

Research Article

Improving Stock Price Volatility Prediction Models Using Machine Learning and Statistical Techniques

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ABSTRACT

This research aims to improve forecasting models for the volatility of stock prices in Saudi banks by using machine learning algorithms and parameter optimization techniques such as Grid Search. The goal of this study is to improve forecasting models. Grid Search is going to be used in order to attain this goal. We examined the price information that Al Rajhi Bank has accumulated over a considerable length of time and the results were analyzed. The starting and closing prices, the highest and lowest values, the trading volume, and the daily percentage change were all included in this. Additionally, the trade volume was an important factor. In order to throw light on the general patterns that were present, we used descriptive data analysis. Given that the Saudi financial market is driven by both internal and external variables, the data indicated that there was a substantial degree of variation in both the trading volume and the price. This is typical for the Saudi market since it is influenced by both types of factors. Next, a machine learning model that was produced based on Random Forest was developed, along with a linear regression model and a ridge model. After that these models were constructed. Taking into account the outcomes of the research, the Random Forest model, which had been enhanced via the use of Grid Search, was the most accurate in terms of predicting future volatility. The coefficient of determination (R^2) value of about 0.86 makes it superior than linear models in terms of its capacity to make assumptions and predictions. Moreover, the results indicate the need of using nonlinear models in combination with optimization methodologies in order to focus on the complicated relationships that exist between financial issues and price fluctuations. This is because the outcomes highlight the need to use nonlinear models.

1. INTRODUCTION

The volatility of stock prices is a critical factor that influences the investment techniques and risk management in the stock market, and that is why the volatility of stock prices has become a matter of concern to academics and investors alike to an immense extent. A knowledge of the factors that lead to this instability could assist the actors to enhance their decision making ability. To minimize the risk of exposure to financial unsettling, the investors can minimize their exposure through analyzing the past and the present trends in the market. The fact that Saudi banks constitute an indispensable part of

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the economy and financial system of the country makes people more interested in this issue. It is possible to keep the economy stable and to enable the investors to make their choices based on the correct forecasts and knowledge of the fluctuations in the stock prices of these companies. The governments can choose to impose more stringent laws to safeguard the banking industry through the information they have gathered. The risk and the possibility of enhancing the market forecasts are enabled by access to large data sets of data by banks and other financial institutions. These solutions are increasingly being adopted by more and more businesses as a way of ensuring that they do not lose operational efficiency and competitiveness. The model can be made predictive by simply altering the model parameters. The use of optimization strategies like the Grid Search may make this a reality. One can achieve greater readiness to market volatility through risk management systems that are driven by artificial intelligence. Banks or other financial institutions can utilize massive bodies of data to enhance their predictability of the market and to minimize the risk. More and more companies are resorting to such solutions to retain their operational effectiveness as well as to maintain their competitiveness at a good level. All that is required to be able to develop the predictive strengths of a model is to effect some adjustments to the parameters of the model. One of the optimization processes that could be employed to achieve this goal is the Grid Search. Once the aspect of artificial intelligence is incorporated into the risk management structures, it will become significantly easier to develop strategies that are less vulnerable to market fluctuations and more capable of adjusting to new realities. With these complicated strategies, companies can enhance their decision-making activities, and achieve the most promising outcomes. Artificial intelligence (AI)-powered solutions to risk management are increasingly used by more and more companies, which implies that such solutions will become the norm in the nearest future.

This study will involve the use of Al Rajhi Bank data to explain how developed deep machine learning models can be effective at predicting stock price volatility of Saudi institutions and companies traded on the Saudi Stock Exchange. This will equip the shareholders, investors and financial analysts with the means to make better and more accurate judgment, this will be good to everyone concerned. Further equipping its existing financial models with these machine learning technology could assist financial organizations in a better analysis and management of risk. These new technologies can be used by the businesses to improve the way they risk assess and react to changes in the market faster. Such measures may render the financial industry more stable and capable of managing the shifts in the economy.

These are the sections, which constitute the framework of this investigation: In the next section we will examine the summary of the previous research and literature. Sections 3 and 4 are devoted to explaining the methods used in the study and discussing the results and their meanings, respectively.. The fifth section contains the reasons and conclusions. The findings of this research will enhance scholarly debate on the subject and aid specialists in forecasting financial events. The main goal of the research is to make the economy more stable by helping us understand how the market works better via a mix of theory and practice. This will be done by combining both theoretical and practical uses. The study's authors said that the objective is to bring together theory and practice so that professionals

can make better judgments. Researchers and practitioners will find the data very helpful as they try to better comprehend the complicated world of contemporary banking.

2. REVIEW OF LITERATURE AND PRIOR RESEARCH

The many approaches of forecasting and time series simulation are gaining an increasing amount of attention among investors in the financial industry. They want to improve their investment decisions and gain knowledge about the trends that will emerge in the future market [1]. The growing relevance of the problem introduces the necessity of new techniques to the predictability of the market shift. Moreover, the combination of empirical information and the contemporary analytical methodologies could provide investors with the ability to manage the uncertainties in a more effective manner and make judgment based on the information that can be trusted. Consequently, investors can make decisions that are more informed. Volatility has been part of financial markets since the initial financial bubble in the history of the world that occurred in the 17th century as an after-effect due to excessive speculation on the price of tulip bulbs. This started in the case of inflation of the price of the tulip bulbs to an unrealistic level. A good understanding of such patterns that have been in existence over time is very critical to make out in the economic maze that is in existence today. When investors take advantage of the new technology and data analytics, they can enhance their capacity to anticipate movements and implement changes to their strategy that are opportune and appropriate. The significance of possessing an understanding of the psychological factors that influence the actions of the investors is demonstrated through an analysis of the past having the hindsight advantage. By integrating the insights that are provided by behavioral finance with data analytics, the stakeholders can more accurately predict shifts in market sentiment. Also, this will enable them to make improved decisions. This means that it will be easier to make the necessary adjustments to the strategic plans of businesses at the right time. With intraday data it is possible to provide a more accurate estimate of past volatility, especially at higher sampling frequency. This is particularly in cases where the frequency of the sample is raised. This is also translated into a more detailed and standardized picture of the behavior of prices [3]. Recurrent statistical stochastic volatility (SR-SV) model is an amalgamation between stochastic volatility (SV) and recurrent neural network (RNN) models that has been produced as part of a realistic methodological framework. Stochastic volatility models are sometimes traditional models of volatility that fail to capture complex volatility dynamics, including nonlinearity and long-memory auto-dependence. This new model embodies these and many more. The proposed model has both high statistical interpretability, which it is possible due to the underlying statistical structure, and high out-of-sample predictive performance, which is possible due to the capability of recurrent neural networks to learn complex temporal patterns. SR-SV model is regarded as one of the most adequate long-term models to forecast volatility in stock markets and financial markets as it is the most appropriate to balance between accuracy and clarity [4]. The simplified and new approach provides improved insight into the market mechanisms to the analysts and, as such, it enables them to predict volatility. This plan is being implemented, which promotes the creation of new approaches to risk management and investment, which ultimately results in the further improvement of the quality of decision-making in the banking and financial industry. By having ambiguity in the

