Title: Anomaly Detection and Time Series Forecasting in the Irish Finance Market: Evaluating the Performance of the Prophet Model

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**ABSTRACT**

This study evaluates the Prophet model's performance in the Irish finance market, aiming to understand its forecasting capabilities and anomaly detection potential.

Three main objectives were pursued: First, assessing the Prophet model's ability to capture market trends, which it demonstrated effectively, although with limitations in precision. Second, investigating its anomaly detection capabilities, revealing high recall but moderate precision, indicative of a common trade-off. Lastly, validating the approach with real-world financial data through comparative metrics, showing a reasonable balance between precision and recall in anomaly detection.

The Prophet model excels in capturing broad market trends, making it adaptable to changing dynamics. However, it has limitations in forecasting precision. In anomaly detection, the model reliably identifies actual anomalies but raises some false alarms, necessitating parameter fine-tuning. The validation process highlights its potential for tasks where both precision and recall are vital.

This research contributes valuable insights to anomaly detection and time series forecasting in the Irish finance market. It emphasizes the Prophet model's versatility but also underscores the importance of refining its parameters for enhanced precision and reduced false positives. The model represents a valuable tool for data scientists and decision-makers across diverse domains. Understanding its nuanced strengths and weaknesses is crucial for its effective application in specific financial contexts, driving advancements in forecasting and anomaly detection strategies.

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**1. INTRODUCTION**

In the ever-evolving landscape of financial markets, accurate forecasting and timely detection of anomalies hold paramount importance. Amidst the complex interplay of economic factors and market dynamics, these tasks have become critical for informed decision-making and risk management. The Irish finance market, known for its resilience and adaptability, is no exception to these imperatives. In this era of data-driven finance, harnessing advanced tools and models is pivotal to staying ahead of the curve. Our thesis embarks on a journey through the Irish finance market, guided by the powerful Prophet model, to illuminate the path toward more accurate time series forecasting and robust anomaly detection.

The Prophet model, introduced by Taylor and Letham (2017), has emerged as a formidable tool in the realm of time series forecasting. Its strength lies in its ability to handle seasonality, holidays, and abrupt changes in data patterns, making it particularly appealing for financial time series analysis (Khayyat et al., 2021). As we delve into our exploration of the Irish finance market, we are poised to evaluate the effectiveness of the Prophet model in capturing the intricacies of this dynamic environment.

In the realm of financial markets, as demonstrated by Saiktishna et al. (2022), the capacity to predict stock prices hinges on the model's adaptability to volatile market conditions. A deep dive into historical stock market data awaits us, as we aim to unearth the potential of the Prophet model in forecasting the Irish finance market's twists and turns.

Financial stability, a cornerstone of any thriving market, is explored through the lens of Hlongwane and Sheefeni (2022). Their research delves into the impact of financial market shocks on stability, shedding light on the necessity of anomaly detection in averting market crises. As we navigate through this landscape, we aim to assess how anomalies, when detected and addressed, can contribute to the Irish finance market's resilience.

Mizuta et al. (2022) delved into the instability of financial markets and the optimization of investment strategies. The significance of their research lies in its implications for risk management and anomaly detection, concepts that intertwine intricately with our study's objectives. The ability to predict market instabilities and optimize strategies in response is a testament to the Prophet model's versatility, a facet we are keen to harness.

The dynamic interplay of trading strategies within financial markets, as studied by Cliff (2022), not only piques our curiosity but also reinforces the need for anomaly detection. By exploring the metapopulation differential co-evolution of trading strategies, we aim to uncover how anomalies influence trading behaviours and, consequently, market dynamics.

Fang mean (2019) combined the Prophet model with LSTM for forecasting the Morgan Taiwan Index. Their innovative approach underlines the potential for hybrid models in financial forecasting, setting the stage for our exploration of anomaly detection and time series forecasting within the Irish finance market.

we will utilize the Prophet model's capabilities to unravel the hidden patterns and trends that drive the Irish finance market. Alongside the model's forecasting prowess, we will scrutinize its ability to detect anomalies and assess how these anomalies impact the reliability and accuracy of our forecasts.

As we conclude this introduction, we reflect on the profound implications of our research for the Irish finance market. With our sights set on evaluating the Prophet model's performance in a real-world financial context, we aim to empower market stakeholders with enhanced forecasting tools and anomaly detection strategies, ultimately contributing to the market's resilience and stability. Our journey promises to be both enlightening and transformative, offering valuable insights into the Irish finance market's past, present, and future.

In pursuit of these objectives, we shall navigate a landscape populated by financial data, anomalies, and the powerful Prophet model, always mindful of the potential it holds for shaping the financial future of Ireland.

**1.1 FRAMEWORK OF METHODOLOGY**

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***Fig 01 - framework of methodology.***

**1.2 RESEARCH OBJECTIVES**

* Evaluate the Prophet model's effectiveness as a forecasting tool by comparing its forecasts against historical data, while also analysing its strengths and limitations to assess its overall performance in capturing the distinctive characteristics of financial data within the Irish finance market.
* Examine the Impact of detected anomalies on the accuracy and reliability of time series forecasting within the Irish finance market. By systematically analysing how identified anomalies affect the Prophet model's forecasting performance, researchers can gain insights into potential risks and opportunities associated with anomalous events.
* Validate the Proposed Approach with Real-world Data on a comprehensive dataset comprising historical financial records. Through rigorous validation, researchers can ascertain the generalizability and practicality of the developed framework and assess its potential for real-world application in financial decision-making.

By addressing these objectives, this thesis contributes to the growing body of literature on time series analysis and anomaly detection in financial markets. It provides valuable insights into the suitability of the Prophet model for the unique dynamics of the Irish finance market, facilitating more informed decision-making and risk management strategies in this specific context.

**1.3 SCOPE AND LIMITATIONS**

***Scope:***

* **Dataset Sources:** The study focuses on financial datasets obtained from Finance.Yahoo and Euronext for six major European stock market indexes, including BEL20 (Belgium), FTSE100 (UK), CAC40 (France), ISEQ20 (Ireland), DAX40 (Germany), and PSI20 (Portugal) spanning three years from 24/08/2020 to 22/08/2023. This scope ensures a comprehensive analysis of the Irish finance market.
* **Model Selection:** The primary focus of the study is on evaluating the performance of the Prophet model, a forecasting tool developed by Facebook. The study aims to assess the suitability of this model for predicting financial time series data.
* **Analysis:** The study involves two main aspects: anomaly detection and time series forecasting. It analyses the ability of the Prophet model to detect anomalies or irregularities in the financial market data and to provide accurate forecasts. The analysis will involve quantitative evaluation metrics to measure the model's performance.
* **Three-Year Horizon:** The selected three-year period for the dataset is chosen to capture enough historical data for meaningful forecasting and anomaly detection. This timeframe allows for insights into market trends and anomalies over a reasonable duration.
* **Comparative Analysis:** The study may include a comparative analysis between the Prophet model's performance and other forecasting models. This can provide insights into the strengths and weaknesses of the Prophet model in the context of financial market data.
* **Practical Implications:** The research aims to provide practical insights into the application of the Prophet model for financial forecasting and anomaly detection, which can be valuable for investors, financial analysts, and decision-makers in the Irish finance market.

***Limitations:***

* **Data Quality:** The quality of financial data, including missing values, outliers, and inconsistencies, can significantly impact the effectiveness of forecasting and anomaly detection models. The study will address any data quality issues encountered.
* **Model Dependency:** Focusing primarily on the Prophet model may limit the study's generalizability. It's essential to acknowledge that model performance can vary across different datasets and market conditions. The comparative analysis with other models will mitigate this limitation.
* **Market Dynamics:** Financial markets are influenced by various macroeconomic, geopolitical, and exogenous factors. The study should acknowledge that the predictive power of any model, including Prophet, may be limited in the face of unforeseen events or market shocks.
* **Assumption of Stationarity:** Financial time series data often violate the assumption of stationarity and addressing non-stationarity and selecting appropriate transformations or models to handle it is a challenge that should be acknowledged.
* **Model Hyperparameters:** The performance of the Prophet model may depend on its hyperparameters.
* **Interpretability:** While Prophet is known for its ease of use, its inner workings may not be as interpretable as traditional statistical models.
* **Data Privacy:** The use of financial data raises privacy concerns. This study complies with data privacy regulations and guidelines.
* **Generalizability:** While the study focuses on the Irish finance market, generalizing the findings to other markets or time periods should be done cautiously, considering market-specific characteristics and dynamics.

**2. LITERATURE REVIEW**

Neural Prophet, LSTM, Isolation Forest, One-Class SVM

We have split into two literature reviews: the Prophet model (Appendix A) and other models (Appendix B).

Conclusions and insights from these studies from Appendix A.

* **Prophet Model in Financial Forecasting:**

Several studies have highlighted the Prophet model's strong performance in forecasting financial time series data, such as stock prices and GDP growth. The Prophet model often outperforms traditional forecasting models like ARIMA and LSTM, as demonstrated by its superior accuracy and lower mean absolute error (MAE) and mean squared error (MSE).

* **Prophet Model in Anomaly Detection:**

The Prophet model has shown its capability to detect anomalies in various domains, including financial markets, industrial control systems, and social media data. In anomaly detection tasks, the Prophet model consistently achieved high true positive rates (TPR) while maintaining low false positive rates (FPR), emphasizing its effectiveness in identifying irregular patterns and outliers.

* **Prophet Model for Short and Long-Term Forecasting:**

Researchers have successfully applied the Prophet model for both short-term and long-term forecasting, such as predicting daily COVID-19 cases, intraday stock prices, and quarterly GDP growth. The model's adaptability to various forecasting horizons makes it a valuable tool for decision-makers in different industries.

* **Factors Affecting Prophet Model Performance:**

Some studies have examined factors that influence the Prophet model's forecasting performance. These factors include the length of the training set, the number of changepoints, and the presence of additional features. Understanding these factors can help practitioners fine-tune the model for specific applications and achieve optimal forecasting results.

* **Superiority of the Prophet Model:**

Across multiple studies, the Prophet model consistently demonstrated its superiority over other forecasting and anomaly detection methods. It often produced more accurate predictions and better anomaly detection results. The model's ability to capture seasonality, holidays, and trend components in time series data contributes to its competitive advantage.

* **Limitations and Considerations:**

While the Prophet model has proven highly effective, researchers have noted its limitations, such as its potential challenges in capturing abrupt changes in data or adapting to structural shifts. Practitioners must consider the specific characteristics of their data and the context of their applications when deploying the Prophet model.

In Appendix B, the research papers on time series forecasting and anomaly detection showcase a diverse array of methodologies and challenges.

* Various models, including ARIMA, SARIMA, LSTM, and ensemble methods like Isolation Forest and One-class SVM, are employed. Feature selection sensitivity is a recurring theme, emphasizing its critical role in model performance. Deep learning models like LSTM, while powerful, often entail significant computational costs.
* A common challenge is capturing sudden market changes and unforeseen events, highlighting the difficulty of modeling extreme events.
* Performance metrics vary, encompassing MAE, RMSE, MAPE, R2, F1 score, accuracy, precision, and recall, depending on task-specific needs.
* Ensemble methods excel in anomaly detection, achieving high F1 scores and AUC scores. Real-time forecasting challenges and data delays are addressed.
* However, modeling long-range dependencies remains a challenge, notably in NeuralProphet.
* Hyperparameter tuning significantly impacts performance, underlining the need for careful experimentation.

**3. DATA COLLECTION AND PREPROCESSING**

**3.1 DATA SOURCES**

**3.1.1 Indexes**

Stock market indices are composite measures representing the performance of a group of stocks or securities in a specific market, sector, or asset class. When it comes to time series analysis and anomaly detection, using these indices can be advantageous:

***Concept of Using Indices for Time Series and Anomaly Detection:***

* **Baseline for Comparison**: Stock market indices serve as a point of reference to assess the performance of individual assets or portfolios across time. For instance, the ISEQ20 frequently acts as a standard to gauge the performance of the Irish stock market. When contrasting the performance of an asset or portfolio with the relevant index, it becomes possible to pinpoint irregularities or deviations from the anticipated market patterns.
* **Pattern Identification**: Time series data derived from these indices can reveal recurring patterns and trends in the market's historical performance. This historical information is valuable for understanding market behaviour and recognizing deviations from established patterns.
* **Volatility Assessment**: Indices often represent diversified portfolios of assets, which can dampen extreme volatility caused by individual securities. Analysing the volatility of an index helps in identifying periods of unusual market instability or unexpected movements.
* **Sector or Market-Wide Anomaly Detection**: Stock market indices are designed to represent specific segments of the market, like a country's stock market or a particular industry. Monitoring these indices enables the detection of anomalies or shifts that affect entire markets or sectors. For example, the NASDAQ Composite Index is a good indicator of the performance of the technology sector.

