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Application and Development of Mathematical Model in Stock Price Prediction

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Abstract. Stock price prediction is extremely important for financial investment. Quantitative analysis based on mathematical models is the main research method. In order to further study and analyze the development trend of stock price prediction models, this paper retrieves the academic paper with the highest number of citations on stock price prediction in the past 10 years and conducts research and analysis. It is found that the number of research works on stock price prediction has increased exponentially in the past 10 years. Researchers mainly use deep learning models to predict and analyze stock prices. In the past two years, the big data model has shown great potential to predict stock prices and will become the most important modeling tool in the future. Meanwhile, the advantages and disadvantages of various mathematical models are analyzed, and the future stock price prediction methods are discussed. This work is of great significance for researchers to predict stock prices.

Keywords: Time Serials Analysis, Machine Learning, Large Language Model

1. Introduction

Stock is an important component of the financial market. Price change has nonlinear and multi-source driving characteristics (such as policy, public opinion, macro economy, etc). The prediction of stock price is a hot research topic with both theoretical value and practical significance. For a long time, it has been an important research method to predict stock prices by quantifying the factors that have an impact on stock prices and using mathematical models.

Investors predict stock prices based on two aspects: fundamental analysis and technical analysis. Fundamental analysis includes the company's business environment, financial performance, economic data, social and political behavior, etc. Technical analysis is mainly used to predict the future stock price through historical data that includes the daily opening price, the highest price, the lowest price and the closing price. Technical analysis is mainly through establishing mathematical models to process historical data to predict future prices. With the development of statistics and machine learning, relevant researchers have adopted a variety of models to do this work, such as time series analysis [1, 2], support vector machine [3, 4], random forest [5], deep learning [6], etc. Although the stock price is easily affected by political, social and economic factors, which have great uncertainty. Related research works show that the accuracy of prediction can exceed 70%

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under some conditions by combining historical stock data and other influential data to establish a mathematical model [7].

In order to clarify the development of stock price prediction methods, this paper retrieves the highest cited papers on stock price prediction in the past 10 years, and selects 2 to 3 of the most important papers every year to read and analyze. It is found that the primary method is to establish a mathematical model for quantitative analysis. Time series models were the main method 10 years ago, machine learning models have been very popular in the past 10 years, and large language models have been gradually adopted in the past 2 years [8-13]. According to the intrinsic characteristics of these modeling methods, the history of stock prediction is analyzed and the future of stock price prediction is discussed. More specifically, the contributions are:

(1) The main stock price prediction methods in the past 10 years are systematically analyzed, including time series models, machine learning models and large language models.

(2) Taking the factors that are related to the stock market into consideration, the advantages and disadvantages of various mathematical models are summarized.

(3) By analyzing the intrinsic features of the stock market and establishing conditions of various mathematical models, it is found that the big language model will have a great potential impact on future stock price prediction.

2. Stock price prediction based on time series analysis

For discovering the influential mathematical models that are used to predict stock prices, this paper retrieves relevant academic literature in Google Scholar. Figure 1 shows the number of documents retrieved from 2014 to 2024. It can be clearly seen from Figure 1 that the related research works on stock price prediction are exponentially increasing. It indicates that with the gradual improvement of the financial market, people have shown more and more interest in stock prices.

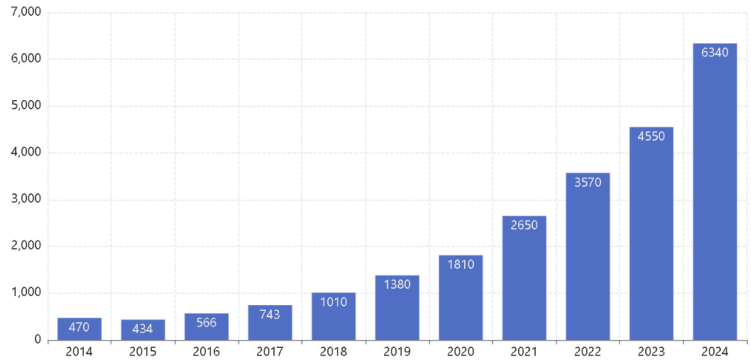

Figure 1. The number of stock price research works from 2014 to 2024

Stock price prediction is mainly based on statistical time series analysis. Firstly, the historical data of stock prices are collected, and then the future stock prices are predicted based on a variety of time series analysis models.

$$X(t) = T(t) + S(t) + R(t), t = 1,2,3 \ldots\ldots \quad (1)$$

The time series is represented as formula (1), where X is the time series, T is the trend term, S is the periodic term, and R is the random term. Time series analysis should decompose X into T, S and

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R, and then according to the law of series data to establish a mathematical model to discover the changing rules. Finally, the value of X in the next time window will be calculated [1].

