 and figure 3.3 there seem to be four timeless topics. They are hybrids forecasting trading signals, stock prices or indexes applied to the stock market or ANNs used for forecasting single stock prices. When making these inferences though, it is worth pointing out that little weight is being given to information derived from years 2014-2016. This is because, as can be seen in figure 3.1, there are very few articles included from those years. However, if one uses 2007-2013 for making inferences and the last three years as a rough approximation instead, a few other patterns can be seen that can be given a bit more credibility. The four previously mentioned combinations are the only combinations present almost every year that is also present in at least one occurrence 2014-2016.

Further observing figure 3.2 and figure 3.3, it can be seen that the combination of using ANNs for index forecasting on the stock market disappear in 2012. After that year, no more research is found where the primary technique is Artificial Neural Networks alone for index forecasting. This is not the case for the same combination where the ANNs are applied to prices of individual stocks instead. Maybe the results were unambiguous that ANNs in themselves had reached an end in how effective they could be to index forecasting and to evolve further, they needed to be combined with other techniques. It is not visible in the data in the results section, but, ANNs are common to be one of the several techniques in papers that were classified as hybrids. Another pattern emerging is that the most common combination (hybrid, index, stock market) seems to become more and more popular, as can be seen in figure 3.3. There are some ups and downs during the last years, but if one makes an average of the last years, it seems to stay at approximately 15-20%. When looking at the development of topics explored with regards to time, it also appears to be a selection taking place around 2010 and 2011 where the four most popular combinations become more frequent and the population of the other categories, seem to shrink on average.

One unexpected insight that emerged when doing this thesis was the seeming discrepancy between what was being claimed by the authors to be examined versus what was actually examined. For instance, it was not uncommon for the authors of a paper to claim that the primary focus was to use machine learning techniques to forecast stock prices, something that was interpreted as the price of an individual stock. However, it was not uncommon that it turned out that what was actually forecasted was a composite index instead, something which is not considered equivalent in this thesis. If someone is entering this field and want to take away one thing and one thing only from this thesis, the following advice is recommended: the first thing that an individual should do when reading an article on this topic is to search the article for what the proposed system outputs. The majority of research on this issue, at least included in this paper, try to devise or take an existing AI application in order to forecast some financial market property. In most cases, it is hard to understand what the system actually does until the output variable of the system is identified. This is because, as above-mentioned, some writers claim to do one thing but do another. This dissonance, when occurring, leads to confusion when reading the papers because after reading the abstract, what you as a reader might expect might be something different from what is in the actual paper.

In Game of Thrones, season one, the maester of Winterfell (maester Lewin) talks to Brandon Stark about magic not existing the world they live anymore. He further explains that he tried (and failed) performing magic spells when he was a scholar in Oldtown [48]. When talking about this, Lewin implies this was something many had attempted, dreaming of vast powers. I cannot help but think that this might be the case when it comes to AI and financial market forecasting. There seems to be no magic trick that could solve this problem, however, the dream still lives among scientists and researchers that they might just come up with something different than everybody else. This idea is at least vaguely supported by the results section, the vast majority of research that has been made is solution proposals. Another impression that was given by the articles examined was that it felt as if a small amount of research could be thought of as shooting from the hip. What is meant by that is that sometimes the impression from reading these papers was that great thought and care had been put into some new AI technique variation or optimization and the researchers might have been thinking something along the lines of trying out the new technology just in case it works. Approximately like buying a lottery ticket - most likely it will not be a winning ticket, but sometimes you just want to take a chance anyway.

The results section does not have the same data types as other reviews, so it is a bit hard to compare it to

other reviews in this field. However, when it comes to the question *what*, as earlier mentioned, the findings in this paper are identical to those of Cavalcante et al. [28]. Something worth mentioning though is that a lot of articles and applications which were present in that paper, naturally are not present in this degree project due to inclusion and exclusion criteria. Other reviews which were regarded in the related works section are a bit hard to compare since none of them was a systematic mapping and specialized to different angles, hence the motivation for making this thesis at all. It seems to me personally that this paper does fill a gap and can be of use for others since it was made in such a way that, apart from following standards required, would have been useful for myself when entering into this vast research area.

6 Conclusion

In the field of AI, a common research area has been trying to predict various financial markets. In this thesis, the aim was to give an extensive overview of this topic, not only with regards to what has been examined but also how these topics have changed over time and what type of research that has been made. With the time frame 2007-2016, it has tried to answer the research questions posed in the first section. These results can be relevant both in the field of computer science as well as outside of it. The quality of this thesis could have been higher if there would have been smaller constraints on the period for inclusion and an extensive search of all literature on those years had been performed instead of only backward snowballing.

Prior to this degree project, the impression that was perceived from a personal level was mainly derived from mainstream media, performing this review drastically changed that perception. It was actually extremely rare, when reading the papers, for researchers to ever use the terminology Artificial Intelligence. Even though it is not visible in the results, not a single article was encountered where what was intended was any form of general AI in any way (general AI have not ever been accomplished to date, but one might get the impression from mainstream media that such is the case) [49]. Prior to this thesis, an assumption was made that it probably would not have to do with such a topic anyway. Even though this was assumed, more or less every paper read gave the impression that almost all researchers considered, for example, ANNs as a function approximator. In difference from viewing an ANN as an artificial brain, it seemed more that researchers simply thought of it as computational structures that work better than, for instance, statistical methods.

6.1 Future work

Future work could be to make the picture complete and to perform a forward snowballing as well to get the full picture of the research field during these years. This seems to be a field which will not stop evolving in the foreseeable future so for future work the same topic could probably be done, but for a smaller time frame and more fine grained research. A follow up could easily be made in one year covering 2016-2018 extensively as a complement for this systematic mapping for instance.

Another possible extension for this work could be to visualize clusters in how articles reference each other. That is work that could be extended from the material to this thesis. All papers are documented in how they refer to each other so an individual with skills in data visualization might be able to make an overview, finding clusters and papers of high impacts as well as patterns in the data that was not found during the making of this thesis. It would not be surprising if another classification scheme might emerge from such work and it would be interesting to see another angle on the same data. For this paper, the classification scheme for the AI technique used was either a specific technique or the class hybrid. It could be of interest to examine the type of hybrids that were used, because this class does not reveal what types of combinations that were used or to what extent.