***Benefits of Using Indices for Time Series and Anomaly Detection:***

* **Noise Reduction**: Individual stock prices can be noisy and sensitive to company-specific news or events. Indices provide a smoother, aggregated view of market trends, facilitating the detection of anomalies that impact the overall market.
* **Diversification**: Indices inherently offer diversification, as they comprise multiple stocks or securities. This diversification lessens the impact of anomalies in individual assets, as a single asset's anomaly is unlikely to significantly affect the entire index.
* **Historical Context**: Indices offer historical context by showcasing how the market has behaved over time. This historical perspective aids in spotting anomalies and deviations from past trends.
* **Benchmarking**: Stock market indices serve as benchmarks for assessing the performance of investment portfolios or strategies. Anomalies in portfolio performance become evident when compared to the benchmark index.
* **Market Sentiment Insight**: Anomalies in market indices can reflect shifts in market sentiment or macroeconomic factors. Detecting these anomalies provides valuable insights for investors and traders.
* **Risk Management**: Anomalies in market indices play a pivotal role in risk management strategies. Investors and portfolio managers can adjust their strategies in response to market anomalies, thereby mitigating potential losses.



***Table 01 - Composition of the Irish index (ISEQ20)***

Our Analysis will contemplate the Irish Index with the major Irish companies (Table 01).

In summary, the use of stock market indices in time series analysis and anomaly detection provides structure and efficiency for monitoring and analysing market behaviour. It offers historical context, reduces noise, and allows for the identification of anomalies that can affect the broader market or specific market segments, aiding investors, analysts, and risk managers in making informed decisions.

**3.1.2 Sources**

All the financial indexes’ datasets used for this study on the Irish index (ISEQ20) are available for the public domain and from Finance. Yahoo.com and Euronext.com. They have three years from 24 August 2020 to 22 August 2023, considered good for the study, particularly to forecast to preprocess and have comparable data.

**3.2 EXPLORATORY DATA ANALYSIS**

**3.2.1 Data Preprocessing Steps**

**3.2.1.1 Missing Values**

Missing Values in 'ISEQ20.xlsx' - 'Close' Column: 0

No missing values from the dataset.

# **3.2.2.2 Outliers**

Columns: [Close]

Index: []

Let's use z-scores, to measure how far a data point is from the mean of a dataset in terms of standard deviation. Z-scores are computed for the 'Close' column. These scores indicate how far each data point deviates from the column's mean in terms of standard deviations. Identifying Outliers: The code identifies potential outliers by comparing the absolute Z-scores to a specified threshold value z\_threshold. If the absolute Z-score of a data point exceeds this threshold, the data point is considered an outlier.

Using z-scores, we have no outliers.

**3.2.2 Basic statistics**

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***Table 02 - Basiq statistics from ISEQ20***

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***Fig 02 - Basiq statistics from ISEQ20 using Box plot.***

From Table 02 and Fig.02, we get 764 data points in the 'Close' column, indicating a substantial amount of data for analysis. The mean (average) value of the 'Close' column is approximately 1337.51, which represents the central tendency of the dataset. The standard deviation of around 131.40 measures the dispersion or spread of data points around the mean. A higher standard deviation indicates greater variability in the 'Close' prices. The minimum 'Close' price observed in the dataset is about 1063.24, representing the lowest value during the analysed time period. The maximum 'Close' price observed in the dataset is roughly 1545.07, indicating the highest value during the analysed time-period.

For percentiles, we have the 25th percentile (Q1) value of approximately 1233.24 is the boundary below which 25% of the data points fall, representing the lower quartile of the data. The median value of around 1368.86 is the middle value when the data is sorted. It divides the data into the lower 50% and upper 50% and is often used as a measure of central tendency. The 75th percentile (Q3) value of approximately 1451.91 marks the boundary below which 75% of the data points fall, representing the upper quartile of the data.

In Result: The 'Close' prices in the ISEQ20 dataset exhibit variation over time, with a mean close to 1337.51. The data appears to follow a relatively normal distribution, as indicated by the proximity of the mean and median. The standard deviation of approximately 131.40 suggests a moderate degree of variability. The range between the minimum and maximum values (1063.24 to 1545.07) reflects the price range observed during the analysed time period.

**3.2.3 Data distribution**

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***Table 03 - Data distribution with 10 bins from ISEQ20***

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***Fig 03 - Frequency distribution with 10 bins from ISEQ20***

As shown in Table 03 and Fig 03, the most common price range for 'Close' prices falls within the interval of (1448.704, 1496.887], with a frequency of 138. This suggests that a significant portion of the observed prices are in this range. There is also a notable frequency in the range of (1400.521, 1448.704], with 124 data points. The ranges (1207.789, 1255.972] and (1255.972, 1304.155] also have substantial frequencies, indicating that prices are relatively evenly distributed in these ranges. The lowest frequency is in the range (1304.155, 1352.338], which suggests that fewer data points fall in this range compared to others.

Overall, the frequency distribution provides insights into the distribution of 'Close' prices and highlights the concentration of prices within certain ranges. It appears that there are more data points in the mid to higher price ranges, with fewer data points in the lower and higher extremes of the data.

**3.2.4 PLOTS**

***DENSITY PLOT***

Let’s see the ISEQ20 dataset density and let's use Kernel Density Estimation (KDE), a statistical method employed to estimate the probability density function of a collection of data points. It provides a means to grasp how data is distributed by crafting a smoothed curve that closely resembles the presumed underlying distribution of probabilities.

this method helps understand data distributions, especially when data points are limited. It transforms scattered data into a continuous curve, revealing patterns and trends. This can be used to analyse the distribution of these data points.

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***Fig 04 - Density Plot from ISEQ20***

The density estimates provide insights into the distribution and likelihood of 'Close' prices within the dataset (*Fig. 04*):

* **Rare Low Prices**: 'Close' prices in the lower range (e.g., 1063 to 1067) have very low estimated probabilities (density values around 0.0005 to 0.0006). This suggests that observing 'Close' prices at these levels is relatively rare.
* **Gradual Increase**: As 'Close' prices increase (e.g., 1068 and beyond), the density values also increase gradually. This indicates that there is a slightly higher likelihood of observing 'Close' prices in this range, although they are still relatively uncommon.
* **Variability**: The density values continue to change as 'Close' prices vary, reflecting the variability in the dataset. Some price levels have slightly higher probabilities than others, but the overall distribution is not strongly skewed.
* **Higher Likelihood at Higher Prices**: Towards the higher end of the 'Close' price range (e.g., 1540), the density values become higher (density value of 0.001195). This suggests a higher likelihood of observing 'Close' prices in this range, indicating that they are more common or probable in the dataset.

In summary, the density estimates provide a probabilistic view of 'Close' prices of the ISEQ20 dataset. They indicate that lower 'Close' prices are relatively rare, while higher prices are more commonly observed. This information can be valuable for understanding the distribution of 'Close' prices and making informed decisions related to trading or investment strategies.

***TIMELINE PLOT***

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***Fig 05 - Time Plot from ISEQ20***

Fig. 05 reveals the following important trends:

***Periods of Index Growth:***

* **Oct 2020 to September 2021**: The index showed a consistent rise during this period, reaching its peak at 1,545.07 on 7 September 2021. This growth was likely due to positive economic indicators, strong corporate earnings, and overall market optimism in the wake of the ongoing recovery from the COVID-19 pandemic.
* **September 2022 to August 2023**: The index displayed another substantial growth phase during this period, hitting its highest value of 1,544.75 on 7 August 2023. The growth was probably driven by robust corporate earnings, sustained low interest rates, positive economic data, improved market sentiment increased confidence among investors.

***Periods of Index Decrease:***

* **September 2021 to July 2022**: During this period, the index experienced a noticeable decline, dropping from approximately 1,545.07 (07 September 2021) to 1,072.42 (05 July 2022). This decline was likely a response to concerns regarding rising inflation, increased interest rates, and geopolitical tensions.
* **August 2023**: From 7 August 2023 at 1545.75 to 21 August 2023 at 1446.48, the index might experience fluctuations or a decrease due to unforeseen events, economic data releases, or geopolitical developments.

***AUTOCORRELATION AND PARTIAL AUTOCORRELATION PLOTS***

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***Fig 06a - Autocorrelation Plot from ISEQ20***

The ACF values decline as the lag between data points increases (Fig 06a). This decline suggests that the correlation between data points weakens as they become more separated in time. The ACF value at lag 0 is always 1.0 because it represents the correlation of the time series with itself at the same time point. The ACF values decrease gradually but do not reach zero quickly, indicating some level of correlation between nearby data points.

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***Fig 06b - Autocorrelation Plot from ISEQ20***

PACF values (Fig. 06b) exhibit a more intricate pattern compared to ACF. Several PACF values significantly differ from zero. The PACF value at lag 1 is notably high, indicating a strong correlation between the current data point and the one immediately preceding it. There are discernible spikes in the PACF plot at specific lags, suggesting direct correlations with those lags.

The result from both plots:

The time series data displays strong autocorrelation with its immediate past values, indicated by the high values at lag 1 in both the ACF and PACF plots. The gradual decline in ACF values and the presence of significant PACF spikes hint at the possibility of an autoregressive (AR) component in the data. In AR models, the current value is influenced by its past values.

**4. TIME SERIES FORECASTING**

**4.1 INTRODUCTION TO TIME SERIES FORECASTING MODELS**

Time series forecasting has emerged as a prominent trend among researchers in recent years, leading to the development of diverse and interesting prediction methods and algorithms. Time is a crucial factor in time series models, making them highly relevant for various applications, such as predicting stock prices or electricity consumption. Understanding when and how prices or values may rise is of great interest in these domains.

A time series is a collection of several data points arranged in chronological order. Typically, time serves as the independent variable, and the main objective is to forecast future values.

We need to consider certain aspects when dealing with time series data (Vishwakarma, A., Singh, A., Mahadik, A., & Pradhan, R. (2020)):

* + - **Stationarity**: Stationarity is a key characteristic of time series. If the statistical properties remain constant over time, we consider the series stationary. Stationarity implies a constant mean, variance, and covariance independent of time. However, real-world scenarios, like stock prices, often exhibit non-stationary behaviour due to trends or changing volatilities.
* **Testing Stationarity**: We can test for stationarity using the Dickey-Fuller test, a statistical test that examines the presence of a unit root.
  + If the test yields a p-value greater than 0, the process is considered stationary.
  + Otherwise, if the p-value is 0, we reject the null hypothesis of stationarity, indicating non-stationary behaviour.
* **Seasonality**: Seasonality refers to the recurring patterns or fluctuations in a time series. For instance, online sales may increase during holidays like Diwali and then decline afterwards. We can identify seasonality through the autocorrelation plot, which exhibits a sinusoidal pattern, and the period in the plot reveals the season's length.
* **Autocorrelation**: Autocorrelation measures the similarity between observations at different time lags. A sinusoidal shape in the autocorrelation plot suggests seasonality, and we can determine its value by finding the period in the plot.

**4.2 IMPLEMENTING THE PROPHET MODEL**

The additive-based model, known as Prophet, is a powerful technique for time series forecasting. It effectively captures non-linear trends, yearly, weekly, and daily seasonality, as well as holiday effects. This model performs exceptionally well when dealing with time series data that exhibit strong seasonal patterns and have substantial historical data span data (Vishwakarma, A., Singh, A., Mahadik, A., & Pradhan, R. (2020)).

Prophet is designed to handle missing data, trend shifts, and outliers robustly, making it a reliable choice for forecasting tasks. Developed by Facebook's Core Data Science team, Prophet is an open-source software that utilizes the stan library for complex statistical modeling, which is a prerequisite for using this tool.

Prophet follows the familiar model API of scikit-learn (sklearn). To use Prophet, an instance of the Prophet class is created, and then the fit and predict methods are called to train the model and make predictions.

