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Psychological Barriers in the Global Bond Market: An Empirical Analysis of Government and Corporate Bonds

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Biographical Note

Bruno Silva was born in Viseu, Portugal on February 3rd, 2000. He completed his bachelor's degree in Economics at Nova School Business of Economics in 2021. In the following year he enrolled in the Master's in Finance program at Faculdade de Economia da Universidade do Porto, in which this dissertation is held.

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Finally, I would like to highlight my family, for all the support and sacrifices they made so I could continue my journey. This work is as mine as is theirs.

Abstract

Psychological barriers can be seen as specific price levels that carry, in the perspective of investors, a higher relevance and can then impact and influence their behaviour and decision-making process. These levels are often round numbers and their multiples. Since the early 90's their impact has been studied for a variety of asset classes: from exchange rates, bonds, stocks and even gold. So far, evidence seems to suggest some significant impacts of this phenomenon in the returns and variances of several securities, especially in the stock market, as most of the emphasis has been on that market, leaving, for example, the bond market with its last study in 2001, accomplished by Burke.

This study aims to explore the existence of psychological barriers in the bond market. Data from seven different government bonds is used – USA, Canada, China, Germany, France, UK, Japan – with different maturities – 30, 10, 5 and 2 years – as well as data from four corporate bonds – Apple, Pfizer, Shell and Citigroup – for the same maturities. The data is comprised from January 3, 2000 to December 29, 2023.

For most of the analysed bonds, no consistent psychological barriers are found at the integer multiples of 0.25%. Furthermore, through market prediction tests, it is also concluded that barrier effects do not lead to significant predictable influences in the conditional mean or volatility of the yield series. The results thus appear to reject such a worldwide-spoken market anomaly in the bond market.

The lack of significant psychological barriers in bond yields supports the Efficient Market Hypothesis (EMH) in the bond market, while the lack of predictive power may indicate to investors that bond market prices are less susceptible to behavioral biases, which may highlight the importance of fundamental factors over psychological biases for the investing decision.

Key words: Psychological barriers, Q-values, bond market, round numbers

JEL-Codes: G12, G14, G15

Resumo

As barreiras psicológicas podem ser vistas como níveis de preços específicos que, na perspetiva dos investidores, têm uma maior relevância e podem afetar e influenciar o seu comportamento e processo de tomada de decisão. Estes níveis são frequentemente números redondos, bem como, os seus múltiplos. Desde o início dos anos 90, o seu impacto tem sido estudado para uma variedade de classes de ativos: desde taxas de câmbio, obrigações, ações e até ouro. Até ao momento, as evidências parecem sugerir um certo grau de significância no impacto deste fenómeno nos retornos e variações dos diversos ativos, especialmente no mercado de ações, cujo qual a maioria dos estudos se tem debruçado, deixando, por exemplo, o mercado de obrigações com o seu último estudo em 2001, realizado por Burke.

Este estudo tem como principal objetivo explorar a existência de barreiras psicológicas no mercado obrigacionista. São utilizados dados de sete obrigações de dívida pública diferentes – EUA, Canadá, China, Alemanha, França, Reino Unido, Japão – com maturidades diferentes – 30, 10, 5 e 2 anos – bem como dados de quatro obrigações de empresas – Apple, Pfizer, Shell e Citigroup – para as mesmas maturidades. Os dados estão compreendidos entre 3 de janeiro de 2000 a 29 de dezembro de 2023.

Para a maioria dos títulos analisados, nenhuma barreira psicológica consistente é encontrada nos múltiplos inteiros de 0,25%. Além disso, através de testes de previsão de mercado, os efeitos de barreira também não conduzem a influências previsíveis significativas na média condicional ou volatilidade das séries. Os resultados parecem, assim, rejeitar a anomalia no mercado obrigacionista.

O facto de nenhuma barreira psicológica consistente ser encontrada nos rendimentos de obrigações suporta a Hipótese de Mercado Eficiente, enquanto a falta de poder de previsão pode indicar aos investidores que os preços das obrigações são menos suscetíveis a aspetos comportamentais, o que pode destacar a importância de fatores fundamentais aos psicológicos para a decisão de investimento.

Palavras-chave: Barreiras psicológicas, valores Q, mercado obrigacionista, números redondos

Códigos JEL: G12, G14, G15

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1. Introduction

Psychological barriers are a phenomenon widely mentioned by several financial market analysts and commentators throughout the years across different markets. The following quotes serve as examples of the special treatment and attention that certain price levels carry: "When the S&P 500 reached 1.000 for the first time in February of 1998, Kenny Polcari was trading equities for ICAP from the floor of the New York Stock Exchange. The excitement was palpable" (Financial Times, August 25, 2014).
This statement clearly shows the importance attributed by financial participants of breaking a specific price level on one of the most followed indices. There are, however, other types of financial market indices with similar declarations, as is the case of the 30-year US treasury bond yield that increase to 5,96% on June 6, 1999, which led to the following statement: "The 30-year bond yield stood at its highest in about a year and just below the psychologically key 6% level, which it hasn't breached since November 1997" (Wall Street Journal, June 7, 1999).

Since the early 90's, the impact of psychological barriers in investors' decisions was raised and some pioneers' studies were developed, for the different variety of asset classes. Donaldson (1990) and De Grauwe and Decupere (1992) were the first to document the special importance given by market participants to certain price levels near round numbers in stock indices and foreign exchange markets, respectively. Then, studies on bonds and gold were also conducted, with Burke (2001) and Aggarwal and Lucey (2007), respectively. Even stock options were put to the test by Jang (2013). It is relevant to clarify that the empirical literature reports a mix of results, with some studies finding evidence of barriers, as it is the case of Donaldson and Kim (1993) that found evidences of barriers in the DJIA index, while others fail to provide significant support to their existence, even for the same index – Ley and Varian (1994), using a different approach found no evidences of barriers on the DJIA index. The literature does not also give a clear response to potential market predictability prompted by the existence of barriers.

This study intends to contribute to the literature of market anomalies, more specifically the focus will be to examine the presence and potential effects of psychological barriers in the bond market. The only relevant study, to our knowledge, to focus on the bond market was made in 2001 by Burke. So, using, essentially, 20 years of new data, also, adding more diversity in the selection of the bonds, as the mentioned study only focused on US treasury bonds, this study aims to improve the literature of psychological barriers in different types of bonds.

The tests on bond yield series to detect barrier effects is made at the integer multiples of 0.25% (e.g., X.00%, X.25%, X.50%, X.75% for all observed integers X).
Frequency distribution tests and market prediction tests are conducted follow the methodology of Burke (2001). The former tests are designed to measure anomalies in the observed frequency of certain digits in the two decimal places of the yield series. While the latter are designed to determine whether the hypothesized barriers lead to predictability in the yield series.

Overall, no evidence in favour of the existence of psychological barriers is found. Similarly, there is no evidence that barriers lead to significant predictable effects in the conditional mean or volatility of the yield series. This study is then in line with the ones supporting market efficiency.

This study is organized in chapters. After this introductory one, the literature review is presented, where the evolution of the market efficiency theory is deconstructed, the concept of psychological barriers is reviewed, as the main reasons/causes behind this phenomenon. The chapter ends with a review of the most important studies performed in the past in every market. Chapter 3 addresses methodological aspects, data and the tests to be performed are also described in this section. Chapter 4 contains the empirical results and finally the last chapter concludes and present the discussion and main findings.

2. Literature Review

The existence of psychological barriers has been studied in a wide array of securities, throughout different time periods and in different countries. However, a clear observation is that, so far, the main focus has been in the stock market, especially on stock indices, such as NASDAQ, DJIA or the FTSE 100. Despite such concentration of studies, in more recent years there has been efforts to expand them to accommodate other assets' group, such as the commodities, currencies, futures, individual stocks, bonds, among others.

This chapter will start with a brief introduction on the evolution of the theories on market efficiency, as psychological barriers are included in the subject of behavioural biases which have the capability of impacting the outcome expected at the end of a trading day. After the concept of psychological barriers is introduced, the chapter will dig into the relationship between this phenomenon and market inefficiency. Later, possible theoretical explanations for the occurrence of the phenomenon are presented, as well as the most relevant studies performed on different type of securities.

2.1. Market efficiency theory evolution

The present study contributes to check the efficiency of the financial markets, more specifically the bond market, and anomalies, particularly by identifying deviations from traditional financial theories, such as the Efficient Market Hypothesis (EMH). The presence of psychological barriers shows potential mispricing opportunities and then allows for an examination of market dynamics.

Fama (1970) introduced the efficient market hypothesis in which it was suggested that asset prices fully reflect all available information, which makes it impossible for investors to, in a consistent manner, achieve above-average returns (abnormal returns). Fama categorized market efficiency into three forms: Strong form – asset prices to reflect all information, whether public or private, leaving no investor with the possibility to consistently earn abnormal returns; Semi-strong form – asset prices to reflect all publicly available information, leading investors who trade on publicly information with no possibility to achieve abnormal returns; and Weak form – asset prices to reflect all past trading information.

In the following years there were several works showing the presence of inefficiencies in the market, attempting to contest the Fama's theory. For example, Sheifer and Vishny (1997) proposed that market inefficiencies persist due to limits on arbitrage, such as noise trader risk or short selling constraints, which deter arbitrageurs to fully correct mispricing. In other study, Hirshleifer (2001) argues that investors are not always rational and may demonstrate various psychological biases that affect the decision-making process and limit arbitrage. Mispricing caused by these factors can endure for prolonged periods, leading to potential opportunities for profit but also contributing to market inefficiencies.

Other studies throughout time brought to live and acknowledge the existence of other anomalies and psychological biases. For example, Lo and MacKinlay (1988) found consistent positive autocorrelation while analysing weekly returns on portfolios of NYSE stocks and that autocorrelation is stronger for portfolios of small companies. Also, Conrad and Kaul (1988) found that daily and Wednesday-to-Wednesday returns are positively autocorrelated, and the effect is greater for small stocks.

Ariel (1987) showed that stocks appear to earn positive average returns during the first half of the calendar months and zero average returns in the second half.

In more recent years, Yen and Lee (2008) realized a review of the empirical evidence on the EMH over the last decades. According to the authors, EMH has clearly much less support comparing to its prosperous era of the 1960s and it faces very strong opposition from the school of behaviour finance since the 1990s.

In an attempt to reconcile these two opposing views, Lo (2004) calls for an evolutionary alternative, in which he proposed a new hypothesis called AMH – adaptive markets hypothesis. In this new paradigm EMH would co-exist with ideas from behavioural finance.

2.2. Psychological barriers

Psychological barriers are specific price levels that carry, in the perspective of investors, a higher relevance and can then impact and influence their behaviour and decision-making process. These levels are often round numbers and their multiples. Two terms that are very often mentioned in discussions related to psychological barriers occurrence are "support-level" and "resistance level". If the price struggles to cross through a certain level, it can act as resistance, slowing down or reversing the price movement. However, if a certain level, seen as barrier, is crossed, then traders may "jump on the bandwagon", driving the price even further. Donaldson and Kim (1993) link these findings with the investor's interpretation on the strength or weakness of the market.

These barriers do not have a fundamental and economic justification, but because of how investors perceive these levels and give them a greater relevance, they can influence their decisions.

Since the early 90's this phenomenon caught the attention of market participants, and some studies were developed. Donaldson (1990) and De Grauwe and Decupere (1992) were the first to document the attribution of a special importance to round numbers on behalf of market participants in the stock and foreign exchange markets, respectively. Donaldson and Kim (1993) also demonstrated that multiples of 100, and specially of 1000, cause a certain hurdle in the Dow Jones Industrial Average Index. According to the authors, breaking through a barrier may be interpreted as a sign of market strength, while the opposite, the resistance to break the barrier may be seen as a sign of a weaken market.

2.3. Reasons for psychological barriers

There are several reasons that have been appointed and may be behind the existence of psychological barriers. The next section aims at describing each of them in a more detailed fashion.

2.3.1. Anchoring

The anchoring effect is a well-known behavioural bias firstly identified by Tversky and Kahneman in 1974. It can be understood by the investors' tendency to fixate ("to anchor") on one piece of information, even if irrelevant for the estimation. This initial information can set the tone for subsequent decisions, as rounding provides faster computation and processing of numbers (Hornik et al. 1994), which may lead to potentially less costly decisions (Yule 1927; Preece 1981).

Several other authors also have discussed and expanded the findings throughout the years. Shiller, in his book "Irrational Exuberance", states how round numbers can often function as a good proxy, when making price estimation in the presence of no clear agreement.

Also, Westerhoff (2003) studies the relationship among anchoring and psychological barriers in the Foreign Exchange market. The author also develops a simple behavioral exchange rate model in which investor perception of the fundamental value is anchored to the nearest round number. Psychological barriers are found to be present in the market, as the model predicted excessive volatility and fluctuations of the exchange rate around the perceived fundamentals. It is also mentioned that the exchange rate fluctuations tend to be limited within a band around the already mentioned perceived fundamentals, and that the lower and upper boundaries of the band resemble the so-called support and resistance levels.

2.3.2. Clustering

"Clustering is broadly defined as the grouping together or congestion of items. Price clustering is a concentration of the distribution associated with a particular value or values when various values of price (digits) occur more frequently than other prices (digits)" (Mitchell, 2001, p. 402). One can easily verify that is not odd to confirm that prices often end with specific digits or decimals, creating patterns that can be observed in financial markets.