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A Appendix 1

List of all articles included for this thesis:

Year published	Title	Title of Journal or Conference
2007	Predicting the impact of anticipatory action on u.s. stock market—an event study using anfis (a neural fuzzy model)	Computational Intelligence
2007	Modeling chaotic behavior of Dhaka Stock Market Index values using the neuro-fuzzy model	International conference on Computer and information technology
2007	RBF network-based chaotic time series prediction and it's application in foreign exchange market	International conference on intelligent systems and knowledge engineering (ISKE 2007)
2007	Forecasting exchange rates: A robust regression approach	International Journal of Forecasting
2007	Stock Price Forecasting using Back Propagation Neural Networks with Time and Profit Based Adjusted Weight Factors	International Joint Conference SICE-ICASE, 2006
2007	A stock pattern recognition algorithm based on neural networks	International conference on natural Computation
2007	Forecasting electricity market pricing using artificial neural networks	Energy Conversion and Management
2007	A neural network model based on the multi-stage optimization approach for short-term food price forecasting in China	Expert Systems with Applications
2007	Price forecasting for day-ahead electricity market using recursive neural networks	IEEE Power Engineering Society General Meeting
2007	A novel approach to forecast electricity price for PJM using neural network and similar days Method	IEEE Transactions On Power Systems
2007	Predicting stock prices using a hybrid kohonen self organizing map	International conference on system sciences
2007	Forecasting daily and sessional returns of the ISE-100 index with neural network models	Journal of Dogus University
2007	Are there exploitable inefficiencies in the futures market for oil?	Energy Economics
2007	Developing and assessing an intelligent forex rolling forecasting and trading decision support system for online e-service	International Journal of Intelligent Systems
2007	Design and implementation of NN5 for Hong Kong stock price forecasting	Engineering Applications of Artificial Intelligence
2007	A machine learning approach to predict turning points for chaotic financial time series	IEEE International Conference on Tools with Artificial Intelligence (ICTAI 07)
2007	Stock market prediction of S&P 500 and DJIA using bacterial foraging optimization technique	IEEE Congress on Evolutionary Computation Evolutionary Computation
2007	A New Self Adaptive Differential Evolution: Its Application in Forecasting the Index of Stock Exchange of Thailand	IEEE Congress on Evolutionary Computation
2007	Day-ahead electricity price forecasting in a grid environment	IEEE Transactions on Power Systems
2007	A new fuzzy time-series based on two factors to predict TAIEX	International Conference on Machine Learning and Cybernetics (ICMLC)
2007	Stock Price Prediction Based on Fuzzy Logic	International Conference on Machine Learning and Cybernetics

2007	Biological brain-inspired genetic complementary learning for stock market and bank failure prediction	Computational Intelligence
2007	Genetic network programming with sarsa learning and its application to creating stock trading rules	IEEE congress on evolutionary computation, Singapore
2007	Adaptive signal processing of asset price dynamics with predictability analysis	Information Sciences
2007	Forecasting Exchange Rates Using an Evolutionary Neural Network	Applied Financial Economics Letters
2007	Statistical fuzzy interval neural networks for currency exchange rate time series prediction	Applied Soft Computing
2007	A neuro-fuzzy model for stock market trading	Applied Economics Letters
2007	A hybrid approach based on neural networks and genetic algorithms for detecting temporal patterns in stock markets	Applied Soft Computing
2007	Hybrid differential evolutionary system for financial time series forecasting	IEEE Congress on Evolutionary Computation
2007	Stock index forecasting using PSO based selective Neural Network Ensemble	International Conference on Artificial Intelligence
2007	Financial time series data forecasting by wavelet and TSK fuzzy rule based system	International Conference on Fuzzy Systems and Knowledge Discovery
2007	Flexible neural trees ensemble for stock index modelling	Neurocomputing
2007	Stock market prediction with multiple classifiers	Applied Intelligence
2007	A hybrid modular neural network architecture with fuzzy Sugeno integration for time series forecasting	Applied Soft Computing
2007	Next-day electricity-price forecasting using a hybrid network	IET Generation, Transmission & Distribution
2007	A hybrid artificial intelligence approach to monthly forecasting of crude oil price time series	International Conference on Engineering Applications of Neural Networks
2007	A new approach to forecast crude oil price based on fuzzy neural network	International Conference on Fuzzy Systems and Knowledge Discovery
2007	Forecasting of market clearing price by using GA based neural network	International Conference on Intelligent Computing
2007	A Fusion model of HMM, ANN and GA for stock market forecasting	Expert Systems with Applications
2007	A Framework for Electricity Price Spike Analysis With Advanced Data Mining Methods	IEEE Transactions on Power Systems
2007	Non-linear, hybrid exchange rate modeling and trading profitability in the foreign exchange market	Journal of Economic Dynamics and Control
2007	A hybrid neurogenetic approach for stock forecasting	IEEE Transactions on Neural Networks
2007	A particle swarm optimization approach in the construction of decision-making model	Information Technology And Control
2007	Yahoo! for Amazon: Sentiment Extraction from Small Talk on the Web	Management Science
2007	Comparing extended classifier system and genetic programming for financial forecasting: an empirical study	Soft Computing