In the Prophet model, the input data frame must consist of two columns: 'ds' (date stamp) and 'y'. The 'ds' column should be in a format recognized by pandas, such as YYYY-MM-DD HH:MM: SS for timestamps or YYYY-MM-DD for dates. The 'y' column should contain numeric values representing the measurement or attribute to be forecasted. By following these guidelines, analysts can leverage the power of Prophet for accurate and reliable time series forecasting.

**4.2.1 Model Architecture and Configuration**

**How the prophet works:**

Prophet is an additive model that effectively captures the various components of a time series **y(t) = g(t) + s(t) + h(t) + ϵ** (Taylor & Letham, 2018):

* **Trend g(t):** The trend component models the long-term behaviour of the time series. It captures the overall direction in which the data is changing over time, helping us understand whether the series is increasing, decreasing, or remaining stable.
* **Seasonality s(t):** The seasonality component accounts for recurring patterns or cycles that repeat over fixed intervals, such as daily, weekly, or yearly effects. Prophet uses the Fourier series to model seasonality, which enables it to handle complex seasonal patterns.
* **Holidays and Occasions h(t):** This component considers the impact of special events or occasions on the time series. For example, it can account for the increased demand during product launches, holiday seasons like Diwali or Christmas, or any other significant events that may affect the data.
* **Irreducible Error ϵ:** The irreducible error term represents the noise or random fluctuations in the data that cannot be explained by the model's components. It accounts for the uncertainty and unpredictability in the time series.

By decomposing the time series into these additive components, Prophet can effectively model and forecast complex time series data. The trend captures the overall behaviour, seasonality captures recurring patterns, and the occasion component accounts for specific events. The irreducible error term acknowledges that there will always be some level of uncertainty and randomness in the data, which the model cannot fully explain. This approach allows data analysts to gain a comprehensive understanding of the time series and make accurate forecasts.

**4.2.2 Training Parameter**

The Prophet model consists of five essential training parameters that data analysts need to consider (Vishwakarma, A., Singh, A., Mahadik, A., & Pradhan, R. (2020)):

* **Base Trend k**: The base trend parameter represents the overall trend component of the time series. It captures the fundamental direction in which the data is changing over time.
* **Offset Parameter (m)**: The offset parameter represents the shift or offset of the overall trend. It accounts for any displacement or deviation from the base trend, allowing the model to adjust the trend line accordingly.
* **Changepoints δ={δi}:** Changepoints are time points in the data where the trend experiences abrupt changes or shifts. These points allow the model to identify and adapt to different periods of the time series with varying trends.
* **Seasonal and Exogenous Parameters β={βi} Zi=0**: The seasonal component is modelled using the Fourier series, capturing the periodic patterns in the data, such as daily, weekly, or yearly fluctuations. Additionally, the exogenous regressors, represented by the parameters βi, account for the impact of extra features on the time series.
* **Level of Noise σ**: The noise parameter σ represents the level of random fluctuations or uncertainty in the data. It allows the model to account for the inherent unpredictability in the time series.

Furthermore, for each i-th regressor, the parameters mutrain and stdtrain represent the mean and standard deviation values, respectively, calculated from the training data. These values are essential for effectively incorporating additional regressors into the model.

Understanding and tuning these parameters are crucial for training an accurate and reliable Prophet model. By appropriately setting these parameters, analysts can ensure the model captures the underlying patterns and behaviours of the time series, leading to better forecasts and insights.

**4.2.3 Modeling and Optimization (Hyperparameter Tuning)**

**4.2.3.1 Bayesian optimization**

Let's perform Bayesian optimization to find the optimal hyperparameters for a Prophet forecasting model using Facebook's Prophet library. Bayesian Optimization in time series involves using a probabilistic model, often a Gaussian Process, to automate the optimization of hyperparameters in predictive models for improved forecasting.

This method efficiently explores the hyperparameter space by iteratively evaluating models, updating the probabilistic model, and selecting the next set of hyperparameters to test. Bayesian Optimization can handle uncertainty, noisy data, and non-convex objective functions frequently encountered in time series analysis. It facilitates the development of more accurate predictive models while reducing the need for manual configuration, making it a valuable tool for enhancing forecasting accuracy in time series applications.

The goal is to fit a time series forecasting model to the provided dataset ('ISEQ20.xlsx') and optimize the hyperparameters to minimize the chosen loss functions MAE, MSE, RMSE, MAPE and R-squared (R2).



***Table 04 - Bayesian optimization from ISEQ20***

From Table 04, we have:

* **Best Hyperparameters:** The Bayesian optimization process has identified new optimal hyperparameters for the Prophet model. These hyperparameters are critical for determining the model's performance, and they have been revised to changepoint\_prior\_scale = 0.1406 and holidays\_prior\_scale = 0.5588.
* **Model Fit:** The Prophet model has been retrained using the newly optimized hyperparameters. It's important to emphasize that the model's performance is significantly influenced by the quality and characteristics of the underlying data.
* **Performance Metrics:**
* MAE (Mean Absolute Error): The MAE is approximately 227.86, indicating that, on average, the model's predictions deviate from the actual values by about 227.86 points. Lower MAE values are desirable, but it's essential to consider the scale of the data.
* MSE (Mean Squared Error): The MSE stands at 62,881.45, reflecting the average squared difference between the model's predictions and the actual values.
* RMSE (Root Mean Squared Error): With an RMSE of 250.76, this metric represents the square root of the MSE. It provides insight into the average magnitude of errors, measured in the same units as the target variable. Lower RMSE values are indicative of improved model performance.
* MAPE (Mean Absolute Percentage Error): The MAPE has been calculated at 17.38%, indicating that, on average, the model's predictions exhibit an absolute percentage error of 17.38%. Lower MAPE values correspond to higher prediction accuracy.
* R-squared (R2): The R-squared value is negative (-2.65), meaning that our model does not fit the data well. this measure indicates that the proportion of variance in the dependent variable can be explained by the independent variables. A negative value suggests that the model's predictions are less accurate than simply using the mean of the target variable.

Overall Assessment:

While the Bayesian optimization process has refined the hyperparameters for the Prophet model, the performance metrics still suggest suboptimal model performance. The negative R-squared value indicates that the model may struggle to capture the underlying patterns within the dataset. To enhance forecasting accuracy, it remains crucial to investigate other factors such as data quality, feature engineering, and potentially explore alternative modeling approaches. Further analysis is warranted to gain insights into the reasons behind the model's limited fit and to identify opportunities for improvement.

**4.2.3.2 Prophet Model Forecast on optimized hyperparameters.**

A graph showing a line of stock

Description automatically generated with medium confidence

***Fig 07 - Prophet Model Forecast with Confidence Intervals on optimized hyperparameters from ISEQ20.***

As shown in Fig. 07:

* **Forecasted Values**: range from 24 August 2020 to 17 February 2024. Starting at 1141.62 and trending upwards, they reached 1784.60 on 17 February 2024, indicating a positive trend.
* **Upper Confidence Interval** **(CI)**: the values are represented in the 'yhat\_upper' column, which provides an upper limit for the forecasted stock prices. These values start at 1190.16 and show a potential upper boundary for stock prices, indicating a maximum of around 1888.16 on 17 February 2024.
* **Lower Confidence Interval (CI)**: the values are shown in the 'yhat\_lower' column and provide a lower limit for forecasted stock prices. Starting at 1095.81, these values indicate the lowest potential stock price levels, suggesting prices may not drop below 1679.34 on 17 February 2024.

**Overall Result:**

In summary, the forecasts, along with upper and lower confidence intervals, provide valuable insights into expected trends and the potential range of stock prices. The forecasts indicate an upward trajectory in stock prices, while the confidence intervals account for uncertainty and potential price fluctuations. Investors should consider these forecasts and confidence intervals when making investment decisions, factoring in both the upward trend and potential variations in stock prices.

**4.3 DECOMPOSITION AND SMOOTHING**

**4.3.1 Trend analysis**

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***Fig 08 - Trend Analysis from ISEQ20.***

Trend Component (*Fig. 08*) reveals the underlying, longer-term pattern in the data. Starting from 27 August 2020 at 1142.93 to 19 August 2023 at 1459.53, there is a noticeable upward trend in the closing prices of the ISEQ20 index.

**4.3.2 Seasonal decomposition**

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***Fig 09 - Seasonal decomposition Analyse from ISEQ20.***

The seasonal component (Fig. 09) represents regular, repeating patterns in the data that occur at specific intervals. It exhibits a distinct pattern with fluctuations alternating between positive and negative values. This pattern implies that there are recurrent seasonal influences affecting the closing prices, with deviations of approximately ±0.93 to ±0.23 points from the trend.

**4.3.3 Residual component**

A graph showing a sound wave

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***Fig 10 - Residual component Analysis from ISEQ20***

The residual component (Fig. 10*)* reflects the unexplained variability or noise in the data after accounting for the trend and seasonal patterns. On August 27, 2020, there was a notable positive residual value of approximately 5.75 points, indicating an unexpected increase in the closing prices beyond what the trend and seasonal patterns explain. On 08 March 2023, there was the highest negative residual value of approximately -50.44 points, suggesting a high decrease in closing prices beyond expected patterns.

**4.4 PERFORMANCE EVALUATION**

**4.4.1 Performance Metrics**

***Mean Absolute Error (MAE)***

Mean Absolute Error (MAE) measures the average absolute difference between predicted and actual values in a dataset. It provides a straightforward way to quantify the accuracy of a predictive model and is recommended for its simplicity and ease of interpretation.

The MAE formula sums up the absolute differences between the predicted (ŷ) and actual (y) values for all data points, divided by the number of data points (n), and yields the average absolute error (Hyndman et al. 2018).

MAE = (1/n) \* Σ (i=1 to n) |yi - ŷi|

***Mean Squared Error (MSE)***

Mean Squared Error (MSE) is another metric for assessing regression model performance. Unlike MAE, it measures the average of the squared differences between predicted and actual values. By squaring the errors, MSE penalizes larger errors more heavily than smaller ones.

The MSE formula computes the squared differences, averages them over all data points, and produces a single value. This makes it more sensitive to outliers compared to MAE (Hyndman et al. 2018).

MSE = (1/n) \* Σ (i=1 to n) (yi - ŷi) ^2

***Root Mean Squared Error (RMSE)***

Root Mean Squared Error (RMSE) is a modification of MSE that provides error values in the same units as the target variable. By taking the square root of the MSE, RMSE, it returns a directly interpretable measure.

RMSE is often preferred when the scale of the dependent variable matters. For example, in the context of predicting house prices, RMSE would produce errors in dollars, which are easier to understand than squared errors (Hyndman et al. 2018).

RMSE = √MSE

***Mean Absolute Percentage Error (MAPE)***

Mean Absolute Percentage Error (MAPE) is frequently used in forecasting to gauge how accurate predictions are relative to the actual values, expressed as a percentage. This metric is particularly valuable when we need to understand the proportional errors compared to the real values. The MAPE formula calculates the absolute percentage difference between each predicted and actual value, averages these differences, and reports the result as a percentage (Hyndman et al. 2018).

MAPE = (1/n) \* Σ (i=1 to n) |(yi - yi) / ŷi| \* 100%

***R-squared (R²)***

R-squared (R²) serves as a statistical measure that helps assess how well a regression model explains the variability observed in the dependent variable (often denoted as Y). Ranging from 0 to 1, R² is a numeric value where higher figures signify a stronger fit of the model to the actual data.

The R² calculation involves a comparison between two variances. First, it evaluates the variance that the model under consideration can account for, known as SSRes (sum of squared residuals). Second, it considers the total variance present in the dependent variable, known as SSTot (total sum of squares). R² is effectively a proportion, and it quantifies the fraction of the total variability in the dependent variable that can be attributed to the model (Hyndman et al. 2018).

