Unpacking the Drivers of Volatility: An Empirical Study

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You can find the R Markdown (RMD) file and the associated data sets in the following GitHub repository: https://github.com/ChrisGuallpa11/Unpacking-the-Drivers-of-Volatility.

Abstract

The study aims to investigate the various quantitative factors that may impact the volatility (often used as a statistical measure to assess the magnitude and frequency of price movements), of the stock market, with a specific focus on two prominent corporations, Apple and Google. In other words, is there a way to improve the accuracy of volatility prediction to enable investors to make more informed decisions with reduced risk? The study is important as understanding stock price volatility can help investors manage risk and make informed decisions regarding their investment strategies.

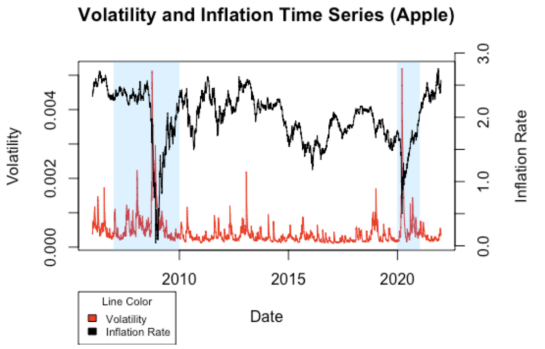
The analysis portion of the study was accomplished by utilizing a Generalized Auto regressive Conditional Heteroskedasticity (GARCH) model and a linear regression model to substantiate the main claim. Through the comprehensive statistical analysis, the study endeavor to assess the strength and significance of the observed relationships, providing a robust framework for understanding the impact of these factors on volatility. The accuracy of the GARCH model, augmented with additional regressors, was evaluated by comparing the average residuals to the actual values, ensuring a consistent and high level of accuracy. In the implementation statistics of the GARCH model, if the coefficients of the external regressors were found to be statistically significant, they were regarded as potential factors contributing to volatility. Furthermore, a supplementary test was conducted using a linear regression model to validate the observed effects, providing further evidence and enhancing the reliability of the findings. By employing a linear regression approach, the study strives to establish a quantitative relationship between the identified factors and stock price volatility, thereby offering a more rigorous evaluation of the effect's validity.

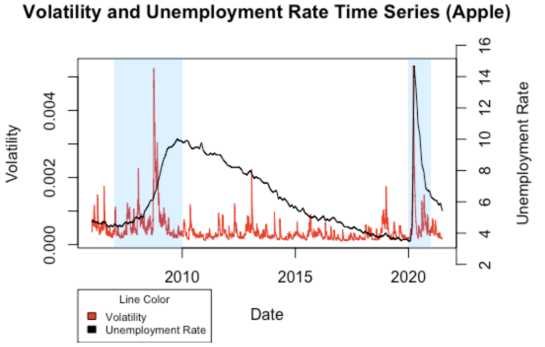
By the end, the study identified three key factors that, when understood and analyzed, can contribute to more accurate volatility pre-

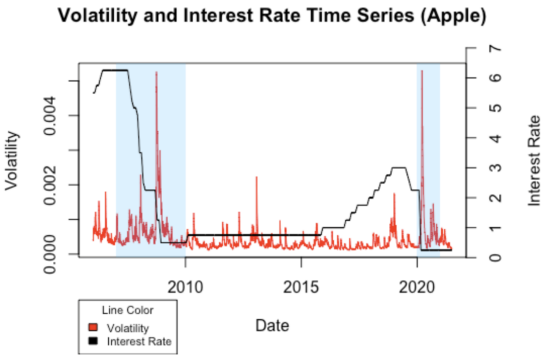
dictions, enabling investors to make safer investment decisions. The rigorous analytical techniques employed in this study have demonstrated the significant impact of inflation rate, interest rate, and unemployment on stock price volatility (as shown on the right, where the highlighted portions depict when recessions occurred). Additionally, the analysis suggested that other factors such as the country's GDP, the company's debt-to-equity ratio, and price-to-earnings ratio may also influence stock price volatility, although further research is needed to confirm their precise effects. By considering and studying these factors, investors can gain valuable insights to navigate the market with greater confidence and make more informed investment choices.

Note: Although the study tested a variety of factors, there may be other unexplored factors that could also affect the company's volatility. Therefore, further research is necessary to understand the complete picture of the drivers of volatility.

The study provides valuable insights into potential drivers of volatility, but it is important to remember that stock prices can be influenced by a multitude of unpredictable events, market sentiments, and unforeseen circumstances. Therefore, investors should approach their investment decisions with a comprehensive understanding of the risks involved, conduct thorough research, and diversify their portfolios to manage uncertainties effectively.







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1. Introduction

1.1 Background

Investing is a difficult task that requires knowledge, experience, and careful decision-making. There are many factors that contribute to the complexity of investing, including the unpredictability of financial markets and the constantly changing economic landscape. Investors must also be able to analyze and interpret vast amounts of data to identify opportunities and assess risk. Additionally, investing always carries some degree of risk. Even the most well-researched investment can be impacted by unforeseeable events, such as economic downturns, geopolitical unrest, or natural disasters. Investors must accept this risk and be prepared to adapt their strategies accordingly.

However, one possible way investors can combat these financial risks is by understanding volatility, which is the statistical measure of the degree of variation or fluctuation in the price of a particular stock over a specified period of time. By comprehending the level of volatility associated with different assets, investors can assess the risk-reward trade off more effectively. Higher volatility assets typically offer the potential for greater returns, but they also come with a higher level of risk. Conversely, lower volatility assets tend to be more stable but may offer relatively modest returns. By understanding the volatility of various investments, investors can align their choices with their risk tolerance, investment objectives, and time horizons. This knowledge allows for the construction of well-balanced portfolios that can withstand market fluctuations. Moreover, understanding volatility helps investors to manage their expectations. They can anticipate and mentally prepare for potential price swings, minimizing the impact of short-term market fluctuations on their long-term investment strategy. Additionally, understanding volatility allows investors to fine-tune their risk management strategies. By diversifying their portfolios across different asset classes with varying levels of volatility, investors can reduce overall risk and potentially enhance returns. Overall, a thorough understanding of volatility empowers investors to make more informed decisions, manage their portfolios effectively, and set realistic expectations, leading to better investment outcomes over the long run.

1.2 Literature Review

The study of volatility and its underlying factors has been extensively researched and widely discussed, particularly due to the inherent

unpredictability of the stock market. For instance, in a research paper by Chi, the impact of volatility was thoroughly examined using an OLS regression and various robust checks. The findings of this study concluded that the unemployment rate significantly influences volatility.

In another paper by Hajilee and Al Nasser (2017), a different methodology employing natural logarithm sliding mode control was utilized to investigate the relationship between interest rates and volatility. The results of this study also indicated a significant impact of interest rates on volatility.

To build upon these existing findings and contribute to the ongoing conversation, I aim to validate these conclusions through an alternative approach. Additionally, I intend to explore other potential factors that might influence volatility, thereby providing a more comprehensive understanding of the subject.

1.3 Purpose

The objective of this study is to validate previous literature findings using a distinct methodology (through the use of the GARCH model and linear regression model). Furthermore, it aims to contribute to the ongoing discourse by examining the correlation between a company's financial performance and the volatility of its stock price. By conducting this analysis, the study intends to expand our understanding of the underlying factors that drives volatility and provide valuable insights into the dynamics of the stock market.

Therefore, the goal of the study is to validate the notion that a deeper understanding of the driving forces behind volatility can lead to more accurate investment decisions since volatility plays a crucial role in determining the magnitude of fluctuations in stock prices.

1.4 Information

The focus of the study is on two well-known corporations, namely Apple and Google.

Apple and Google (Alphabet Inc.) are both well-known companies with stocks that have been traded for a significant period of time. Understanding the stock market and its volatility can provide context for analyzing the behavior of these stocks.

Apple Inc. is a multinational technology company renowned for its consumer electronics, software, and online services. Founded by Steve Jobs, Steve Wozniak, and Ronald Wayne, Apple's stock has been traded for a considerable period. The exact date of Apple's initial public offering (IPO) was December 12, 1980, and it has since become one of the most valuable companies in the world.

Google, now operating under the parent company Alphabet Inc., is a multinational technology company known for its Internet-related services and products. Founded in September 1998 by Larry Page and Sergey Brin, Google's stock has been traded on the public markets since August 19, 2004. The company had its IPO at a price of $85 per share.

The stock market, in general, refers to the collection of exchanges and markets where buying and selling of stocks and other securities take place. It provides a platform for companies to raise capital and for investors to buy and sell ownership stakes in those companies.

While Apple and Google are both prominent technology companies, their stock behavior can differ due to factors such as their business models, industry dynamics, financial performance, and market sentiment.

Apple primarily focuses on consumer electronics and software, while Google operates in the internet services and advertising sector. The nature of their businesses can lead to differences in revenue streams, growth opportunities, and market dynamics, which can influence their stock performance.

Both Apple and Google hold significant market shares in their respective industries. However, the competitive landscapes for internet services and consumer electronics can vary, leading to differences in investor perceptions and market reactions to news or events affecting each company.

There are only two distinctions between the two companies that can result in contrasting behavior within the stock market. However, there are many more differences between Apple and Google, so concentrating on these significant companies will not impede the precision of the study.

2. Data Exploration

2.1 Data Collection

The data was collected from two primary sources: Yahoo Finance and FRED (Federal Reserve Economic Data). I used Yahoo Finance to gather financial data on individual companies (specifically Apple and Google), including stock prices, historical data, and financial statements. To collect the data, I used the search function to find the relevant company or stock, and then I extracted the data from the historical data or financial statements section of the website.

Note: The data collection process for the study does not raise any privacy concerns, as both companies involved are publicly traded entities and their stock prices are openly available to the public. The study utilizes publicly accessible data from Yahoo Finance, ensuring that there are no infringements on privacy rights or confidential information. The use of this data adheres to standard practices for conducting research in the field of financial analysis and does not compromise any sensitive or private data.