For example, Osborne (1962) finds a prominent trend for closing prices of US share prices to gather on whole numbers, halves, quarters and odd one-eights in descending preference.

According to Niederhoffer (1965), in theory, in an efficient market, prices should be uniformly distributed in all possible pricing grids. However, the author found evidence of clustering on limit orders taken from the order book of a specialist on the NYSE. In the study it is shown that the ratio of limit order closing prices at the even eighths (0, 2, 4, 6) to those at the odd eighths (1, 3, 5, 7) was 8.8: 1.
Niederhoffer attributed these findings as the result of the tendency of stock market participants to place their orders at "numbers with which they are accustomed to deal", such as whole and round numbers.

Harris (1991) provides a different view for the occurrence of this phenomenon. The author suggests that price clustering occurs because traders want to simplify their negotiations, in order to make them less costly. By using a restricted set of discrete prices known to all traders, a reduction in the negotiation time would be expected, since it limits the number of different prices at which bids and offers will be made. It also limits the amount of information exchanged between traders.

Terrence Odean (1998) explores various aspects of investor behavior, including the tendency of stock prices to cluster around multiples of 5 and 10. His findings suggest that investors might exhibit preferences for round numbers when making trading decisions.

2.3.3. Odd Pricing

Odd pricing is a marketing and pricing strategy where prices are set just below a round number, typically ending in .99 or .95. The idea behind odd pricing is to make the price appear more attractive to consumers, creating a perception of a lower cost. It's based on the psychological tendency of consumers to focus on the first digits when evaluating prices. For example, when a price is $299, the digit 2 is more significant as information than the first 9, which in turn is more significant than the next 9 (Holdershaw et al, 1997).

Holdershaw et al (1997) highlight that by setting a price at, say $39.95 rather than $40.00, an illusion is created which makes the product seem much cheaper to consumers than the nearest (and higher) round figure. This illusion of cheapness can then trigger an increased buyer response.
In the same study, the authors show that in a sample of more than 800 advertisements, in 1997, 87% of values were defined as odd prices, with 60% ended with the number 9 and 30% with the number 5.

Brenner and Brenner (1982) gave as explanation for this phenomenon the limited capacity of people to store information. In this sense, as consumers are constantly receiving new information regarding goods' prices, they will only store the more relevant piece of information, meaning the first digits. Furthermore, as, according to the authors, rounding up involves additional decision and attention, when a price is labelled as €4,99 consumers will more likely link the good with the price of €4 than €5.

Kahn et al (1999) to prove that consumers, in order to compare two numbers, use a very efficient procedure, a left to right comparison, uses data of bank deposit rates. His prediction would be that, in contrast with consumer goods, the bank deposit rates should cluster on integer values, due to the fact that consumers would pay higher attention to the first digit, and they would prefer in this case higher values. In their study such finding is found, as rates are indeed observed more often just above integers than bellow.

2.3.4. Aspiration Levels

Aspiration levels are desired or targeted levels of performance/outcomes which investors aim to achieve.

"Investors who buy an asset already have a target price in mind for which they are willing to sell in the future" (Sonnemans, 2006, p. 1938). And due to bounded rationality, those target prices are usually round numbers. According to the author, this will lead to "relatively many limit sell offers to be posted at round whole numbers" (Sonnemans, 2006, p. 1942), which will obviously make crossing such levels more challenging.

In the same line, Simon (1955) and in several studies made from 1955 onwards, considers that consumers face, in fact, several limitations – from time, information to calculation limitations. As a result, they are more likely to cope with an outcome, that he called "good enough" solution, an outcome that is pursued when individuals are no longer trying to maximize their utility function. These values tend to be, once again, round numbers.

2.3.5. Cost efficiency

Several reasons that were discussed above for the existence of psychological barriers could be viewed as a cost efficiency perspective. In the study of odd pricing or aspiration levels, for example, those levels were obtained due to the need of investors to simplify their calculations, as they prefer a quicker and a most cost-effective process over a detailed and more time-consuming analysis. These points are precisely the ones presented in studies, like the one from Preece (1981) or Takayanagi et al. (1995), in which the former proves that people do indeed tend to simplify information when mentally processing numbers, while the latter demonstrates that they perform comparisons and calculations quicker when using round numbers.

Hornik et al. (1994) confirm the latter inferences, as by using data from seven different studies established that rounding occurs more frequently than chance and, also, larger values seem to be rounded more frequently. The author appointed that rounding may be partially a "product of the retrieval process" in which stored values become rounded as memory becomes less precise.

Sonnemans (2005) in the study of the Dutch's stock market also mentioned that round numbers are, in fact, more convenient. Calculations with round numbers are easy to perform, which limits informational load and decreases the probability of costly mistakes.

2.3.6. Rational Explanations

So far it was only considered behavioral biases as reasons for the existence of psychological barriers. However, as contra intuitive as it seems, there may be some rational explanations.

For example, Dorfleitner and Klein (2009) mention a purely technical reason, derived from the fact that option exercise price are usually round numbers. This can cause additional trading activity in the underlying asset around those values.

Harris (1991) argues that there is a trade-off to have more precise information. In other words, investors may be better off doing simplifications – rounding numbers, for example – if, in fact, the costs of acquiring such precise information are too costly and do not outweigh the benefits from it.

2.4. Previous Studies

2.4.1. Stock Market

Donaldson (1990) and Donaldson and Kim (1993) published one of the first significant studies on this subject. The authors analysed the Dow Jones Industrial Average (DJIA) and the Wilshire Associates 5000's (WA) closing prices, between 1974 and 1990. The authors did not find evidence for the presence of psychological barriers in one of the indices – for the WA index. However, the results on the DJIA were different: "the DJIA closes less frequently on index values whose last two digits are in the neighbourhood around the 00" (Donaldson and Kim, 1993, p. 320-321). According to the authors, such finding is related to the fact that if the closing price of the DJIA index were to breach a 100-level, a wave of optimism among investors, which they called "bandwagon effect", would push the index well past the 00-level. In the other way, the reluctance to break a barrier may be regarded as bad news by the market. The extra selling pressure associated with a downward breakout would push the DJIA further away from the 00-level.

Ley and Varian (1994) also studied the DJIA index, however considered a wider interval of time (1952-1993) and employed a different test design to examine the distribution of the DJIA's digits. The authors concluded that the distribution of the closing price's decile was not uniform. In fact, days when the DJIA ended with the pattern "9*x*" as last digits, the returns were three times higher than the average returns. However, they emphasized that such finding are not necessarily synonyms of price barriers, since they were not robust and would disappear if the sample were to be split in subsamples. Also, little if any predictive power in the closing values of the DJIA was concluded.

Koedijk and Stork (1994) also developed a study on 5 stock indices using the daily middle rate (average between the bid and the ask spread). Data between 1980 and 1992 for the Brussel Stock Exchange (Belgium), the FAZ General (Germany), the Nikkei Stock Average 225 (Japan) and the Standard and Poors Composite (United States) was used, while for the FTSE-100 (United Kingdom) the data was collected between 1984 and 1992. The authors discovered significant indications of psychological barriers' existence on the FAZ, the FTSE and the S&P, but weak indications on the Brussels Index, and none for the Nikkei. Nevertheless, no predictivity power on future prices and return can be linked to psychological barriers.

Cyree, Domian, Louton and Yobaccio (1999) used daily closing values of the DJIA, the S&P 500, the TSE 300 (Toronto), the CAC 40 (Paris), the DAX (Frankfurt), the Hang Seng (Hong Kong), the Nikkei 225 (Tokyo), and the Financial Times UK Actuaries (London). The authors concluded that despite the return dynamics do not appear to be uniform across the indices in their sample, evidence of barriers in seven of the eight indices tested was found. In the study, a new method was applied - GARCH (generalized autoregressive conditional heteroskedastic) in mean model with indicator variables in the mean and variance in order to identify changes in the conditional returns immediately before and after crossing a barrier. The authors acknowledge the inconsistency across the indices, however they were able to draw some conclusions: in an upward trend, the expected conditional mean return increases, while in a downward trend, it is very difficult to estimate the influence on the returns. Secondly, conditional variance tends to be higher in subperiods prior to crossing a price barrier and lower in post-crossing subperiods.

Bahng (2003) dive into the Asian stock market, investigating the daily stock price indices of South Korea (KOSPI), Taiwan (Taiwan Weighted), Hong Kong (Hong Kong Hang Seng), Singapore (Straits Times Index), Thailand (Bangkok S.E.T.), Malaysia (Kuala Lumpur Composite), and Indonesia (Jakarta Composite). The author found clear evidence of psychological barriers within the Taiwan Weighted index, which was, in his view, evidence in favor of market inefficiency, since under the presence of price barriers, prices will not reflect their true values around certain psychological reference levels.

Dorfleitner and Klein (2009) focused on four stock indices - DAX30, CAC40, FTSE100 and DJ EURO STOXX50 - from 1996 until 2003, as well as the prices of eight major German stocks. The authors concluded that there were no consistent barriers in European stock indices or individual stocks. Also referred was the fact that some of the barriers found in previous studies seem to have disappeared. A finding consistent with the current literature about disappearing stock market anomalies (Dimson and Marsh (1999), Kohers et al. (2004) and Marquering et al. (2006)).

Despite the previous study, one of the first to focus on individual stocks was Cai et al. (2007). A total of 1050 A-shares and 100 B-shares during June 2002 were examined (A-shares could only be traded by domestic Chinese investors and were denominated in renminbi (RMB), while B-shares were denominated either in US dollars in the SHSE, or in Hong Kong dollars (HKD) in the SZSE and were traded mainly by foreign investors from both the Shanghai Stock Exchange (SHSE) and the Shenzhen Stock Exchange (SZSE)). However, no evidence of psychological barrier was found significant.

2.4.2. Foreign Exchange Market

De Grauwe and Decupere (1992) were the first to study this phenomenon on the foreign exchange market. The authors analysed the daily DM/Dollar and Yen/Dollar exchange rates throughout 10 years, between 1980 and 1990. They determined that psychological barriers exist and are significant in the dollar-yen market, as market exchange rates tend to resist movements towards numbers such as 130, 140, etc. (multiples of ten) yen per dollar. In addition, once these barriers have been crossed, exchange rates accelerate away from them; same conclusion as Donaldson and Kim (1993) that once a barrier is broken the investors "jump on the bandwagon" driving the price further away. It was not found any barrier effect in the dollar/DM market.

Westerhoff (2003) discovered that currency values are often anchored to the nearest round numbers. This anchoring phenomenon, as argued by the author, can cause potential misalignments in exchange rates. These fluctuations create resistance and support levels, two types of psychological barriers. According to Westerhoff, central authorities could address these distortions by pushing exchange rates towards less biased anchors.

2.4.3. Derivative Market

Jang et al. (2012) was one of the first studies on psychological barriers and option pricing in relation to the S&P 500 index. The authors had two main objectives: demonstrate the existence of psychological barriers in the S&P 500 Index and consequentially examine their impact on the index's rate of return and volatility. Secondly, they suggested a superior model on option pricing and hedging, called the "threshold model", that would incorporate the impact of these barriers. An examination of its empirical performance relative to the existing models such as the Black– Scholes and constant elasticity of variance (CEV) models was also performed by the authors. The authors used a very interesting method in order to have better insights in the derivative pricing, by using the VIX index, a real-time volatility index of the S&P 500 index. By performing a mean regression analysis, it was found that the VIX index is dependent on the barrier because it declines relatively by 0.5% on average when the S&P 500 index is close to psychological barriers (inferences in accordance with several previous studies, such as Donaldson and Kim (1993)). Therefore, they were able to improve an option pricing model, for European call options on the S&P 500 by allowing the expected rate of return and volatility to vary if a stock price reaches a psychological barrier. According to their conclusions, adding the aspect of barriers in option pricing appears to be valuable and important, as their new model performed better than the Black-Scholes and the Constant Elasticity of Variance models. It produced lower values of root mean squared errors, as well as in terms of hedging, since it generated lower dollar-value hedging errors.

Schwartz et al. (2004) examine price clustering of the S&P 500 futures contracts traded on the Chicago Mercantile Exchange. It was found that the S&P 500 futures contract prices tend to cluster at pricing increments of x.00 as well as of x.50. Moreover, a higher degree of clustering in the opening and closing prices was found comparing with the settlement prices.

More recently, Dowling et al. (2016) investigated the hypothesis of psychological barriers in oil futures. The study focused on Brent and WTI contracts, covering the period from 1990 to 2012. The results indicated that psychological barriers around 10-digit levels influenced prices only during the pre-credit crisis period of 1990-2006; this effect dissipated during the subsequent oil price bust. Stronger evidence was found for Brent compared to WTI.

2.4.4. Commodities

Aggarwal and Lucey (2007) were the first ones to study the presence of psychological barriers in the daily and intra-day gold price. They used daily gold prices from the official London AM Fix (the generally accepted benchmark for gold bullion) between 1980 to 2000; as well as daily data from COMEX for cash and futures gold between 1982 to 2002. They found evidence to the presence of psychological barriers at the 100's digits (price levels such as $200, $300, etc) do exist in daily gold prices. For the intra-day, high frequency gold prices dataset – which consisted of 15 min interval data over the period 2001 to 2003 – no evidence was found.