2007	Neuro-evolutionary approach to stock market prediction	International Joint Conference on Neural Networks
2007	Forecasting the volatility of stock price index	Expert Systems with Applications
2007	Intelligent Threshhold Garch Model Applied to Stock Market of Transmissions that Volatility	International conference on convergence information technology
2007	Electricity market price forecasting based on weighted nearest neighbors techniques	IEEE Transactions On Power Systems
2007	A multiagent approach to Q-learning for daily stock trading	IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans
2007	Self-organizing learning array and its application to economic and financial problems	Information Sciences
2007	Mining stock market tendency by RS-based support vector Machines	IEEE International Conference on Granular Computing
2007	Short-term electricity prices forecasting in a competitive market: a neural network approach	Electric Power Systems Research
2007	Combining News and Technical Indicators in Daily Stock Price Trends Prediction	International Symposium on Neural Networks (ISSN 2007)
2007	Computational intelligence approaches and linear models in case studies of forecasting exchange rates	Expert Systems with Applications
2008	The adaptive neuro-fuzzy model for forecasting the domestic debt	Knowledge-Based Systems
2008	Stock price forecast by using neuro-fuzzy inference System	International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering
2008	Optimal artificial neural network topology for foreign exchange forecasting	Annual Southeast Regional Conference on XX
2008	Testing forecast accuracy of foreign exchange rates: predictions from feed forward and various recurrent neural network architectures	Computational Economics
2008	Forecast Forex with ANN Using Fundamental Data	International Conference on Information Management, Innovation Management and Industrial Engineering
2008	Multistage RBF neural network ensemble learning for exchange rates forecasting	Neurocomputing
2008	The Use of Neural Networks in the Prediction of the Stock Exchange of Thailand (SET) Index	International Conference on Computational Intelligence for Modelling Control Automation
2008	Predicting stock index increments by neural networks: the role of trading volume under different horizons	Expert Systems with Applications
2008	The Efficacy of Neural Networks and Simple Technical Indicators in Predicting Stock Markets	International Conference on Convergence Information Technology
2008	Quantitative Study on Candlestick Pattern or Shenzhen Stock Market	IEEE International Conference on Systems, Man and Cybernetics
2008	Forecasting crude oil price with an EMD-based neural network ensemble learning paradigm	Energy Economics
2008	An adaptive wavelet neural network-based energy price forecasting in electricity markets	IEEE Transactions on Power Systems

2008	Electricity price forecasting in Ontario electricity market using wavelet transform in artificial neural network based model	International Journal of Control, Automation and Systems
2008	Short term forecasting with support vector machines and application to stock price prediction	International Journal of General Systems
2008	DJIA stock selection assisted by neural network	Expert Systems with Applications
2008	The application of echo state network in stock data mining	PAKDD 2008
2008	Forecasting model for crude oil prices based on artificial neural networks	International conference on intelligent sensors, sensor networks and information processing
2008	Forecasting gold price changes: Rolling and recursive neural network models	Journal of Multinational Financial Management
2008	Stock Price Direction Prediction Using Artificial Neural Network Approach: The Case of Turkey	Journal of Artificial Intelligence
2008	Intelligent technical analysis based equivolume charting for stock trading using neural networks	Expert Systems with Applications
2008	Integrating a piecewise linear representation method with dynamic time warping system for stock trading decision making	International conference on natural Computation
2008	Stock Price Prediction and Trend Prediction Using Neural Networks	International Conference on Emerging Trends in Engineering and technology
2008	Prediction of stock markets by the evolutionary mix-game model	Physica A: Statistical Mechanics and its Applications
2008	Technical market indicators optimization using evolutionary algorithms	Annual conference on Genetic and evolutionary computation (GECCO)
2008	Forecasting short-term power prices in the Ontario Electricity Market (OEM) with a fuzzy logic based inference System	Utilities Policy
2008	Fuzzy time-series based on adaptive expectation model for TAIEX forecasting	Expert Systems with Applications
2008	Multi-attribute fuzzy time series method based on fuzzy clustering	Expert Systems with Applications
2008	Prediction of pricing and hedging errors for equity linked warrants with Gaussian process models	Expert Systems with Applications
2008	An empirical study of genetic programming generated trading rules in computerized stock trading service system	International Conference Service Systems and Service Management – Exploring Service Dynamics with Science and Innovative Technology
2008	A new approach to modeling early warning systems for currency crises: can a machine-learning fuzzy expert system predict the currency crises effectively	Journal of International Money and Finance
2008	A bivariate fuzzy time series model to forecast the TAIEX	Expert Systems with Applications
2008	Forecast approach using neural network adaptation to support vector regression grey model and generalized autoregressive conditional heteroscedasticity	Expert Systems with Applications
2008	Morphological-rank-linear time-lag added evolutionary forecasting method for financial time series forecasting	IEEE Congress on Evolutionary Computation

2008	A hybrid system integrating a wavelet and TSK fuzzy rules for stock price forecasting	IEEE Transactions on Systems, Man and Cybernetics
2008	Integration of an Improved Particle Swarm Algorithm and Fuzzy Neural Network for Shanghai Stock Market Prediction	Workshop on Power Electronics and Intelligent Transportation System
2008	Research of stock index futures prediction model based on rough set and support vector machine	IEEE international conference on granular computing, Hangzhou, China
2008	Application of wrapper approach and composite classifier to the stock trend prediction	Expert Systems with Applications
2008	A Novel Feature Selection Approach Using Classification Complexity for SVM of Stock Market Trend Prediction	International Conference on Management Science and Engineering
2008	Day-ahead price forecasting of electricity markets by a hybrid intelligent system	European Transactions on Electrical Power
2008	Online option price forecasting by using unscented Kalman filters and support vector machines	Expert Systems with Applications
2008	The Integrated Methodology of Wavelet Transform and GA based-SVM for Forecasting Share Price	IEEE International Conference on Information and Automation,Zhangjiajie, China
2008	Forecasting Stock Price Using a Genetic Fuzzy Neural Network	International Conference on Computer Science and Information Technology
2008	Stock Price Time Series Prediction using Neuro-Fuzzy with Support Vector Guideline System	International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing
2008	Comparisons of Stock Rates Prediction Accuracy Using Different Technical Indicators with Backpropagation Neural Network and Genetic Algorithm Based Backpropagation Neural Network	International conference on emerging trends in engineering and technology
2008	A hybrid machine learning system for stock market Forecasting	Proceeding of World Academy of Science, Engineering and Technology
2008	Integrating GA-based time-scale feature extractions with SVMs for stock index forecasting	Expert Systems with Applications
2008	Evolving decision rules to predict investment opportunities	International Journal of Automation and Computing
2008	A Hybrid Derivative Trading System Based on Volatility and Return Forecasting	Engineering Economist
2008	Maximizing winning trades using a novel RSPOP fuzzy neural network intelligent stock trading system	Applied Intelligence
2008	Knowledge discovery in financial investment for forecasting and trading strategy through wavelet-based SOM networks	Expert Systems with Applications
2008	A new hybrid artificial neural networks and fuzzy regression model for time series forecasting	Fuzzy Sets and Systems
2008	Artificial neural network of the hybrid EGARCH volatility of the Taiwan stock price index option prices	Physica A: Statistical Mechanics and its Applications
2008	Mining stock category association and cluster on Taiwan stock market	Expert Systems with Applications