I used FRED to collect economic data on a variety of indicators, including inflation rates, unemployment data, and GDP growth. I used the search function to find the relevant economic indicator, and then I accessed the relevant data series.

Both Yahoo Finance and FRED are considered reliable sources of financial and economic data. Yahoo Finance's data is sourced from reputable providers such as Morningstar, S&P Global Market Intelligence, and Refinitiv, while FRED's data is provided by the Federal Reserve Bank of St. Louis, which is a highly trusted source of economic data.

2.2 Data Description

The consolidation of data involved the combination of financial statements (income statement, balance sheet, cash flow) for each company. The focus was on specific variables, such as net income, total debt, and stockholder's equity. Historical stock price data, including high, low, and volume information, was available for each company starting from January 5, 2006. However, for the volatility analysis, I used the adjusted close stock price. In addition, there was access to daily inflation rates and the dollar index, along with other macroeconomic indicators. The GDP and the country's total debt were recorded quar-

terly, while the interest rates and unemployment rates were recorded monthly, both dating back to January 01, 2005.[1].

[1] For definitions and ranges of variables, see the Appendix 1: Data Dictionary

2.3 *Exploratory Analysis*

To investigate the volatility change of the two companies and its possible underlying factors, it was necessary to observe the relative trends of each company's daily adjusted close stock price before any analysis.

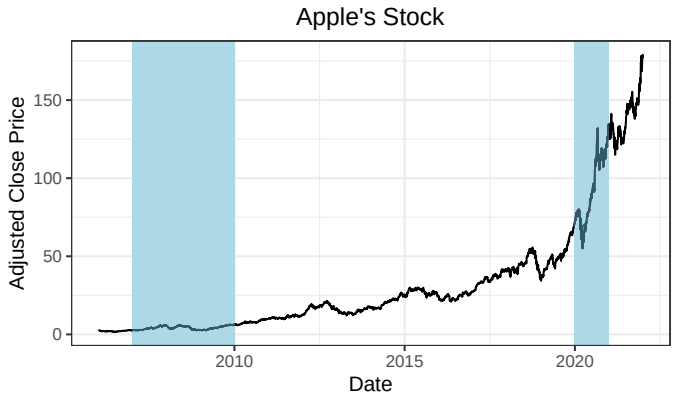

Figure 1: Apple's Stock Price Time Series

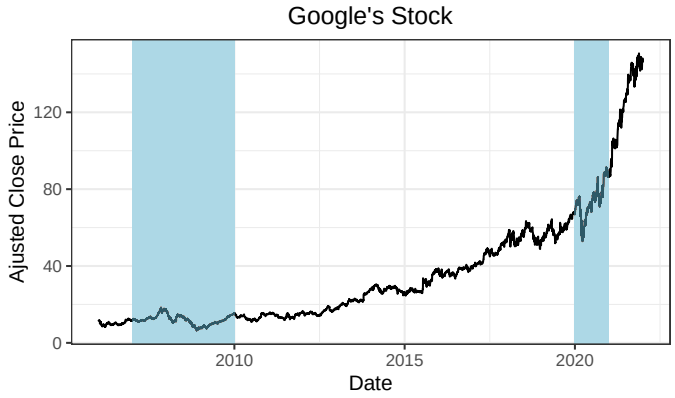

Figure 2: Google's Stock Price Time Series

Through an examination of the two graphs, a consistent trend was evident among both companies. Notably, despite the initial impact of the COVID-19 pandemic in 2020 on both companies, and of the Great Recession (more significant on Google) from 2007 to 2009 (both recessions are highlighted), both companies experienced a steady increase in their stock prices, with one outperforming the other in certain years.

3. Data Analysis

3.1 Method

For the analysis, the objective was to examine any possible influence of external factors, such as economics indicators, on the volatility of the company's stock price. The initial approach involved modeling the stock price volatility using a GARCH model.

The GARCH (Generalized Auto regressive Conditional Heteroskedasticity) model is a statistical approach used to analyze and predict the volatility of financial assets. The model assumes that volatility is time-varying and that it is influenced by past shocks. The study used the GARCH(1,1) model, which is one of the most commonly used GARCH models. The 1,1 in the model's name refers to the order of the auto regressive and moving average components in the mean equation and the order of the auto regressive component in the variance equation, respectively. As a result GARCH model does have two components: the mean equation and the variance equation. The mean equation specifies how the conditional mean of the asset price changes over time, while the variance equation describes how the conditional variance of the asset price changes over time.

Mean Equation: $r_t = \mu + \epsilon_t$, where r_t is the log return of the asset at time t, μ is the constant mean of the asset returns, and ϵ_t is the residual or error term, which follows a normal distribution with a mean of zero and a constant variance.

Variance Equation: $\sigma_t^2 = \omega + \alpha\epsilon_{t-1}^2 + \beta\sigma_{t-1}^2$, where σ_t^2 is the conditional volatility (referred to as "conditional" because it is estimated based on the past values of the error term and its variance, as well as other information that is available up to that point in time) at time t, ω is the constant (≥ 0) variance of the asset returns, α (≥ 0) is the coefficient of the lagged squared residual term ϵ_{t-1}^2, and β (≥ 0) is the coefficient of the lagged conditional variance term σ_{t-1}^2.

The GARCH model's coefficients, α and β, have distinct interpretations. The α coefficient reflects the magnitude of volatility's response to unexpected returns or shocks, whereas the β coefficient reflects the persistence of volatility, or how long it takes to revert back to long-run volatility. Typically, the sum of these coefficients, $(\alpha + \beta)$, is less than one.

The verification of the two conditions for GARCH, namely volatil-

ity clustering and the auto regressive conditional heteroskedasticity (ARCH) effect, was deemed necessary prior to modeling the log returns using a simple GARCH model. Volatility clustering is the tendency for volatility to persist for some time before transitioning to a different regime while the ARCH effect suggests that the volatility of a financial asset or security is not constant but changes over different periods (implies that the past volatility of an asset affects its future volatility).

Through this analysis, the estimation of the conditional variance of the asset returns and the ability to forecast future volatility were enabled. Subsequently, the consideration was given to the incorporation of external regressors. These regressors could encompass economic indicators or other pertinent financial data that may exert an influence on asset volatility. By including these external regressors, the intention was to encompass supplementary information that has the potential to affect volatility.

Incorporating the external regressor in the variance equation allowed for the consideration of its influence, leading to the following outcome:

Variance Equation: $\sigma_t^2 = \omega + \alpha\epsilon_{t-1}^2 + \beta\sigma_{t-1}^2 + \gamma x_{t-1}^2$, where x_{t-1} is the value of the external regressor at time $t-1$, and γ is the estimated coefficient of the external regressor.

It was noteworthy that the models that exhibit statistically significant coefficients for external regressors may not show much improvement, which can be attributed to the considerable capabilities of the GARCH model[2]. It was possible that the effect of the external regressors was already accounted for by the lagged values of the conditional variance and squared errors in the GARCH model. Nonetheless, for the study, the identification of a few factors that may have an impact on volatility was the aim. Hence, when the coefficients exhibited statistical significance, they were regarded as potential factors influencing volatility. In other words, the significant coefficient (> 0) of x_{t-1}^2 confirmed the contribution of the external regressor to volatility prediction. In addition, to evaluate the effectiveness of the external regressors, the accuracy of the GARCH model with the added regressors was compared to that of the original GARCH model. I did this by analyzing and comparing their respective average residuals to the actual number.

[2] More information can be found at "Forecasting Volatility Using GARCH Models" Costa (2017)

3.2 *Pre-Analysis*

To conduct a preliminary analysis, it was crucial to verify whether the GARCH model fulfills two essential criteria: volatility clustering and the ARCH effect. To ensure the correct application of the GARCH model, I, firstly, generated a plot of the log returns, derived from the computation of the differences between the logarithmic adjusted closing stock prices of each company over time. This examination helped ascertain the presence of volatility clustering.

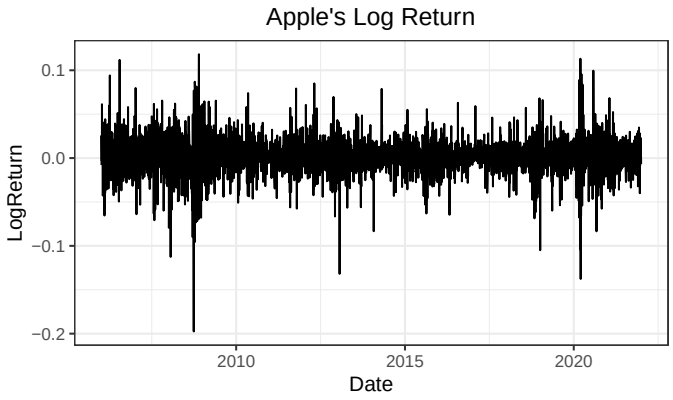

Figure 3: Apple's Log Return Time Series

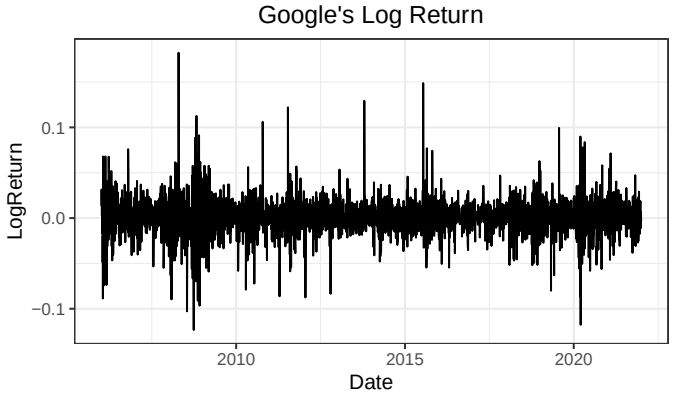

Figure 4: Google's Log Return Time Series

Upon analyzing the graphs, it became evident that the GARCH model met the criterion of volatility clustering. This was evident as significant changes were consistently followed by substantial changes, while minor changes were consistently followed by modest changes as well.