Lucey and O'Connor (2016) also investigated the existence of psychological barriers in gold and silver prices, specifically at numbers ending in 0 and 00. They analysed intraday gold prices from the London AM and PM fix and daily silver prices from the London fix, between 1975 and 2015. Their findings revealed the presence of psychological barriers at 0 and 00 endings in gold prices, while for silver prices, there were no such psychological barriers observed.

2.4.5. Bond Market

Burke (2001) realized the first major work in the bond market, using U.S benchmark bonds' yields, for a diverse number of maturities, from 2, 5, 10 and 30 year, between 1983 and 2000. The author found evidence of yield barriers at integer multiples of 0.25% (e.g., 6.00%, 6.25%, 6.50%, 6.75%) in the 10-year and 30-year benchmark bonds. However, the same did not happen in a GARCH6 framework, which led the author to conclude that barrier effects do not lead to significant predictive power.

3. Methodological Aspects

This chapter will start with the presentation and description of the data used. Then some considerations are made for the barrier structures used in the analysis. Finally, it is presented the theoretical fundamentals of all the empirical tests performed in this study.

3.1. Data

The main focus of this study it to examine the presence of psychological barriers in the bond market and consequentially several bonds were selected, from government to corporate ones. All the yield data was obtained from *Datastream Refinitiv*. The data base includes yields of government bonds from seven countries, USA, Canada, China, Germany, France, UK, Japan with different maturities – 30, 10, 5 and 2 years. The data is comprised from January 3, 2000 to December 29, 2023 for each country and each maturity, which amounts to 166 770 data points in total. Since Datastream fills weekday holiday dates with previous day market values, it was necessary the removal of the holiday observations to avoid double counting. This is necessary to prevent possible sources of bias in the frequency distribution tests which are based upon the frequency of occurrence for certain digit combinations in the decimal portion of the yield.

To improve the scope of this study, in addition to the analysis of government bonds, corporate bonds were also added – also for the same four different maturities. Their selection was based on several criteria. First of all, high levels of liquidity needed to be present. Then, the bonds were required to be traded in markets from different countries to have some degree of diversity in the analysis. In addition, to further increase the diversity, bonds were chosen from corporations from different industries. There was, however, some limitations in the data base, since for the majority of the bonds initially selected there were massive gaps in the intended years. The described data omission in the sample led to the exclusion of several bonds. In the end, four corporate bonds – Apple, Pfizer, Shell and Citigroup – from four different industries – information technology, pharmaceutical, oil and gas, and financial services, respectively – were left.

For the majority of the maturities, the data started on April 1, 2014 (exception for Apple that starts on August 4, 2014) and ends on December 29, 2023.

Following the work of Burke (2001), the 30-year and 10-year bond issues will act as bellweather candidates for barriers in the bond market, since the bonds with such maturities are widely available and continuously updated during the trading session and they are also representative of a large proportion of the trading activity. The shorter-term bonds are "not as purely indicative of bond investor sentiment alone" (Burke, 2001, p. 11), as they can be more easily influenced by monetary policies, for example. As a result, the 5-year and 2-year will serve as a control series.

It is also important to point out that benchmark bond yields rather than prices are used, since the former are considered to be the best candidates to detect barrier effects. "The seasoned and new issue bonds may have very different coupon rates but yields differing by only a few basis points, the price differences between the two can be large." (Burke, 2001, p. 11). So, by using yield forms, a greater continuity is secured. Besides the fact that bond yields are widely regarded as indicators of market sentiment and investor expectations.

Furthermore, the data base offered *zero yields* as well as *par yields,* being the former preferred to proceed with the analysis. The choice was made due to consistency considerations, as zero yields provide a standardized measure of yield that can be directly compared across different maturities and issuers. A very important concern as it allows for a more straightforward comparison between government bonds and corporate bonds in terms of yield behaviour and the presence of psychological barriers. Finally, zero yields serve as key inputs for pricing models and can be used to assess the predictability of bond yields over time, something that will be tested in the present work.

3.1.1. Data Description

In general, bond yields of the government bonds decrease from the beginning of the sample period – 2000 – until around 2020, period in which they reached their minimum values, around 0% or, in many cases, even negative yields. Afterwards, one can clearly see an increase in the yields, until the end of the sample period – 2023. This occurred in most of the bonds (except for China), however the higher the maturity the more predominant and the easier it is to check this trend.

The first differenced form, which represents the daily change in the yield, is also presented and allows, among other things, to analyse the volatility. From the observations of the figures in Appendix B, one can easily confirm the increases in the volatility from the 2009 financial crisis in the graph for the US bonds, China and for the countries in Europe. The effect of Covid in 2020 and the conflict between Russia and Ukraine is also observable with visible spikes in the graphs, corresponding to massive changes in the daily yield of government bonds. Graphs for the yield series and first difference form appear in Appendix B.

Additional descriptive statistics for these series in their yield level and daily differenced form are found in Appendix A. There are some statistics from the tables that are worthy of note. For example, the unconditional mean of all differenced series, which the exception of China, is -0.001%, which is in conformity with the already observed downward time trend in yield levels over most of the sample period.

Regarding the corporate bonds, there are some similar features comparing to the government ones, as yields also reach their minimum values in 2020/2021, after which some visible increases occurred. Each first difference series depicted very high volatility in 2020 – linked to the Covid-19 pandemic – and also in the last years of the sample period – linked to the conflict among Russia and Ukraine.

Nevertheless, Table 6 to 9 of Appendix A shows additional descriptive statistics for these series in their yield level and daily differenced form. From the tables some interesting features can be highlighted as is the fact that, for the yield series, the higher the maturity of the corporate bonds, the lower the standard deviation.

3.2. Methodology

The methodology pursued by the majority of past studies follow the pioneers Donaldson and Kim (1993), which introduced tests around the so-called M-values, which essentially refer to the last digits in the integer portion of prices. However, in this study, the M-values are not going to be used, instead the so-called Q-values will. This approach is used to be in accordance with Burke (2001), in which the concept was introduced.

Nevertheless, the same type of tests commonly used by researchers in the subject will be performed. Accordingly, a uniformity test will be conducted to examine the distribution of the Q-values. This test is based on the assumption that the Q-values would follow a uniform distribution in the absence of psychological barriers.

Afterwards, two different frequency distribution tests are introduced – the barrier proximity and hump shape tests, attempting to investigate the influence of the predetermined barriers on the yields.
Later, the final approach to examine the barriers are market prediction tests, which evaluate the predictability of future bond yields based on their current states.

3.2.1. Definition of Barriers

Let Y_t denote the yield level on date t, rounded to 2 decimal places where t =1...T.
Two decimal numbers are used as it is the norm followed by, for example, financial market commentators, who typically refer to barriers up to two decimal places.
Also, it is assumed investors not to be able to distinguish between barrier proximities at the one thousandths percent place.

These decimal portions range from 0.00 to 0.99 and will now be referred to as basis point values – BP-values. The BP-value for a yield series at time t is denoted BP_t and it is formally calculated by $BP_t = Y_t - \text{integer}(Y_t)$.

Since the analysis of the existence of barriers will be conducted at the quarter percent level, BP-values are presented into their corresponding positions in the quarter point range, from 0.00 to 0.24. These values will be mentioned as Q-values. The time t Q-value is denoted Q_t and is defined more precisely as follows:

$$Q_t = \begin{cases} BP_t & \text{for } BP_t < 0.25 \\ BP_t - 0.25 & \text{for } 0.25 \leq BP_t < 0.50 \\ BP_t - 0.50 & \text{for } 0.50 \leq BP_t < 0.75 \\ BP_t - 0.75 & \text{for } BP_t > 0.75 \end{cases}$$

Given this configuration, in the presence of a psychological barrier, one would expect to observe Q-values in proximity to Q = 0.00 less frequently than other Q-values in the middle of the range. Contrarily, in the absence of barriers one would expect all Q-values to occur with equal frequency.

3.2.2. Negative yields

One could notice the presence of negative yields, only in the government bonds, especially for the shorter-term maturities, in European countries – Germany, France and UK – and Japan. Without dive into the specifics that led to this situation, as it is not the focus of this study, the aftermath of the global financial crisis and the European sovereign debt crisis that led to economic stagnation and deflationary pressures were one of the reasons. Central banks were bound to respond with aggressive monetary easing, leading to the negative yields.
Investors searched for the so called safe-haven assets during that time, which led to an increase in the demand for Japanese government bonds. As a result, bond prices rose, and yields turned negative.

The negative yields appeared once again between 2019 until 2021/2022, depending on the bond, due to some trade tensions, geopolitical risks, and the COVID-19 pandemic.

These negative yields occurred due to what was considered as abnormal economic conditions, which were not representative of normal market conditions. Also, negative yields are generally a temporary phenomenon, motivated by extraordinary monetary policies, which do not clearly represent long-term behaviour for the bond market.

With the above-mentioned justifications, negative yield observations, that only represented a small fraction of the overall data, were considered outliers and were, then, excluded from the analysis. This decision was also made due to methodology consistency, as the benchmarked study – Burke (2001) – does not featured negative yields.

3.2.3. Uniformity Test

If psychological barriers are not present in the market, then one should expect the distribution of the decimal place digits of a yield series to be uniform. This would translate into, for example, X.25% yield to not appear more or less frequently than X.27% or X.23%. Opposingly, if barriers are indeed present, then one should expect a lower frequency of yields at or closed to the hypothesized barriers. This effect is explained by Donaldson and Kim (1993), which link the barriers to sentiment signals for market participants. As a result, the yield series is expected to either deviate away from or rapidly move through these barriers, rather than remain stable or settle around them. According to Burke (2001), near barrier closing yields can be seen as "unstable equilibriums", with a higher likelihood of not being sustained until market closure.

To formally test uniformity, a Kolmogrov-Smirnov Z-statistic test will be performed. This test will compare the Q-values distribution of each bond with a uniform one. Thus, the null hypothesis of this test is H0: uniformity against H1: non-uniformity.

It is important to point out the disclaimer made by Ley and Varian (1994), as the rejection of uniformity is not by itself a sufficient condition to attest for the existence of the mentioned barriers. Additionally, other studies made by different authors also advert to not make conclusions solely from this test. As an example, De Ceuster et al. (1998) claim as series grow without limit and intervals between barriers become larger, uniformity tend to no longer be present.

3.2.4. Barrier Tests

Following the pioneer study of Donaldson and Kim (1993), two different barrier tests will be conducted to determine whether yield observations occur less frequently on and near the quarter percent barriers than it would be expected under a uniform distribution. In general terms, both tests are designed to analyse the shape of the frequency distribution of the observations' decimal place. However, while the first – barrier proximity test – gives more focus on the frequency of observations near the barriers, the second one – hump shape test – examine the whole shape of the distribution.

3.2.4.1. Barrier Proximity Test

As previous mentioned, this test is designed to evaluate the frequency of the observations near the psychological barrier, according to the following equation:

$$f(Q) = a + \beta D + \in \quad (3.1)$$

Where $f(Q)$ represents the frequency with which a yield series closes with a Q-value in cell Q. The regression includes a constant and a dummy variable, D, which will take the value 1 for the Q-cells 0.00, 0.01 and 0.24 (symbolizing a barrier proximity) or the value 0 otherwise.

The test is then reduced to a t-test on the coefficient β in equation 3.1. The null hypothesis of no barriers implies β to be equal to zero. On the other hand, if barriers are present, it is expected a lower frequency near them, causing β to be negative and significant.

3.2.4.2 Barrier Hump Test

The second test does not only examine the frequency around the barrier, but it will also take into consideration the entire shape of the distribution.
Donaldson and Kim (1993) note the study of Bertola and Caballero (1992) regarding the behaviour of exchange rates when target zones are present, in which a hump-shape is an appropriate alternative for the Q-value frequency distribution when barrier effects are present. Consequently, the following equation will be used:

$$f(Q) = a + \beta Q + \Upsilon Q^2 + \in \qquad (3.2)$$

Where the frequency of each Q-cell, $f(Q)$, is regressed on the Q-cell decimal values raised to the first and second power. The test is then reduced to a t-test on the coefficient Υ in equation 3.2. Under the null hypothesis of no barriers Υ is expected to be zero, implying a flat distribution of the Q-values. Whereas if barriers are indeed present, Υ should be negative and significant.

3.2.5. Market Prediction Tests

This next group of tests dedicated to analyse barrier effects will be comprised into three market prediction tests. The rationality to engage in these tests is to verify if the hypothesized yield barriers lead to any kind of predictability in the first differenced yield series, which would allow investors to develop a strategy around this superior forecasting advantage.

The first test uses a dummy variable that will take different values depending on the current position of the yield in the quarter percent barrier interval, to analyse the one day mean yield change, according to the following equation:

$$\Delta Y_{t+1} = a + \beta DM_t + \in \qquad (3.3)$$

Where DM_t:

$$DM_t = \begin{cases} 1 \quad \text{for} \quad Q_t = 0.01, \ldots, \text{or } 0.12 \\ -1 \quad \text{for} \quad Q_t = 0.13, \ldots, \text{or } 0.24 \\ 0 \quad \text{for} \quad Q_t = 0.00 \end{cases}$$

The construction for the DM_t follows the reasoning of Burke (2001) and the definition of resistance and support levels. Accordingly, all other things equal, when the current yield is slightly above a yield barrier, one would anticipate the barrier below to act as a supportive level for the series. Conversely, if the yield series is positioned just below the barrier, a symmetric but inverse effect on the yield series is expected. In scenarios in which the yield series sits precisely on the center barrier value, one would anticipate the yield to move away from the barrier. However, there would be no particular bias towards upward or downward movement in this case.