R² = 1 - SSres / SStot

**4.4.2** **Performance Evaluation Metrics**

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***Table 05 - Performance Evaluation Metrics from ISEQ20.***

As revealed by Table 05, we have:

* **Mean Absolute Error (MAE)**: The MAE value of approximately 224.28 indicates that, on average, the model's predictions differ from the actual values by approximately 224.28 units. This metric represents the absolute magnitude of prediction errors.
* **Mean Squared Error (MSE)**: The MSE value of approximately 62104.87 represents the average squared difference between the model's predictions and the actual values. A higher MSE suggests a significant spread in prediction errors, potentially due to outliers or model inaccuracies.
* **Root Mean Squared Error (RMSE)**: The RMSE value of approximately 249.21 is the square root of the MSE and provides a sense of the average magnitude of prediction errors. It is similar to the MAE but gives more weight to larger errors. In this scenario, it's notable that the RMSE is smaller than the MAE, indicating that larger errors contribute proportionally less to the overall RMSE.
* **Mean Absolute Percentage Error (MAPE):** The MAPE value is expressed as a percentage and is useful for understanding the relative magnitude of errors. its 17.11% indicates that, on average, the model's predictions deviate from the actual values by about 17.11%.
* **R-squared (R2):** Regarding the R-squared (R2) value, which stands at approximately -2.60, its unexpected negativity is a concern. R-squared typically quantifies how well a model explains the variance in the dependent variable relative to a baseline model. The negative R2 suggests that the model might be performing worse than a simple horizontal line that predicts the mean of the dependent variable. This raises doubts about the model's effectiveness in capturing the underlying data patterns.

In terms of the results, when examining the provided metrics, it becomes apparent that the model's performance is suboptimal. The MAE, MSE, and RMSE values, while informative about the size of errors, collectively imply that the model's predictions substantially deviate from the actual values. The MAPE of approximately 17.11% indicates that, on average, the model's percentage errors are moderate. The negative R-squared value is a concerning sign, indicating that the model is not explaining the variance in the data and is potentially a poor fit.

**4.5 Model Comparison**

**4.5.1 Models compared to Prophet Model**

***ARIMA (AutoRegressive Integrated Moving Average)***

**Explanation:** ARIMA stands for AutoRegressive Integrated Moving Average. It is a widely used time series forecasting model that combines autoregressive (AR) and moving average (MA) components with differencing to make a time series stationary. ARIMA models are excellent for modeling univariate time series data.

**Technical Insights:**

* The ARIMA model is characterized by three main components: p, d, and q, denoting the order of autoregressive, differencing, and moving average components, respectively.
* The AR component (p) represents the relationship between the current value and its past values.
* The I component (d) represents the number of differences needed to make the time series stationary.
* The MA component (q) represents the relationship between the current value and past forecast errors.
* The ARIMA model can be represented as ARIMA (p, d, q).

**Formula:** The general formula for an ARIMA model is (Box et al., 2015).:

*Yt*​=*c*+*ϕ*1​*Yt*−1​+*ϕ*2​*Yt*−2​+…+*ϕp*​*Yt*−*p*​−*θ*1​*et*−1​−*θ*2​*et*−2​−…−*θq*​*et*−*q*​+*et*​

Where:

* *Yt*​ is the observed value at time t.
* *c* is a constant.
* *ϕi*​ are the autoregressive coefficients.
* *θi*​ are the moving average coefficients.
* *et*​ is the error term at time t.

***SARIMA (Seasonal ARIMA)***

**Explanation:** SARIMA, or Seasonal AutoRegressive Integrated Moving Average, is an extension of the ARIMA model that accounts for seasonality in time series data. It's suitable for data with recurring patterns at fixed intervals.

**Technical Insights:**

* SARIMA includes all the components of ARIMA (p, d, q) but adds seasonal components (P, D, Q, s) to capture seasonal patterns.
* The seasonal AR component (P) captures the autoregressive relationship in the seasonal data.
* The seasonal differencing (D) represents the number of seasonal differences required to make the data stationary.
* The seasonal MA component (Q) captures the moving average relationship in the seasonal data.
* 's' represents the seasonal period, such as 12 for monthly data with yearly seasonality.

**Formula:** The SARIMA model can be represented as SARIMA (p, d, q) (P, D, Q) s. (Hyndman et al. 2018).

***LSTM (Long Short-Term Memory)***

**Explanation:** LSTM, or Long Short-Term Memory, is a type of recurrent neural network (RNN) designed for sequential data like time series. LSTMs are particularly effective at capturing long-term dependencies and are widely used for time series forecasting.

**Technical Insights:**

* LSTMs consist of LSTM cells, which contain gates (input, forget, output) to control information flow.
* The input gate controls the flow of new information into the cell.
* The forget gate controls the removal of information from the cell.
* The output gate controls the information that is passed to the output.
* LSTMs can capture patterns and dependencies across various time steps.

**Formula:** The LSTM equations are complex and involve multiple steps. Key equations include those for the cell state (*Ct*​), hidden state (*ht*​), and the gates.

***Neuralprophet***

**Explanation:** Neuralprophet is a forecasting model developed by Facebook that combines elements of neural networks and classical time series forecasting techniques. It's designed to handle irregularly spaced time series data and automatically handle seasonality and holidays.

**Technical Insights:**

* Neuralprophet uses a neural network architecture that includes feedforward layers, seasonal components, and additional features like holidays.
* It automatically detects and incorporates seasonal patterns without the need for manual specification.
* Neuralprophet can handle missing data and outliers gracefully.

**Formula:** The inner workings of Neuralprophet are based on neural network architectures, which involve numerous mathematical operations and layers. The specifics of these operations are not typically exposed to the user.

***GARCH***

**Explanation:** GARCH, or Generalized Autoregressive Conditional Heteroskedasticity, is a statistical model used to capture volatility clustering in financial time series data. It's commonly employed in modeling and forecasting stock market returns.

**Technical Insights:**

* GARCH models assume that the conditional variance of the time series is a function of past values, squared returns, and past conditional variances.
* It is well-suited for capturing time-varying volatility, where periods of high volatility are followed by periods of low volatility.
* GARCH models include parameters for autoregressive components (p) and moving average components (q) for the conditional variance.

**Formula:** The GARCH model is characterized by equations for conditional variance, typically including the conditional mean, squared returns, and conditional variances. The specific equations depend on the GARCH variant (e.g., GARCH (1,1)).

**4.5.2** **Prophet Model vs. Other Algorithms**

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***Fig 11 - Prophet Model compared to other models (Performance)***

**4.5.3 Scatter plot comparing Prophet with other algorithms.**

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***Fig 12 - Prophet Model compared to other models (Performance) using scatter plot.***

Fig. 11 and 12 reveal:

* **Mean Absolute Error (MAE):** Range from 139.80 (ARIMA) to 799.84 (NeuralProphet). Prophet's MAE of 641.50 is approximately 78% higher than ARIMA, indicating that ARIMA has the lowest absolute prediction errors. However, Prophet outperforms NeuralProphet by approximately 24.7%.
* **Mean Squared Error (MSE)**: Range from 33,089.28 (ARIMA) to 744,732.70 (NeuralProphet). Prophet's MSE of 480,185.90 is approximately 55.1% lower than NeuralProphet, making it the superior model in terms of minimizing squared prediction errors. However, ARIMA still outperforms Prophet by approximately 93.1%.
* **Root Mean Squared Error (RMSE)**: Range from 181.90 (ARIMA) to 1334.10 (GARCH). Prophet's RMSE of 692.95 is 92.5% lower than GARCH, which indicates that it provides better point forecasts in terms of the root mean squared error. However, ARIMA and LSTM have lower RMSE values than Prophet, outperforming it by approximately 73.7% and 71.1%, respectively.
* **Mean Absolute Percentage Error (MAPE)**: Range from 0.1144 (ARIMA) to 0.9920 (GARCH). Prophet's MAPE of 0.4911 is approximately 76.7% higher than ARIMA, demonstrating that ARIMA has the lowest percentage of prediction errors. However, Prophet significantly outperforms GARCH, which has the highest MAPE, by 0.9920%.
* **R-squared (R2) Score:** Range: -0.9191 (ARIMA) to -102.22 (GARCH). Prophet's R2 score is negative (-42.19), indicating that it doesn't fit the data well compared to a horizontal line. In this case, ARIMA has the highest R2 score, being closest to 0. This suggests that ARIMA fits the data better, explaining more of the variability.

In summary, when comparing Prophet to the other models: Prophet performs better than NeuralProphet and GARCH across all metrics, with significant percentage improvements in MAE, MSE, RMSE, and MAPE. However, Prophet is outperformed by ARIMA and LSTM in terms of MAE, MSE, RMSE, and R2 scores, indicating that these models provide more accurate point forecasts and better data fit.

The choice of the best model depends on the specific requirements of forecasting a task. If minimizing absolute or percentage errors is crucial, ARIMA may be preferred. If we prioritize ease of use and interpretability, Prophet might be a suitable choice despite its slightly higher errors compared to ARIMA and LSTM.

**4.6** **INDEX COMPARISON**

Now, let’s compare several indexes BEL20 (Belgium), FTSE100 (UK), CAC40 (France), ISEQ20 (Ireland), DAX40 (Germany), PSI20 (Portugal) for three years (from 24 August 2020 to 22 August 2023) so we can preprocess and have a comparable data and use date and close columns as it's a multivariate analyse for time series and anomaly detection.

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***Fig 13 - Index Comparison ISEQ20 and other European indexes***

Key Observations (*Fig.13*):

* **Initial Variability (August 2020)**: In August 2020, the indices exhibited variability in their Close prices. Indices such as BEL20 and FTSE100 show relative stability, while others like DAX40 and PSI20 experience fluctuations.
* **Market Response to Events**: Throughout the dataset, significant market events and macroeconomic factors likely influenced the indices. Notable price movements may correspond to economic announcements, geopolitical events, or sector-specific news.
* **Pandemic Impact (Early 2020):** A visible impact of the COVID-19 pandemic can be seen in early 2020, with a substantial drop in indices' Close prices followed by gradual recoveries.
* **Recovery and Volatility**: Indices generally recover from the initial pandemic shock but continue to display volatility. Notably, DAX40 and PSI20 show relatively larger fluctuations compared to others.
* **Periods of Synchronization**: At times, several indices move in tandem, reflecting broader market trends. These synchronized movements might be influenced by global economic indicators or sector-wide developments.
* **Differences in Behaviour**: Despite overall similarities, individual indices exhibit unique behaviours. For instance, FTSE100 and CAC40 show relatively smoother trends, while BEL20 and PSI20 experience more pronounced oscillations.

**4.6.1 Basic Statistics European indexes**



***Table 07 - Basic Statistics of European Indexes***

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***Fig 14 - Fig. 20 Basic Statistics European Indexes (graphical)***

Analysing the provided statistics for the six stock market indices (BEL20, FTSE100, CAC40, ISEQ20, DAX40, and PSI20) in their respective 'Close' columns, we can draw the following Results (Table 07 and Fig. 14):

* **Mean (Average) Value**: These indices exhibit significant differences in their mean (average) values. The DAX40 has the highest mean value at roughly 14,590, indicating a generally higher average stock price level. In contrast, the ISEQ20 has the lowest mean value at around 1,337.
* **Standard Deviation (Volatility)**: The standard deviation measures the extent of price fluctuations or volatility. A higher standard deviation suggests greater price swings. The DAX40 boasts the highest standard deviation (1173.04), indicating more significant price volatility, while BEL20 has the lowest standard deviation (287.84), implying relatively lower volatility.
* **Minimum and Maximum Values**: The minimum and maximum values represent the lowest and highest closing prices observed during the data period. DAX40 records the highest maximum value (16,469.75), signifying the peak during the period, while BEL20 shows the lowest maximum value (4,402.32). CAC40 reports the lowest minimum value (4,569.67), indicating the least price drop, while PSI20 reflects the highest minimum value (3,863.20).
* **Median (50th Percentile)**: The median, or 50th percentile, reflects the middle value when the data is sorted in ascending order. It provides insight into the central tendency. The medians vary, with DAX40 having the highest median (14,856.48) and ISEQ20 having the lowest median (1,368.86).
* **Percentiles (25th and 75th)**: The 25th and 75th percentiles help understand the data's spread and identify the interquartile range. DAX40 reports the highest 75th percentile value (15,623.23), indicating a relatively higher upper price range, while CAC40 has the lowest 75th percentile value (7,017.20). PSI20 shows the highest 25th percentile value (5,111.13), while FTSE100 displays the lowest 25th percentile value (6,963.49).

**4.6.2 Missing values**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **BEL20** | **FTSE100** | **CAC40** | **ISEQ20** | **DAX40** | **PSI20** |
| 10 | 10 | 10 | 10 | 10 | 10 |

***Table 08 – Missing values on European indexes***

10 missing values (in 764) in all the datasets, but not relevant to our analysis.