To investigate the presence of volatility clustering beyond an observation, I utilized the autocorrelation function (ACF). The ACF is a statistical and signal processing tool used to measure the correlation

between a time series and its lagged versions. By analyzing the ACF, I was able to determine whether significant correlations exist between observations at different time points, thus identifying any recurring patterns or trends. Here, the ACF graphs for both the log returns of Apple and Google are shown.

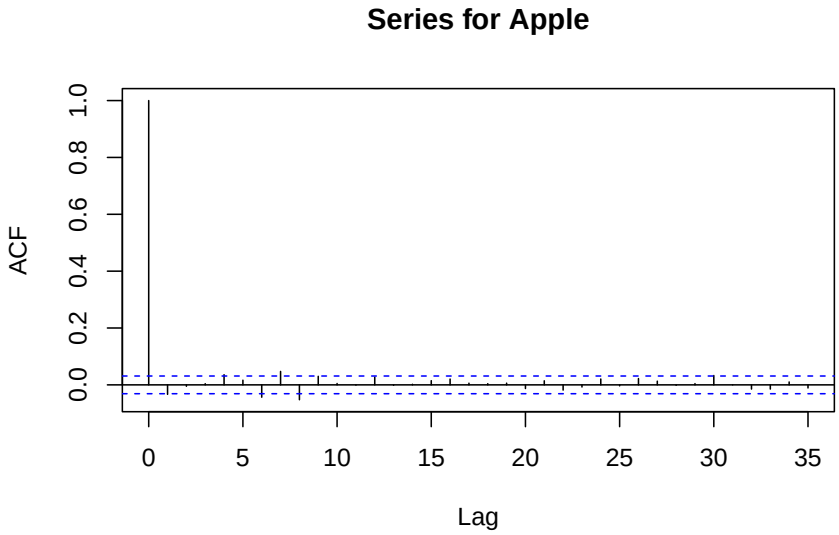

Figure 5: Apple's ACF Plot

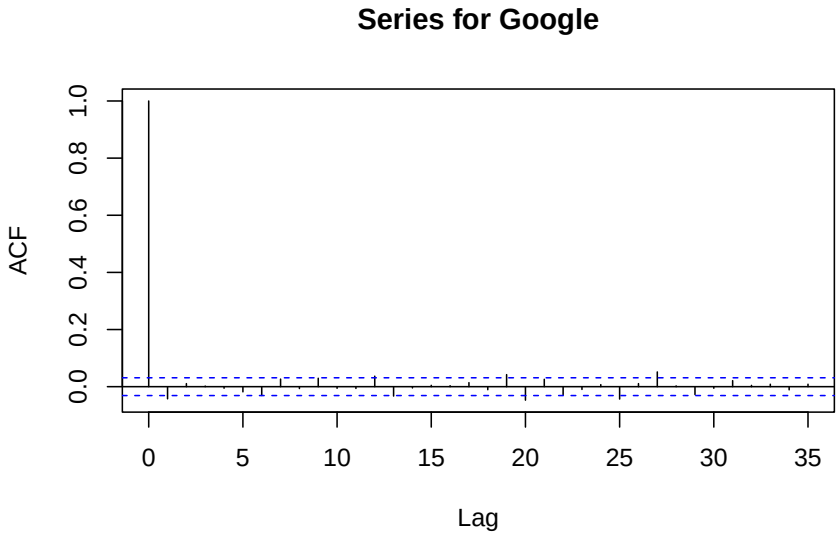

Figure 6: Google's ACF Plot

To assess volatility clustering from the ACF plots, I analyzed them. The ACF plot provides confidence intervals represented by horizontal dashed lines. These intervals help determine the statistical significance of autocorrelation values at different lags. Autocorrelation values outside these intervals indicate a significant correlation. However, in both plots, none of the values crossed the horizontal dashed

lines, suggesting no statistically significant correlations.

It was worth noting the presence of an initial peak in both ACF plots. This peak, often called a "spike" or "spike at lag 0," represents the correlation between each observation in the time series and itself (autocorrelation at lag 0). At lag 0, the autocorrelation is always 1 since each observation perfectly correlates with itself. This was an expected result.

Next, I conducted an examination to assess the fulfillment of the ARCH effect condition.

```
##
##  ARCH LM-test; Null hypothesis: no ARCH effects
##
## data:  apple_stock$LogReturn
## Chi-squared = 477.56, df = 12, p-value < 2.2e-16
```

```
##
##  ARCH LM-test; Null hypothesis: no ARCH effects
##
## data:  google_stock$LogReturn
## Chi-squared = 204.53, df = 12, p-value < 2.2e-16
```

The test results indicated that the p-value for both cases was less than 0.05, which confirmed the presence of the ARCH effect.

3.3 Analysis

Once the prerequisites for modeling the GARCH model were confirmed, the subsequent step involved implementing the GARCH model for each company. This allowed for testing whether any external factors exert an influence on the volatility changes[3] [4].

To begin, by utilizing the "rugarch" library in R and including only the coefficients that are statistically significant at 0.05, I obtained the subsequent equations for each company (without any external factors).

Apple:
$\sigma_t^2 = 0.000013 + 0.100249(\epsilon_{t-1}^2) + 0.869840(\sigma_{t-1}^2)$, having an average of residuals of -0.00081

Google:
$\sigma_t^2 = 0.000011 + 0.076529(\epsilon_{t-1}^2) + 0.891138(\sigma_{t-1}^2)$, having an average of residuals of -0.00025

[3] Graphical displays and outcomes are solely for Apple. For Google's graphical displays and outcomes, see the Appendix 2: Graphical Displays for Google

[4] The graphical displays also include highlighted sections representing the two significant recessions: Great Recession and COVID Recession. These highlights aim to establish a point of reference between the recessions and the observed relationships

At this stage, the study presents an analysis regarding various factors that have displayed statistical significance in influencing the volatility of each company, meaning the p-values for the constants of the external regressors were statistically significant, with the majority having a p-value of 0.

3.3.1 Macroeconomic Indicators

The initial phase of the analysis involved integrating external regressors into the GARCH model and examining the statistical significance of the coefficients. The obtained results are presented in the following tables, allowing for a closer evaluation of the findings.

Company	Updated Formulas with Inflation Rate	Average Residuals
Apple	$\sigma_t^2 = 0.099359(\epsilon_{t-1}^2) + 0.870555(\sigma_{t-1}^2) + 0.000003(x_{t-1}^2)$	-0.00081
Google	$\sigma_t^2 = 0.075265(\epsilon_{t-1}^2) + 0.893809(\sigma_{t-1}^2) + 0.000004(x_{t-1}^2)$	-0.00026

Company	Updated Formulas with Unemployment Rate	Average Residuals
Apple	$\sigma_t^2 = 0.102359(\epsilon_{t-1}^2) + 0.867087(\sigma_{t-1}^2) + (3.99 \times 10^{-07})(x_{t-1}^2)$	-0.00085
Google	$\sigma_t^2 = 0.077281(\epsilon_{t-1}^2) + 0.888856(\sigma_{t-1}^2) + 0.000001(x_{t-1}^2)$	-0.00026

Company	Updated Formulas with Interest Rate	Average Residuals
Apple	$\sigma_t^2 = 0.102957(\epsilon_{t-1}^2) + 0.863345(\sigma_{t-1}^2) + 0.000001(x_{t-1}^2)$	-0.00084
Google	$\sigma_t^2 = 0.081589(\epsilon_{t-1}^2) + 0.884310(\sigma_{t-1}^2) + 0.000001(x_{t-1}^2)$	-0.00025

The results indicate that all coefficients in the GARCH model were statistically significant, suggesting that each variable made a significant contribution to the model (prediction of volatility). To further explore the relationship between volatility, as predicted by the GARCH model, and macroeconomic indicators, the following plots have been provided. These plots for Apple offer insights into the trends and patterns observed in the relationship between volatility and the selected macroeconomic variables.

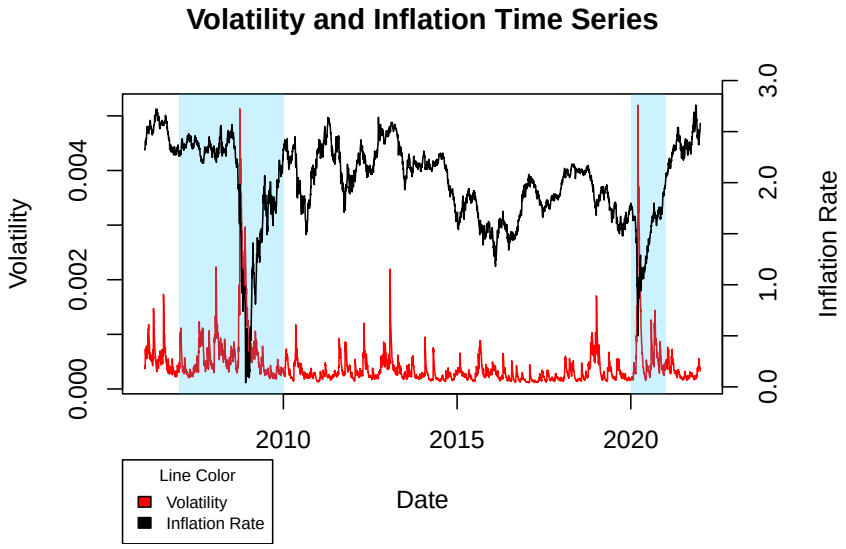

Figure 7: Relationship between Inflation Rate and the GARCH Model with Inflation Rate as an External Regressor for Apple