market, the investors can make intelligent decisions based on the SR-SV model, which provides a better understanding of the market dynamics. It is due to this that this is the case. This is due to the fact that the model provides better understanding of the dynamic in the market. It also leads to the stability of the financial markets as a whole with each individual portfolio performing better and overall performance of portfolios. Existence of interdependences among financial resources and changes in such interdependences that is induced by the action of a multitude of stakeholders offer a serious obstacle to the undertaking of volatility prediction. Analysts would find it difficult to focus on the entire historical information and ignore the economy as a whole due to the possible implications that can be imposed on the market. In order to overcome these difficulties and improve the accuracy of predictions, stakeholders may considerably profit from the use of contemporary analytical approaches and machine learning. Reactions to changes in the value of alternative assets, such as bonds, currencies, and macroeconomic data, cause the financial and stock markets to readjust their equilibrium. Because of this process, they are now a component of a sophisticated and integrated financial system [5].

The international financial market network is a highly globalized and interconnected network of organizations which are associated by common standard structures. These interrelated working dynamics enhance effectiveness and solvency, yet it increases the possibility of cross-border shocks [6]. With this consideration, it can be stated with utmost regard that there is a dire need to come up with models that can effectively capture these complicated structural interrelationships simultaneously. However, the past few decades have witnessed the creation of an abundance of novel solutions to this issue [7], all of which utilize the most advanced technologies in the sphere of artificial intelligence. It can be done, say, through the analysis of trading by socially connected investors with the help of graph neural networks (GNNs) [8]. This would enable a better monitoring of the market besides the detection of anomalous trading patterns. These new ideas, besides, enabling us to make more correct projections, also assist us to understand the more basic variables that are involved in the functioning of the market better. Perhaps, the more academics perfect these models, the more new knowledge they can find about how the financial systems that run across the world are linked with each other. Also, Chen and Robert employed the identical methodology in simulating how financial assets are interacting; the ability of their model to predict multivariate volatility was highly improved [9]. Graph neural networks are used by Das et al. to model interactions between financial institutions with the aim of having emotional dynamics and structural dependencies within a single prediction model. This was so as to realize their overall objective. They combined news and social media sentiment analysis in a bid to achieve this objective [10]. This is an innovative way that only increases the precision of financial predictions, not mentioning that it is also insightful on how the market would behave when it faces unforeseen events. With the help of powerful machine learning algorithms, researchers can better predict shifts in investor sentiment and the ensuing impact that changes in investor sentiment have on asset prices. This enables the researchers to be more familiar with the relationship that exists between the two. This enables graph neural networks (GNNs) to address the flaws of the traditional models like recurrent neural networks (RNNs) in the financial sector [11]. Graph neural networks (GNNs) are structured based on the nature of connections among the relationships, instead of the time sequence of events. Unlike recurrent neural networks (RNNs), which view data as linear time series, GNNs analyze data in the perspective of a

network. These characteristics enable us to simulate successfully both direct and indirect relationships between different groups. Against this, they offer a good approach to the analysis of a complex financial data [12]. This is because GNNs can find patterns and relationships which other methods might not. That is why it is so because any person stands a chance of enhancing his/her financial forecasts by utilizing the data that can be accessed on these networks regarding the operations of stock markets and financial deals and the risks that are involved in such operations. Anybody may access this information. Due to this property, global neural networks (GNNs) can identify patterns and correlations not identified by methodologies used before them. They also give a more precise account of how the market operates and the risks that are involved and this can be seen to make financial predictions much more accurate. Due to this, they provide a more precise version of the market. Recent research in quantitative finance is progressively embracing GNNs as a major tool for modeling volatility and forecasting market behavior [13]. This is due to the fact that GNNs are capable of accurately modeling volatility. In this paper, we propose to use a machine learning model known as the Support Vector Machine (SVM) and improve its performance through four distinct optimization algorithms: the Ant Colony Algorithm, the Bee Colony Algorithm, the Genetic Algorithm, the Whale Optimization Algorithm, and the Particle Swarm Optimization Algorithm, to evaluate the computational cost of the SVM after overfitting [14]. In Reference [15], researchers improved machine learning parameters by updating the algorithms used in them, using advanced optimization methodologies. The nature and characteristics of the problem greatly influence the classification accuracy of machine learning techniques, as well as determine the optimal combination of hyperparameters needed to achieve the highest possible classification accuracy [16]. When using neural networks to address machine learning problems, a large number of hyperparameters need to be fine-tuned. This paper [17] discusses the use of the HSIC criterion to analyze and optimize these hyperparameters through a goal-oriented sensitivity analysis. Due to the complex and adversarial nature of environments, hyperparameters are often of various types: categorical, discrete/logical, and continuous, making sensitivity analysis a complex process [18].