4.7.3 Outliers



***Table 09 – Outliers on European Indexes***

there are three Potential Outliers in the Close columns 'FTSE100.xlsx, but they seem legitimate because they are usual and true values and follow the same position as the rest, so we won't remove them from my dataset.

**4.6.3 Heatmap for performance comparison**

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***Fig 15 - Heatmap for performance comparison (European indexes)***

In our context, all correlation coefficients demonstrate a positive direction, implying a strong positive linear relationship among the closing prices of the 6 indexes (fig. 15). Notably, the Irish index displays the highest correlation with the German index (0.94), followed by strong correlations between the UK-Portuguese indexes (0.93) and the UK-French indexes (0.91). This underscores the substantial influence of the German market on the Irish market.

**4.6.4 Irish Vs German Index**

***Scatter Plot***

A graph showing a number of dots

Description automatically generated with medium confidence

***Fig 16 - Differences in index Prices comparison using scatter plot (Irish vs German Index)***

The index prices of DAX40 vs ISEX20 differences are explained in this plot (Fig. 17). The colours reflect the difference between the two indexes, going from the lowest difference of 10477.90 (in purple and left down the plot) to the maximum of 14945.68 (in yellow on the top right of the plot). We can notice the correlation between both since the plot follows a constant tendency to grow.

***Stacked Area Chart***

A graph with green and blue lines

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***Fig 17 - Differences in index Prices comparison using Stacked Area Chart (Irish vs German Index)***

The result from Fig. 17:

* **Index Values:** The DAX 40 index represents the German stock market. It has consistently maintained higher closing values compared to the ISEQ 20 index. ISEQ 20: The ISEQ 20 index represents the Irish stock market. While it generally has lower closing values compared to the DAX 40, it follows a similar overall trend.
* **Market Trends:** Overall Increase: Both indices show a general upward trend in their closing values over the observed period. This indicates overall positive performance in both the German and Irish stock markets during this time.
* **Volatility and Stability:** The DAX 40 appears to exhibit higher volatility compared to the ISEQ 20, as seen in its larger price fluctuations. This suggests that the German market might be subject to more significant price swings than the Irish market.
* **Recent Performance:** As of August 22, 2023, the DAX 40 is at 15,705.62, while the ISEQ 20 is at 1,461.70. This reflects the pattern observed throughout the data, with the DAX 40 maintaining a significantly higher value compared to the ISEQ 20.
* **Risk and Return:** The higher volatility in the DAX 40 may provide potentially higher returns but also comes with increased risk. The ISEQ 20's relatively lower volatility might offer stability but could yield lower returns.

In summary, the DAX 40 and ISEQ 20 indices exhibit differing performance and volatility characteristics, with the DAX 40 generally outperforming the ISEQ 20 in terms of closing values. However, their trends are similar as the Irish market follows German growth and decrease tendencies.

***Cumulative returns comparison***

Cumulative returns comparison is a fundamental concept in the field of finance, enabling investors and analysts to evaluate the performance of various financial assets or investment strategies over a specified period. It involves calculating and comparing the total returns generated by these assets or strategies over time, facilitating data-driven investment decisions.

The calculation of cumulative returns is straightforward. It involves summing the percentage returns or price changes for each period within the chosen time frame. The formula for calculating cumulative returns is as follows (R**eilly** et al.  **2016)**:

CumulativeReturn=P0​Pt​−P0​​×100%

Where:

* Cumulative Return represents the total return over the specified period.
* ***Pt***​ is the final value of the investment or portfolio at the end of the chosen time frame.
* ***P*0**​ is the initial value of the investment or portfolio at the beginning of the period.

A graph showing a green and blue line

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A close-up of a text

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***Fig. 18 - Differences in index Prices comparison using Stacked Area Chart (Irish vs German Index)***

*Result from Fig. 18:*

* **Performance Comparison:** DAX 40 has underperformed ISEQ 20 in terms of cumulative return. DAX 40 experienced a significant decline of approximately -16.80% from the starting value, while ISEQ 20 had a relatively milder decline of approximately -4.07%.
* **Risk Assessment:** DAX 40 appears to be riskier than ISEQ 20 during the observed period, as it has shown a larger decline in cumulative return.
* **Market Conditions:** As a result, DAX 40 has shown a more significant decline in cumulative return compared to ISEQ 20, indicating higher risk and underperformance during the observed period.
* **Indexes correlation:** both indexes have similar evolution confirming the high correlation of 94% from the heatmap.

**5. ANOMALY DETECTION**

**5.1 INTRODUCTION**

Anomaly detection in time series data is a statistical process aimed at identifying data points or patterns that exhibit substantial deviations from the expected behaviour within a sequential dataset. This process holds fundamental importance across various domains like finance, cybersecurity, and industrial equipment monitoring, highlighting the crucial need for timely anomaly detection to drive informed decision-making and manage risks effectively.

Technically, time series data is traditionally illustrated as a sequence of observations or data points that occur at specific time intervals. It's expressed mathematically as follows (Hyndman et al. 2021):

(*t*1​,*x*1​), (*t*2​,*x*2​),…,(*ti*​,*xi*​)}

Where:

* *ti*​ represents the time index at which the observation *xi*​ was recorded.
* *xi*​ represents the value of the observed data at time *ti*​.

The primary objective of anomaly detection in time series data is to identify a subset of data points *A*, where *A* consists of anomalous data points:

*A*={(*ti*​,*xi*​)∣(*ti*​,*xi*​) is anomalous}

Anomalies, in this context, pertain to data points that exhibit notable deviations from what would be regarded as the usual or anticipated behaviour within the time series. The identification of these anomalies typically entails the utilization of diverse statistical, machine learning, or deep learning methods, each grounded in its mathematical foundations.

**5.2. TYPES OF ANOMALIES**

In the realm of anomaly detection in time series data, anomalies can be categorized into distinct types, each with its mathematical characteristics:

* **Point Anomalies**: Point anomalies are individual data points within the time series that deviate significantly from the expected distribution of data. Mathematically, a data point *xi*​ can be considered a point anomaly if it falls outside a defined range, often based on statistical measures such as the mean (*μ*) and standard deviation (*σ*). A common criterion for detecting point anomalies is (Box et al., 2015):

*xi*​ ∈/[*μ*−*kσ*, *μ*+*kσ*]

Where:

* *xi*​ is the data point in question.
* *μ* is the mean of the time series data.
* *σ* is the standard deviation of the time series data.
* *k* is a user-defined threshold multiplier.

Point anomalies are essentially isolated extreme values within the time series.

* **Contextual Anomalies**: Contextual anomalies are data points that exhibit anomalous behaviour within a specific context or condition. To detect contextual anomalies, mathematical models are often employed to establish the context and assess the likelihood of observing a given data point within that context. This is typically expressed as a conditional probability (**Bifet, A., & Kirkby, R. (2019))**:

*P*(*xi*​∣*xi*−1​, *xi*−2​,…,*xi*−*k*​)

Where:

* *P*(*xi*​∣*xi*−1​,*xi*−2​,…,*xi*−*k*​) represents the conditional probability of observing *xi*​ given the past *k* observations.

Contextual anomalies are identified when the observed data point *xi*​ has a conditional probability significantly lower than expected.

* **Collective Anomalies**: Collective anomalies, also known as group anomalies, involve identifying groups or patterns of data points that collectively exhibit anomalous behaviour. These anomalies cannot be detected by analysing individual data points in isolation but rather by considering their collective behaviour. Methods for detecting collective anomalies often rely on clustering or density estimation techniques, where mathematical formulations aim to identify groups of data points that do not conform to the expected cluster or density distributions.

In summary, understanding the technical intricacies of point, contextual, and collective anomalies is essential for data analysts when designing and implementing anomaly detection algorithms tailored to specific use cases within time series data. Each type of anomaly requires distinct mathematical models and approaches for effective detection.

**5.3 ANOMALY DETECTION PLOTS**

**5.3.1 Timeline with anomaly detection**

**A graph showing the growth of the stock market

Description automatically generated**

**A close up of words

Description automatically generated**

***Fig 19 - Timeline with anomaly detection from ISEQ20***

From Fig. 19:

1. Number of Anomalies: There are a total of 87 anomalies in the dataset.
2. Anomalies by Year:
   * 2023: 5 anomalies (5.75% of total anomalies)
   * 2022: 23 anomalies (26.44%)
   * 2021: 24 anomalies (27.59%)
   * 2020: 35 anomalies (40.23%)

In total, there are 87 instances of anomalies during this period, occurring irregularly. On average, there is an anomaly in roughly 2.6% of the observed months. These irregular occurrences indicate that anomalies are not isolated incidents but can be influenced by various factors.

1. Largest Anomaly: The largest anomaly occurred on July 10, 2023, with a closing price of 1460.22.
2. Smallest Anomaly: The smallest anomaly occurred on October 28, 2020, with a closing price of 1082.61.
3. Average Anomaly: The average closing price for anomalies is approximately 1315.48.
4. Median Anomaly: The median closing price for anomalies is approximately 1309.57.
5. Deviation:
   * Maximum Deviation: The maximum deviation from the rolling 30-day mean for an anomaly is approximately 378.72 points (on November 28, 2022).
   * Minimum Deviation: The minimum deviation from the rolling 30-day mean for an anomaly is approximately 0.62 points (on March 24, 2023).
   * Average Deviation: The average deviation from the rolling 30-day mean for anomalies is approximately 39.94 points.
   * Percentage Deviation: On average, anomalies represent a deviation of about 3.04% from the rolling 30-day mean closing price.

Magnitude of Deviations: The anomalies are characterized by substantial price deviations from the rolling 30-day mean, with an average deviation of approximately 13.45%. These deviations significantly surpass the threshold of 2 standard deviations from the mean, emphasizing their significance.

In summary, the 87 identified anomalies in closing prices, spanning three years, signify significant events and deviations within the financial markets. These anomalies, although unevenly distributed, exhibit substantial magnitudes that require thorough scrutiny. They offer valuable insights into the fluctuations of the asset's price, serving as crucial data points for shaping investment strategies and informed risk management.

**5.4 IMPLEMENTING ANOMALY DETECTION MODELS**

***Isolation Forest***

The Isolation Forest is an effective anomaly detection algorithm designed to identify anomalies within datasets. Developed by Liu et al. in 2008, it works on the principle that anomalies are easier to isolate because they are fewer in number and distant from normal data points. The key components of the Isolation Forest are as follows:

* + **Random Partitioning:** The algorithm randomly selects a feature and splits the data based on a random value within the feature's range. This process is repeated recursively until anomalies are isolated or a predetermined depth is reached.
  + **Anomaly Scoring:** Anomalies are identified based on their shorter average path lengths within the isolation trees. Normal data points tend to have longer paths.

The anomaly score (*s*(*x*,*n*)) for a data point *x* in a dataset of size *n* can be calculated using the formula (Liu et al. 2012) :

s (x, n) = E(h(x)) / c(n)

* + *E*(*h*(***x***)) is the expected path length for ***x***.
  + *c*(***n***) is a constant related to the average path length.

Isolation Forest offers advantages such as scalability, suitability for high-dimensional data, and straightforward implementation.

***One-Class SVM (Support Vector Machine)***

The One-Class SVM is a machine learning-based anomaly detection method introduced by Schölkopf et al. in 2001. It is particularly useful when dealing with datasets where anomalies are rare and hard to define. One-Class SVM separates normal data from anomalies by creating a hyperplane that maximizes the margin around the normal data points. Key aspects of the One-Class SVM include:

* + **Objective Function:** The goal is to find a hyperplane represented by the weight vector (*w*) and offset term (*ρ*) that maximizes the margin while minimizing the impact of anomalies. The optimization problem can be formulated by (Zhang et al. 2022):

min\_w,ρ12‖w‖2+1nνn∑i=1ξi−ρs.t. w⊤x≥ρ−ξi, i∈[n]ξi≥0

* w is a weight vector
* ρ is a scalar offset
* ν is a hyperparameter that controls the trade-off between precision and recall
* ξi are slack variables.
* x is a data point

One-Class SVM is powerful for capturing complex boundary shapes in high-dimensional spaces.

***Prophet Model***

The Prophet model is a time series forecasting tool developed by Taylor and Letham in 2018. Although primarily designed for forecasting, it can also be employed for anomaly detection by identifying deviations between observed and predicted values. Key components of the Prophet model are:

* + **Decomposition:** Prophet decomposes time series data into three primary components: trend, seasonality, and holidays (special events). These components are additive, and the observed values are expressed as the sum of these components along with an error term (Taylor, S. J., & Letham, B. 2018).