In the end, the test for predictability in the mean one day ahead change in yield is reduced to a t-test on the coefficient β on equation 3.3. Under the null hypothesis of no predictive value, β should be equal to zero. On the other hand, if barriers lead to some kind of predicable effect, β should be positive and significant.

The second test is similar but addresses the one day ahead mean squared yield change, in order to only consider the magnitude of the yield change, instead of also consider the direction of the change.

Thus, the one day ahead squared yield change is regressed on a dummy variable DV_t, which will take the values one or zero, depending on the location of the closing yield. Accordingly, the equation is as it follows:

$$(\Delta Y_{t+1})^2 = a + \beta DV_t + \in \tag{3.4}$$

Where:

$$DV_t = \begin{cases} 1 & \text{for} \quad Q_t = 0.00,\ 0.01 \text{ or } 0.24 \\ 0 & \text{for} \quad \text{otherwise} \end{cases}$$

The idea behind the construction of DV_t is that the yield series once within the barrier zone tend to take larger moves to move away from the barrier, reflecting the idea that yields are the freest to move in either direction when starting on the barrier on near it (in this case Q = 0.00, 0.01 or 0.24).

The test is then reduced to a t-test on the coefficient β on the equation 3.4. Under the null hypothesis of no predictive value, β should be equal to zero. However, if barriers lead to predictive effects, β should be positive and significant, reflecting the larger changes from starting yield levels in the barrier zone.

4. Empirical Results

Chapter 4 contains the results obtained in the above-mentioned empirical tests, as well as the main conclusions and analysis of firstly the government bonds and afterwards the corporate bonds.

4.1. Uniformity Test

Table 1 displays the result of the uniformity test. For the government bonds, results vary substantially according to the country and maturity of the bond. France and Germany were the most critical as p-values for both longer maturities (30 and 10 years) were considerable high, which does not allow for the rejection of uniformity, not even at a 10% level. It is important to point out once again that the 30 and 10-year maturities are the focus of the analysis, since, as already explained in the section 3.1, it is not expected to find significant effects in the 5-year and 2-year control series. The US and the UK presented mixed results, as the 30-year maturity US bond depicted a very high p-value, while for the 10-year bond, uniformity is rejected at a 5% level. For the UK bonds if a 10% level is considered then uniformity is rejected for all the maturities, however at a 5% level uniformity is not rejected for the 10-year maturity bond. The other government bonds presented more consistent results: Canada, China and Japan clearly rejected uniformity for all the maturities, most of them even at the 1% level.

However, there are some additional considerations and disclaimers for France and Germany, the countries for which uniformity was clearly not rejected, and for Japan, for which the p-values were extremely low derived for the unusual distribution of the Q-values. This can be derived from the fact that these three countries presented negative yields, for some consecutive periods, which were removed as mentioned in the methodology chapter. To meet this potential drawback, graphs for the distributions with the negative yields are also presented in the Appendix D.

As the government bonds, corporate bonds also shown diversity in the results. Focusing on the longer maturities' bonds, while the uniformity is rejected at a 10% level for the 30 and 10-year Citigroup bonds (being the 10-year way more significant with rejection at a 1% level), Shell bonds fail to reject uniformity. Regarding Pfizer bonds, the 10-year bond clearly rejects uniformity at a 1% level, and for Apple, results are not that significant, as only the largest maturity rejects uniformity but for a 10% level.

Table 1. Uniformity test results

BOND	Z-stat	p-value
CN_30Y	0.022	0.006***
CN_10Y	0.019	0.030**
CN_5Y	0.018	0.033**
CN_2Y	0.027	0.000***
CH_30Y	0.025	0.003***
CH_10Y	0.022	0.012**
CH_5Y	0.028	0.001***
CH_2Y	0.027	0.001***
DE_30Y	0.011	0.506
DE_10Y	0.015	0.208
DE_5Y	0.037	0.000***
DE_2Y	0.014	0.376
FR_30Y	0.011	0.424
FR_10Y	0.014	0.241
FR_5Y	0.042	0.000***
FR_2Y	0.017	0.163
JP_30Y	0.032	0.000***
JP_10Y	0.103	0.000***
JP_5Y	0.034	0.000***
JP_2Y	0.187	0.000***
UK_30Y	0.028	0.000***
UK_10Y	0.017	0.066*
UK_5Y	0.029	0.000***
UK_2Y	0.018	0.039**
US_30Y	0.010	0.556
US_10Y	0.021	0.011**
US_5Y	0.013	0.275
US_2Y	0.010	0.536
Apple_30Y	0.027	0.066*
Apple_10Y	0.023	0.160
Apple_5Y	0.081	0.000***
Apple_2Y	0.082	0.000***
Citigroup_30Y	0.025	0.087*
Citigroup_10Y	0.036	0.004***
Citigroup_5Y	0.037	0.002***
Citigroup_2Y	0.019	0.350

Pfizer_30Y	0.015	0.641
Pfizer_10Y	0.035	0.005***
Pfizer_5Y	0.016	0.534
Pfizer_2Y	0.034	0.007***
Shell_30Y	0.024	0.118
Shell_10Y	0.012	0.879
Shell_5Y	0.067	0.000***
Shell_2Y	0.053	0.000***

Table 1 shows the results of the Kolmogorov-Smirnov test for uniformity. Z-stat stands for the value of the test statistic, while p-value gives the marginal significance of this statistic. H0: uniformity, H1: non uniformity.

4.2. Barrier Tests

4.2.1. Barrier Proximity Test

Table 2 displays the results for the barrier proximity test. As mentioned in the description of each test, in the presence of psychological barriers one should expect β to be negative and significant, representing the lower frequency of closing yields in those Q-values. However, most of the government bonds exhibit non-significant results, which demonstrates that for these bonds, the frequency of closing yields in on each of the 3 cells centered on Q = 00 does not significantly differ from other Q-cells.
Nonetheless, there are some exceptions, for example, the 30-year China and Germany's government bond and the 10-year France's government bond were statistically significant at a 10% level for the first two bonds and at a 1% level for the latter one. But, in these cases, β is positive, which do not support the theory of lower frequency of Q-values at barrier points. Once again, France and Germany bonds are highlighted for not supporting the theory tested in the present study, which can be related to the fact that for several years of the sample period, these countries displayed very low yields, near 0%, even reaching negative yields for some periods, which could have increased the frequency of yields near the 3 cells in examination centered in Q=0. This is most likely the reason why β is positive and statistically significant.

Regarding corporate bonds, once again, similar conclusions can be derived as most of the beta estimates are not statistically significant, with p-values well above 0.05. This indicates lack of evidence of a significant impact of psychological barriers on yield changes.

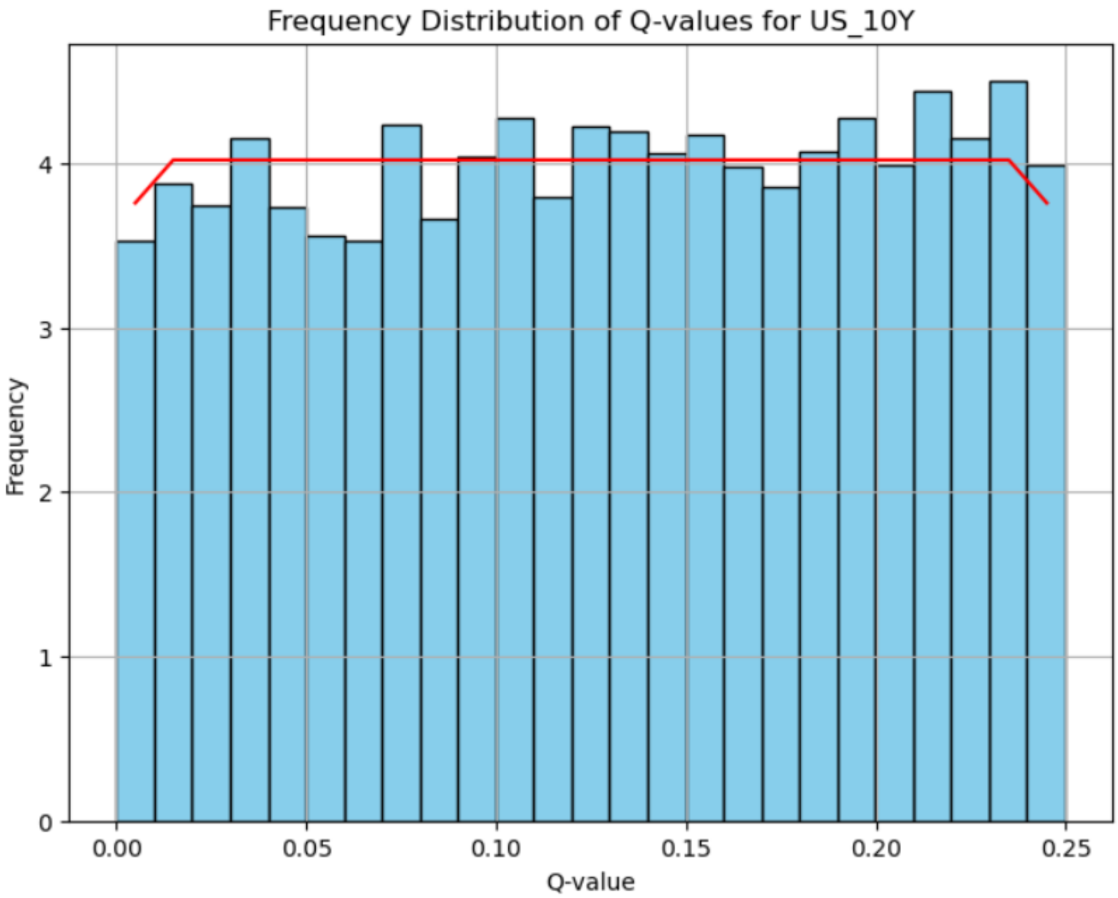
Table 2. Barrier Proximity results

BOND	β	p-value	R^2
CN_30Y	0.366	0.194	0.072
CN_10Y	0.253	0.303	0.046
CN_5Y	-0.024	0.929	0.0004
CN_2Y	0.009	0.978	$3.447e^{-05}$
CH_30Y	1.151	0.069*	0.136
CH_10Y	-0.026	0.968	$7.334e^{-05}$
CH_5Y	1.418	0.050**	0.156
CH_2Y	0.476	0.554	0.015
DE_30Y	0.532	0.057*	0.148
DE_10Y	0.126	0.591	0.013
DE_5Y	-0.311	0.397	0.031
DE_2Y	-0.185	0.548	0.016
FR_30Y	0.208	0.465	0.023
FR_10Y	0.629	0.006***	0.285
FR_5Y	0.540	0.282	0.050
FR_2Y	0.161	0.694	0.007
JP_30Y	-0.101	0.894	0.001
JP_10Y	1.019	0.138	0.093
JP_5Y	-0.454	0.365	0.036
JP_2Y	-0.742	0.583	0.013
UK_30Y	-0.089	0.767	0.004
UK_10Y	0.349	0.178	0.078
UK_5Y	0.123	0.643	0.010
UK_2Y	0.505	0.053*	0.153
US_30Y	-0.191	0.309	0.045
US_10Y	-0.262	0.192	0.073
US_5Y	-0.087	0.719	0.006
US_2Y	0.573	0.033**	0.183
Apple_30Y	0.330	0.336	0.040
Apple_10Y	-0.240	0.544	0.016
Apple_5Y	-0.193	0.758	0.004
Apple_2Y	-0.501	0.437	0.026
Citigroup_30Y	0.236	0.389	0.032
Citigroup_10Y	0.642	0.110	0.107
Citigroup_5Y	-0.645	0.089*	0.121
Citigroup_2Y	0.778	0.015**	0.229

Pfizer_30Y	0.261	0.359	0.037
Pfizer_10Y	0.213	0.537	0.017
Pfizer_5Y	-0.190	0.474	0.023
Pfizer_2Y	-0.592	0.103	0.111
Shell_30Y	0.568	0.085*	0.124
Shell_10Y	0.140	0.696	0.007
Shell_5Y	0.073	0.896	0.001
Shell_2Y	-0.309	0.450	0.025

Table 2 shows the results of the regression f(Q)=α+βD+ε, where f(Q) stands for the frequency of appearance of the Q values, D is a dummy variable that takes the value 1 when Q=0.00, Q=0.01 or Q=0.24 and 0 otherwise.

Figure 1. Frequency distribution of Q-values of the 10 years US government bond with the barrier proximity regression



The frequency distribution of Q-values for all the bonds with respective regression are presented in the Appendix E. The red line represents the regression f(Q)=α+βD+ε.

An important remark is related to the fact that the results of these tests may be sensitive to the chosen width for the barrier, which affects the construction of the dummy variable D. To investigate this possibility, an alternative and wider barrier was defined. So, in this new analysis, the new dummy would take the value 1 for the following Q-values: 0.00, 0.01, 0.02, 0.23 and 0.24.
All the results of the regression described by Equation 3.1 but now utilizing this alternative dummy variable definition are presented in Table 5 shown in Appendix A. The results are qualitatively similar to those reported in Table 2, with an important exception on the government bonds, the 30-year Japan's government bond now rejects the no barrier hypothesis at a 10% level.