2.1. An Examination of the Correlation Between Financial Strain and Affirmative Indicators

Since the beginning of corporate finance, one of the most contentious theoretical issues has been the effect that announcements of capital reductions have on the view of the market. According to the notion of financial distress, a decline in capital might be read in a negative manner, implying that a firm is either unable to create adequate internal finance or that it has basic operational problems. In the event that this action shows that cumulative losses have resulted in a reduction of the shareholders' equity, it is possible that they will want an adjustment to the capital basis. This position contends, on the basis of the results shown in [10], that the disclosure may result in unfavorable responses from investors as well as a fall in the value of the company's shares. It is possible that the market may see it as evidence of instability in the financial system or managerial failure.

In contrast, the signaling hypothesis proposes that a decrease in capital might be seen as a sign of optimism from management. This view is in opposition to the previous interpretation. This

interpretation is based on the firm's future prospects, its commitment to achieving profitability, and its operational proficiency.

To strengthen the balance sheet of the company, increase the value of the company's shareholders, and give the impression to the market that the company is exercising fiscal constraint, [11] propose that management make these modifications on their own volition. This is done to strengthen the firm's balance sheet. Therefore, investors may view a voluntary reduction in capital to be evidence of innovative leadership and effective management, particularly when it is followed by an increased potential for profit. This is especially true when the amount of capital that is reduced is voluntary. Real statistics on global markets continue to lack consistency.

In a study that was carried out by [12], the researchers came to the conclusion that the response of the market to the news of a decrease in capital is impacted by several different factors. Numerous factors impacted the market's response, proving this. The company's position, investor expectations, and market maturity are some factors that may be considered. There are a number of other elements that may also be considered. The existence of these contrasting points of view sheds light on the significance of context in a variety of markets, particularly in developing nations such as Saudi Arabia.

It is claimed that around seventy percent of the whole market is accounted for by the Saudi Stock Exchange (Tadawul), which is the most major and active financial market in the region that spans the Middle East and North Africa.

People commonly refer to this exchange as the Qatar Stock Exchange. Although it was initially established as a joint-stock company in 2007, Tadawul continues to exercise control over more than seventy percent of the market value of the whole industry, as stated by the International Monetary Fund [13]. The IMF provided this information. This is the case as of the current moment. This is the current situation. In the process of developing capital, the Capital Market Authority (CMA) area is an essential component. This is due to the fact that it makes it easier for businesses to get cash for extending their operations. Both the goals of Saudi Arabia's Vision 2030 and the aims of this document are supported by it. Consequently, Tadawul serves as a hub for foreign investors seeking to put money into the largest Gulf economy by analyzing its regional activities. Because of the agreement, it is now more liquid and more integrated globally; it is a part of two of the world's main indices: the FTSE Russell and the MSCI Emerging Markets primary indexes. When it comes to examining capital reductions and other corporate restructuring choices, Tadawul provides a novel empirical approach. There are many intriguing aspects of the Saudi market:

There is a large concentration of ownership among powerful families and governments, and there is a rise in the number of individual investors whose sentiments might amplify temporary fluctuations in the market. The changes to the law aim to enhance market transparency and efficiency.

These suggest that investors may see capital depreciation differently than in more affluent countries. Saudi Arabian investors can see capital depreciation differently. For example, instead of seeing these stories as just economic indicators, they may be considered parts of a broader company strategy.

3. RESEARCH METHODOLOGY

3.1 Data Sources

From September 2020 and continuing through September 2025, the research used daily historical data on the stock prices of Al Rajhi Bank, which are listed on the Tadawul, the Saudi Stock Exchange. By analyzing this data, we were able to identify patterns and trends that might potentially assist us in developing new investment strategies. According to the results, there is an attempt to give information on how the bank is doing in comparison to larger market trends. We are confident that the findings of our research will help investors in making choices that are founded on trustworthy information by providing them with helpful counsel. It is possible that if the stakeholders have a better understanding of the relationship between the volatility of Al Rajhi Bank's shares and the volatility of the market, then they will be able to handle the complex world of financial management. In addition to the opening and closing prices, the daily high and low prices, the trading volume, and the daily percentage change, the data also contains the daily percentage change. As a means of preparing the data for statistical and predictive analysis, we cleaned it up, digitized it, and filled in the blanks. Considering the amount of effort that analysts have put in to prepare themselves, it is possible that they may use a wide variety of statistical models and machine learning techniques in order to make predictions about how prices will change in the future. It is possible for investors to utilize this information to improve their decision-making processes and ensure that they are in accordance with their financial goals. Having this preparation helps you detect patterns and trends in the market that may not be immediately visible, which in turn makes your estimates more accurate. It is becoming more necessary to include sophisticated analytics into investment strategies in the modern world of finance, which moves at a breakneck speed daily.

3.2 The Descriptive Analysis Method.

Significant statistical information, such as the mean, median, standard deviation, maximum, and minimum values, were extracted from the data via the use of descriptive analysis. We used line graphs to illustrate how prices and trade volume varied over time, and we also used boxplots to identify outliers and see how variables were distributed. Both of these graphs were created using the same data. This method made it simpler to identify periods of time during which things were steady as well as periods of time during which they were very unstable [19].

3.3 Models Used

As it has been established, three different types of prediction models have been developed: The aim of the linear regression is to determine the degree of the relationship which exists between the independent variables and the price change. In order to evaluate the accuracy and strength of the model, several various statistical studies were employed. Besides this, the decision tree and neural networks were employed in a way that they were to identify the existing complex and non-linear relationships that existed among the different pieces of data. Ridge regression is a linear model which incorporates