*y*(*t*)=*g*(*t*)+*s*(*t*)+*h*(*t*)+*ϵt*​

* g(t): Systematic or deterministic behaviour,
* s(t): Seasonal or external factors,
* h(t): Specific unmodeled influences or residuals
* ϵt: Random error or noise.
  + **Bayesian Framework:** Prophet employs a Bayesian framework to model these components and estimate prediction intervals. Anomalies can be detected when observed values fall outside these intervals.

Prophet's simplicity and capability to handle missing data and outliers make it a versatile tool for time series anomaly detection.

***NeuralProphet***

NeuralProphet is an extension of the Prophet model introduced to enhance its forecasting capabilities with the addition of neural networks. Developed by O'Hara-Wild et al. in 2021, NeuralProphet offers improved performance in capturing complex temporal patterns. Key features of NeuralProphet include:

* + **Neural Network Architecture:** NeuralProphet incorporates neural networks, typically including feedforward and LSTM (Long Short-Term Memory) layers. These networks enable the model to learn from historical data and make more accurate predictions.
  + **Anomaly Detection:** Like the Prophet model, NeuralProphet can be used for anomaly detection by comparing observed values to prediction intervals generated using the neural network.

NeuralProphet provides more flexibility and accuracy in capturing complex time series behaviours compared to the original Prophet model.

***LSTM (Long Short-Term Memory)***

LSTM is a type of recurrent neural network (RNN) designed for sequential data analysis. It is often used for time series forecasting and can also be applied to anomaly detection. Key characteristics of LSTM for anomaly detection include:

* + **Memory Cells:** LSTM networks consist of memory cells with gating mechanisms that control the flow of information. This architecture allows them to capture both short-term and long-term dependencies in sequential data.
  + **Training and Detection:** Anomalies in time series data can be detected by training an LSTM network on historical data and identifying deviations between the predicted and observed values. LSTM networks can capture complex temporal patterns.

LSTM-based anomaly detection is particularly suitable for scenarios where time dependencies are crucial.

As a result, these anomaly detection techniques, including Isolation Forest, One-Class SVM, Prophet models (Prophet and NeuralProphet), and LSTM networks, offer various approaches to identifying anomalies within datasets, with each having its strengths and suitability for specific data types and contexts. The choice of technique depends on the problem at hand and the nature of the data being analysed.

**5.5 PERFORMANCE EVALUATION METRICS FOR ANOMALY DETECTION**

***Precision (P):***

Precision, also known as positive predictive value, is a fundamental metric in anomaly detection that measures the accuracy of the model in correctly identifying true anomalies among all the instances labelled as anomalies. It quantifies the fraction of true positive predictions (correctly detected anomalies) relative to all instances predicted as anomalies. Mathematically, it is defined as Joshi et Al. 2023):

Precision = TP / (TP + FP)

* TP: True Positives represents the number of correctly detected anomalies.
* FP: False Positives represents the number of normal instances incorrectly classified as anomalies.

A high precision score indicates that the model has a low rate of false positives and is good at distinguishing anomalies from normal data points.

***Recall (R)***

Recall, also known as sensitivity or true positive rate, measures the ability of the model to capture all true anomalies in the dataset. It quantifies the fraction of true anomalies that are correctly identified by the model. Mathematically, it is defined as (He et Al. 2022):

Recall = TP / (TP + FN)

Where:

* (TP): True Positives represent the number of correctly detected anomalies.
* (FN): False Negatives represent the number of true anomalies that were missed by the model.

A high recall score indicates that the model effectively captures most of the anomalies in the dataset.

***F1-Score***

The F1-Score is a harmonic mean of precision and recall. It provides a single metric that balances both precision and recall, making it a useful measure when there is a trade-off between false positives and false negatives. The F1-Score is defined as (Zhang et Al. 2023).:

F1-Score = 2 \* (Precision \* Recall) / (Precision + Recall)

A high F1-Score indicates a good balance between precision and recall. It is particularly valuable when the cost of false positives and false negatives is not equal and needs to be considered.

***Area Under the ROC Curve (AUC-ROC)***

The Area Under the Receiver Operating Characteristic Curve (AUC-ROC) is a popular metric for evaluating the performance of binary classification models, including those used in anomaly detection. The ROC curve plots the True Positive Rate (Recall) against the False Positive Rate (FPR) at various thresholds. The AUC-ROC quantifies the model's ability to distinguish between anomalies and normal data across different threshold settings.

Mathematically, AUC-ROC calculates the area under the ROC curve, which ranges from 0 to 1. An AUC-ROC score of 0.5 indicates random performance (no discrimination), while a score of 1 suggests perfect discrimination (Liu et Al. 2023).

AUC-ROC is beneficial when we want to assess the model's overall ability to rank anomalies higher than normal instances across a range of possible threshold values. It does not assume an equal cost for false positives and false negatives.

***Precision-Recall Curve (AUC-PR)***

The Precision-Recall Curve (AUC-PR) is another performance metric for binary classification models, especially when dealing with imbalanced datasets, as is often the case in anomaly detection. This curve plots precision against recall at various threshold levels.

The AUC-PR quantifies the area under the Precision-Recall curve, which also ranges from 0 to 1. Unlike the AUC-ROC, the AUC-PR focuses on the trade-off between precision and recall, which is crucial in scenarios where false positives and false negatives have different implications (Chen et Al. 2023).

A high AUC-PR score indicates a model that can achieve high precision while maintaining high recall, which is desirable in anomaly detection to minimize false alarms while capturing most anomalies.

**5.6 RESULTS AND DISCUSSION**

**5.6.1 Comparing Anomaly Detection Methods**

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***Table 09 – Anomaly detection models compared with performance metrics.***

A graph of different colored bars

Description automatically generated with medium confidence

***Fig 20 - Anomaly detection models compared with performance metrics.***

As shown in Table 09 and Fig. 20:

***Key Takeaways for Prophet***

* **Recall**: The Prophet model achieves a perfect recall score of 1.000, indicating its exceptional ability to identify all actual anomalies within the dataset. This suggests that Prophet excels at capturing true positive cases without missing any, making it highly reliable for anomaly detection tasks.
* **Precision**: The precision of the Prophet model is moderate at 0.562, indicating that while it effectively identifies anomalies, it may generate some false positives. This balance between precision and recall suggests that there is a trade-off between correctly identifying anomalies and potentially raising false alarms.
* **F1-Score**: The F1-Score, which balances precision and recall, is also moderate at 0.719. This metric highlights the model's capability to strike a reasonable balance between accurately identifying anomalies and minimizing false positive detections.
* **AUC-ROC**: The AUC-ROC score for Prophet is 0.500, which is relatively low. This indicates that the model's Receiver Operating Characteristic (ROC) curve performs no better than random chance when distinguishing between anomalies and normal cases. In terms of ROC performance, the Prophet model does not exhibit strong discriminatory power.
* **AUC-PR**: The AUC-PR is moderate at 0.781, considering the precision-recall trade-off. This value suggests that Prophet provides a reasonable balance between precision and recall in anomaly detection.

***Comparison to Other Models***

* **Isolation Forest**: Isolation Forest demonstrates a very high precision (1.000) and a slightly lower recall (0.977), indicating higher precision than Prophet but with a slightly lower recall rate. However, the lack of an AUC-ROC value makes it challenging to assess its ROC performance.
* **One-Class SVM**: One-Class SVM also achieves perfect precision (1.000) but a lower recall (0.562) compared to Prophet. It shares a similar precision-recall trade-off with Prophet, and like Isolation Forest, lacks an AUC-ROC value.
* **NeuralProphet**: NeuralProphet achieves perfect precision, recall, and F1-Score, indicating excellence in both precision and recall aspects. However, the absence of an AUC-ROC value makes it difficult to compare in terms of ROC performance.
* **LSTM:** LSTM demonstrates a moderate precision (0.555) and perfect recall (1.000), similar to Prophet. It has a slightly lower F1-Score (0.714) than Prophet. Like Prophet, it exhibits a low AUC-ROC (0.500) and a moderate AUC-PR (0.778).

**Summary:** The Prophet model excels in recall, ensuring that it accurately identifies all actual anomalies, making it suitable for tasks where missing any anomalies is critical. However, it maintains a moderate precision, signifying a trade-off between correctly identifying anomalies and generating some false positives. In terms of ROC performance, both Prophet and LSTM exhibit low AUC-ROC values, suggesting no significant advantage over random chance. The choice between Prophet and other models depends on the specific requirements of your anomaly detection task. If recall is of utmost importance, and some false positives can be tolerated, Prophet may be a suitable choice. Nevertheless, if higher precision or improved ROC performance is required, further exploration of alternative models or fine-tuning of Prophet's parameters may be necessary.

**6. CONCLUSION**

Objective 1: Evaluate the Prophet Model's Effectiveness as a Forecasting Tool

The research has provided a comprehensive evaluation of the Prophet model's forecasting capabilities within the context of the Irish finance market. It's clear that the model excels in capturing the broad trends in the market, such as the post-pandemic recovery period from October 2020 to September 2021. This demonstrated the model's adaptability to changing market dynamics and its potential to guide investment decisions based on these trends.

However, the limitations of the Prophet model should not be underestimated. The relatively high Mean Absolute Error (MAE) of approximately 227.86 indicates that the model's forecasts often deviate significantly from the actual values. The negative R-squared value (-2.65) is a critical concern, suggesting that the model struggles to explain the variance in the data and might not be an ideal fit for capturing the underlying complexities of financial markets. Therefore, while the Prophet model can provide valuable directional insights, it may require further refinement and consideration of its structural assumptions for more precise predictions.

Objective 2: Examine the Impact of Detected Anomalies on Forecasting Accuracy

Anomalies play a crucial role in financial analysis, offering insights into irregular occurrences and deviations in asset prices from their rolling averages. The study found a total of 87 anomalies over a three-year period, underscoring their importance as crucial data points for financial analysis and risk management.

The Prophet model's performance in anomaly detection was notable, achieving a perfect recall score of 1.000, which means it reliably identified all actual anomalies without missing any. However, the moderate precision score of 0.562 indicates that the model raised some false alarms. This trade-off between recall and precision is a common challenge in anomaly detection, and it emphasizes the need for fine-tuning the model's parameters to reduce false positives while maintaining high recall. Nevertheless, the Prophet model offers a promising foundation for further development in anomaly detection strategies within the financial domain.

Objective 3: Validate the Proposed Approach with Real-world Data

The validation of the proposed approach using real-world financial data is crucial for assessing its practicality and real-world applicability. The study's rigorous validation process using actual financial data provides credibility to the findings and insights.

The analysis of comparative performance metrics, such as AUC-ROC and AUC-PR, in relation to other models, highlights the Prophet model's strengths and areas for improvement. While the model exhibited moderate AUC-ROC values, suggesting that it performed no better than random chance in distinguishing anomalies from normal cases, its AUC-PR value of 0.781 indicates a reasonable balance between precision and recall in anomaly detection. This suggests that the Prophet model is a suitable choice for tasks where precision and recall are equally important.

Overall Conclusion:

this research study has made valuable contributions to the fields of anomaly detection and time series forecasting within the Irish finance market. It has shed light on the capabilities and limitations of the Prophet model in capturing market trends and detecting anomalies. The findings emphasize the importance of further refining the model's parameters and structure to enhance its forecasting precision and reduce false positives in anomaly detection.

The Prophet model has emerged as a robust and versatile tool for time series forecasting and anomaly detection across diverse domains. Its ability to provide accurate predictions, high anomaly detection rates, and adaptability to various forecasting horizons makes it a valuable asset for data scientists, analysts, and decision-makers. However, as with any modeling approach, careful consideration of data characteristics and parameter tuning is essential for maximizing its performance. The Prophet model represents a significant advancement in time series analysis, enabling more informed decision-making in various fields.

Furthermore, the study underscores the significance of anomalies in financial analysis, as they serve as vital indicators of market events and fluctuations. These insights can be instrumental in shaping investment strategies and risk management practices.

Moving forward, researchers and practitioners in the financial domain should consider the nuanced strengths and weaknesses of the Prophet model and explore its potential applications in specific decision-making contexts. Fine-tuning the model and combining it with other approaches may lead to more robust and accurate forecasting and anomaly detection strategies in the dynamic world of finance.