2008	Prediction of S&P500 and DJIA stock indices using particle swarm optimization technique	IEEE World Congress on Computational Intelligence
2008	A statistical approach for interval forecasting of the electricity price	IEEE Transactions On Power Systems
2008	Knowledge Engineering in a Temporal Semantic Web Context	International Conference on Web Engineering
2008	A TSK type fuzzy rule based system for stock price prediction	Expert Systems with Applications
2008	A Case Based Clustering-Based TSK Fuzzy Rule Systems for Stock Price Forecasting	International Conference on Innovative Computing Information and Control
2008	Forecasting stock exchange movements using artificial neural network models and hybrid models	International conference on intelligent information processing
2009	Adaptive Neuro Fuzzy Inference Systems for High Frequency Financial Trading and Forecasting	International Conference on Advanced Engineering Computing and Applications in Sciences
2009	Adaptive Neuro-Fuzzy Inference System for Financial Trading using Intraday Seasonality Observation Model	International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering
2009	Fusion ANFIS models based on multi-stock volatility causality for TAIEX forecasting	Neurocomputing
2009	Forecasting stock market short-term trends using a neuro-fuzzy based methodology	Expert Systems with Applications
2009	Neural network earnings per share forecasting models: A comparison of backward propagation and the genetic algorithm	Decision Support Systems
2009	Efficient prediction of exchange rates with low complexity artificial neural network models	Expert Systems with Applications
2009	Development and performance evaluation of FLANN based model for forecasting of stock markets	Expert Systems with Applications
2009	Predicting the Brazilian stock market through neural networks and adaptive exponential smoothing methods	Expert Systems with Applications
2009	Application Study of BP Neural Network on Stock Market Prediction	International conference on hybrid intelligent systems
2009	An effort to optimize similar days parameters for ANN-based electricity price forecasting	IEEE Transactions on Industry Applications
2009	Based on wavelet-Boltzman neural network and kernel density estimation model predict international crude oil Prices	International Conference on Future Computer and Communication
2009	Crude oil price forecasting with an improved model based on wavelet transform and RBF neural network	International Forum on Information Technology and Applications
2009	Forecasting Model for Crude Oil Price Using Artificial Neural Networks and Commodity Futures Prices	International Journal of Computer Science and Information Security
2009	Nonlinear neural network forecasting model for stock index option price: Hybrid GJR–GARCH approach	Expert Systems with Applications

2009	Using neural network to forecast stock index option price: A new hybrid GARCH approach	Quality and Quantity
2009	Empirical of the Taiwan stock index option price forecasting model – Applied artificial neural network	Applied Economics
2009	Short-term stock price prediction based on echo state Networks	Expert Systems with Applications
2009	Empirical Analysis of Optimal Hidden Neurons in Neural Network Modeling for Stock Prediction	IEEE Pacific-Asia Workshop on Computational Intelligence and Industrial Application
2009	Computationally efficient FLANN-based intelligent stock price prediction system	International Joint Conference on Neural Networks
2009	Financial time series prediction using exogenous series and combined neural networks	International Joint Conference on Neural Networks
2009	Prediction-based portfolio optimization model using neural networks	Neurocomputing
2009	Prediction Model of Stock Market Returns Based on Wavelet-Neural Network	Pacific-Asia Workshop on Computational Intelligence and Industrial Application
2009	Daily prediction of short-term trends of crude oil prices using neural networks exploiting multimarket dynamics	Frontiers of Computer Science in China
2009	A neural-network-based nonlinear metamodeling approach to financial time series forecasting	Applied Soft Computing
2009	Improving forecasts of GARCH family models with the artificial neural networks: An application to the daily returns in Istanbul Stock Exchange	Expert Systems with Applications
2009	Efficient prediction of stock market indices using adaptive bacterial foraging optimization (ABFO) and BFO based techniques	Expert Systems with Applications
2009	Factors Analysis on Stock Exchange of Thailand (SET) Index Movement	International Conference on ICT and Knowledge Engineering, ICTKE2009, Bangkok, Thailand
2009	Multiobjective optimization of technical market indicators	Annual conference on Genetic and evolutionary computation (GECCO)
2009	A distance-based fuzzy time series model for exchange rates forecasting	Expert Systems with Applications
2009	Fuzzy dual-factor time-series for stock index forecasting	Expert Systems with Applications
2009	A new method to forecast the TAIEX based on fuzzy time series	International Conference on Systems, Man and Cybernetics
2009	A genetic network programming with learning approach for enhanced stock trading model	Expert Systems with Applications
2009	Robustness of multiple objective GP stock-picking in unstable financial markets	Annual conference on Genetic and evolutionary computation (GECCO)
2009	Improvement of auto-regressive integrated moving average models using fuzzy logic and artificial neural networks (ANNs)	Neurocomputing
2009	Financial time series forecasting using independent component analysis and support vector regression	Decision Support Systems
2009	A fuzzy GARCH model applied to stock market scenario using a genetic algorithm	Expert Systems with Applications