a penalty factor and utilises regularisation to reduce the effect of multicollinearity between the variables. Ridge regression is a linear model. The models were then subjected to an analysis in an attempt to determine the model that exhibited the best degree of accuracy with regard to prediction. This objective was achieved successfully with the help of such measures as the mean absolute error and the R-squared values. These measurements were all put into use. The findings that indicated the significance of utilizing the appropriate model raised the issue of the need to utilize the pertinent model to enhance the precision of price volatility forecasts. Random Forest model is a type of nonlinear model which is employed in an attempt to disclose complicated nonlinear associations among variables by blending the results of a huge number of random trees [21]. Random Forest is a type of model that is categorized under nonlinear models which are more general. Otherwise, the standard linear models failed in certain cases; however, our procedure was very effective compared to the standard models in such cases. The statement mentioned earlier was particularly appropriate when it came to datasets that indicated complex interrelations between variables. The Random Forest model could have made the forecasts more accurate and offer the insights on the significance of a certain number of factors which ultimately led to better decision-making. This was possible by taking advantage of the benefits of ensemble learning which allowed the model to significantly improve its accuracy. In particular, the third step which is currently under consideration is Model Optimization also known as a Grid Search. This was made possible to get enhanced model performance with the help of the Grid Search strategy [22], comprised of systematic discovery of the best set of parameters. The approach that enabled us to reach this objective was the Grid Search. Using this method it is possible to identify the hyperparameters that are responsible in generating the best accurate predictions. This is a possibility. The alteration of these parameters in a step-by-step fashion could enhance the accuracy of the model prediction in terms of price oscillation that will eventually translate into augment the reliability of the model. In the case of Ridge and random forest respectively, we conducted experiments where we experimented with a wide range of possible values of the regularization parameter (α), the number of trees and depth of the trees [23]. These experiments have been conducted to identify the best values of these parameters. Since the outcomes of such tests indicated that the performance measures of the models had significantly improved, it is essential to introduce alterations to the hyperparameters with a considerable focus being paid to all the details. This is due to the fact that the performance measures of the models were much improved. Through this experiment, however, we were able to test our methods and to gain a deeper insight into how each of the models operates in various diverse environments. Using the information which we obtained, we managed to produce two sets one set which could be used as a training set and another set which could be used as a testing set. After that, we made use of the coefficient of determination (R^2), the mean absolute error (MAE) and the root mean square error (RMSE) to give an analysis of the effectiveness of the models. The discussed findings prove the importance of changing the parameters to increase the accuracy of the forecast. The future work will be mainly focused on the research of different algorithms and methods that can be applied to improve these models and find a solution to any problems that remain unresolved. This will be viewed as the main focus of the future endeavours.

4. RESULTS AND ANALYSIS

This section looks at stock price data from 2020 to 2025. To be more specific, the study is based on daily historical data for Al Rajhi Bank shares that are traded on the Tadawul, which is what is known as the Saudi Stock Exchange. This research will emphasize any significant events that may have had an influence on the stock price during this time period, as well as any major patterns and swings that have happened during this time period with regard to the stock price. Through the analysis of these patterns, we are able to get a more in-depth comprehension of the performance of the bank as well as the general dynamics of the market in the area. There were substantial variations and trends in the values of stocks throughout this time period, as shown by the results of the research, which were taken into consideration. There is a link between the success of stocks and the changes in the market, according to research that is statistically significant. Since this has occurred, Al Rajhi Bank now possesses a deeper comprehension of the current state of the investment environment. The amount of trading volume, the closing price, the beginning price, the high price, the low price, and the daily percentage change are all included in the statistics. In this part, we examine the statistics on stock prices from the years 2020 to 2025. There is a link between the success of stocks and the changes in the market, according to research that is statistically significant. Since this has occurred, Al Rajhi Bank now possesses a deeper comprehension of the current state of the investment environment. The study contains line graphs that illustrate how trading volume and prices have changed over time, an investigation of periods when the market was more or less active, a discussion of how equities behave over time and any evident seasonal tendencies, and a brief summary of relevant metrics. All of these elements are included in the report. Because of this expansive perspective, it is much simpler to comprehend what has occurred in the past as well as speculate about what could occur in the future. Since these findings have been obtained, Al Rajhi Bank will be in a position to make more informed decisions on the management of their assets and risks.

TABLE 1. Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Last Price	1249	80.03311	15.38361	99961.36	40.63	83.1	114.75
Open	1249	80.03991	15.43498	99969.85	40.63	83	114.88
High	1249	80.77371	15.59437	100886.4	41.06	84.2	117.4
LOW	1249	79.32991	15.2083	99083.06	40	82.3	112.2
Volume	891	10.29246	72.13988	9170.58	1.02	4.31	998.95
Change %	1249	7.29E-04	0.01398	0.9103	-0.0653	0	0.0593

During the time period under study, the average closing price per share was discovered to be around SAR 80.0, with a standard range of roughly SAR 15.4 being noted. On the basis of this, it is possible to draw the conclusion that the price displayed a significant amount of fluctuation around the mean. It was in the beginning of October 2020 that the stock achieved its all-time low, with a closing price of

about SAR 40.6 reaching its lowest point. Late in the month of April 2022, it reached its peak price, which was roughly 114.8 Saudi Riyals. A number of economic variables and the emotions of investors have contributed to the volatility of the market, which is shown by this large movement. Since analysts are very interested in the possible recovery and future performance of the company, they pay careful attention to patterns and follow them attentively. Investors are especially interested in the potential path that the stock may take, particularly in light of recent changes in the market and upcoming earnings reports. This is because the stock may eventually travel in a certain route. As a consequence of the steady recovery in the economy, there is a sense of optimism that is somewhat cautious, and that optimism is that prices might move higher over the course of the next few months. As can be seen from the data shown above, the stock price climbed by almost twice as much from its lowest point to its highest point over that time period since it went from being at its lowest point to its highest point. The median closing price was around SAR 83.1, which indicates that it was below the mid-SAR 80 level fifty percent of the time and, on the other hand, it was above it fifty percent of the time. The way the opening and closing prices move is very similar to how the opening price moves (which has a median of about SAR 80.0). The opening price is usually very close to the closing price from the day before, with small changes that show what happened after the market closed. The daily opening price went from a low of about SAR 40.6 to a high of about SAR 114.9. The mean and standard deviation of the opening price and the closing price are very close to each other. This figure means that changes that happened during the session (between the opening and closing) were not very big on most days. The average high for the day was about SAR 80.8, and the average low was about SAR 79.3. This figure means that the stock trades in a range of about SAR 1.5 (about 2% of the stock price) every day. The stock's highest price during the sessions was SAR 117.4 per share (on May 9, 2022), and its lowest price level was around SAR 40 (on October 4, 2020, when it hit a low of SAR 40.63). This graph shows how much the price changed over the five years, going from around SAR 40 to over SAR 110 and then back down to lower levels. The average daily trading volume was about 4.8 million shares, with a median of about 4.3 million.