The basic idea of time series analysis to predict stock price is to establish a mathematical model that can accurately reflect the law of data changes to predict future prices based on the past records of stock prices. In 2014, Reference [2] used the ARIMA model to predict the trading price of the New York stock market and the Nigerian stock market. Early studies have found that a time series model has strong predictive ability for short-term trading prices.

Time series analysis is intuitively a very good mathematical tool for analyzing stock prices. Then, with the deepening of the research, it is found that the change of stock price will be affected by many factors, and only based on historical prices can an effective prediction mechanism be established [14-17]. In the long run, the price time series data show obvious uncertainty and nonlinear characteristics. The classical time series analysis model cannot capture these laws, which leads to the problem of over-fitting in the prediction model [18-21].

3. Stock price prediction based on machine learning

Since 2015, artificial intelligence was developing more quickly than before, machine learning received more attention and gradually became the main method to study stock price prediction.

Compared with the time series analysis method, machine learning has better flexibility and scalability. Based on the stock price time series data, it takes sentiment analysis, social media data analysis and other features into consideration to model the stock price change. The forms of data are more and more diverse, the analysis capability is more and powerful [21-25].

3.1. Stock price prediction based on statistical methods

Machine learning in 2014 and 2015 was mainly applied in data classification, methods such as Support Vector Machine (SVM) and Random Forest (RF) aim to classify all kinds of data. Based on these methods, it is very easy to develop a powerful, flexible and easy-to-use ensemble learning algorithm.

Related research works are mainly based on the historical data of stock trading to establish a prediction model. Reference [3] establishes a stock price prediction model based on SVM, which, through the analysis of the stock price data of Yahoo Finance, it is found that prediction accuracy can reach more than 78%, and it has better performance than a time series prediction model in terms of over-fitting. Reference [4] establishes a hybrid model based on time series analysis and SVM, which firstly decomposes the time series data of stock price into trend term, fluctuation term and random term by singular spectrum analysis, and then establishes a prediction model based on SVM to study the Shanghai stock trading market. Results show the forecasting error of this model outperform models in the past research works. Reference [5] takes people's emotions and opinions into consideration and establishes a model based on Naive Bayes and RF to analyze the stock price in Indonesia. It is found that the prediction accuracy of this model can reach 67%.

Although the stock price prediction model can be established quickly based on SVM and RM models, these models have poor interpretability and weak reasoning ability, and it is difficult to be effective for actual stock investment.

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3.2. Stock price prediction based on deep learning

With the development of Neural Network (NN) technology, the number of layers in NN increases very fast. Deep learning methods are mainly constructed on multilayer neural networks.

The Neural network has a much more powerful reasoning capability than traditional statistical models. Stock price prediction researchers have been more inclined to use a deep learning algorithm to establish a prediction model since 2015.

In 2019, Reference [14] compared the four modeling methods of Artificial Neural Network (ANN), SVM, RF and Long Short Term Memory (LSTM) based on the daily stock closing price of iShares MSCI in the UK stock exchange market from 2015 to 2018. The analysis found that the model established based on LSTM outperforms the other three models.

Table 1. Methods of deep learning in stock prediction

Method	Reference	Advantages and disadvantages
ANN	[6,9]	Advantages: nonlinear modeling; better pattern recognition and feature learning; high-dimensional data processing; good flexibility and adaptability. Disadvantages: difficult to adapt to the dynamic changes of the market; high risk of overfitting; complex model debugging; high requirements for data quality; model training requires high computational resources and costs more.
CNN	[8,12,19,23,25]	Advantages: strong local feature and pattern extraction ability; high training efficiency and low over-fitting risk; it takes short-term fluctuations and long-term trends into consideration; multivariate analysis. Disadvantages: the training model may be ineffective in the future; the input data structure of the model has a great influence on performance.
DNN	[10,16,17]	Advantages: good nonlinear analysis ability; automatic feature extraction; better ability to adapt to high-dimensional feature space; good flexibility and versatility Disadvantages: high risk of overfitting; unexplainable decision-making process; high requirements for data preprocessing; high calculation cost and long training time
RNN LSTM	[11,15,13,18,21,24]	Advantages: good memory ability; variable length sequence data processing; good dynamic modeling and online learning ability, sensitive to data input order and better description of the logic of stock price change. Disadvantages: high risk of overfitting; high computational complexity; difficult to adapt to a non-stationary market; high requirements for input features
GAN	[20]	Advantages: better data enhancement and ability to solve overfitting; ability to generate realistic market scenarios for stress testing; better strengthening robustness for the prediction model; supporting unsupervised learning Disadvantages: complex training; mode collapse; difficult to evaluate; high complexity

Table 1 summarizes the deep learning methods used in stock price prediction in the past 10 years and based on these methods, the highly cited papers are classified, meanwhile, the advantages and disadvantages are illustrated.