Despite this one exception, the barrier proximity test results do not appear to be critically dependent on the first choice for barrier width.

4.2.2. Barrier Hump Test

Table 3 shows the results for the barrier hump test, which is meant to test the entire shape of the distribution of Q-values rather than just the frequencies for Q-cells in proximity to the Q=00 barriers. Assuming it should follow a hump-shape distribution, one could expect ϒ to be negative and significant in the presence of barriers.

This test is in line with the previous one, as most of the bonds exhibit non-significant gamma coefficients, which is an indicator of a no clear hump shape in the Q-value frequency distributions.
Nonetheless, there are some bonds that exhibit significant positive ϒ coefficients, as is the case for the 10-year France, Japan, and UK's government bonds. But all the mentioned bonds presented positive ϒ, which, once again, do not support the theory of lower frequency of Q-values at the extremes of the distribution.

Though there is one bond for which the negative ϒ coefficient rejects the no barriers null hypothesis at a 5% level. The bond in question is the 30-year US government bond. This result is in accordance with Burke (2001), which also found a statistically significant hump-shape in the frequency distributions for the Q-values for the same bond, however for a different sample period. While, the 10-year US government bond despite expressing a negative ϒ, has an extremely high p-value. A finding that is again similar to the one found in

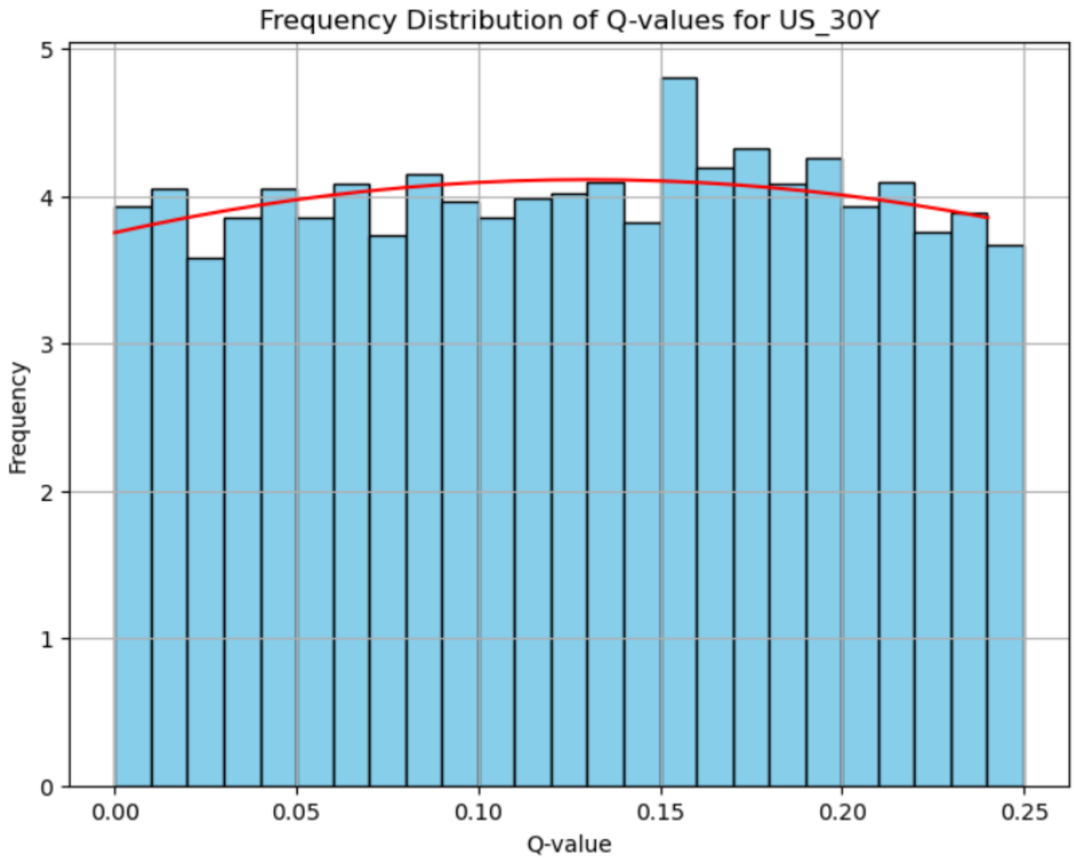
Table 3. Barrier hump test results

BOND	ϒ	p-value	R^2
CN_30Y	18.095	0.266	0.126
CN_10Y	1.619	0.910	0.072
CN_5Y	-8.314	0.608	0.029
CN_2Y	29.512	0.123	0.149
CH_30Y	22.803	0.556	0.037
CH_10Y	-41.698	0.273	0.057
CH_5Y	50.308	0.256	0.066
CH_2Y	-32.116	0.500	0.039
DE_30Y	-4.433	0.799	0.003
DE_10Y	-11.983	0.390	0.041
DE_5Y	-36.706	0.037**	0.430
DE_2Y	-13.027	0.477	0.025
FR_30Y	-5.288	0.756	0.018
FR_10Y	33.183	0.016**	0.245
FR_5Y	4.505	0.863	0.260
FR_2Y	9.392	0.697	0.033
JP_30Y	-68.212	0.121	0.111
JP_10Y	69.569	0.002***	0.786
JP_5Y	4.052	0.891	0.047
JP_2Y	-200.142	0.000***	0.717
UK_30Y	-21.080	0.175	0.282
UK_10Y	37.280	0.011**	0.264
UK_5Y	9.969	0.490	0.186
UK_2Y	46.042	0.001***	0.379
US_30Y	-21.300	0.048**	0.180
US_10Y	-6.630	0.501	0.357
US_5Y	-21.387	0.127	0.103
US_2Y	17.039	0.306	0.049
Apple_30Y	28.240	0.151	0.139
Apple_10Y	-5.812	0.801	0.064
Apple_5Y	-49.524	0.071*	0.506
Apple_2Y	-34.661	0.234	0.456
Citigroup_30Y	25.250	0.085*	0.267
Citigroup_10Y	24.841	0.261	0.223
Citigroup_5Y	-62.951	0.001***	0.491
Citigroup_2Y	27.643	0.164	0.098

Pfizer_30Y	-13.264	0.437	0.029
Pfizer_10Y	26.140	0.164	0.215
Pfizer_5Y	-18.565	0.235	0.069
Pfizer_2Y	-52.371	0.006***	0.389
Shell_30Y	27.967	0.130	0.223
Shell_10Y	-3.774	0.860	0.002
Shell_5Y	-44.602	0.098*	0.383
Shell_2Y	-30.333	0.074*	0.560

Table 3 shows the results of the regression $f(Q)=\alpha + \beta Q + \Upsilon Q^2 + \varepsilon$, where f(Q), the frequency of appearance of each Q values, is regressed on Q, the Q-value itself, and Q^2, its square.

Figure 2. Frequency distribution of Q-values of the 30 years US government bond with the barrier hump regression



The frequency distribution of Q-values for all the bonds with respective regression are presented in the Appendix F. The red line represents the regression $f(Q)=\alpha + \beta Q + \Upsilon Q^2 + \varepsilon$.

Burke (2001) as the author found that the ϒ estimate for the 30-year series is more statistically significant than is the one for the 10-year series.

Regarding the corporate bonds, essentially all longer maturities bonds do not show statistically significant results, and it is actually the shorter maturities ones that exhibit gamma estimates that are statistically significant even at a 1% level, as it is the case of the 5-year Citigroup and the 2-year Pfizer bonds.

4.3. Market Prediction Tests

Table 4 displays the results of the first market prediction tests. The first test uses a dummy variable to relate the one day ahead mean yield change to the current position of the yield in the quarter percent barrier interval. This test, called conditional mean test, as explained in chapter 3.2.5, is linked to two very crucial concepts, support and resistance levels. Consequentially, if the current yield is situated above a barrier, then the latter would act as support; while if the current yield is closer to the barrier but from above, then the barrier would act as a resistance, retarding upward moves. If the yield is at the center of the barrier, then one should expect a move away from the barrier, without any direction's preference.

For the vast majority of the government bonds, the beta estimates are very small, and the p-values are very high, which allows to conclude that there is no significant relationship between the current yield's position relative to the barrier and the next day's yield change. This suggests that the position of the yield in the quarter percent barrier interval does not provide meaningful predictive power for the next day's yield change.

There is only one government bond that reveals marginal significance, and it is the 10-year UK's government bond, for which the no predictive value null hypothesis is rejected at a 10% level. This could suggest some potential predictive power for the differenced yield series, however, even if that is the case, the beta estimate is still very low – approximately 0.00129.

Same findings were obtained for corporations: very small beta estimates and p-values extremely high, and so, no significant relationship can be established among current yield's position and the following day's yield change. The only rejection of the no predictive value null hypothesis occurs in the 10-year Pfizer bond, however, it is only a marginal significance at the 10% level – also, beta estimate is very low (approximately 0.0022).

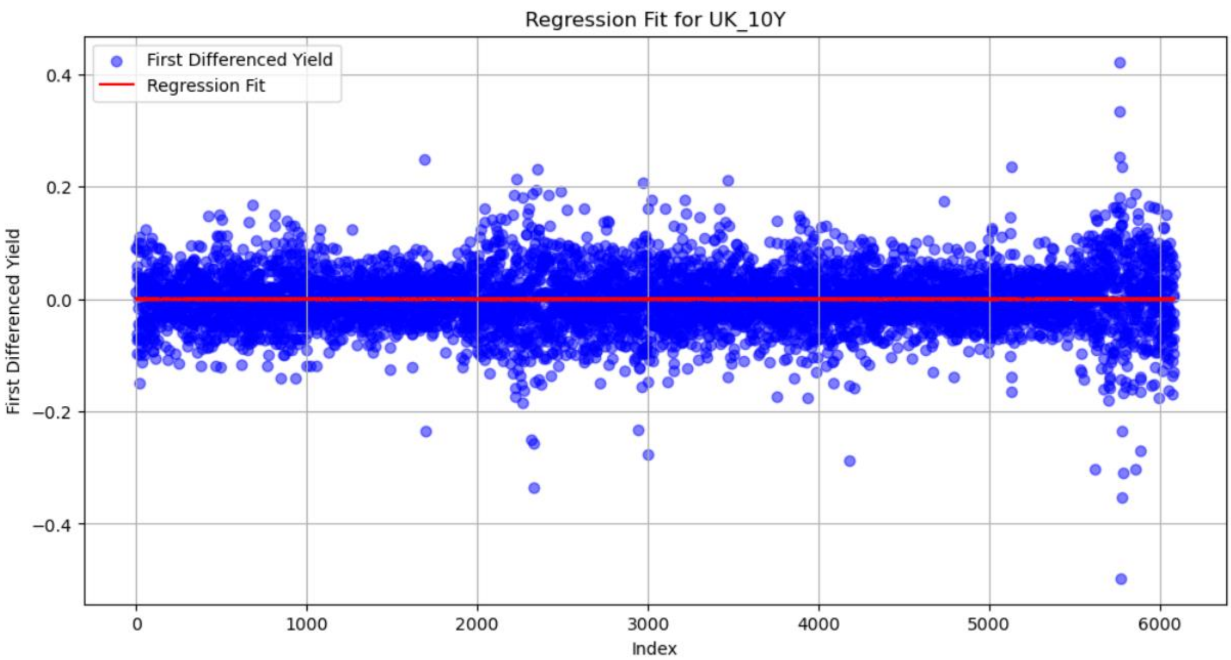
Table 4. Conditional mean test results

BOND	β	p-value	R^2
CN_30Y	0.006	0.285	0.0002
CN_10Y	$-7.949e^{-05}$	0.905	$2.379e^{-06}$
CN_5Y	$-8.744e^{-05}$	0.900	$2.622e^{-06}$
CN_2Y	-0.001	0.218	0.0002
CH_30Y	-0.0002	0.873	$4.855e^{-06}$
CH_10Y	$2.005e^{-05}$	0.978	$1.382e^{-07}$
CH_5Y	0.001	0.119	0.0004
CH_2Y	$1.579e^{-05}$	0.984	$7.438e^{-08}$
DE_30Y	-0.001	0.237	0.0002
DE_10Y	-0.001	0.365	0.0002
DE_5Y	$1.013e^{-05}$	0.990	$3.463e^{-08}$
DE_2Y	$-9.088e^{-05}$	0.914	$2.839e^{-06}$
FR_30Y	-0.0004	0.540	$6.106e^{-05}$
FR_10Y	0.001	0.361	0.0001
FR_5Y	-0.009	0.281	0.0002
FR_2Y	$8.036e^{-05}$	0.931	$1.769e^{-06}$
JP_30Y	0.0005	0.255	0.0002
JP_10Y	-0.0002	0.651	$3.772e^{-05}$
JP_5Y	-0.0004	0.318	0.0002
JP_2Y	-0.0001	0.614	$6.370e^{-05}$
UK_30Y	0.001	0.270	0.0002
UK_10Y	0.001	0.069*	0.001
UK_5Y	0.001	0.208	0.0003
UK_2Y	0.0004	0.719	$2.188e^{-05}$
US_30Y	$-1.370e^{-05}$	0.985	$6.007e^{-08}$
US_10Y	0.001	0.124	0.0004
US_5Y	-0.0005	0.572	$5.276e^{-05}$
US_2Y	-0.001	0.412	0.0001
Apple_30Y	-0.001	0.738	$4.895e^{-05}$
Apple_10Y	0.001	0.602	0.0001
Apple_5Y	0.001	0.568	0.0001
Apple_2Y	-0.003	0.091*	0.001
Citigroup_30Y	-0.002	0.225	0.001
Citigroup_10Y	0.001	0.530	0.0002
Citigroup_5Y	-0.001	0.360	0.0003
Citigroup_2Y	-0.001	0.781	$3.225e^{-05}$
Pfizer_30Y	-0.001	0.547	0.0001
Pfizer_10Y	0.002	0.083*	0.001

Pfizer_5Y	-0.001	0.317	0.0004
Pfizer_2Y	-0.003	0.083*	0.001
Shell_30Y	0.001	0.513	0.0002
Shell_10Y	0.0002	0.885	$8.601e^{-06}$
Shell_5Y	-0.001	0.507	0.0002
Shell_2Y	0.002	0.149	0.001

Table 4 shows the results of the regression $\Delta Y_{t+1} = a + \beta DM_t + \in$, where ΔY_{t+1} represents the one day mean yield change, DM_t is a dummy variable that takes the value -1 when Q belongs to the interval [0.13, 0.24[; 1 when Q is between the interval [0.01, 0.13[; or 0 if Q=0.00.