When these data are considered, it can be concluded that the trading volume was less than 4.3 million shares on half of the days and equal to or more than that amount on the other half. The quantity of businesses that took place during periods of high activity was significantly different from those that took place during times of low activity. For example, in the least active sessions (like those in August 2025), there were only about 0.94 million shares, but in the most active sessions, there were over 38.5 million shares. On February 24, 2022, a total of 38.55 million shares were exchanged, which is the highest number of shares that have ever been moved in the history of commerce. The presence of this symbol suggests that a noteworthy event had happened or that a considerable number of investors were interested in the day in question to a significant degree. It is quite possible that major news or events in the market were the cause of this unexpected increase in activity, which attracted the attention of both traders and investors. Analysts conducted a comprehensive analysis of the following movements to determine the effect that these movements may have on the market throughout the course of a longer period of time. A large divergence between days when there was a lot of trading and days when there wasn't much activity is shown by the fact that the standard deviation of trade volume was very high

(more than fifty percent of the average). This data indicates that there was a big difference between the two types of days. Approximately two and a half million deals were entered into throughout the trading session. The fact that this movement occurred indicates that the attitude of the market may change swiftly in reaction to a range of things, such as news about the economy or events that are taking place all over the world. There is a need for traders to maintain vigilance and the ability to adjust to these developments. Modify on a daily basis: The price of the stock fluctuated by around 0.07% on a daily basis, which indicates that the price increased by a negligible amount on each and every day during the whole time. This figure 2 indicates that the stock price was very volatile on a daily basis, as shown by the standard deviation, which was around 1.4%. The daily change range is fairly big, going from -6.53% on the worst day (May 12, 2022) to +5.93% on the best day (February 20, 2022). But most of the daily changes were small: the price changed by less than 1% up or down in about 62% of sessions, and it moved within a range of only $\pm 2\%$ on about 87% of days. This statistic means that there were very few days when the stock price changed a lot; most sessions saw only small to moderate changes.



Figure 1. Temporal Variation of Closing Price

Figure 1 shows the closing price of the stock for the period spanning from 2020 to 2025. In light of the key trends and developments shown in this picture, it is probable that decisions about future investments will be impacted by these trends and developments. These kinds of timeframes are often used by analysts to uncover patterns and speculate on what may take place in the market from a potential standpoint. Studying these trends and adjusting their strategies to account for past events can help investors make better decisions. To maximize profit from your assets, you must stay aware of market changes. Investors must consider external factors that can influence stock prices when making investment decisions. These components include data pertaining to the economy and events in geopolitical affairs. By looking at both historical data and current market research, students will have a deeper understanding of the complicated world of investment. This is because they will be able to compare and contrast the two. The graph shows the stock price's fluctuations over time. From about SAR 42 in September 2020 to over SAR 88 by the time the year arrived at a close, its value climbed significantly during the course of 2021, almost doubling by the time the year came to a close. The

result represents a significant gain in value. This upward tendency is a reflection of the strong market conditions that persisted during that time as well as the trust that investors had in the market. Although fluctuations are inevitable, it is equally necessary for investors to retain awareness and flexibility in the face of new information that has the potential to change the dynamics of the market. Both of these things are essential. Investors are hopeful that the company's upward trend will continue. In spite of the fact that analysts are continuing to keep a close eye on these movements, prospective investors may be able to make a profit from any volatility that happens in the market. The upward trend continued throughout the beginning of 2022, and by the time April 2022 came to a close, the price had hit an all-time high of more than 115 Saudi Riyals. Additionally, this tendency maintained throughout the whole year. It has never been higher than this amount previously in any of its history. Investors' sustained interest and the favorable market conditions at the time enabled this tremendous growth. As a result of this, several industry professionals are refining their projections, suggesting that the stock may continue to climb if the company continues to create fresh ideas and expand its market share. Because of this, the price started the downward trend in the middle of the year 2022, suffering a significant loss of value and finally reaching about SAR 75 by the end of that year. The huge drop in price that occurred over the course of time was the cause of this reduction. As a consequence of this decline, stakeholders expressed their worries, which in turn led to discussions over the company's capacity to adapt to a market that is experiencing continuous change, as well as its strategy for the long term. As a consequence of this, the leaders came to the conclusion that it would be beneficial to launch a series of strategic workshops with the objective of identifying innovative methods for resolving issues and enhancing the efficiency of operations. This proactive plan will allow the organization to stabilize the current situation and position itself for future growth. This will be accomplished via the execution of the strategy. Consequently, as a result of this, the leaders initiated a series of strategic workshops with the purpose of identifying novel approaches to problem-solving and developing strategies to further enhance the effectiveness of operations. Because team members from a wide variety of sectors were brought together for the sessions, it was much simpler to communicate and exchange ideas during those sessions. This coordinated effort was conducted in order to solve the present issues that the organization was dealing with and to position it for growth over the course of the long term. It was necessary for the members of the team to work closely together in order to accomplish this goal. They need to communicate with one another and share ideas and strategies that make use of the many varied skills that they possess. They intended to find solutions to challenges as quickly as possible and establish a foundation for future success by developing an environment that was conducive to discourse and innovation. This proactive strategy will allow the organization to improve its existing operations and better position itself for future development opportunities. This will be accomplished via the execution of the plan. Throughout the process of working toward these goals, the team maintained their commitment to continually improve the situation by paying careful attention to how they were carrying out their jobs and how successfully they were carrying them out. This was done all throughout the process. With the assistance of this flexible strategy, they were able to operate their business in a more effective manner, which also put the company in an outstanding position to quickly respond to the shifting demands of the customers in the market. To ascertain whether or not the firm is capable of recovering and whether or not it is able to win the trust of investors in the next quarters, analysts are