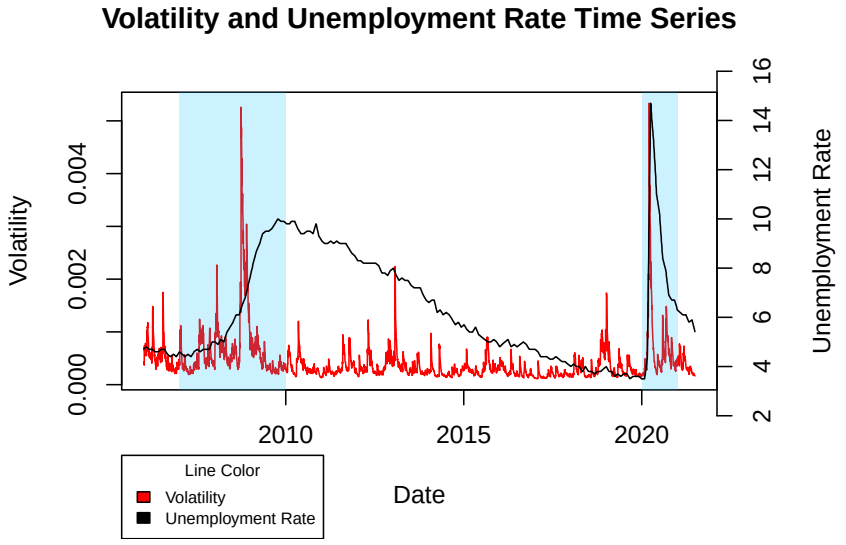

Figure 8: Relationship between Unemployment Rate and the GARCH Model with Unemployment Rate as an External Regressor for Apple

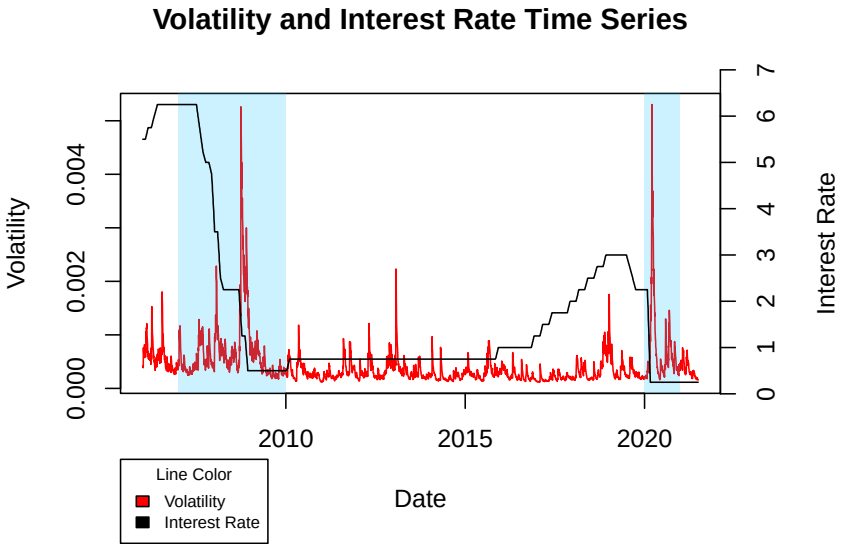

Figure 9: Relationship between Interest Rate and the GARCH Model with Interest Rate as an External Regressor for Apple

In order to further investigate and confirm the relationship between volatility and the chosen macroeconomic variable, I also conducted a linear regression analysis. The outcomes of this analysis specifically for Apple's case can be observed in the subsequent table.

Economic Indicator	Coefficient Estimate	P value	R squared
Inflation	-2.794e-04	2.2e-16	0.07533
Unemployment Rate	2.963e-05	2.2e-16	0.02171
Interest Rate	2.394e-05	7.697e-10	0.009808

The results presented in the table demonstrate that all three variables exhibited statistically significant associations with volatility. To provide a more detailed understanding of the figures, let's focus on the analysis of the inflation rate variable (similar reasoning can be applied to the other two variables) and Figure 7.

The estimated coefficient for the inflation variable was -2.794e-04. This value indicates that, for every 1% increase in inflation, the volatility of Apple stock returns is expected to decrease by approximately 0.0002794 (or 0.02794%) units. The associated p-value for this coefficient was very small (2.2e-16), suggesting that the coefficient is statistically significant, meaning it is unlikely to have occurred by chance.

It is worth noting that the R-squared value of 0.07533 indicates that the model explains only a small proportion of the variation in the

data. This outcome is expected given the inherent complexity of financial markets, where numerous factors contribute to stock volatility.

To visually examine the linear regression analysis for the three variables, the corresponding plots are displayed below.

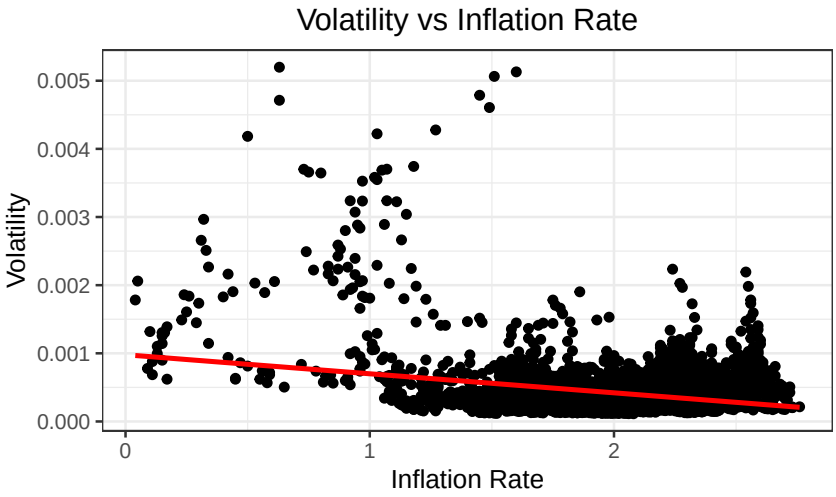

Figure 10: Linear Relationship between Volatility and Inflation Rate for Apple

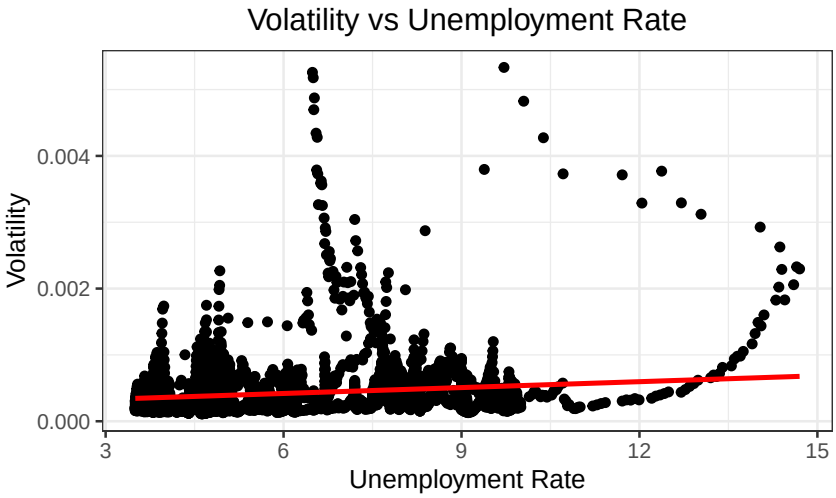

Figure 11: Linear Relationship between Volatility and Unemployment Rate for Apple

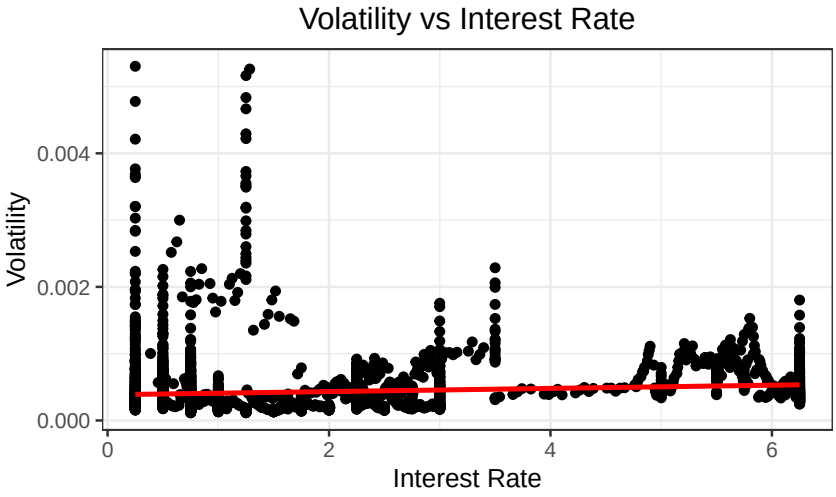

Figure 12: Linear Relationship between Volatility and Interest Rate for Apple

While the visual representation may not clearly show a linear relationship for all variables (e.g. Figure 12), the results of the linear regression test have provided significant evidence to support the presence of a linear relationship. This finding strengthens the previous claim made using the GARCH model regarding the relationship between the variables and volatility.

4.1 Observations

Despite the numerical analysis demonstrating the impact of various factors on volatility changes, there were additional factors that necessitated further exploration. Consequently, graphical displays are presented to identify any common timeline when volatility experiences sharp declines or spikes and to examine how such changes correlate with the release or variations of other factors.

3.4.1 Gross Domestic Product

To commence, the time series relationship between GDP and volatility is presented below in Figure 13. An intriguing observation emerged, wherein every instance of GDP decline coincides with a pronounced peak in volatility.