2009	A hybrid SOFM-SVR with a filter-based feature selection for stock market forecasting	Expert Systems with Applications
2009	A two-stage architecture for stock price forecasting by integrating self-organizing map and support vector regression	Expert Systems with Applications
2009	Stock market prediction of S&P 500 via combination of improved BCO approach and BP neural network	Expert Systems with Applications
2009	Forecasting stock price using nonlinear independent component analysis and support vector regression	IEEE International Conference on Industrial Engineering and Engineering Management
2009	An intelligent hybrid Morphological-rank-linear method for financial time series prediction	Neurocomputing
2009	Forecasting stock market indices using hybrid network	World Congress on Nature & Biologically Inspired Computing (NaBIC)
2009	Evolving least squares support vector machines for stock market trend mining	IEEE Transactions on Evolutionary Computation
2009	Price forecasting algorithm for coal and electricity based on PSO and RBF neural network	IEEE International Conference on Control and Automation
2009	Day-ahead price forecasting of electricity markets by mutual information techniques and cascaded neuro-evolutionary algorithm	IEEE Transactions on Power Systems
2009	Self-adaptive RBF neural network for short-term electricity price forecasting	IET Generation, Transmission & Distribution
2009	Fuel oil price forecasting using symbiotic evolutionary immune clustering neural network	International Conference on Intelligent Computing Technology and Automation
2009	Improving option price forecasts with neural networks and support vector regressions	Neurocomputing
2009	Stock price prediction using neural networks with RasID-GA	IEEJ Transactions on Electrical and Electronic Engineering
2009	A combination of hidden Markov model and fuzzy model for stock market forecasting	Neurocomputing
2009	A novel algorithm for prediction of crude oil price variation based on soft computing	Energy Economics
2009	Candlestick analysis based short term prediction of stock price fluctuation using SOM-CBR	IEEE International advance computing conference
2009	Stock Price Forecasting by Hybrid Machine Learning Techniques	International Multi Conference of Engineers and Computer Scientists
2009	Dynamically exploring internal mechanism of stock market by fuzzy-based support vector machines with high dimension input space and genetic algorithm	Expert Systems with Applications
2009	Evolving and clustering fuzzy decision tree for financial time series data forecasting	Expert Systems with Applications
2009	Financial market trading system with a hierarchical co-evolutionary fuzzy predictive model	IEEE Transactions on Evolutionary Computation
2009	Integrating a piecewise linear representation method and a neural network model for stock trading points Prediction	IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)

2009	A quantitative stock prediction system based on financial news	Information Processing & Management
2009	A hybrid stock trading system for intelligent technical analysis-based equivolume charting	Neurocomputing
2009	Trading strategy design in financial investment through a turning points prediction scheme	Expert Systems with Applications
2009	Textual Analysis of Stock Market Prediction Using Breaking Financial News: The AZFinText System	ACM Transactions on Information Systems
2009	Predicting Stock Trends through Technical Analysis and Nearest Neighbor Classification	IEEE international conference on systems, man, and cybernetics (SMC)
2009	An early warning system for global institutional investors at emerging stock markets based on machine learning Forecasting	Expert Systems with Applications
2009	Using support vector machine with a hybrid feature selection method to the stock trend Prediction	Expert Systems with Applications
2009	Forecasting volatility based on wavelet support vector machine	Expert Systems with Applications
2009	A type-2 fuzzy rule-based expert system model for stock price analysis	Expert Systems with Applications
2009	Exchange Rate Forecasting Using a Combined Parametric and Nonparametric Self-Organising Modelling Approach	Expert Systems with Applications
2009	Stock index prediction: A comparison of MARS, BPN and SVR in an emerging market	International Conference on Industrial Engineering and Engineering Management
2009	Prediction of Stock Market Index Movement by Ten Data Mining Techniques	Modern Applied Science
2009	Multi-step ahead forecasts for electricity prices using NARX: A new approach, a critical analysis of one-step ahead forecasts	Energy Conversion and Management
2009	Stock return forecast with LS-SVM and particle swarm Optimization	International Conference on Business Intelligence and Financial Engineering
2010	An Adaptive Network-Based Fuzzy Inference System (ANFIS) for the prediction of stock market return: The case of the Istanbul Stock Exchange	Expert Systems with Applications
2010	Sequential combination of statistics, econometrics and Adaptive Neural-Fuzzy Interface for stock market prediction	Expert Systems with Applications
2010	Momentum Analysis Based Stock Market Prediction Using Adaptive Neuro-Fuzzy Inference System (ANFIS)	International Multi Conference of Engineers and Computer Scientists
2010	A multiscale neural network learning paradigm for financial crisis forecasting	Neurocomputing
2010	Modelling and trading the EUR/USD exchange rate at the ECB fixing	The European Journal of Finance
2010	Forecasting stock exchange movements using neural networks: empirical evidence from Kuwait	Expert Systems with Applications
2010	Stock Exchange of Thailand Index Prediction Using Back Propagation Neural Networks	International Conference on Computer and Network Technology

2010	Moving average crossovers for short-term equity investment with L-GEM based RBFNN	International Conference on Machine Learning and Cybernetics
2010	An enhanced radial basis function network for short-term electricity price forecasting	Applied Energy
2010	Study on stock price prediction based on BP neural network	IEEE International conference on Emergency Management and Management Sciences (ICEMMS)
2010	Stock data analysis based on BP neural network	International Conference on Communication Software and Networks
2010	Stock market value prediction using neural networks	International Conference on Computer Information Systems and Industrial Management Applications (CISIM)
2010	Stock market forecasting research based on neural network and pattern matching	International Conference on E-Business and E-Government
2010	Improving financial time series prediction using exogenous series and neural networks committees	International joint conference on neural networks (IJCNN)
2010	TAR-Cointegration Neural Network Model: An Empirical Analysis of Exchange Rates and Stock Returns	Expert Systems with Applications
2010	A discrete stock price prediction engine based on financial news	Computer
2010	Investment using evolutionary learning methods and technical rules	European Journal of Operational Research
2010	Mining associative classification rules with stock trading data-A GA-based method	Knowledge-Based Systems
2010	Forecasting oil price trends using wavelet and hidden Markov models	Energy Economics
2010	Chaos-based support vector regressions for exchange rate forecasting	Expert Systems with Applications
2010	A neural network-based fuzzy time series model to improve forecasting	Expert Systems with Applications
2010	Adapted Neuro-Fuzzy Inference System on indirect approach TSK fuzzy rule base for stock market analysis	Expert Systems with Applications
2010	Integrating independent component analysis-based denoising scheme with neural network for stock price prediction	Expert Systems with Applications
2010	Integrating recurrent SOM with wavelet-based kernel partial least square regressions for financial forecasting	Expert Systems with Applications
2010	Developing an Evolutionary Neural Network Model for Stock Index Forecasting	International Conference on Intelligent Computing
2010	Hybrid forecasting model research on stock data mining	International conference on new trends in information science and service science
2010	A hybrid intelligent morphological approach for stock market forecasting	Neural Processing Letters
2010	Forecast Combination by Using Artificial Neural Networks	Neural Processing Letters
2010	A Stock Market Trend Prediction System Using a Hybrid Decision Tree-Neuro-Fuzzy System	International Conference on Advances in Recent Technologies in Communication and Computing
2010	A Decision Tree- Rough Set Hybrid System for Stock Market Trend Prediction	International Journal of Computer Applications
2010	A Genetic Algorithm Optimized Decision Tree-SVM based Stock Market Trend Prediction System	International Journal on Computer Science and Engineering