paying careful attention to the financial performance of the company. Not only do these activities have the potential to result in new initiatives and partnerships that develop the organization, but they also have the potential to be lucrative in the case that they are successful. A culture of resiliency and flexibility among workers is something that leadership has to begin cultivating to adequately prepare staff for future problems. Both 2023 and 2024 were years in which the stock did not do well, and throughout those years, it saw a delayed recovery as well as a tremendous deal of ups and downs. The stock price fluctuated between the mid-1970s and the early 90s. Investors were cautiously hopeful because they believed that the new concepts developed by the firm over time would benefit the company's growth. Because of this, equity analysts began to pay special attention to how customers reacted to new products and the trends in the sector. This focus allowed analysts to better predict the company's future. By the end of the year 2024, the stock had been steadily increasing, which demonstrated that investors were getting more confident. It is possible that this results from the fact that customers adored the innovative approach that the company used. Throughout the whole of the year 2025, there was not a significant amount of movement in the price of the stock, either in an upward or negative direction. During the month of March 2025, it temporarily surpassed 100 riyals; however, by the month of September 2025, it had returned to values that were almost equal to 90 riyals. Throughout the course of the year, analysts conducted careful monitoring of the company's performance data and saw an increase in sales as a result of new marketing efforts. A rise in investor confidence and a favorable position for the firm in comparison to its rivals in the expanding market were both achieved as a result of this comeback.

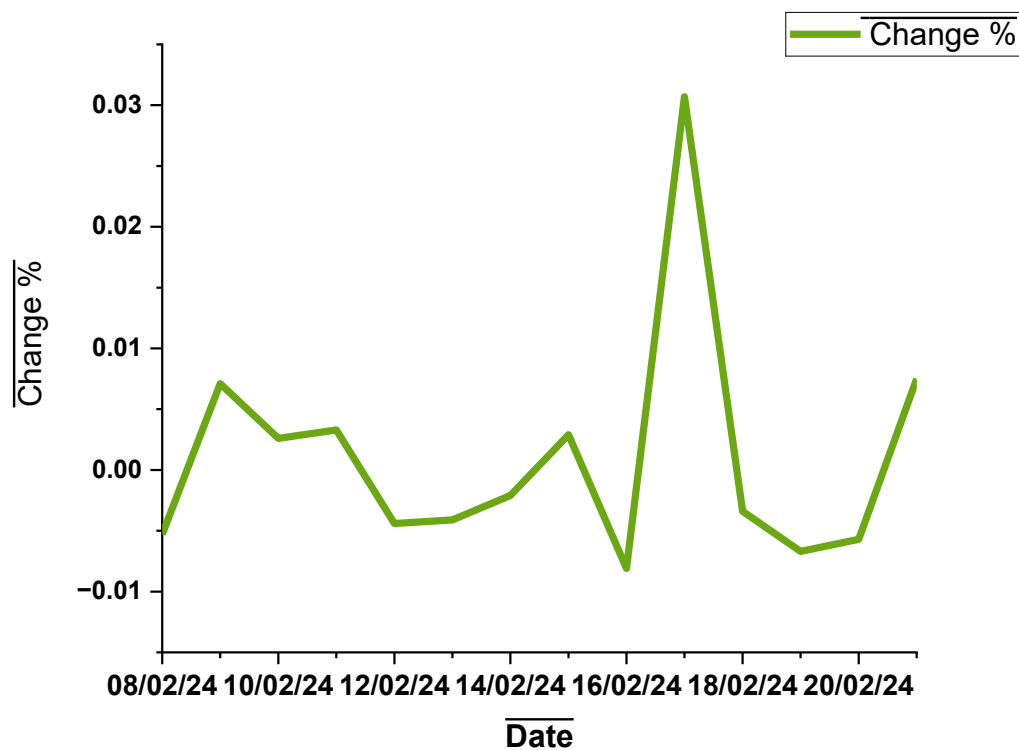


Figure 2. Daily change (%) fluctuations

The graph depicts the overall amount of progress that was made in the % during the course of the time period beginning on February 8 and finishing on February 21, 2024 respectively. A progression like this occurred up to the 21st of February. It can be deduced from the findings of these calculations that the value has been subjected to large swings, which include peaks and troughs that are typical of a variety of market situations. The fact that these alterations have occurred might be seen as evidence that can be observed. Experts are paying a great deal of attention to the study of these patterns in order to arrive at well-informed judgments and generate reliable forecasts about what will occur in the future at different points in time. Taking into mind these insights, market participants can elect to make strategic adjustments to their investment portfolios in order to boost their odds of capitalizing on potential opportunities or to minimize the danger of prospective hazards. Maintaining a current knowledge of these trends is of the highest significance for those individuals who have a vested interest in the subject matter as the situation continues to evolve. Alterations may take place at a variety of different times during the course of time. These moments are referred to as "moments." The change starts off in a negative direction, but then it starts to take a big turn for the better, hitting its highest point of about three percent on February 17th. Immediately after that, it declines precipitously and rapidly. Due to the fact that this pattern indicates that the market is subject to instability, investors should be vigilant and be prepared to adjust their strategies. It will be necessary for us to continue evaluating these developments in order to successfully cope with them and find the most effective strategies to become better. This figure demonstrates that performance or value was very unstable

throughout this time period, with a crucial point (peak) in the center that may have been the consequence of an event or cause that had an influence. After reaching its highest point, the market continued to be volatile and saw a general decline; however, there was a little recovery at the conclusion of the term. Using this graph, you may determine how stable something is or locate spots when daily performance fluctuates. Both of these applications are possible. To make sensible decisions regarding future investments, you need to grasp how these changes happen. By taking a closer look at the factors that led to the market's peak and the subsequent dip, stakeholders may better prepare themselves for any potential changes that may occur in the market. Having this training is essential for minimizing risk and making the most of possibilities as the market continues to develop. In addition, the use of a wide range of analytical tools may assist you in improving your investing strategies and enhancing your ability to forecast trends.