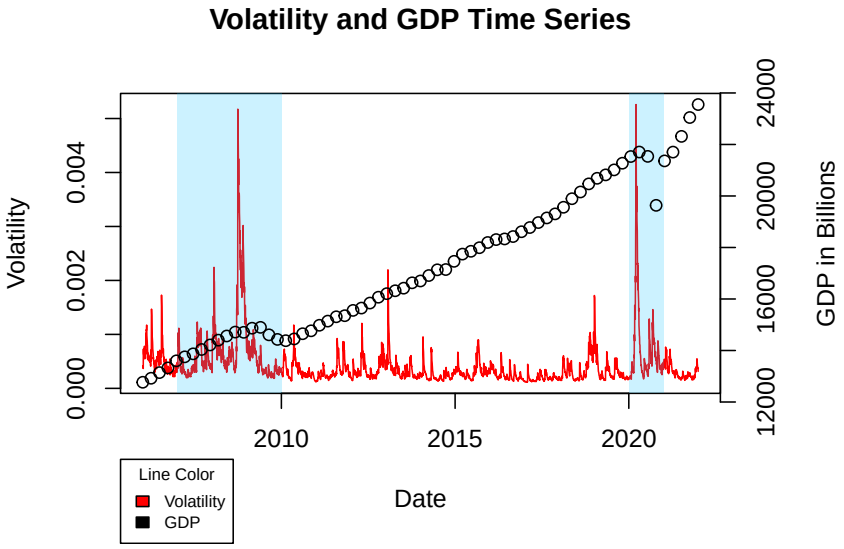

Figure 13: Relationship between GDP and the GARCH Model with no External Regressor for Apple

GDP (Gross Domestic Product) is a measure of a country's economic performance and represents the total monetary value of all goods and services produced within a country's borders over a specified period. When GDP declines, it may indicate a slowdown in economic activity, which can cause uncertainty and volatility in financial markets. For example, companies may see a decline in revenues and profits, which can lead to a decrease in stock prices. As investors react to these changes, it can cause an increase in volatility in the financial markets. Similarly, when GDP increases, it may signal economic expansion, which can lead to increased investment and confidence, potentially resulting in lower volatility.

The highlighted portions in Figure 13 indicate significant declines that coincide with two important recessions: the Great Recession and the COVID Recession. This observation suggests a potential correlation that warrants further investigation.

3.4.2 Debt-to-Equity Ratio

Furthermore, the first financial metric to be presented is the debt-to-equity ratio, utilized to evaluate a company's leverage. This ratio is derived by dividing the total debt of a company by its shareholder equity.

Figure 14 below demonstrates a clear relationship between an increase in the debt-to-equity ratio and an accompanying rise in volatility. It is worth noting that the results may exhibit a slight lag, attributable to the quarterly release of financial statements by compa-

nies. As a result, the effects may take some time to fully manifest, leading to potential misalignment between the peaks.

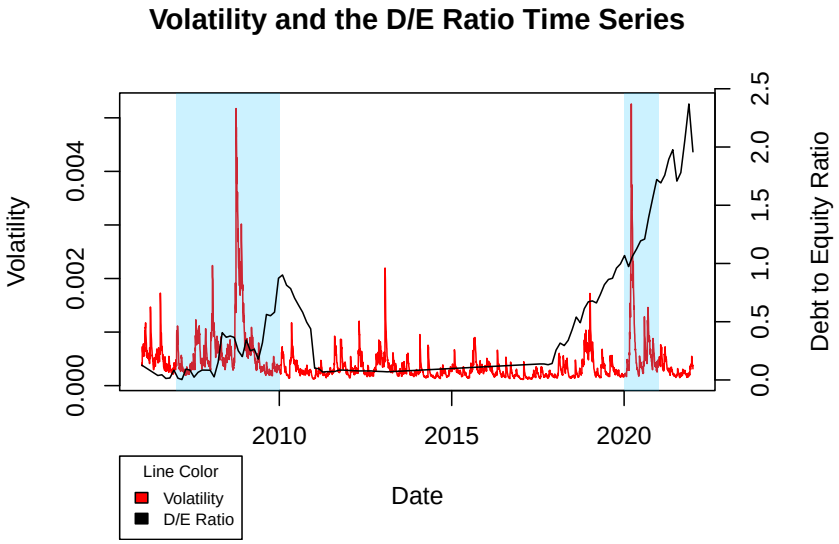

Figure 14: Relationship between Debt-to-Equity and the GARCH Model with no External Regressor for Apple

A high debt to equity ratio indicates that a company has taken on more debt than it has equity in the business, which means the company is more leveraged. This increases the financial risk for the company since they have to pay interest on their debts and may have trouble meeting those obligations if their earnings decline or they face other financial challenges. A higher debt to equity ratio may lead investors to worry about the company's ability to meet its financial obligations, which could lead to a decline in the stock price, resulting in higher volatility.

3.4.3 Price-to-Earnings Ratio

A further financial metric under examination is the price-to-earnings (P/E) ratio, which appraises a company's present stock price concerning its earnings per share. The calculation is achieved by dividing the current market price per share of a company's stock (i.e., its current stock price) by its earnings per share, which is determined by dividing the net income by the outstanding share number.

In contrast to the previous financial metric, the upcoming plot exhibits alignment. This alignment is a result of the calculation incorporating not only the financial statements but also the daily stock price data. By including the daily stock price, a more synchronized relationship between the variables can be observed.

Figure 15 suggests a positive relationship between the release of financial statements by the company and an increase in volatility, although it may not be immediately apparent. Notably, when the company's price-to-earnings ratio experiences a substantial increase, there tends to be a corresponding significant rise in volatility. Further exploration is recommended to investigate the smaller changes in this relationship.

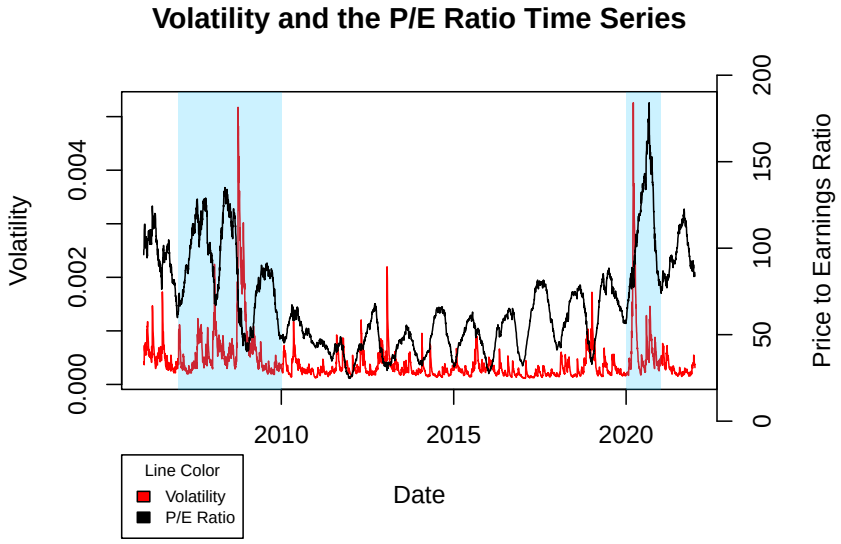

Figure 15: Relationship between Price-to-Earnings and the GARCH Model with no External Regressor for Apple

A higher P/E ratio generally suggests that investors are willing to pay more for each dollar of the company's earnings. This can reflect investor optimism about the company's growth potential and future earnings. Nonetheless, a higher P/E ratio can also increase the volatility of a company's stock price. This is because a higher P/E ratio indicates that investors have high expectations for the company's future performance. If the company's earnings fail to meet these expectations, investors may become disappointed and start selling their shares, causing the stock price to drop. This can lead to increased volatility in the stock price.

Conversely, a lower P/E ratio generally indicates that investors are less optimistic about the company's future performance. While this may result in a more stable stock price, it could also indicate a lack of confidence in the company's long-term prospects.

4. Discussion

4.1 Findings

The empirical study provided compelling evidence of the significant impact of inflation rate, unemployment rate, and interest rate on the volatility of a company's stock price. Furthermore, graphical displays revealed the influence of the country's GDP, as well as the company's debt-to-equity ratio and price-to-earnings ratio, on stock price volatility.

In addition to the empirical data, it is logical to understand the reasons why the inflation rate, unemployment rate, and interest rate influence the volatility of a company's stock price.

Exploring the impact of inflation on volatility is reasonable because inflation can introduce uncertainty and instability into the market, resulting in fluctuations in prices and returns When inflation is high, investors often become more cautious and risk-averse, leading to reduced investment levels and heightened volatility.

The presence of high unemployment rates can contribute to volatility for various reasons. Firstly, it can give rise to social and political unrest, which can subsequently impact the financial markets. Furthermore, elevated unemployment rates tend to reduce consumer spending, resulting in decreased revenues and profits for businesses. This decline in economic activity can cause stock prices to decline, thus contributing to increased volatility within the stock market[5]. Given these factors, it is reasonable to assess the potential influence of the unemployment rate on volatility.

[5] More information can be found at "Unanticipated Unemployment Rate News on the Stock Market" written by David Chi

Considering the impact of interest rates on volatility is also logical. Lower interest rates make borrowing money cheaper and more accessible, encouraging increased investment and economic activity. However, this can also elevate the risk of market volatility, as investors may pursue riskier investments in the pursuit of higher returns. Thus, it is reasonable to acknowledge the potential impact of the interest rate on volatility[6].

[6] More information can be found at "The Impact of Interest Rate Volatility on Stock Market Development: Evidence from Emerging Markets" written by Massomeh Hajilee and Omar M. Al Nasser Chi

4.2 Limitations

Apart from the findings, it is important to acknowledge the limitations of the study. Like any data source, there are inherent limitations, and it is always advisable for users to conduct their own

research and analysis before making economic decisions or drawing conclusions based solely on the data provided.

One notable limitation was that certain data was unavailable for all time periods. There can be various factors contributing to this issue. For instance, in general, newer companies may have limited historical data compared to well-established companies. Additionally, some companies may choose not to disclose specific financial information due to concerns about privacy or competition. Moreover, gaps or errors in the data collection process can also result in limitations in the available data.

In fact, during the initial phases in the study, I observed a noticeable pattern of missing data, which could be attributed to factors such as less widespread or comprehensive record-keeping practices in the past, limited technology impeding data collection and analysis, or a lack of interest in collecting or preserving certain types of data. These factors may have influenced the completeness and accuracy of the data utilized in the study. For Apple, during the period of 1985 to 1989, Apple's financial statements had missing data. However, there was only a single entry recorded for each of those years. This suggests the possibility that Apple was not disclosing quarterly data during that time. For Google, similar justification can be provided for the missing data in 2003-2004 in Google's financial statements. Just as in the case of Apple, there is a possibility that Google did not release quarterly data during that period, as indicated by the absence of comprehensive financial information for those years.