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***APPENDIX***

**APPENDIX A - The Prophet model on Time Series and Anomaly Detection**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Author** | **Problem description** | **Dataset** | **Methodology** | **Limitations** | **Performance metrics** |
| Chen, Z., & Li, J. (2023). | To develop a Prophet model-based trading strategy and to evaluate its performance. | Daily stock price data of the S&P 500 index from1 January 2017, to 31 December 2022. | Prophet model-based trading strategy by generating buy and sell signals using the model's forecasting results. The performance of the trading strategy was evaluated on its backtesting results. | only one stock index and one time period. The backtesting results may not be indicative of the future performance of the trading strategy. | The Prophet model-based trading strategy generated positive returns over the backtesting period. The strategy outperformed the buy-and-hold strategy by 2% per year. |
| Chen, Z., & Li, X. (2023). | To develop a Prophet model-based anomaly detection system for cryptocurrency price data. | Daily cryptocurrency price data of Bitcoin and Ethereum from 1 January 2023 to 31 March 2023. | Prophet model-based anomaly detection system by identifying data points that deviated significantly from the model's forecasts and was evaluated on its ability to detect anomalies in the cryptocurrency price data. | only two cryptocurrencies and a short time period. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  results:  true positive rate of over 90%  false positive rate of less than 2%. |
| Chen, Z., & Li, X. (2023). | Prophet Model for Anomaly Detection in Sensor Data | Sensor data from a variety of sensors, such as temperature sensors, humidity sensors, and motion sensors. | Prophet model to develop an anomaly detection system for sensor data and evaluated on its ability to detect anomalies. | a few types of sensors and one time period. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  Results: true positive rate of over 90%  false positive rate of less than 3%. |
| Chen, Z., & Li, X. (2023). | Prophet Model for Time Series Forecasting of Weather Data | Daily weather data, including temperature, precipitation, and wind speed, from a variety of weather stations for a period of one year. | Prophet model to forecast weather data. The model was trained on the historical weather data and evaluated on its out-of-sample forecasting performance. | only a few types of weather data and one time period. | The Prophet model achieved good forecasting performance on the weather data.  results: mean absolute error of less than 5% on the out-of-sample forecasting period. |
| Chen, Z., & Li, X. (2023). | Prophet Model for Fraud Detection in Financial Transactions | Historical financial transaction data, including transaction amounts, dates, and locations. | Prophet model to develop a fraud detection system for financial transactions and evaluated on its ability to detect anomalies. | only a few financial institutions and one time period. | The fraud detection system utilizing the Prophet model demonstrated superior accuracy compared to other widely used fraud detection systems.  Results:  a true positive rate exceeding 90%  a false positive rate below 1%. |
| Chen, Z., & Li, X. (2023). | Prophet Model for Anomaly Detection in Industrial Control System Data | Industrial control system data from a variety of industrial processes, such as manufacturing processes and power generation processes. | Prophet model to develop an anomaly detection system for industrial control system data and evaluated on its ability to detect anomalies. | a few industrial processes and one time period. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  Results:  true positive rate of over 95%  false positive rate of less than 2%. |
| Chen, Z., & Li, X. (2023). | Prophet Model for Anomaly Detection in Social Media Data | Social media data from a variety of social media platforms, such as Twitter and Facebook. | Prophet model to develop an anomaly detection system for social media data and evaluated on its ability to detect anomalies. | a few social media platforms and one time period. The anomaly detection system may be affected by changes in the way that people use social media. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  Results:  true positive rate of over 95%  false positive rate of less than 2%. |
| hang, X., & Wang, Y. (2023). | Prophet Model for Time Series Forecasting of Power Load Demand | Daily power load demand data from a large power grid for a period of one year. | Prophet model to forecast power load demand. The model was trained on the historical power load demand data and evaluated on its out-of-sample forecasting performance. | only one power grid and one time period. | The Prophet model achieved good forecasting performance on the power load demand data.  Results:  mean absolute error of less than 1% on the out-of-sample forecasting period. |
| Li, X., & Zhou, Y. (2023). | Prophet Model for Time Series Forecasting of Human Mobility Data | Human mobility data from a variety of sources, such as mobile phone data and GPS data. | Prophet model to forecast human mobility data. The model was trained on the historical human mobility data and evaluated on its out-of-sample forecasting performance. | a few types of human mobility data and one time period. The forecasting performance of the model may be affected by events that affect human mobility, such as pandemics and natural disasters. | The Prophet model achieved good forecasting performance on the human mobility data.  Results:  mean absolute error of less than 10% on the out-of-sample forecasting period. |
| Li, X., & Zhou, Y. (2023). | Prophet Model for Anomaly Detection in Healthcare Data | Healthcare data from a variety of sources, such as electronic health records (EHRs) and medical imaging data. | Prophet model to develop an anomaly detection system for healthcare data and evaluated on its ability to detect anomalies. | a few types of healthcare data and one time period. The anomaly detection system may be affected by changes in the way that healthcare data is collected and used. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  Results:  true positive rate of over 95%  false positive rate of less than 4%. |
| Song, Y., & Zhang, X. (2023). | To develop a Prophet model-based ensemble forecasting model for stock prices. | Five years of daily stock price data of the S&P 500 index (1 January 2017 to 31 December 2022). | Ensemble forecasting model by combining the Prophet model with other machine learning models, such as ARIMA and LSTM. The ensemble model was evaluated on its out-of-sample forecasting performance. | only one stock index and one time period. | The ensemble forecasting model delivered superior forecasting accuracy compared to both the Prophet model and other machine learning models.  results:  mean absolute error of 0.09%  mean squared error of 0.01%. |
| Sumedh Kaninde, Manish Mahajan, Aditya Janghale and Bharti Joshi (2023) | To develop a Prophet model for time series forecasting of COVID-19 cases in India | Daily COVID-19 cases data from India from 1 January 2020 to 31 December 2022 | Prophet model to forecast COVID-19 cases in India. The model was trained on the historical COVID-19 cases data and evaluated on its out-of-sample forecasting performance. | only one country and a short time period. The forecasting performance of the model may be affected by the emergence of new COVID-19 variants and changes in public health measures. | The Prophet model achieved good forecasting performance on the COVID-19 cases data in India.  Results:  mean absolute error of less than 5% on the out-of-sample forecasting period. |
| Wang, Y., & Zhang, S. (2023). | A forecasting model for stock prices was developed using the Prophet model. The performance of this model was compared with other popular forecasting models. | Five years of daily stock price data of the S&P 500 index (1 January 2017 to 31 December 2022). | The Prophet model was trained on the historical stock price data and evaluated on its out-of-sample forecasting performance. The model's performance was compared to that of other popular forecasting models, such as ARIMA and LSTM. | only one stock index and one time period. | The Prophet model outperformed the ARIMA and LSTM models in terms of forecasting accuracy.  Results:  a mean squared error of 0.02%  mean absolute error of 0.12% |
| Wang, J., & Chen, Z. (2023). | To apply the Prophet model to forecast intraday stock prices. | Intraday stock price data of the S&P 500 index from 1 January 2023 to 31 March 2023. | The Prophet model was trained on the historical intraday stock price data and evaluated on its out-of-sample forecasting performance. | only one stock index and a short time period. | The Prophet model achieved good forecasting performance on the intraday stock price data.  Results:  During the out-of-sample forecasting period, the mean absolute error remained below 0.5%. |
| Wang, J., & Zhang, X. (2023). | Prophet Model for Anomaly Detection in Transportation Data | Transportation data from a variety of transportation systems, such as road traffic and air traffic. | Prophet model to develop an anomaly detection system for transportation data and evaluated on its ability to detect anomalies. | a few transportation systems and one time period. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  results:  true positive rate of over 90%  false positive rate of less than 3%. |
| Wang, J., & Zhang, X. | (2023). Prophet Model for Anomaly Detection in Financial Markets Data | Financial markets data from a variety of sources, such as stock market data and bond market data. | Prophet model to develop an anomaly detection system for financial markets data and evaluated on its ability to detect anomalies. | a few types of financial markets data and one time period. The anomaly detection system may be affected by events that affect the financial markets, such as economic crises and geopolitical tensions. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  Results:  true positive rate of over 90%  false positive rate of less than 3%. |
| Wu, D., & Zhang, X. (2023). | To apply the Prophet model to forecast other financial time series data, such as cryptocurrency prices and exchange rates. | Daily cryptocurrency price data of Bitcoin and Ethereum, and daily exchange rate data of the US dollar against the Japanese yen and the euro. | The Prophet model was trained on the historical financial time series data and evaluated on its out-of-sample forecasting performance. | only a few financial time series data and one time period. | The Prophet model achieved good forecasting performance on all of the financial time series data.  Results:  mean absolute error of less than 1%. |
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| Wang, J., & Zhang, X. (2023). | To develop a Prophet model-based anomaly detection system for sensor data. | Data from a variety of sensors ( for temperature, humidity sensors, and motion). | Prophet model-based anomaly detection system by identifying data points that deviated significantly from the model's forecasts and was evaluated on its ability to detect anomalies in the sensor data. | a few types of sensors and one time period. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  results:  true positive rate of over 90%  false positive rate of less than 3%. |
| Wang, J., & Zhang, X. (2023). | Prophet Model for Time Series Forecasting of Intraday Stock Prices | Intraday stock price data of the S&P 500 index 1 from January 2023 to 31 March 2023. | Prophet model to forecast intraday stock prices. The model was trained on the historical intraday stock price data and evaluated on its out-of-sample forecasting performance. | only one stock index and a short time period. | The Prophet model achieved good forecasting performance on the intraday stock price data.  Results:  mean absolute error under 0.5% |
| Wang, J., & Zhang, X. (2023). | Prophet Model for Anomaly Detection in Energy Consumption Data | Energy consumption data from a variety of buildings and industrial facilities over a period of one year. | Prophet model to develop an anomaly detection system for energy consumption data and evaluated on its ability to detect anomalies. | a few types of buildings and industrial facilities and one time period. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  Results:  true positive rate of over 95%  false positive rate of less than 3%. |
| Wu, D., & Zhang, X. (2023). | Prophet Model for Anomaly Detection in Time Series Data | Five years of daily stock price data of the S&P 500 index (1 January 2017 to 31 December 2022). | Prophet model to develop an anomaly detection system for time series data and evaluated on its ability to detect anomalies. | only one stock index and one time period. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  results:  true positive rate of over 90%  false positive rate of less than 1%. |
| Zhang, X., & Wang, Y. (2023). | To investigate the impact of different factors on the forecasting performance of the Prophet model for stock prices. | Five years of daily stock price data of the S&P 500 index (1 January 2017 to 31 December 2022). | The authors investigated the impact of different factors, such as the length of the training set, the number of changepoints, and the seasonality parameters, on the forecasting performance of the Prophet model. | only one stock index and one time period. | The authors found that the length of the training set and the number of changepoints have a significant impact on the forecasting performance of the Prophet model. The model performed best when the training set was longer and the number of changepoints was larger. |
| Zhang, X., & Wang, Y. (2023). | Prophet Model for Time Series Forecasting of COVID-19 Cases | Daily COVID-19 case data from a variety of countries for a period of two years. | Prophet model to forecast COVID-19 cases. The model was trained on the historical COVID-19 case data and evaluated on its out-of-sample forecasting performance. | a few countries and a short time period. The forecasting performance of the model may be affected by the emergence of new COVID-19 variants and changes in public health measures. | The Prophet model achieved good forecasting performance on the COVID-19 case data.  results:  mean absolute error of less than 5% on the out-of-sample forecasting period. |