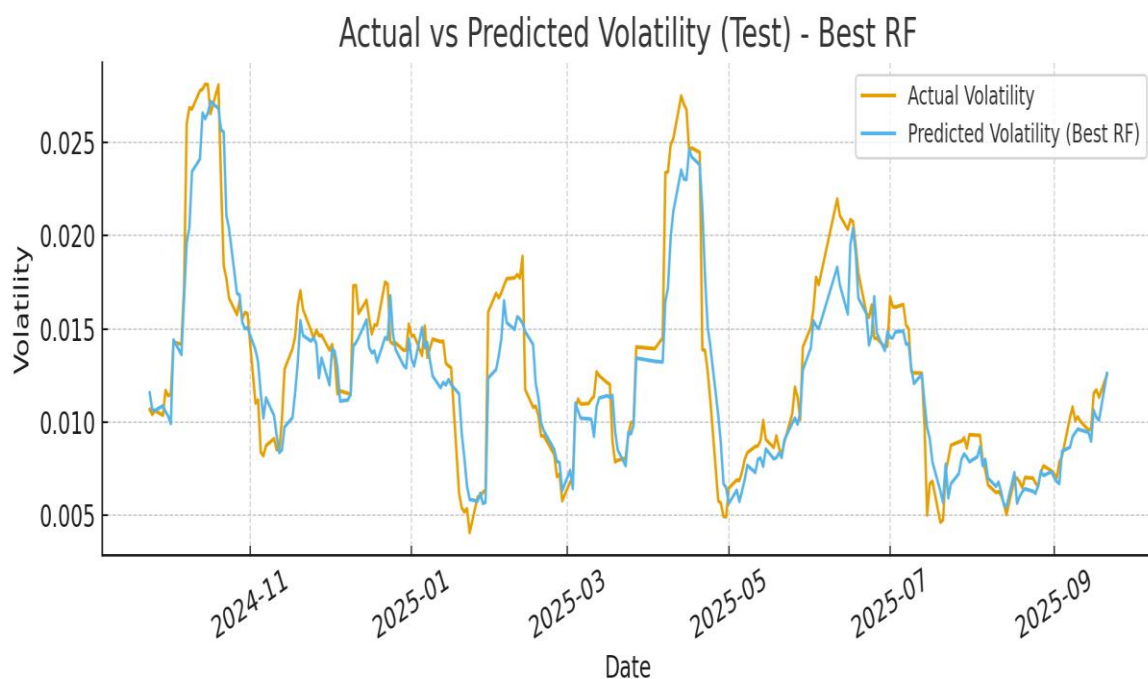


Figure 3 .Actual vs. Predicted Volatility – Best RF)

According to the Figure 3 that is given above (actual vs. Predicted Volatility—Best RF), the Random Forest model, which was updated using the Grid Search algorithm, is able to follow the real volatility of the stock price during the duration of the test period. This is demonstrated by the fact that the graph displays the real volatility vs the predicted volatility. As a result of this discovery, it is possible to draw the conclusion that the model is successful in capturing how the market evolves, and that machine learning has the ability to dramatically improve the accuracy of predictions produced in the financial markets. It is also feasible that the process of enhancing the model and carrying out further tests on it might result in projections that are even more accurate than they already are. Because there is a clear convergence between the actual curves and the projected curves, it is apparent that the model is able to detect broad patterns of volatility. This is because the model is able to recognize these patterns. This outstanding performance is reinforced by the fact that the model is able to explain a substantial amount

of the stock's volatility. The coefficient of determination (R^2) is about 0.86, which indicates that the model is able to explain a considerable portion of the stock's volatility. On the other hand, the model has a propensity to smooth out extreme values, which causes some powerful peaks and troughs to seem to be less severe than they really are. The process of smoothing out results may have the benefit of making projections more consistent over time; nevertheless, it also has the ability to ignore important market moves that may have an influence on investment choices that are expected to be made. Therefore, despite the fact that the model has strong predictive skills, it may be required to improve it in order to get a better reaction to the quick changes that are occurring in the market. This was caused by the fact that the financial market is unpredictable and that we could not have predicted when changes can occur suddenly as a direct consequence of some unexpected news or shock. This is the conclusion that we expected due to the fact that the market is unpredictable. Though it is necessary that the investors must be on the lookout, they also need to consider the possibility of integrating other data sources or real-time analytics in conclusions of the model. By doing this, they are in a better position to cope with the complications of the dynamics of the market and make reasonable decisions which consider the short term changes as well as the long term trends. However, regardless of the fact that these limitations are present it remains possible to utilize the model to determine the future volatility level estimates. The latter applies particularly to the aim to identify overarching tendencies and times of the market when it is either smooth or rough. The use of both new tools and conventional analysis will put investors in a better position to react to changing circumstances. The reason behind this is that investors will be in a better position to adjust to the new circumstances. Reading between the lines, this proactive measure will not only help them cope with any unexpected situation much easier, but will help them create a more efficient investment strategy overall at the same time. Investors who exercise this initiative approach will find that it is much easier to go through the twists and turns that are common in the financial arena. To position themselves to achieve greater heights of success in a market that is perpetually under a state of constant flux, they continue to strive to get their processes better and utilize new fresh information.