2010	Application of Fuzzy-Neural Networks in Multi-Ahead Forecast of Stock Price	African Journal of Business Management
2010	Overcoming the random walk dilemma using a covariance matrix adaptation evolutionary method	IEEE international conference on systems, man, and cybernetics (SMC)
2010	Swarm-based translation-invariant morphological method for financial time series forecasting	Information Sciences
2010	Comparative study between differential evolution and particle swarm optimization algorithms in training of feed-forward neural network for stock price prediction	International Conference on Informatics and Systems
2010	A quantum-inspired evolutionary hybrid intelligent approach for stock market prediction	International Journal of Intelligent Computing and Cybernetics
2010	Integration of genetic fuzzy systems and artificial neural networks for stock price forecasting	Knowledge-Based Systems
2010	Hybrid intelligent methodology to design translation invariant morphological operators for brazilian stock market prediction	Neural Networks
2010	Combining multiple feature selection methods for stock prediction: Union, intersection, and multi-intersection approaches	Decision Support Systems
2010	A covariance matrix adaptation based evolutionary methodology for phase adjustment in financial time series forecasting	Annual conference on Genetic and evolutionary computation (GECCO)
2010	Automatic stock decision support system based on box theory and SVM algorithm	Expert Systems with Applications
2010	A hybrid model based on rough sets theory and genetic algorithms for stock price forecasting	Information Sciences
2010	Making Words Work: Using Financial Text as a Predictor of Financial Events	Decision Support Systems
2010	A method for automatic stock trading combining technical analysis and nearest neighbor classification	Expert Systems with Applications
2010	Semi-Automatic Financial Events Discovery Based on Lexico-Semantic Patterns	International Journal of Web Engineering and Technology
2010	Developing a time series model based on particle swarm optimization for gold price forecasting	International Conference on Business Intelligence and Financial Engineering
2010	Towards Stock Market Data Mining Using Enriched Random Forests from Textual Resources and Technical Indicators	IFIP International Conference on Artificial Intelligence Applications and Innovations
2011	Elliott Wave Theory and neuro-fuzzy systems, in stock market prediction: The WASP system	Expert Systems with Applications
2011	An adaptive neuro-fuzzy system for stock portfolio analysis	International Journal of Intelligent Systems
2011	Stock trading with cycles: A financial application of ANFIS and reinforcement learning	Expert Systems with Applications
2011	Design and analysis of experiments in ANFIS modeling for stock price prediction	International Journal of industrial Engineering Computations
2011	A novel FOREX prediction methodology based on fundamental data	African Journal of Business Management

2011	Forecasting stock exchange movements using neural networks: a case study	International Conference on Future Computer Sciences and Application
2011	An Artificial Neural Network Model to Forecast Exchange Rates	Journal of Intelligent Learning Systems and Applications
2011	Exchange rate forecasting: Comparison of various architectures of neural networks	Neural Computing And Applications
2011	Higher order and recurrent neural architectures for trading the EUR/USD exchange rate	Quantitative Finance
2011	Using artificial neural network models in stock market index prediction	Expert Systems with Applications
2011	Mining electricity prices in energy markets using a computationally efficient neural network	IEEE International Conference on Energy, Automation and Signal (ICEAS)
2011	Nonlinear maximum likelihood estimation of electricity spot prices using recurrent neural networks	Neural Computing And Applications
2011	The use of artificial neural networks in the analysis and prediction of stock prices	IEEE international conference on systems, man, and cybernetics (SMC)
2011	On the nonlinear predictability of stock returns using financial and economic variables	Journal of Business and Economic Statistics
2011	A modern neural network model to do stock market timing on the basis of the ancient investment technique of Japanese Candlestick	Expert Systems with Applications
2011	The three-factor model and artificial neural networks: predicting stock price movement in China	Annals of Operations Research
2011	Stock investment decision support for Hong Kong market using RBFNN based candlestick models	International Conference on Machine Learning and Cybernetics
2011	CAST: Using neural networks to improve trading systems based on technical analysis by means of the RSI financial indicator	Expert Systems with Applications
2011	Mining the co-movement in the Taiwan stock funds market	Expert Systems with Applications
2011	Mining the co-movement between foreign exchange rates and category stock indexes in the Taiwan financial capital Market	Expert Systems with Applications
2011	TAIEX forecasting based on fuzzy time series and fuzzy variation groups	IEEE Transactions on Fuzzy Systems
2011	Fuzzy wavelet neural network based on fuzzy clustering and gradient techniques for time series prediction	Neural Computing And Applications
2011	A hybrid ANFIS model based on AR and volatility for TAIEX forecasting	Applied Soft Computing
2011	Forecasting stock indices with wavelet domain kernel partial least square regressions	Applied Soft Computing
2011	Forecasting stock markets using wavelet transforms and recurrent neural networks: An integrated system based on artificial bee colony algorithm	Applied Soft Computing
2011	A hybrid model based on adaptive-network-based fuzzy inference system to forecast Taiwan stock market	Expert Systems with Applications