Figure 3. First differenced yield series of the 10 years UK bond with the regression of the first market prediction test – the conditional mean test



The first differenced yield series for other bonds with respective regression are presented in the Appendix G. The red line represents the regression $\Delta Y_{t+1} = a + \beta DM_t + \in$

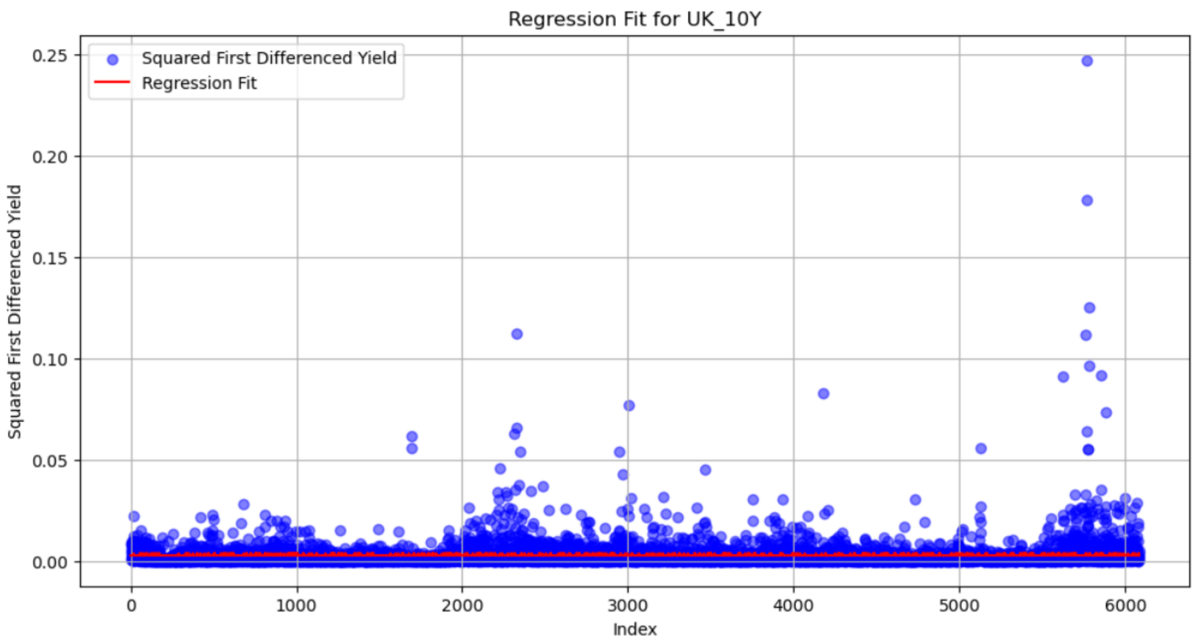
Table 5. Conditional volatility test results

BOND	β	p-value	R^2
CN_30Y	-0.0003	0.086*	0.0005
CN_10Y	-0.0001	0.540	$6.243e^{-05}$
CN_5Y	-0.0001	0.601	$4.531e^{-05}$
CN_2Y	$6.188e^{-05}$	0.858	$5.334e^{-06}$
CH_30Y	0.007	0.207	0.0003
CH_10Y	0.0002	0.773	$1.573e^{-05}$
CH_5Y	-0.001	0.176	0.0003
CH_2Y	0.001	0.188	0.0003
DE_30Y	$1.048e^{-05}$	0.956	$5.276e^{-07}$
DE_10Y	$4.250e^{-05}$	0.842	$7.414e^{-06}$
DE_5Y	$1.037e^{-05}$	0.977	$1.916e^{-07}$
DE_2Y	-0.0003	0.570	$7.836e^{-05}$
FR_30Y	0.0002	0.234	0.0002
FR_10Y	0.0004	0.047**	0.001
FR_5Y	0.0002	0.589	$5.999e^{-05}$
FR_2Y	0.001	0.223	0.0003
JP_30Y	0.0002	0.138	0.0004
JP_10Y	-0.0002	0.002***	0.002
JP_5Y	-0.0002	0.068*	0.001
JP_2Y	$-4.556e^{-05}$	0.430	0.0002
UK_30Y	$9.118e^{-05}$	0.903	$2.444e^{-06}$
UK_10Y	0.001	0.002***	0.002
UK_5Y	-0.0003	0.499	$7.678e^{-05}$
UK_2Y	-0.002	0.716	$2.243e^{-05}$
US_30Y	-0.0002	0.577	$5.146e^{-05}$
US_10Y	0.0001	0.741	$1.799e^{-05}$
US_5Y	0.0003	0.427	0.0001
US_2Y	-0.0003	0.543	$6.093e^{-05}$
Apple_30Y	0..0004	0.811	$2.494e^{-05}$
Apple_10Y	-0.001	0.176	0.001
Apple_5Y	0.017	0.007***	0.003
Apple_2Y	-0.006	0.654	$8.787e^{-05}$
Citigroup_30Y	-0.003	0.289	0.0005
Citigroup_10Y	-0.003	0.543	0.0001
Citigroup_5Y	-0.001	0.634	$9.456e^{-05}$
Citigroup_2Y	-0.005	0.408	0.0003

Pfizer_30Y	-0.001	0.731	$4.879e^{-05}$
Pfizer_10Y	0.0005	0.391	0.0003
Pfizer_5Y	0.0002	0.766	$3.657e^{-05}$
Pfizer_2Y	0.0001	0.978	$2.995e^{-07}$
Shell_30Y	-0.002	0.452	0.0002
Shell_10Y	-0.001	0.417	0.003
Shell_5Y	-0.001	0.367	0.0003
Shell_2Y	-0.002	0.203	0.001

Table 5 shows the results of the regression $(\Delta Y_{t+1})^2 = a + \beta DV_t + \in$, where $(\Delta Y_{t+1})^2$ represents the one day mean yield change squared, DV_t is a dummy variable that takes the value 1 when Q=0.00, Q=0.01 or Q=0.24 and 0 otherwise.

Figure 4. First differenced yield series of the 10 years UK bond with the regression of the second market prediction test – the conditional volatility test



The first differenced yield series for other bonds with respective regression are presented in the Appendix G. The red line represents the regression $(\Delta Y_{t+1})^2 = a + \beta DV_t + \in$

The empirical results from this test are the same as the ones in Burke (2001), as the author did also find insignificant values in forecasting the conditional mean of the differenced yield series.

In his study, Burke (2001) proposed some intuitive potential explanations for these findings, which essentially were based on the idea that there are multiples ways a series could avoid the barrier on the next move. According to the author, the series could: "move upward by a small amount and remain below the barrier; move upward by a large amount and pass through the barrier; move down and away from the barrier" (Burke, 2001, p. 27). All of these possibilities would make the barrier's effect on yield changes extremely hard to predict.

The second market prediction test is the conditional volatility prediction test. Table 5 shows its results. In this test the squared of the subsequent day's yield change was regressed on a dummy that reflects if the current yield is inside the narrow barrier region.

Most of the government and corporate bonds exhibit high p-values and low R-squared values, which shows the lack of significant predictive power of the current yield's position within the barrier region for future volatility. Once again, these results are the same as the ones in Burke (2001).

There are, however, some exceptions with significant results. The 10-year France, Japan and UK's government bonds show significant beta estimates with relatively low p-values, suggesting some predictive relationship. However, the low R-squared values imply that the relationship, while statistically significant, still explains only a small fraction of the variability in yield changes.

In regressions unreported in the present study, several different versions of DVt were tried, considering wider barrier region, but similar results were obtained.

5. Conclusion

Market efficiency is one of the most study concept in both economics and finance, as it ensures that prices reflect all available information, which is essential for fair pricing and informed investment decisions. For investors, an efficient market offers confidence that securities are properly priced, which allows them to effectively allocate resources. By investigating potential anomalies, such as psychological barriers, this study contributes to the broader understanding of market dynamics and analyses strategies that can improve investment performance and market stability.

The behaviour and potential significant patterns near specific thresholds of bond yields was analysed, for not only government but also for corporate bonds. Data ranged from 2000 until 2023, and for each bond examined, four different maturities were considered.

Following the methodology of the most relevant study made on this specific market – Burke (2001) – this study provides new evidence, as a more diverse selection of bonds is made available. The countries selected were USA, Canada, China, Germany, France, UK and Japan, while the corporate bonds were Apple, Pfizer, Shell and Citigroup.

Despite the uniformity in the distribution is rejected for some of the bonds, as it is the case of Canada, China, Japan, Citigroup, among others, barrier tests show no consistent sign of psychological barriers around integer multiples of 0.25% for any yield series.

Furthermore, an examination of the yield series to determine whether the hypothesized barriers lead to any form of predictability in the series is also conducted. Through market prediction tests, it is, however, concluded that barrier effects do not lead to significant predictable influences in the conditional mean or volatility of the yield series. A finding in line with the one of Burke (2001).

Overall, the findings of this study are significantly different and much less consistent that what previous studies found, especially Burke (2001) in which significant barrier effects at integer multiples of 0.25% for the 30-year and 10-year bond yield series were found. Results are quite diverse but only slightly significant with no relevant pattern found. A possible explanation for this occurrence may be related to one of the fundamental principles of the Efficient Market Hypothesis (EMH) – any known market anomaly is quickly arbitraged away by market participants, so once Burke documented such anomaly in the bond market, it is

plausible that traders adjusted their strategies scattering these effects away. The increased awareness may have led to the dissipation of the barrier effects over time.
Regarding the no predictable effects in the conditional mean or conditional volatility results, it can be explained, as explain in chapter 4.3, with the diversity of possible ways a series possess to avoid a nearby barrier during the next move.

Future research could extend the analysis by incorporating a broader range of bonds, especially in the corporation realm, since this study only analyse four of them. Also, the development of a methodology to accommodate negative yields may be interesting. Another curious path future studies could take would be to perform the analysis in a specific time frames such as the 2008 crisis or during the Covid-19 lockdown, periods in which psychological barriers may have had an additional relevance.