TABLE 2. Evaluation of Model Efficacy (Baseline versus Optimized Models)

Model	Train RMSE	Test RMSE	Train MAE	Test MAE	Train R^2	Test R^2
Linear Regression (baseline)	0.00239	2.34E-03	0.00166	0.00162	0.8179	0.8203
Ridge Regression (optimized)	0.00465	5.08E-03	0.00377	0.00418	0.3481	0.1567
Random Forest (baseline)	0.0018	2.07E-03	0.00134	0.00151	0.8946	0.8605
Random Forest (optimized)	0.0018	2.07E-03	0.00134	0.00151	0.8946	0.8605

Despite the fact that the linear regression model worked well (R^2 = around 0.82), it struggled to recognize nonlinear connections between the variables that were being investigated. It is possible that a more profound understanding of the fundamental patterns that are present in the data might be gained via the investigation of more adaptable models, such as polynomial regression or decision trees. If

these models are used, it is possible that this limitation will be resolved. There is also the possibility that the model might be improved by the incorporation of interaction variables, which would enable it to better comprehend complicated interactions. Despite the fact that the ridge model did not result in an improvement in the accuracy of the results, the regularization factor ($R^2 =$ around 0.16) actually resulted in a worsening of the findings. It is abundantly obvious, as a result of the results of this study, that simple linear models are not enough to adequately capture the way in which prices change over time. While the Random Forest model, which is the most basic of all the models, scored the best ($R^2 =$ around 0.87), the other models only performed averagely. If this is the case, then it would seem that ensemble techniques have the potential to be more successful in capturing the non-linearities that are present in the original dataset. When it comes to analyzing financial data, these results illustrate how important it is to choose the proper modeling methodologies due to the relevance of the data. There is a possibility that hybrid models may be investigated in the future for the goal of enhancing the precision of forecasts. It would be advantageous to combine the advantages of linear and nonlinear techniques with these models. In further studies, it could be conceivable to examine hyperparameter tweaking for the Random Forest algorithm or even investigate sophisticated methods such as Gradient Boosting in order to enhance the functionality of the predictive model. Both of these options provide the potential to increase the predictive model's performance. In comparison to this method, which is better, the linear models are not to be considered. Grid Search was used in order to determine the optimal parameters for the model. The findings of this investigation showed that the predictive ability of the model was not impacted by either the increase in the number of trees or the modification of their depth. The fact that the adjustment was not considerable, on the other hand, suggests that the core model was already very close to being optimum.

5. CONCLUSION AND RECOMMENDATIONS

Based on the findings of this research, it was discovered that machine learning techniques, such as the Random Forest model, are more effective than traditional linear models in forecasting the degree of volatility that Saudi bank stock prices would exhibit. On the basis of these results, it is recommended that financial institutions do extensive research into the incorporation of machine learning algorithms inside their analytical frameworks to improve the process of decision-making. There is a possibility that future study may examine the use of alternative sophisticated algorithms in order to enhance the accuracy of forecasting models in the stock market, which is inherently unstable. However, linear models such as Ridge and linear regression are unable to achieve the same degree of accuracy as the model. This is the reason why the volatility data is so variable (R^2 is around 0.86). Changing the parameters of the model was one of the ways that the grid search strategy improved its performance. An assessment of the quality of the baseline model was carried out in order to limit the Random Forest model's potential for further development. Based on the findings, it can be concluded that the Random Forest model is already doing fairly well, which is an extremely positive sign. For it to be improved any more, it is possible that we will need some fresh ideas or the addition of some new data sources. There is a possibility that performance might be improved by looking at various modeling methodologies or ensemble methods. There is a possibility that you may be able to get more valuable

information by including other attributes or by experimenting with different algorithms. Furthermore, there is the possibility that doing an exhaustive examination into the significance of the attributes might provide light on areas in which enhancements are required, which would ultimately lead to the development of a prediction model that is more trustworthy. Another strategy that can be applied in order to enhance the results of your work and promote innovations is feature engineering. The practice unites the experience and skills of the specialists working in the fields of a broad spectrum. Given that the market is always under a state of flux, it is extremely vital that we undertake periodic analysis and make sure that our estimations are kept up to date. As it would appear based on the findings, the combination of the advanced machine learning methods with the parameter optimization tools can significantly increase the knowledge of market processes as well as the ability to predict the impending volatility. It is the conclusion that can be made through the use of these approaches. This is the conclusion that may be drawn out of it based on the evidence. Having this information, the prediction models can be improved, and the stakeholders provided with knowledge that they require to make wise decisions in a world that is ever-growing, even though it is ever-changing.

The investors may find it better to utilize more enhanced nonlinear models to gain a better insight of the degree of risk they are going through and make better decisions regarding their investments. The initiators of the social policy should also be able to build mechanisms that can manage the effects of these results. These developments will enable future economic policies to adapt to diverse market conditions. Individuals interested in the economy can possibly stand at a better position to foresee changes and work on its growth in the long run provided they are given an environment that encourages the growth of a new concept in predictive modeling. This proactive strategy can be helpful to the industry by promoting the creation of new ideas and creating the financial industry stronger. Provided that the adaptive strategies are employed by the stakeholders and implemented, they will be in a better position to handle the uncertainty and exploit the emerging opportunities. Such flexibility will not only allow each of the organizations to work more efficiently, but it will also help to grow and change the economy in a way that will simplify the process of conducting business. Working in a team and exchanging their views, the stakeholders can possibly find new ideas which would help not only in addressing the current problems but also in addressing the issues which are going to arise in the future. By collaborating and exchanging their stances, the stakeholders could develop new ideas that could solve the current problems they are currently experiencing as well as those they will experience in future.

It is vital to the decision-makers to enhance the quality and accessibility of the already available financial data since such data is an important ingredient in ensuring that predictive models are effectively run. Finally, but definitely not the least, it is advised that financial institutions should come up with Volatility Early Warning Systems (VEWS) which is founded on the most predictive models to help financiers in risk management. When these mechanisms are put in place, organizations are able to react fast with the changes arising in the fashion industry. This will protect their assets and make them have the capability of operating over a reasonable duration. This information would assist companies to deal with uncertainty and exploit new opportunities. Perhaps, the results will be of use

to us in formulating the following recommendations in order to improve on the situation: In the future, researchers need to include the macroeconomic factor like the oil prices and interest rates, GARCH and other specialist volatility analysis models in their work in order to enhance the accuracy of their predictions. This will enable them to make better predictions. The current economy will present more challenges to businesses in a way that business will be more proficient in dealing with them if they instill a culture of flexibility and constant development.

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