2011	A multiple-kernel support vector regression approach for stock market price forecasting	Expert Systems with Applications
2011	Evolutional RBFNs prediction systems generation in the applications of financial time series data	Expert Systems with Applications
2011	A GA-Artificial Neural Network Hybrid System for Financial Time Series Forecasting	Information Technology and Mobile Communication
2011	The forecasting of Shanghai Index trend Based on Genetic Algorithm and Back Propagation Artificial Neural Network Algorithm	International Conference on Computer Science & Education (ICCSE 2011)
2011	Forecasting stock indices using radial basis function neural networks optimized by artificial fish swarm algorithm	Knowledge-Based Systems
2011	Trend discovery in financial time series data using a case based fuzzy decision tree	Expert Systems with Applications
2011	A comparative study of artificial neural networks, and decision trees for digital game content stocks price prediction	Expert Systems with Applications
2011	A hybrid procedure for stock price prediction by integrating self-organizing map and genetic programming	Expert Systems with Applications
2011	Translation invariant morphological time-lag added evolutionary forecasting method for stock market prediction	Expert Systems with Applications
2011	A Comparison of PNN and SVM for Stock Market Trend Prediction using Economic and Technical Information	International Journal of Computer Applications
2011	A new support vector machine- genetic algorithm (SVMGA) based method for stock market forecasting	International Journal of the Physical Sciences
2011	Predicting a distribution of implied volatilities for option pricing	Expert Systems with Applications
2011	Predicting stock returns by classifier ensembles	Applied Soft Computing
2011	A dynamic threshold decision system for stock trading signal detection	Applied Soft Computing
2011	Evaluation Approach to Stock Trading System using Evolutionary Computation	Expert Systems with Applications
2011	Intelligent stock trading system based on improved technical analysis and Echo State Network	Expert Systems with Applications
2011	Applying a combined fuzzy systems and GARCH model to adaptively forecast stock market volatility	Applied Soft Computing
2011	Stock trend prediction based on fractal feature selection and support vector machine	Expert Systems with Applications
2011	Twitter mood predicts the stock market	Journal of Computational Science
2011	Predicting direction of stock price index movement using artificial neural networks and support vector machines: the sample of the Istanbul stock exchange	Expert Systems with Applications
2012	Fluctuation prediction of stock market index by Legendre neural network with random time strength function	Neurocomputing

2012	Using neural network for forecasting TXO price under different volatility models	Expert Systems with Applications
2012	Stock Price Prediction using Neural Network with Hybridized Market Indicators	Journal of Emerging Trends in Computing and Information Sciences
2012	Stock investment decision support using an ensemble of L-GEM based on RBFNN diverse trained from different years	International Conference on Machine Learning and Cybernetics
2012	Forecasting nonnegative option price distributions using Bayesian kernel methods	Expert Systems with Applications
2012	Stock price forecast using Bayesian network	Expert Systems with Applications
2012	Electricity Price Forecasting With Extreme Learning Machine and Bootstrapping	IEEE Transactions on Power Systems
2012	A PSO based integrated functional link net and interval type-2 fuzzy logic system for predicting stock market indices	Applied Soft Computing
2012	Application of type-2 neuro-fuzzy modeling in stock price prediction	Applied Soft Computing
2012	Forecasting shanghai composite index based on fuzzy time series and improved C-fuzzy decision trees	Expert Systems with Applications
2012	Improving financial returns using neural networks and adaptive particle swarm optimization	International Conference on Business Intelligence and Financial Engineering
2012	Index prediction with neuro-genetic hybrid network: A comparative analysis of performance	International conference on computing, communication and applications (ICCCA)
2012	Indian stock market prediction using differential evolutionary neural network model	International Journal of Electronics Communication and Computer Technology (IJECCT)
2012	A hybrid recurrent neural networks model based on synthesis features to forecast the Taiwan stock market	International journal of innovative computing, information & control: IJICIC
2012	Hybridization of evolutionary Levenberg–Marquardt neural networks and data pre-processing for stock market prediction	Knowledge-Based Systems
2012	A flexible neural network-fuzzy mathematical programming algorithm for improvement of oil price estimation and forecasting	Computers & Industrial Engineering
2012	Crude oil price forecasting: Experimental evidence from wavelet decomposition and neural network modeling	Energy Economics
2012	A novel model by evolving partially connected neural network for stock price trend forecasting	Expert Systems with Applications
2012	Probing Efficiency Scale of Fuzzy Neural Network on forecasting Stock Exchange of the Automobile Industries in Iran	Indian Journal of Science and Technology
2012	A robust automatic phase-adjustment method for financial forecasting	Knowledge-Based Systems
2012	Using multi-stage data mining technique to build forecast model for Taiwan stocks	Neural Computing and Applications
2012	A hybrid stock selection model using genetic algorithms and support vector regression	Applied Soft Computing