Another limitation of the study was the inherent unpredictability of the stock market, which poses a significant challenge in making precise forecasts about future volatility and its determining factors. Additionally, the study focused on only two companies with limited yearly information available, making it difficult to thoroughly analyze the impact of total revenue and other financial factors on volatility. Consequently, further investigation is necessary to explore and understand these relationships more comprehensively.

Finally, while there may be factors that exhibit a close relationship with other factors, the available data set alone was insufficient to definitively conclude this. To establish a strong causal relationship, additional data and rigorous analysis are necessary. This includes obtaining more detailed and granular data, such as sector-specific or industry-specific information, to capture specific dynamics within the economy. Additionally, cross-country data can provide insights into

the relationship's consistency across different regions and economies. Furthermore, incorporating complementary qualitative data and employing advanced econometric techniques can help account for confounding factors and spurious correlations. By considering a broader range of data sources and employing robust analytical methods, researchers can enhance their understanding of whether these indicators truly have a significant relationship. Thus, based on this comprehensive analysis and understanding, researchers and investors would have the ability to substantiate the study's results.

5. Conclusion

In summary, the empirical study uncovered a diverse range of factors that exhibited potential influence on the volatility changes. The findings of the study shed light on several variables that could potentially impact volatility, highlighting the intricate dynamics within the market. These factors encompassed a broad spectrum, including macroeconomic indicators, company-specific financial metrics, and external market conditions.

Among the macroeconomic indicators, variables such as inflation rate, unemployment rate, and interest rate were identified as potential drivers of volatility. The study revealed that fluctuations in these economic factors could introduce uncertainty and instability, consequently impacting the volatility of stock prices. Changes in inflation rates could create an environment of market uncertainty, leading to price fluctuations and altering investor behavior. Similarly, high unemployment rates were found to contribute to volatility through their association with social unrest and reduced consumer spending, adversely affecting businesses and, consequently, stock prices. Additionally, variations in interest rates were shown to influence volatility by influencing investment patterns and prompting investors to undertake riskier ventures to pursue higher returns.

In addition to macroeconomic indicators, the study examined the impact of company-specific financial metrics on volatility. It found that factors such as debt-to-equity ratio, and price-to-earnings ratio could potentially influence volatility. The debt-to-equity ratio, which represents a company's financial leverage, was found to have a potential association with volatility. Higher levels of debt relative to equity could amplify market sensitivity and increase volatility. Additionally, variations in the price-to-earnings ratio, reflecting the market's perception of a company's value, were identified as potential contributors to volatility.

While the empirical study provided valuable insights into the potential factors influencing volatility changes, it is crucial to acknowledge that the analysis focused on a limited set of variables. The complex and ever-changing nature of the stock market suggests that there are likely additional factors that could contribute to volatility fluctuations. Therefore, future research endeavors should aim to explore and expand upon the findings by considering a more comprehensive range of factors, particularly delving deeper into the company's financial aspects.

Examining the company's finances in greater detail would provide deeper insights into the relationship between financial performance and stock price volatility. Factors such as profit margins, cash flow, capital structure, and liquidity could be investigated to understand their potential impact on volatility. Analyzing these financial indicators may uncover important patterns and correlations, allowing for a more nuanced understanding of how a company's financial health influences stock price volatility.

Additionally, in order to enhance the comprehensiveness of future research, it is advisable to incorporate a broader range of companies. The current study focused exclusively on two large companies, which may not adequately represent the entire stock market. By including a more diverse set of companies in the analysis, researchers can obtain a more comprehensive understanding of the dynamics and trends within the stock market as a whole.

In summary, the report highlights clear relationships and potential factors associated with volatility. This implies that volatility is not purely random but influenced by underlying drivers. Consequently, investors can analyze the presented factors to gain insights into how volatility might behave, allowing them to make informed investment decisions accordingly. However, investors should approach the results from the report with caution, as stock volatility remains unpredictable. Further research is necessary to obtain a comprehensive understanding of how to predict volatility accurately and as a result make more informed investment decisions.

6. References

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7. Appendix

7.1 Appendix 1: Data Dictionary

Financial Variables:

The number of missing values (NA) is shown below.

Below are the ranges for each variable and company

For the financial data sets, there are approximately 206 different variables, so I will concentrate on the few important ones for the study (more could possibly be examined in the future).

Date: When the entries were filed or collected. The date variable ranges from the end of 1986 to the end of 2022 (varies for each company - Apple starts at 1986 and Google starts at 2004).

Outstanding Share Number: It represents a unit of ownership in a company and typically entitle the shareholder to participate in the profits of the company through dividends and to vote on corporate matters. There is no unit for the numeric (double) variable since it is a total number.

The following financial variables are numeric (double) and are measured in dollars

Net Income: A financial metric that represents the amount of profit a company has earned over a specific period of time.

Total Debt: The sum of all outstanding debt that a company or individual owes to creditors, lenders or financial institutions.

Stockholders Equity: The residual claim on a company's assets after deducting its liabilities. It represents the amount of a company's assets that are financed by the owners rather than by creditors

Apple's Financial Distribution

```
##       Date            StockholdersEquity  OrdinarySharesNumber
##  Min.   :1986-09-30   Min.   :6.941e+08   Min.   :3.308e+09
##  1st Qu.:1997-06-30   1st Qu.:2.283e+09   1st Qu.:1.417e+10
##  Median :2005-12-31   Median :8.380e+09   Median :1.941e+10
##  Mean   :2005-12-18   Mean   :4.101e+10   Mean   :1.916e+10
##  3rd Qu.:2014-06-30   3rd Qu.:7.662e+10   3rd Qu.:2.368e+10
##  Max.   :2022-12-31   Max.   :1.402e+11   Max.   :2.632e+10
##
##    TotalDebt           NetIncome
##  Min.   :6.000e+06   Min.   :-7.400e+08
##  1st Qu.:3.073e+08   1st Qu.: 9.760e+07
##  Median :9.540e+08   Median : 5.420e+08
##  Mean   :3.592e+10   Mean   : 5.429e+09
##  3rd Qu.:8.742e+10   3rd Qu.: 1.022e+10
##  Max.   :1.247e+11   Max.   : 3.463e+10
##  NA's   :39          NA's   :4
```

Google's Financial Distribution

```
##       Date            StockholdersEquity  OrdinarySharesNumber
##  Min.   :2004-06-30   Min.   :1.017e+09   Min.   :6.095e+09
##  1st Qu.:2009-02-14   1st Qu.:2.904e+10   1st Qu.:1.261e+10
##  Median :2013-09-30   Median :8.299e+10   Median :1.318e+10
##  Mean   :2013-09-29   Mean   :1.017e+11   Mean   :1.296e+10
##  3rd Qu.:2018-05-15   3rd Qu.:1.614e+11   3rd Qu.:1.369e+10
##  Max.   :2022-12-31   Max.   :2.561e+11   Max.   :1.392e+10
##
##    TotalDebt           NetIncome
##  Min.   :1.000e+04   Min.   :-3.020e+09
##  1st Qu.:3.968e+09   1st Qu.: 1.299e+09
##  Median :5.234e+09   Median : 2.970e+09
##  Mean   :9.413e+09   Mean   : 4.881e+09
##  3rd Qu.:1.331e+10   3rd Qu.: 6.694e+09
```

```
##  Max.   :2.968e+10   Max.   : 2.064e+10
##  NA's   :19
```

Stock Variables:

Below are the ranges for each variable and company

Date: When the entries were filed or collected. The date variable ranges from the beginning of 2006 to the end of 2021.

Volume: The total number of shares of a stock or other financial asset that have been traded during a specific period of time, usually a trading day. The numeric (double) variable is measured as a total quantity. The ranges depends on the company (volume distribution for each company will be shown below).

Inflation: A market-based measure of the rate at which the general level of prices for goods and services is increasing over time expectations for the next 10 years. The numeric (double) variable is measured as a proportion, representing the difference between the yield of a nominal 10-year Treasury bond and the yield of a 10-year Treasury inflation-protected security (TIPS).

Dollar Index: A measure of the value of the U.S. dollar relative to a basket of currencies from major U.S. trading partners. The numeric (double) variable is measured as an index, where changes in the index represent the percentage change in the dollar index.

Log Return: A financial metric that measures the relative change in the price of a security or asset over a specific period of time. It is calculated by taking the natural logarithm of the ratio of the price at the end of the period to the price at the beginning of the period.The numeric (double) variable is unit less as it is defined as the logarithmic difference between two adjusted close prices.

The following stock variables are numeric (double) and are measured in dollars

Adj. Close: The stock price that has been adjusted to reflect any corporate actions that may have occurred, such as stock splits, dividends, or spin-offs.