It can be shown that these deep learning methods have common advantages and disadvantages, but also have their own characteristics. For example, deep learning has good nonlinear modeling ability to overcome over-fitting influence. ANN is a basic NN-based deep learning model with strong scalability. Convolutional Neural Network (CNN) has strong feature extraction ability, Deep Neural Network (DNN) has automatic feature extraction ability, and Recurrent Neural Network (RNN) can process long sequence data and has stronger learning ability. Although Generative

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Adversarial Networks (GAN) can enhance the data quality to solve the problem of partial overfitting, the training is difficult and the extracted features are prone to lapse.

Deep learning method enhances the prediction ability of stock price, but when faced with stock market dynamic changes, it still cannot significantly improve the prediction accuracy of stock price.

3.3. Stock price prediction based on a Large Language Model

Large Language Model (LLM) is a revolutionary technology in the field of artificial intelligence. It is trained based on massive text data and establishes a powerful probability prediction mechanism and knowledge compression mechanism. The rise of LLM is inseparable from the Transformer architecture proposed by Google in 2017. It is a new generation of deep learning models that replaces RNN and LSTM. The prominent feature of LLM is the self-attention mechanism, which can well understand the relationship within the data.

Reference [22] uses the Transformer model to study the Bangladesh stock market based on five stock price indexes. The study found that the prediction error was lower and the efficiency was higher than the results in past research works that used deep learning to model the stock price change. It can not only predict the stock price of a trading day, but also predict the stock price in a week, and this prediction method has long-term and short-term prediction capabilities. Reference [26] took GDP growth, consumer price, unemployment into consideration based on the five stock price data in reference [22], and proposed an improved Transformer-based model to predict Apple's stock price. This work shows that the model can better capture the correlation of long-term and short-term time series data, and performs better than traditional machine learning models in terms of prediction error and stability. Research work in reference [27] used Apple's six-year transaction data on the Nasdaq as data sources. For improving the prediction accuracy, it also takes other auxiliary data into consideration, such as transaction data from Amazon, Google, and Microsoft, the Chicago Board Options Exchange VIX index and the exchange rate of the RMB against the US dollar. A novel model based on GAN and an improved Transformer was put forward to do stock price prediction work. Results showed that this hybrid model has very good performance. Compared with the traditional machine learning model, it significantly reduces the square root error and can provide valuable information for making investment decisions.

Through the study of the above research works and the comprehensive review of papers related to LLM, it can be concluded that the LLM has the following two significant advantages for stock price prediction.

Firstly, Unstructured data processing capability. Traditional quantitative models can only process digital and structured data, such as price, volume, financial indicators, etc. However, LLM can process and understand massive unstructured text data, especially multimodal large models, which can process voice, text, pictures, video and other data formats. Stock prediction often needs to analyze a lot of factors, which have a variety of data forms, such as corporate fiscal records, news articles, and media reports. Social media sentiment, analyst research reports, macroeconomic policy announcements, important speeches, etc., and only an LLM can integrate so many kinds of data into a unified model to conduct stock price prediction.

Secondly, strong reasoning and logical analysis ability. LLM can discover the correlation in high-volume data to implement causal reasoning and logical chain analysis. For example, it can make a multi-step inference that the Federal Reserve issued a statement of interest rate hikes, resulting in rising bank loan costs, which in turn inhibited the investment of technology companies, so the Nasdaq index may be under pressure. The traditional model cannot perform this type of reasoning, which can catch the intrinsic attributes in stock prediction.

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However, LLM has the risk of illusion, for example, it may fake a financial report, fabricate a non-existent number, or wrongly place the news of one company on the head of another company. Therefore, it is absolutely impossible for LLM to directly output a target stock price without fact checking. Meanwhile, the training cost and operation cost of LLM are very high. When faced with the changing stock market, it is necessary to continuously monitor prediction results and re-train the model to prevent over-fitting.

4. Conclusion

In this paper, the mathematical models in the high-quality papers on stock prediction in the past 10 years are studied and analyzed systematically. The development of mathematical modelling methods for stock prediction is clearly illustrated, and the advantages and disadvantages of these methods are studied. The stock market has great uncertainty and the stock price is susceptible to many factors such as policy, politics, military, society, and economy. Based on historical data, 100 % accuracy cannot be achieved. Meanwhile, these laws for stock prediction can be concluded:

Time series analysis is the basic method for establishing a stock price model, and deep learning has dominated the past 10 years of research work in this field. With the rapid progress in artificial intelligence, researchers are paying more and more attention to stock price prediction, and LLM will be used widely to establish models to do this work.

In the future, the stock price prediction will depend on a variety of data sources, including social media data, sentiment data, industry research reports, bank consulting, financial analysis, etc., and the capability of a mathematical model that can process various polymorphic data. With the improvement of LLM and the complement to the data, stock price prediction will benefit all investors, and the stock market will get better and better.

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