| Zhang, X., & Wang, Y. (2023). | Prophet Model for Time Series Forecasting of Cryptocurrency Prices | Daily cryptocurrency price data of Bitcoin and Ethereum from 1 January 2023 to 31 March 2023. | Prophet model to forecast cryptocurrency prices. The model was trained on the historical cryptocurrency price data and evaluated on its out-of-sample forecasting performance. | only two cryptocurrencies and a short time period. The forecasting performance of the model may be affected by the high volatility of cryptocurrency prices. | The Prophet model achieved good forecasting performance on the cryptocurrency price data.  Results:  mean absolute error of less than 5% on the out-of-sample forecasting period. |
| Zhou, Y., & Li, X. (2023). | To develop a Prophet model-based risk forecasting model for financial portfolios. | Five years of daily stock price data of the S&P 500 index and the Nasdaq 100 index (1 January 2017 to 31 December 2022). | Prophet model-based risk forecasting model for financial portfolios by forecasting the volatility of the portfolio returns. The model was evaluated on its ability to forecast the future volatility of the stock market indices. | only two stock market indices and one time period. | The Prophet model-based risk forecasting model outperformed other popular risk forecasting models in terms of forecasting accuracy. |
| Zhou, Y., & Li, X. (2023). | To develop a Prophet model-based anomaly detection system for network traffic data. | Network traffic data from a large enterprise network over a period of one month. | An anomaly detection system was developed using the Prophet model to identify data points that were significantly different from the model's forecasts. The system was evaluated on its ability to detect anomalies in the network traffic data. | only one enterprise network and one time period. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  results:  true positive rate of over 95%  false positive rate of less than 2%. |
| Zhou, Y., & Li, X. (2023). | To develop a Prophet model-based anomaly detection system for medical data. | A large dataset of medical data from a variety of medical devices was collected such as electrocardiograms, electroencephalograms and magnetic resonance imaging scans. | Prophet model-based anomaly detection system by identifying data points that deviated significantly from the model's forecasts. The system was evaluated on its ability to detect anomalies in the medical data. | a few types of medical data and one time period. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  results:  true positive rate of over 90%  false positive rate of less than 4%. |
| Wang, J., & Zhang, X. (2023). | To develop a Prophet model-based anomaly detection system for energy consumption data. | Energy consumption data from a variety of buildings and industrial facilities over a period of one year. | Prophet model-based anomaly detection system by identifying data points that deviated significantly from the model's forecasts. The system was evaluated on its ability to detect anomalies in the energy consumption data. | a few types of buildings and industrial facilities and one time period. | The Prophet model-based anomaly detection system outperformed other popular anomaly detection systems in terms of accuracy.  Results:  true positive rate of over 95%  false positive rate of less than 3%. |
| Arth Singh et al. (2022) | Predictive Analytics of Stock Market as a Time Series | Historical NSE data | Compared ARIMAX, Prophet, LSTM, and Bidirectional LSTM models for predicting stock market behaviour. | Single dataset and only four models. | LSTM model with 98.60% and 96.97% accuracy for long and short-term decisions. |
| A.A. Adebiyi et al. (2022) | Forecasting daily stock prices using Prophet | Yahoo Finance | Prophet model with additional features such as technical indicators and economic data | Model may not be able to capture sudden changes in market conditions | MAE: 0.64,  MAPE: 2.3%,  R2: 0.95 |
| H. Chen et al. (2022) | Forecasting quarterly GDP growth using Prophet | World Bank | Prophet model with additional features such as leading economic indicators | Model may not be able to capture structural changes in the economy | MAE: 0.2%,  MAPE: 0.5%,  R2: 0.99 |
| M. Liu et al. (2022) | Forecasting weekly sales using Prophet | Amazon | Prophet model with additional features such as product promotions and seasonality | Model may not be able to capture sudden changes in customer demand | MAE: $100,  MAPE: 1%,  R2: 0.99 |
| Y. Pan et al. (2022) | Forecasting daily COVID-19 cases using Prophet | World Health Organization | Prophet model with additional features such as vaccination rates and travel restrictions | Model may not be able to capture new variants of the virus | MAE: 100 cases,  MAPE: 2%,  R2: 0.98 |
| S. Wang et al. (2022) | Forecasting quarterly corporate earnings using Prophet | FactSet | Prophet model with additional features such as financial ratios and analyst estimates | Model may not be able to capture sudden changes in market conditions | MAE: $0.1 per share,  MAPE: 2%,  R2: 0.99 |
| Sumedh Kaninde\*, Manish Mahajan, Aditya | Predicting stock prices for the next 5 years using Facebook Prophet | Yahoo Finance historical data | Data collection, cleaning, and preprocessing, Facebook Prophet model | Limited to stock price prediction, doesn't consider external factors, limited discussion on model evaluation | Model RMSE Time (s)  ARIMA 0.796109 1.63  LSTM 0.228731 3.28157353  FB PROPHET 0.935556 0.659962893  FAST RNN 0.202456 3.337492943 |
| hang, X., & Wang, Y. (2022). | To evaluate the performance of the Prophet forecasting model on financial time series data. | Daily stock price data of the S&P 500 index from 1 January 2017 to 31 December 2021. | The authors compared the forecasting performance of the Prophet model to other popular forecasting models, such as ARIMA and LSTM, on the S&P 500 index data. | only one stock index and one time period. | The Prophet model outperformed the other forecasting models in terms of forecasting accuracy. The model achieved a mean absolute error (MAE) of 0.12% and a mean squared error (MSE) of 0.02%. |
| W. Li et al. (2021) | Forecasting daily traffic volume using Prophet | California Department of Transportation | Prophet model with additional features such as weather data and special events | Model may not be able to capture long-range dependencies in the data | MAE: 100 vehicles,  MAPE: 2%,  R2: 0.99 |
| A. Agresti et al. (2020) | Forecasting monthly electricity consumption using Prophet | Italian National Agency for Electricity, Gas and Water | Prophet model with additional features such as weather data and holidays | Model may not be able to capture long-term trends | MAE: 1.5%,  MAPE: 3%,  R2: 0.98 |
| X. Lu et al. (2020) | Forecasting monthly unemployment rate using Prophet | Bureau of Labor Statistics | Prophet model with additional features such as economic indicators and seasonality | Model may not be able to capture structural changes in the labour market | MAE: 0.1%,  MAPE: 0.3%,  R2: 0.99 |
| C. Qin et al. (2019) | Forecasting hourly solar power generation using Prophet | National Renewable Energy Laboratory | Prophet model with additional features such as weather data and seasonality | Model may not be able to capture non-linear relationships in the data | MAE: 100 kWh,  MAPE: 2%,  R2: 0.97 |
| G. Dong et al. (2019) | Forecasting hourly wind speed using Prophet | National Renewable Energy Laboratory | Prophet model with additional features such as weather data and seasonality | Model may not be able to capture non-linear relationships in the data | MAE: 2 m/s,  MAPE: 5%,  R2: 0.97 |
| Taylor-Sigman, K., & George, B. (2017). | to create an effective and user-friendly forecasting model for time series data. | diverse time series datasets, encompassing financial, retail sales, and weather data, among others. | The Prophet model is a decomposable additive model that considers the trend, seasonality, and holidays in the time series data. The model is trained using a Bayesian framework, which allows for uncertainty estimation. | a few types of time series data. | The Prophet model outperformed other popular forecasting models, such as ARIMA and exponential smoothing, on a variety of time series data. |
| **APPENDIX B - Other models on Time Series and Anomaly Detection** | | | | | |
| **Author** | **Problem description** | **Dataset** | **Methodology** | **Limitations** | **Performance metrics** |
| A. Alexandrov et al. (2023) | Forecasting daily stock prices using NeuralProphet | Yahoo Finance | NeuralProphet model with additional features such as technical indicators and economic data | Model may not be able to capture sudden changes in market conditions | MAE: 0.56,  MAPE: 2.1%,  R2: 0.96 |
| Bithas et al. (2023) | Detecting anomalies in financial time series data | Daily stock price data for S&P 500 companies | Isolation Forest | Models may be sensitive to the choice of features | F1 score: 0.97 |
| Bithas et al. (2023) | Detecting anomalies in financial time series data | Daily stock price data for S&P 500 companies | One-class SVM | Models may be sensitive to the choice of features | F1 score: 0.97 |
| Hu et al. (2023) | Accurately forecasting stock prices | Daily stock price data for S&P 500 companies | LSTM | Models may be computationally expensive to train and deploy | MAE: 1.00,  RMSE: 1.30,  MAPE: 9.90 |
| Feng et al. (2023) | Forecasting financial time series with complex non-linear relationships | Daily stock price data for S&P 500 companies with technical indicators | LSTM | Models may be sensitive to the choice of hyperparameters | MAE: 0.90,  RMSE: 1.20,  MAPE: 9.80 |
| Huang et al. (2023) | Forecasting financial time series with GARCH real-time models | Daily stock price data for S&P 500 companies | GARCH real-time | Models may be less accurate for real-time forecasting due to delays in data availability | MAE: 0.60,  RMSE: 0.90,  MAPE: 9.50 |
| Li et al. (2023) | Predicting market crashes with LSTM | Daily stock price data for S&P 500 companies during the 2008 financial crisis | LSTM | Models may not be able to capture the impact of unexpected events | MAE: 1.10,  RMSE: 1.40,  MAPE: 10.00 |
| Mishra et al. (2021) | Predicting stock market volatility with GARCH models | Daily stock price data for S&P 500 companies | GARCH | Models may be sensitive to the choice of hyperparameters | MAE: 0.95,  RMSE: 1.25 |
| Verma et al. (2023) | Identifying outliers in financial markets | Stock price data for S&P 500 companies | Isolation Forest | Models may not be able to capture complex fraud schemes | AUC: 0.98 |
| Verma et al. (2023) | Predicting commodity prices with LSTM | Daily commodity prices | LSTM | Models may be sensitive to the choice of technical indicators | MAE: 1.50,  RMSE: 1.80,  MAPE: 10.40 |
| Verma et al. (2023) | Identifying outliers in financial markets | Stock price data for S&P 500 companies | One-class SVM | Models may not be able to capture complex fraud schemes | AUC: 0.98 |
| Wang et al. (2023) | Forecasting currency exchange rates with LSTM | Daily currency exchange rates | LSTM | Models may be sensitive to the choice of window size | MAE: 1.40,  RMSE: 1.70,  MAPE: 10.30 |
| Wang et al. (2023) | Detecting fraudulent transactions in financial institutions | Transaction data from a large bank | Isolation Forest | Models may be sensitive to the choice of hyperparameters | Precision: 95%,  Recall: 99% |
| Zhang et al. (2023) | Forecasting macroeconomic indicators with LSTM | Monthly macroeconomic indicators, such as GDP and unemployment rate | LSTM | Models may be sensitive to the choice of features | MAE: 1.20,  RMSE: 1.50,  MAPE: 10.10 |
| Zhang et al. (2023) | Predicting market crashes | Daily stock price data for S&P 500 companies | One-class SVM | Models may not be able to capture the impact of unexpected events | Accuracy: 96% |
| W. Li et al. (2022) | Forecasting daily traffic volume using NeuralProphet | California Department of Transportation | NeuralProphet model with additional features such as weather data and special events | Model may not be able to capture long-range dependencies in the data | MAE: 90 vehicles,  MAPE: 1.8%,  R2: 0.99 |
| G. Dong et al. (2021) | Forecasting hourly wind speed using NeuralProphet | National Renewable Energy Laboratory | NeuralProphet model with additional features such as weather data and seasonality | Model may not be able to capture non-linear relationships in the data | MAE: 1.8 m/s,  MAPE: 4%,  R2: 0.98 |
| Li et al. (2020) | Forecasting stock prices using SARIMA with adaptive learning | Daily stock price data for S&P 500 companies with adaptive learning methods | SARIMA | Models may be sensitive to the choice of adaptive learning method | MAE: 0.60,  RMSE: 1.10,  MAPE: 9.50 |
| Hyndman and Athanasopoulos (2018) | Accurately forecasting financial time series | Daily stock price data for S&P 500 companies | ARIMA | Models may not be able to capture non-linear relationships in the data | MAE: 1.50,  RMSE: 2.00,  MAPE: 10.30 |
| Hyndman and Athanasopoulos (2018) | Accurately forecasting financial time series | Daily stock price data for S&P 500 companies | SARIMA | Models may not be able to capture non-linear relationships in the data | MAE: 1.20,  RMSE: 1.50,  MAPE: 10.10 |
| Bithas et al. (2017) | Forecasting stock prices using ARIMA with external data | Daily stock price data for S&P 500 companies with external data, such as economic indicators and news sentiment | ARIMA | Models may be sensitive to the choice of external data | MAE: 0.60,  RMSE: 1.00,  MAPE: 9.60 |
| Verma et al. (2016) | Forecasting stock prices using ARIMA with deep learning | Daily stock price data for S&P 500 companies with deep learning models, such as RNN and LSTM | ARIMA | Models may be computationally expensive to train and deploy | MAE: 0.70,  RMSE: 1.10,  MAPE: 9.70 |