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Appendices

Appendix A - Descriptive Statistics

Table 6. Summary Statistics for Yield Series of Government Bonds

Bond	N	Mean	Std. Dev.	Skew.	Kurt.	Min.	Max.
CH_2Y	5307	2.7292	0.6339	0.1360	-0.4914	-0.6000	0.6690
CH_5Y	5307	3.1153	0.5904	0.5641	-0.4405	-0.4060	0.3800
CH_10Y	5307	3.4649	0.5393	0.5850	-0.3136	-0.6470	0.5110
CH_30Y	5307	3.8464	0.5331	0.0744	-0.4730	-2.1210	1.9760
CN_2Y	6012	2.3164	1.5379	0.5759	-0.6739	-0.4320	0.3790
CN_5Y	6034	2.6924	1.5022	0.3870	-0.7974	-0.2910	0.3040
CN_10Y	6013	3.1129	1.4673	0.2567	-0.9827	-0.2510	0.2540
CN_30Y	6007	3.4817	1.3759	0.2493	-1.0801	-0.2510	0.2390
DE_2Y	6150	1.4092	1.8451	0.3488	-1.3047	-0.5390	0.2920
DE_5Y	6150	1.7852	1.8690	0.1417	-1.4037	-0.4300	0.2700
DE_10Y	6150	2.3222	1.8268	-0.0440	-1.3645	-0.3360	0.2010
DE_30Y	6150	2.8705	1.7858	-0.1060	-1.2968	-0.3000	0.2320
FR_2Y	6167	1.4929	1.8178	0.3413	-1.2810	-0.6810	0.7780
FR_5Y	6167	1.9804	1.8039	0.0509	-1.3480	-0.3990	0.3170
FR_10Y	6166	2.6351	1.7231	-0.1959	-1.2587	-0.3050	0.2470
FR_30Y	6167	3.2864	1.5540	-0.2614	-1.1160	-0.2570	0.3290
JP_2Y	5900	0.1309	0.2873	1.2101	1.0512	-0.1170	0.1650
JP_5Y	5900	0.3712	0.4466	0.6381	-0.4543	-0.1240	0.1900
JP_10Y	5899	0.8394	0.6375	-0.0576	-1.4147	-0.1680	0.2250
JP_30Y	5900	1.6658	0.7130	-0.4542	-1.1252	-0.2600	0.2150
UK_2Y	6087	2.3236	2.0902	0.3977	-1.5281	-1.9130	2.2420
UK_5Y	6087	2.6940	1.8735	0.1707	-1.5204	-0.4160	0.5010
UK_10Y	6086	3.0714	1.6129	-0.1815	-1.4151	-0.4970	0.4220
UK_30Y	6087	3.3930	1.2932	-0.6446	-1.0159	-1.0520	0.4960
US_2Y	6075	2.0993	1.7555	0.7613	-0.5298	-0.5690	0.5203
US_5Y	6071	2.6529	1.4974	0.5101	-0.5266	-0.4597	0.5034
US_10Y	6065	3.2302	1.3168	0.2036	-0.6905	-0.4702	0.3519
US_30Y	6053	3.8300	1.1775	-0.0610	-0.9006	-0.3554	0.2560

Table 7. Summary Statistics for Yield Series of Corporate Bonds

Bond	N	Mean	Std. Dev.	Skew.	Kurt.	Min.	Max.
Apple_2Y	2289	1.9651	1.4129	0.8784	-0.2261	0.2558	5.5141
Apple_5Y	2289	2.5130	1.1079	0.5013	-0.4062	0.6649	5.4540
Apple_10Y	2289	3.1935	0.9061	-0.0967	-0.4653	1.2295	5.5461
Apple_30Y	2289	4.0769	0.7850	-0.4305	-0.6866	2.2338	5.9972
Citigroup_2Y	2407	2.39168	1.5130	0.9545	0.1972	0.3295	6.3980
Citigroup_5Y	2407	3.1243	1.2003	0.6945	-0.1629	1.1683	6.2865
Citigroup_10Y	2407	4.25296	0.9247	0.4228	-0.1895	2.5173	6.8982
Citigroup_30Y	2407	4.3789	0.9257	0.2055	-0.1770	2.4707	7.1837
Pfizer_2Y	2431	1.97166	1.4038	1.0088	0.0997	0.2498	5.6804
Pfizer_5Y	2431	2.59017	1.1089	0.6572	-0.0406	0.7782	5.7447
Pfizer_10Y	2431	3.43797	0.9428	0.1776	-0.1674	1.4955	6.1917
Pfizer_30Y	2429	3.84756	0.7154	0.3969	0.2172	2.3105	6.3028
Shell_2Y	2422	2.06929	1.3961	0.8388	-0.1834	0.2634	5.5895
Shell_5Y	2422	2.64576	1.1109	0.5652	-0.1957	0.7332	5.6649
Shell_10Y	2422	3.42428	0.9203	0.4369	-0.0734	1.6003	6.1725
Shell_30Y	2421	3.95665	0.7062	-0.0845	-0.7029	2.4376	5.9087

Table 8. Summary Statistics for Differenced Yield Series of Government Bonds

Bond	N	Mean	Std. Dev.	Skew.	Kurt.	Min.	Max.
CH_2Y	5306	0.0001	0.0551	0.1348	16.4972	-0.6000	0.6690
CH_5Y	5306	0.0001	0.0478	-0.0407	11.4666	-0.4060	0.3800
CH_10Y	5306	-0.0001	0.0517	-0.4023	22.1412	-0.6470	0.5110
CH_30Y	5306	0.0000	0.1049	-1.1054	138.0815	-2.1210	1.9760
CN_2Y	6011	-0.0003	0.0500	0.0219	6.2162	-0.4320	0.3790
CN_5Y	6033	-0.0005	0.0518	0.0563	2.7022	-0.2910	0.3040
CN_10Y	6012	-0.0005	0.0493	0.0649	1.4399	-0.2510	0.2540
CN_30Y	6006	-0.0005	0.0405	0.0438	1.8547	-0.2510	0.2390
DE_2Y	6149	-0.0003	0.0440	-0.2469	9.7019	-0.5390	0.2920
DE_5Y	6149	-0.0005	0.0468	-0.0580	4.3410	-0.4300	0.2700
DE_10Y	6148	-0.0006	0.0435	-0.0327	2.7594	-0.3360	0.2010
DE_30Y	6149	-0.0006	0.0451	0.0363	2.1425	-0.3000	0.2320
FR_2Y	6166	-0.0003	0.0496	0.3925	23.7780	-0.6810	0.7780
FR_5Y	6166	-0.0004	0.0492	0.0577	4.5436	-0.3990	0.3170
FR_10Y	6165	-0.0005	0.0456	-0.0014	2.7786	-0.3050	0.2470
FR_30Y	6166	-0.0005	0.0444	0.1301	2.5219	-0.2570	0.3290
JP_2Y	5899	-0.0001	0.0134	0.5631	16.1871	-0.1170	0.1650
JP_5Y	5899	-0.0001	0.0213	0.5034	7.0948	-0.1240	0.1900
JP_10Y	5898	-0.0002	0.0242	0.4507	5.8153	-0.1680	0.2250
JP_30Y	5899	-0.0001	0.0300	-0.0717	7.1795	-0.2600	0.2150
UK_2Y	6086	-0.0004	0.0709	3.0749	309.6063	-1.9130	2.2420
UK_5Y	6086	-0.0004	0.0524	0.2165	6.7312	-0.4160	0.5010
UK_10Y	6085	-0.0004	0.0530	-0.1196	4.5809	-0.4970	0.4220
UK_30Y	6086	-0.0001	0.0490	-1.4409	40.2674	-1.0520	0.4960
US_2Y	6074	-0.0003	0.0541	-0.3134	9.8887	-0.5690	0.5203
US_5Y	6070	-0.0004	0.0611	-0.0335	3.5954	-0.4597	0.5034
US_10Y	6064	-0.0004	0.0583	0.0156	2.3697	-0.4702	0.3519
US_30Y	6052	-0.0004	0.0537	-0.0071	2.1559	-0.3554	0.2560

Table 9. Summary Statistics for Differenced Yield Series of Corporate Bonds

Bond	N	Mean	Std. Dev.	Skew.	Min.	Max.
Apple_2Y	2288	0.0017	0.0908	0.4036	-2.3688	2.4367
Apple_5Y	2288	0.0009	0.0751	0.7745	-1.5675	1.6713
Apple_10Y	2288	0.0003	0.0650	0.1192	-0.4994	0.6289
Apple_30Y	2288	0.0000	0.0910	0.2103	-0.6270	0.6759
Citigroup_2Y	2406	0.0017	0.0843	0.6203	-1.5836	1.6114
Citigroup_5Y	2406	0.0008	0.0685	-0.2874	-0.9473	0.8474
Citigroup_10Y	2406	0.0003	0.0834	4.2615	-1.1057	1.6753
Citigroup_30Y	2406	-0.0001	0.0905	-0.7278	-1.0016	0.7210
Pfizer_2Y	2430	0.0016	0.0688	1.3473	-1.2025	1.4152
Pfizer_5Y	2430	0.0009	0.0606	-0.0766	-0.3006	0.3185
Pfizer_10Y	2430	0.0003	0.0608	-0.0234	-0.2844	0.2867
Pfizer_30Y	2428	0.0002	0.0847	0.0796	-0.7118	0.7933
Shell_2Y	2421	0.0016	0.0655	0.5917	-0.6173	0.7365
Shell_5Y	2421	0.0009	0.0621	0.4729	-0.3845	0.6753
Shell_10Y	2421	0.0004	0.0676	-1.1693	-0.8901	0.4432
Shell_30Y	2420	0.0001	0.0875	0.7538	-0.8588	1.2166

Table 10: Barrier proximity results – wider barrier

BOND	β	p-value	R^2
CN_30Y	0.103	0.625	0.011
CN_10Y	-0.060	0.744	0.005
CN_5Y	-0.249	0.213	0.067
CN_2Y	0.035	0.888	0.001
CH_30Y	0.280	0.564	0.015
CH_10Y	-0.578	0.218	0.065
CH_5Y	0.302	0.588	0.013
CH_2Y	-0.517	0.383	0.033
DE_30Y	0.133	0.537	0.017
DE_10Y	-0.128	0.459	0.024
DE_5Y	-0.320	0.235	0.061
DE_2Y	-0.253	0.262	0.054
FR_30Y	0.165	0.433	0.027
FR_10Y	0.387	0.026	0.197
FR_5Y	-0.101	0.789	0.003
FR_2Y	0.009	0.975	$4.321e^{-5}$
JP_30Y	-1.019	0.059*	0.147
JP_10Y	0.629	0.219	0.065
JP_5Y	-0.376	0.310	0.045
JP_2Y	-0.917	0.356	0.037
UK_30Y	-0.269	0.220	0.065
UK_10Y	0.260	0.174	0.079
UK_5Y	-0.065	0.740	0.005
UK_2Y	0.427	0.025**	0.200
US_30Y	-0.155	0.264	0.054
US_10Y	-0.036	0.810	0.003
US_5Y	-0.105	0.555	0.015
US_2Y	0.392	0.050**	0.157
Apple_30Y	0.361	0.149	0.088
Apple_10Y	0.049	0.868	0.001
Apple_5Y	-0.432	0.347	0.039
Apple_2Y	-0.419	0.379	0.034
Citigroup_30Y	0.233	0.246	0.058
Citigroup_10Y	0.345	0.252	0.057
Citigroup_5Y	-0.459	0.103	0.112
Citigroup_2Y	0.505	0.036**	0.177

Pfizer_30Y	-0.045	0.834	0.002
Pfizer_10Y	0.282	0.264	0.054
Pfizer_5Y	-0.171	0.382	0.033
Pfizer_2Y	-0.697	0.006***	0.282
Shell_30Y	0.524	0.028**	0.192
Shell_10Y	-0.031	0.907	0.001
Shell_5Y	-0.461	0.256	0.056
Shell_2Y	-0.375	0.210	0.067

Table 10 shows the results of the regression $f(Q)=\alpha+\beta D+\varepsilon$, where $f(Q)$ stands for the frequency of appearance of the Q values, D is a dummy variable that takes the value 1 when Q=0.00, Q=0.01, Q=0.02, Q=0.23 or Q=0.24 and 0 otherwise.