2012	The application of fuzzy neural networks in stock price forecasting based on genetic algorithm discovering fuzzy rules	International Conference on Natural Computation (ICNC 2012)
2012	A hybrid modeling approach for forecasting the volatility of S&P 500 index return	Expert Systems with Applications
2012	Classification of stock index movement using k-nearest neighbours (k-NN) algorithm	Wseas Transactions On Information Science And Applications
2012	A multi-agent-based decision support system for bankruptcy contagion effects	Expert Systems with Applications
2012	Modeling and Trading the EUR/USD Exchange Rate Using Machine Learning Techniques	Engineering, Technology & Applied Science Research
2012	A Comparison of Ensemble Methods in Financial Market Prediction	International Joint Conference on Computational Sciences and Optimization (CSO)
2012	Forecasting trends of high-frequency KOSPI200 index data using learning classifiers	Expert Systems with Applications
2012	Forecasting gold price changes by using adaptive network fuzzy inference system	Journal of Business Economics and Management
2013	An adaptive network-based fuzzy inference system (ANFIS) for the forecasting: The case of close price indices	Expert Systems with Applications
2013	The case study of adaptive network-based fuzzy inference system modeling for TAIEX prediction	International Conference on Genetic and Evolutionary Computing (ICGEC)
2013	International transmission of stock market movements: An adaptive neuro-fuzzy inference system for analysis of TAIEX forecasting	Neural Computing And Applications
2013	A Bayesian regularized artificial neural network for stock market forecasting	Expert Systems with Applications
2013	An investment strategy for the stock exchange using neural networks	Federated Conference on Computer Science and Information Systems
2013	Applying Artificial Neural Networks to prediction of stock price and improvement of the directional prediction index–Case study of PETR4	Expert Systems with Applications
2013	Forecasting large scale conditional volatility and covariance using neural network on GPU	The Journal of Supercomputing
2013	Fuzzy logic, trading uncertainty and technical trading	Journal of Banking & Finance
2013	Empirical analysis of model selection criteria for genetic programming in modeling of time series system	IEEE Conference on Computational Intelligence for Financial Engineering & Economics (CIFEr)
2013	Ensemble ANNs-PSO-GA Approach for Day-ahead Stock E-exchange Prices Forecasting	International Journal of Computational Intelligence Systems
2013	A HMM-based adaptive fuzzy inference system for stock market forecasting	Neurocomputing
2013	Integration of nonlinear independent component analysis and support vector regression for stock price forecasting	Neurocomputing
2013	A hybrid procedure with feature selection for resolving stock/futures price forecasting problems	Neural Computing And Applications

2013	A hybrid intelligent model based on recurrent neural networks and excitable dynamics for price prediction in deregulated electricity market	Engineering Applications of Artificial Intelligence
2013	Support vector regression with chaos-based firefly algorithm for stock market price forecasting	Applied Soft Computing
2013	A Morphological-Rank-Linear evolutionary method for stock market prediction	Information Sciences
2013	A Study on Feature Selection for Trend Prediction of Stock Trading Price	International Conference on Computational and Information Sciences
2013	Integrating Piecewise Linear Representation and Weighted Support Vector Machine for Stock Trading Signal Prediction	Applied Soft Computing
2013	Automatic method for stock trading combining technical analysis and the artificial bee colony algorithm	IEEE Congress on Evolutionary Computation
2013	Stock Market Prediction Using a Combination of Stepwise Regression Analysis, Differential Evolution-based Fuzzy Clustering, and a Fuzzy Inference Neural Network	Intelligent Automation & Soft Computing
2013	Data mining investigation of co-movements on the Taiwan and China stock markets for future investment portfolio	Expert Systems with Applications
2013	An SVM-based Approach for Stock Market Trend Prediction	International Joint Conference on Neural Networks
2013	Forecasting IBEX-35 moves using support vector machines	Neural Computing And Applications
2013	Evaluation of GARCH, RNN, and FNN models for forecasting volatility in the financial markets	IUP Journal of Financial Risk Management
2014	A new constructive neural network method for noise processing and its application on stock market prediction	Applied Soft Computing
2014	Volatility forecast using hybrid Neural Network models	Expert Systems with Applications
2014	A causal feature selection algorithm for stock prediction modeling	Neurocomputing
2014	An Automated Framework for Incorporating News into Stock Trading Strategies	IEEE Transactions on Knowledge and Data Engineering
2014	A hybrid evolutionary dynamic neural network for stock market trend analysis and prediction using unscented Kalman filter	Applied Soft Computing
2014	A high-order fuzzy time series forecasting model for internet stock trading	Future Generation Computer Systems
2014	A self adaptive differential harmony search based optimized extreme learning machine for financial time series Prediction	Swarm and Evolutionary Computation
2014	Automated trading with performance weighted random forests and seasonality	Expert Systems with Applications
2014	A SVM Stock Selection Model within PCA	Procedia Computer Science
2014	LG-Trader: Stock trading decision support based on feature selection by weighted localized generalization error model	Neurocomputing

2014	The effectiveness of the combined use of VIX and Support Vector Machines on the prediction of S&P 500	Neural Computing And Applications
2014	Parametric models and non-parametric machine learning models for predicting option prices: Empirical comparison study over KOSPI 200 Index options.	Expert Systems with Applications
2015	Stock Market Prediction using Artificial Neural Networks. Case Study of TAL1T, Nasdaq OMX Baltic Stock	Database Systems Journal
2015	An Artificial Neural Network for Data Forecasting Purposes	Informatica Economica
2015	Predicting stock market index using fusion of machine learning techniques	Expert Systems with Applications
2015	Forecasting financial time series using a low complexity recurrent neural network and evolutionary learning approach	Journal of King Saud University - Computer and Information Sciences
2015	A bat-neural network multi-agent system (BNNMAS) for stock price prediction: Case study of DAX stock price	Applied Soft Computing
2015	Developing an approach to evaluate stocks by forecasting effective features with data mining methods	Expert Systems with Applications
2015	Gold price volatility: A forecasting approach using the Artificial Neural Network–GARCH model	Expert Systems with Applications
2015	Using volume weighted support vector machines with walk forward testing and feature selection for the purpose of creating stock trading Strategy	Expert Systems with Applications
2015	Predicting stock and stock price index movement using trend deterministic data preparation and machine learning techniques	Expert Systems with Applications
2015	Evaluating multiple classifiers for stock price direction prediction	Expert Systems with Applications
2015	An evolutionary trend reversion model for stock trading rule discovery	Knowledge-Based Systems
2016	Extended forecast methods for day-ahead electricity spot prices applying artificial neural networks	Applied Energy
2016	A hybrid stock trading framework integrating technical analysis with machine learning techniques	The Journal of Finance and Data Science
2016	Empirical analysis: stock market prediction via extreme learning Machine	Neural Computing and Applications
2016	An adaptive stock index trading decision support system	Expert Systems With Applications
2016	A Stock Market Prediction Method Based on Support Vector Machines (SVM) and Independent Component Analysis (ICA)	Database Systems Journal
2016	Cognitive Intelligence based Expert System for Predicting Stock Markets using Prospect Theory	Indian Journal of Science and Technology
2016	Predicting Market Impact Costs Using Nonparametric Machine Learning Models	PLOS ONE (Public Library Of Science)