Apple's Stock Distribution

```
##       Date              Adj.Close           Volume            Inflation
##  Min.   :2006-01-05   Min.   :  1.540   Min.   :4.545e+07   Min.   :0.040
##  1st Qu.:2009-12-25   1st Qu.:  6.141   1st Qu.:1.295e+08   1st Qu.:1.750
##  Median :2013-12-25   Median : 18.461   Median :2.906e+08   Median :2.100
##  Mean   :2013-12-29   Mean   : 31.376   Mean   :4.254e+08   Mean   :2.004
##  3rd Qu.:2017-12-28   3rd Qu.: 39.420   3rd Qu.:6.054e+08   3rd Qu.:2.320
##  Max.   :2021-12-30   Max.   :179.016   Max.   :3.373e+09   Max.   :2.760
##   DollarIndex       LogReturn
##  Min.   : 85.47   Min.   :-0.197470
##  1st Qu.: 92.83   1st Qu.:-0.008237
##  Median : 98.83   Median : 0.001000
##  Mean   :102.14   Mean   : 0.001097
##  3rd Qu.:112.78   3rd Qu.: 0.011798
##  Max.   :126.13   Max.   : 0.118294
```

Google's Stock Distribution

```
##       Date              Adj.Close           Volume            Inflation
##  Min.   :2006-01-05   Min.   :  6.412   Min.   :1.584e+05   Min.   :0.040
##  1st Qu.:2009-12-25   1st Qu.: 13.326   1st Qu.:3.013e+07   1st Qu.:1.750
##  Median :2013-12-25   Median : 25.751   Median :6.594e+07   Median :2.100
##  Mean   :2013-12-29   Mean   : 35.447   Mean   :1.049e+08   Mean   :2.004
##  3rd Qu.:2017-12-28   3rd Qu.: 51.368   3rd Qu.:1.331e+08   3rd Qu.:2.320
##  Max.   :2021-12-30   Max.   :150.709   Max.   :1.651e+09   Max.   :2.760
##   DollarIndex       LogReturn
##  Min.   : 85.47   Min.   :-0.1234016
##  1st Qu.: 92.83   1st Qu.:-0.0071645
##  Median : 98.83   Median : 0.0006331
##  Mean   :102.14   Mean   : 0.0006499
##  3rd Qu.:112.78   3rd Qu.: 0.0092763
##  Max.   :126.13   Max.   : 0.1822511
```

Economic Variables:

The number of missing values (NA) is shown below.

Below are the ranges for each variable

Date: When the entries were filed or collected. The date variable ranges from the beginning of 2005 to the end of 2021.

Interest Rate: The rate of cost of borrowing money at which eligible financial institutions can borrow money directly from the Federal Reserve. The numeric (double) variable is measured in a proportion.

Unemployment Rate: A measure of the percentage of the labor force that is currently unemployed and actively seeking employment. The numeric (double) variable is measured in a proportion.

Total Debt: The amount of money owed by the federal government of the United States to creditors. The numeric (double) variable is measured in millions of dollars.

GDP: (Gross Domestic Product) Economic indicator that measures the total value of all goods and services produced within a country's borders in a specific period, usually a year or a quarter (quarter for the study). The numeric (double) variable is measured in billions of dollars.

```
##       Date             InterestRate   UnemploymentRate   TotalDebt
##  Min.   :2005-01-01   Min.   :0.250   Min.   : 3.500   Min.   : 60.36
##  1st Qu.:2009-02-15   1st Qu.:0.750   1st Qu.: 4.600   1st Qu.: 78.69
##  Median :2013-04-01   Median :0.750   Median : 5.400   Median : 99.77
##  Mean   :2013-04-01   Mean   :1.918   Mean   : 6.222   Mean   : 92.55
##  3rd Qu.:2017-05-16   3rd Qu.:2.625   3rd Qu.: 7.900   3rd Qu.:103.83
##  Max.   :2021-07-01   Max.   :6.250   Max.   :14.700   Max.   :134.84
##                                                        NA's   :132
##       GDP
##  Min.   :12767
##  1st Qu.:14711
##  Median :16700
##  Mean   :17221
##  3rd Qu.:19433
##  Max.   :23550
##  NA's   :132
```

7.2 Appendix 2: Graphical Displays for Google

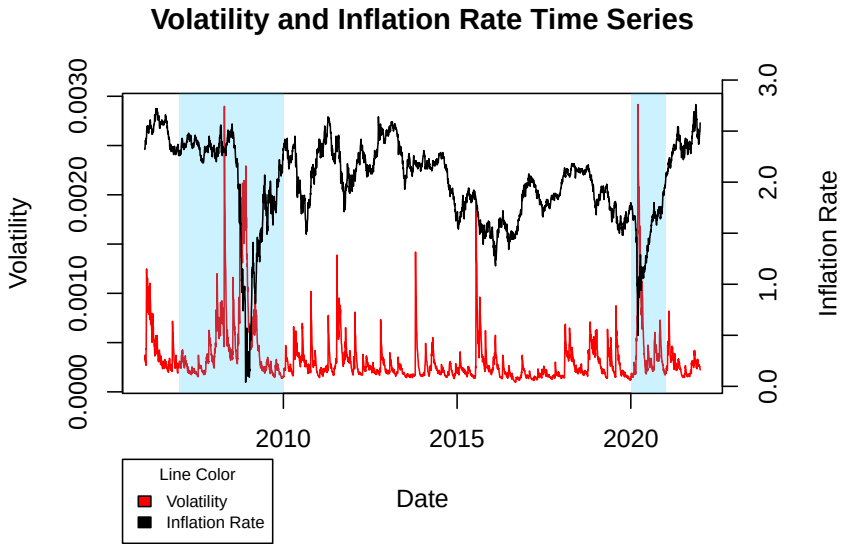

Figure 16: Relationship between Inflation Rate and the GARCH Model with Inflation Rate as an External Regressor for Google

```
##
## Call:
## lm(formula = volatility ~ inflation, data = df)
##
## Residuals:
##        Min         1Q     Median         3Q        Max
## -3.571e-04 -1.564e-04 -6.574e-05  5.157e-05  2.621e-03
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  7.615e-04  2.184e-05   34.87   <2e-16 ***
## inflation   -2.098e-04  1.067e-05  -19.66   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.0002774 on 3964 degrees of freedom
## Multiple R-squared:  0.08882,    Adjusted R-squared:  0.08859
## F-statistic: 386.4 on 1 and 3964 DF,  p-value: < 2.2e-16
```

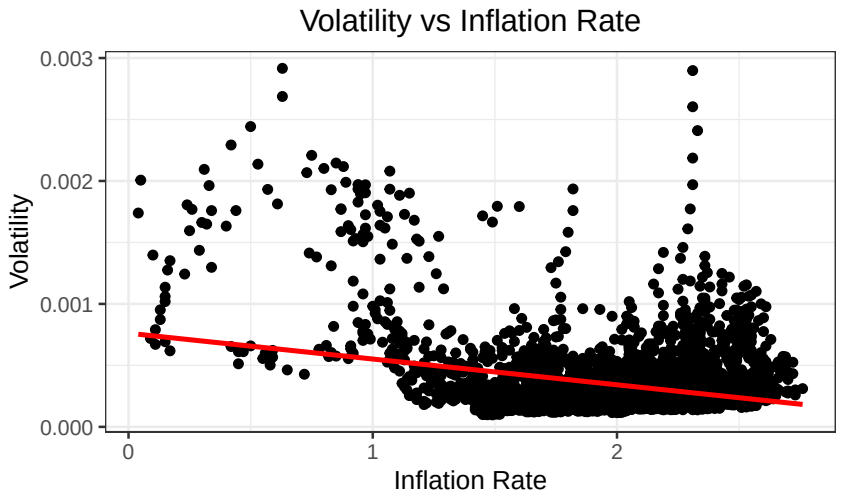

Figure 17: Linear Relationship between Volatility and Inflation Rate for Google

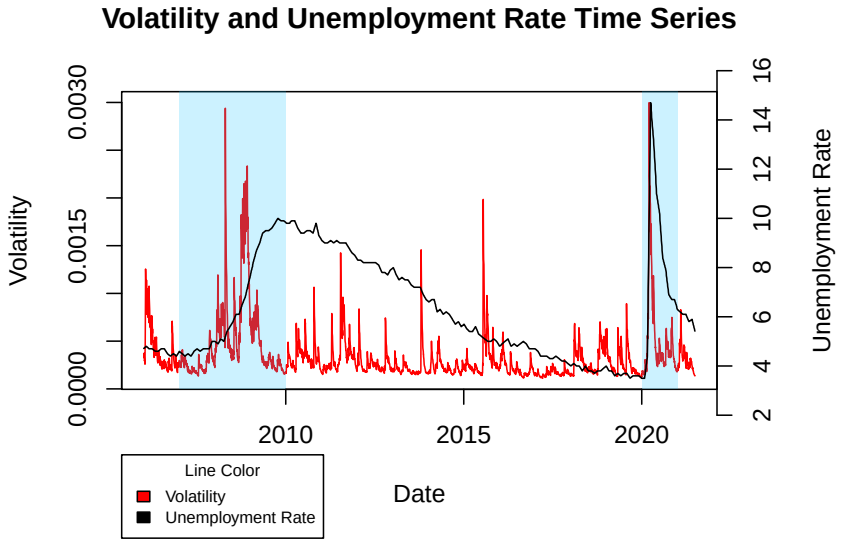

Figure 18: Relationship between Unemployment Rate and the GARCH Model with Unemployment Rate as an External Regressor for Google

```
##
## Call:
## lm(formula = volatility ~ unemployment_rate, data = df)
##
## Residuals:
##        Min         1Q     Median         3Q        Max
## -2.870e-04 -1.496e-04 -9.064e-05  3.236e-05  2.621e-03
##
## Coefficients:
##                    Estimate Std. Error t value Pr(>|t|)
## (Intercept)       1.749e-04  1.458e-05   12.00   <2e-16 ***
## unemployment_rate 2.727e-05  2.188e-06   12.46   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.0002917 on 3839 degrees of freedom
## Multiple R-squared:  0.03887,    Adjusted R-squared:  0.03862
## F-statistic: 155.2 on 1 and 3839 DF,  p-value: < 2.2e-16
```

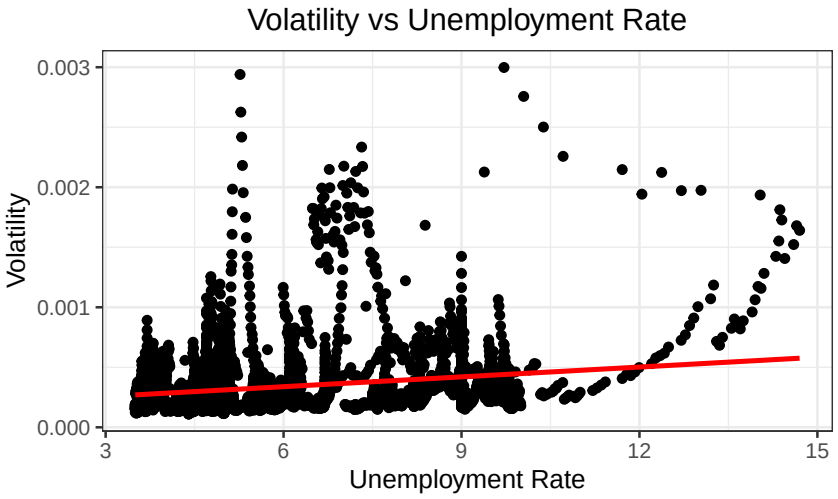

Figure 19: Linear Relationship between Volatility and Unemployment Rate for Google

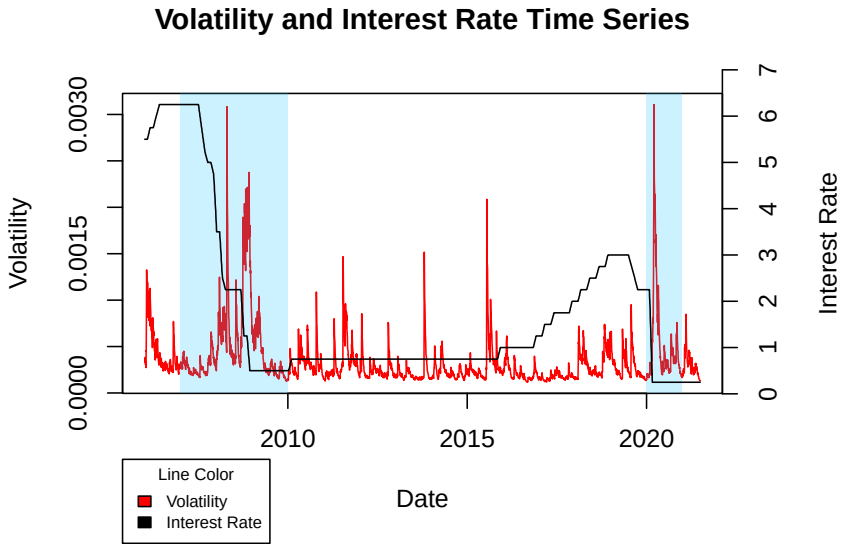

Figure 20: Relationship between Interest Rate and the GARCH Model with Interest Rate as an External Regressor for Google

```
##
## Call:
## lm(formula = volatility ~ interest_rate, data = df)
##
## Residuals:
##        Min         1Q     Median         3Q        Max
## -2.305e-04 -1.590e-04 -9.989e-05  2.191e-05  2.763e-03
##
## Coefficients:
##                Estimate Std. Error t value Pr(>|t|)
## (Intercept)   3.426e-04  6.919e-06  49.508   <2e-16 ***
## interest_rate 3.392e-06  2.771e-06   1.224    0.221
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.0003032 on 3839 degrees of freedom
## Multiple R-squared:  0.0003903,  Adjusted R-squared:  0.0001299
## F-statistic: 1.499 on 1 and 3839 DF,  p-value: 0.2209
```

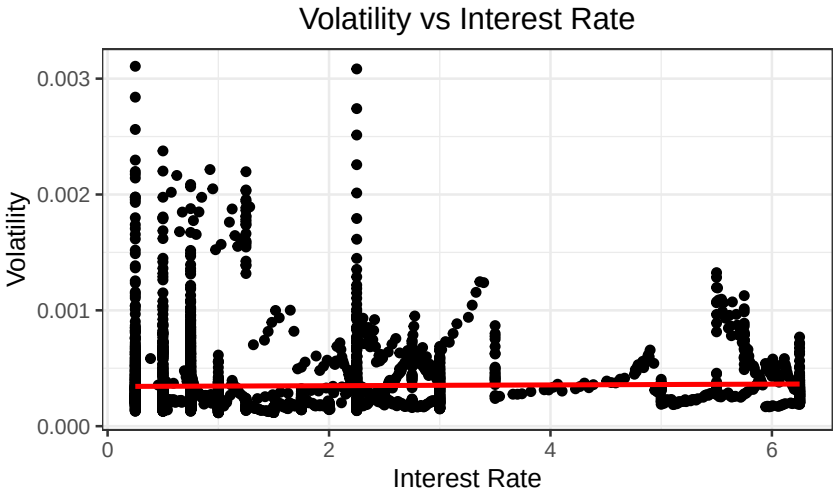

Figure 21: Linear Relationship between Volatility and Interest Rate for Google

Although the GARCH model showed a similar relationship between interest rates and volatility for Google as it did for Apple, the results of the linear regression analysis were statistically insignificant.

A potential explanation for this disparity in the relationship between interest rates and stock price volatility between Google and Apple could be attributed to differences in their respective product offerings and corresponding consumer demand patterns. Additionally, varying macroeconomic factors such as global economic conditions and geopolitical events may impact each company differently, ultimately influencing their response to fluctuations in interest rates.

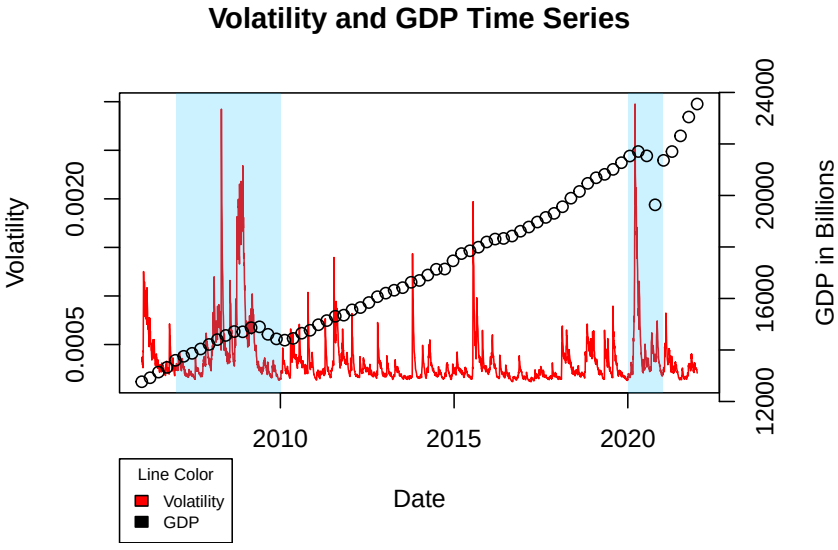

Figure 22: Relationship between GDP and the GARCH Model with no External Regressor for Google

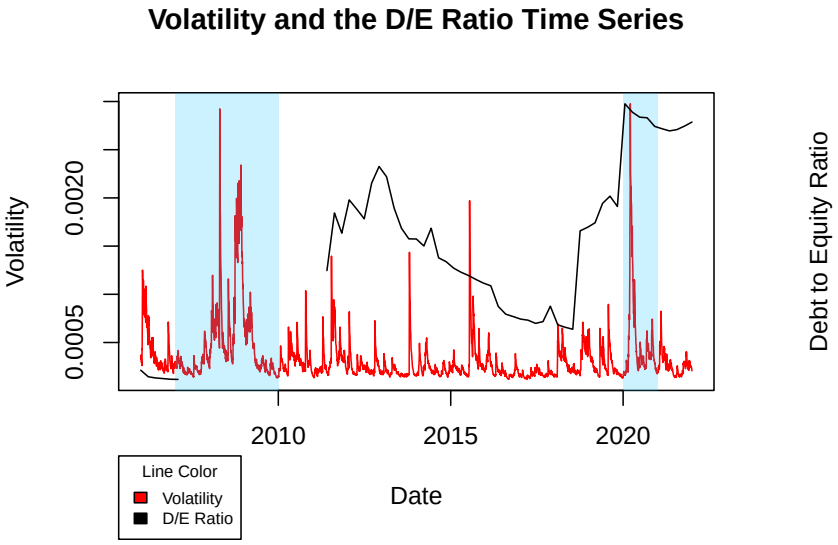

Figure 23: Relationship between Debt-to-Equity and the GARCH Model with no External Regressor for Google

It should be noted that the total debt information was not available on Yahoo Finance during the 2007-2009 recession and some time after. This may be attributed to Google's failure to report its total debt amount during that period, or a potential issue with gathering historical data.

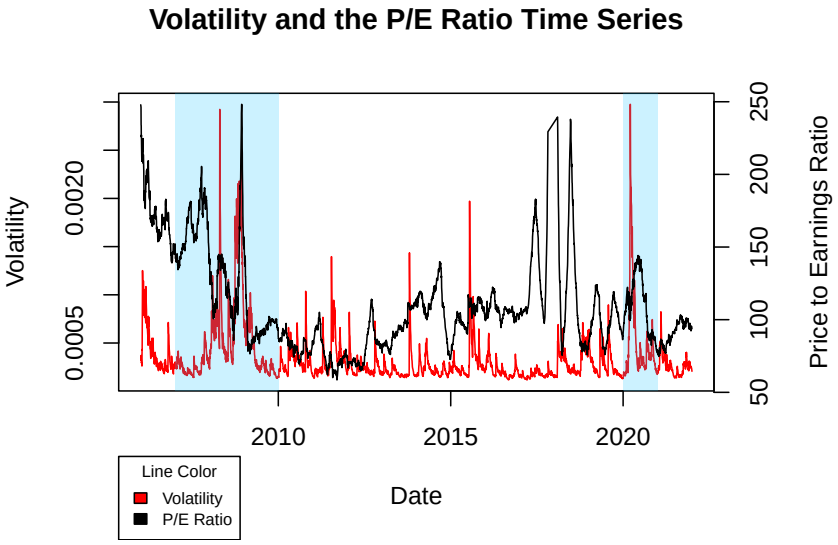

Figure 24: Relationship between Price-to-Earnings and the GARCH Model with no External Regressor for Google

Although there was little change in the price to earnings ratio when volatility increased substantially during 2020, the general trend is similar to that of Apple.