Appendix B – Yield and First Differenced Yield Series

Figure 5. United States Bond Yield Series

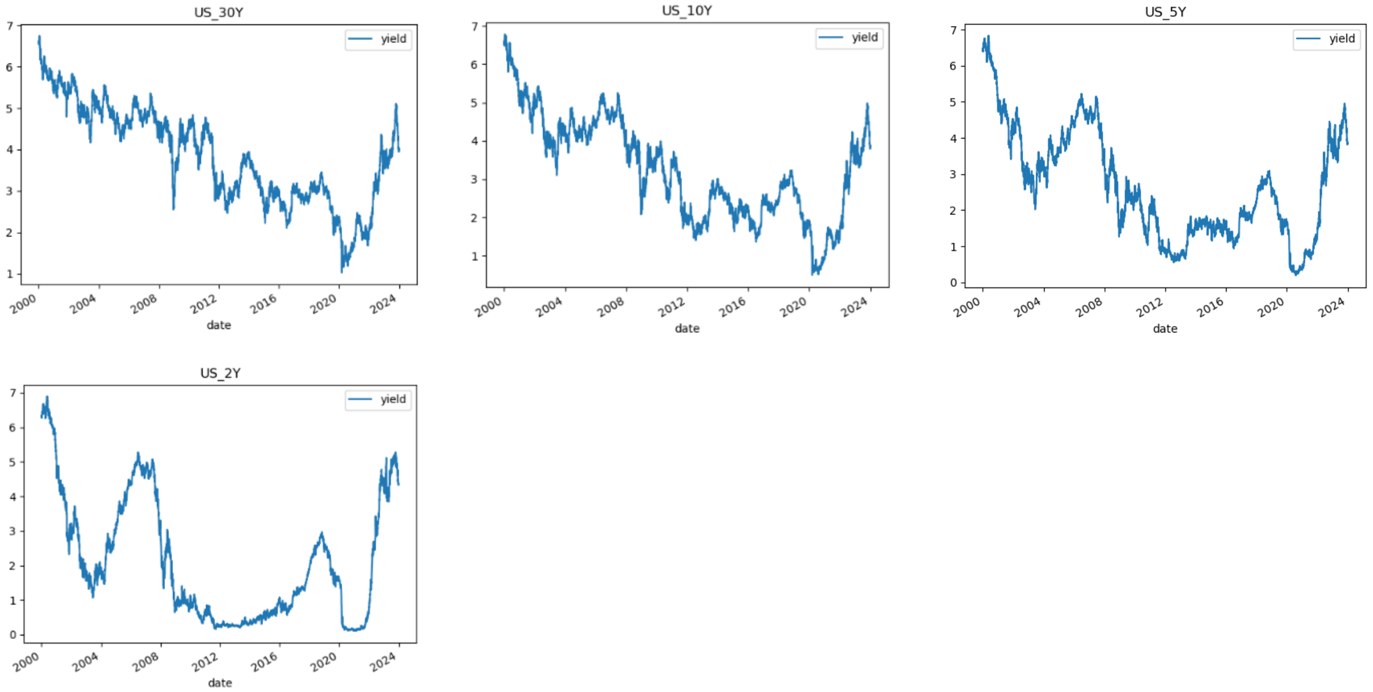


Figure 6. China Bond Yield Series

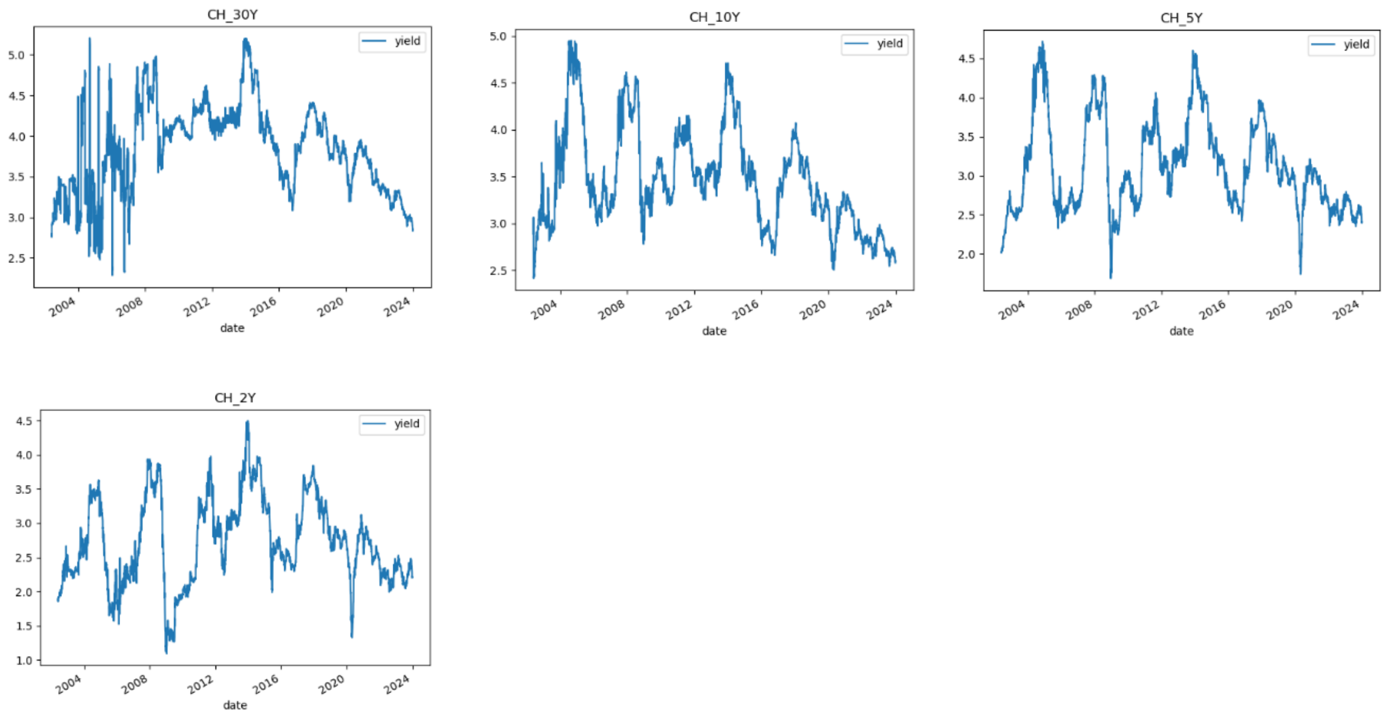


Figure 7. Canada Bond Yield Series

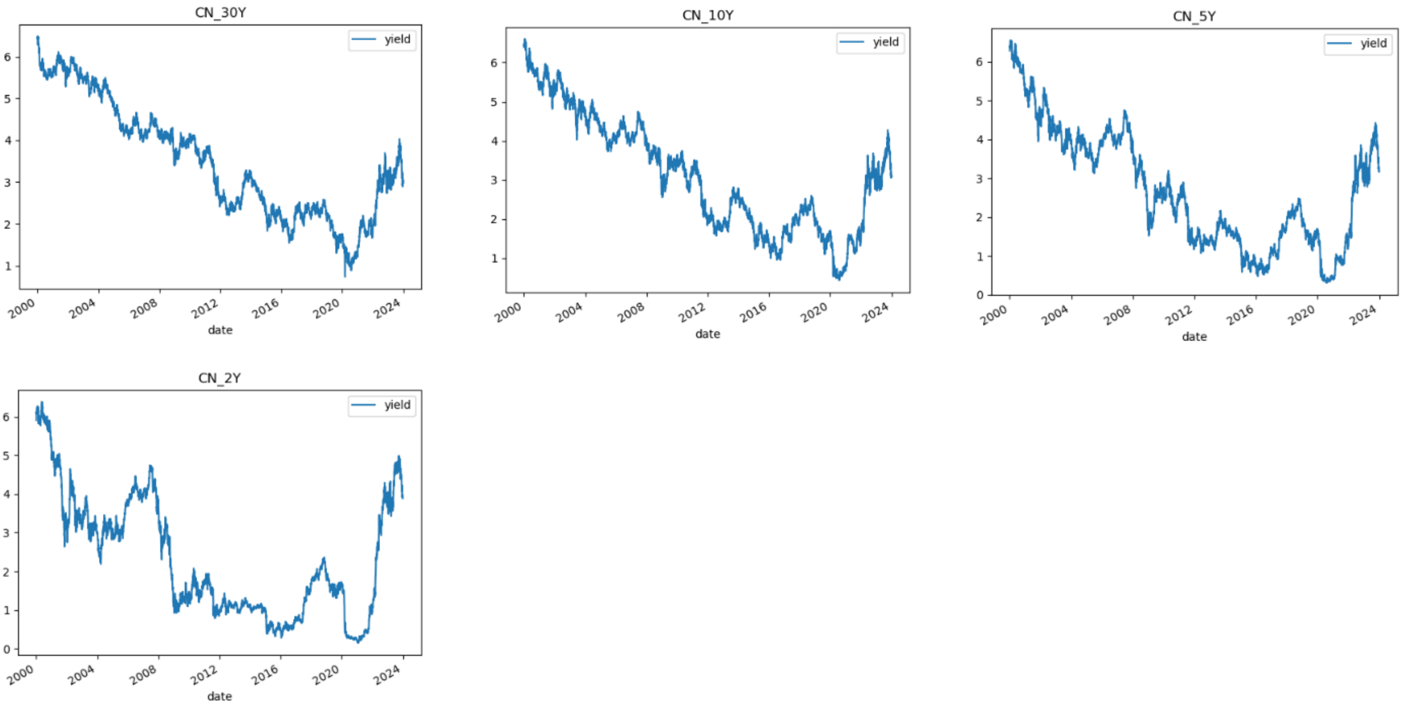


Figure 8. Germany Bond Yield Series

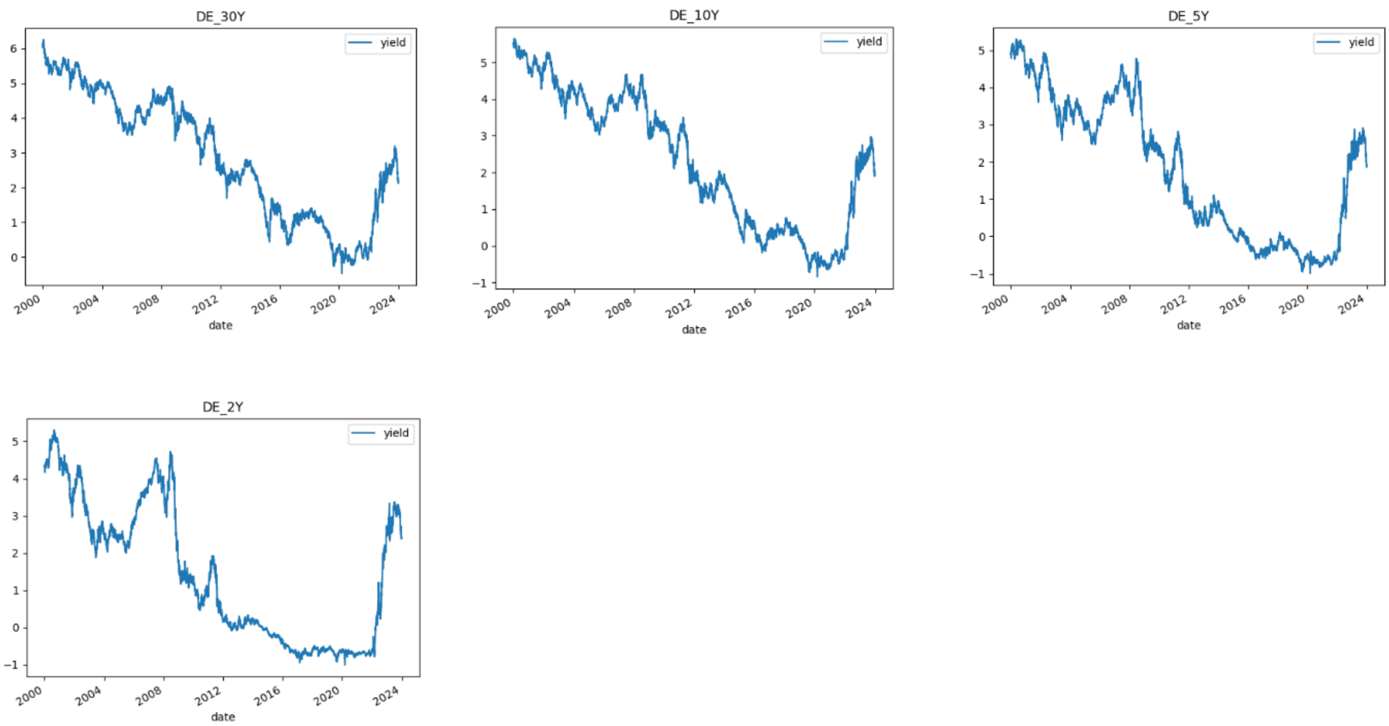


Figure 9. France Bond Yield Series

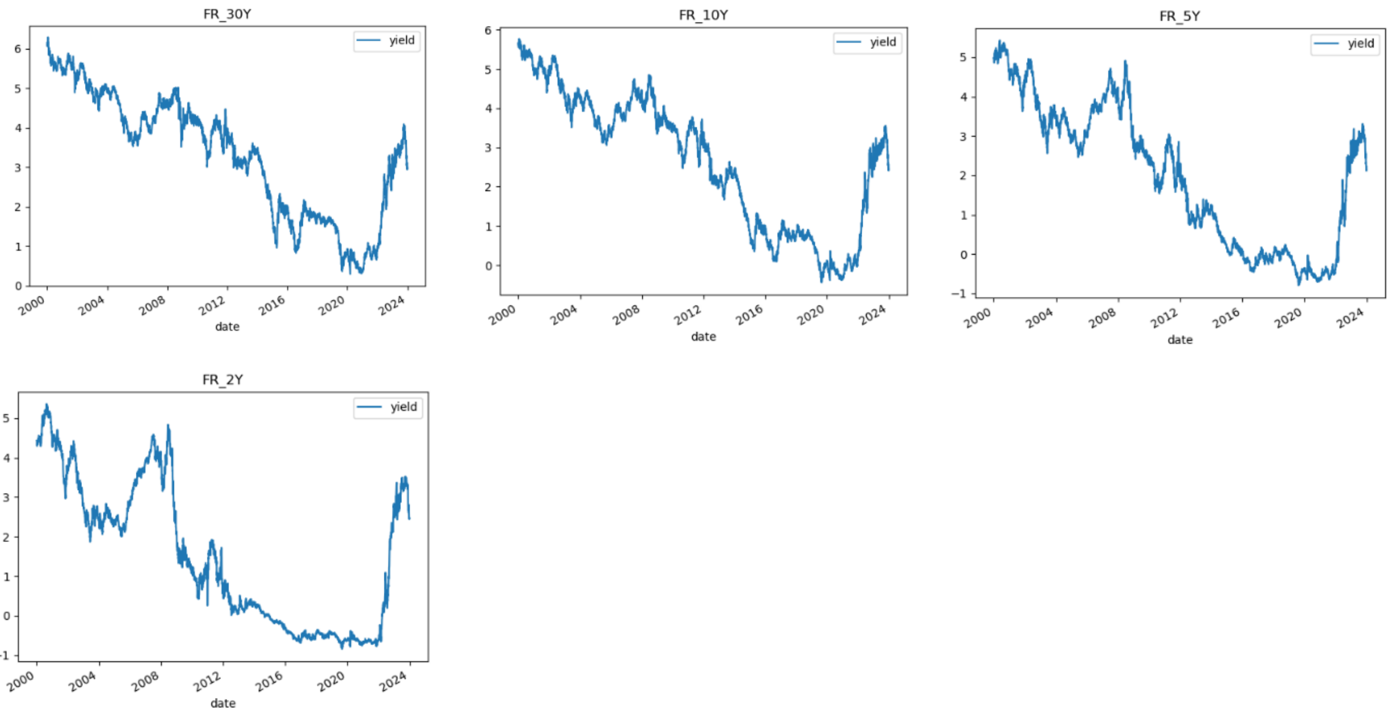


Figure 10. Japan Bond Yield Series

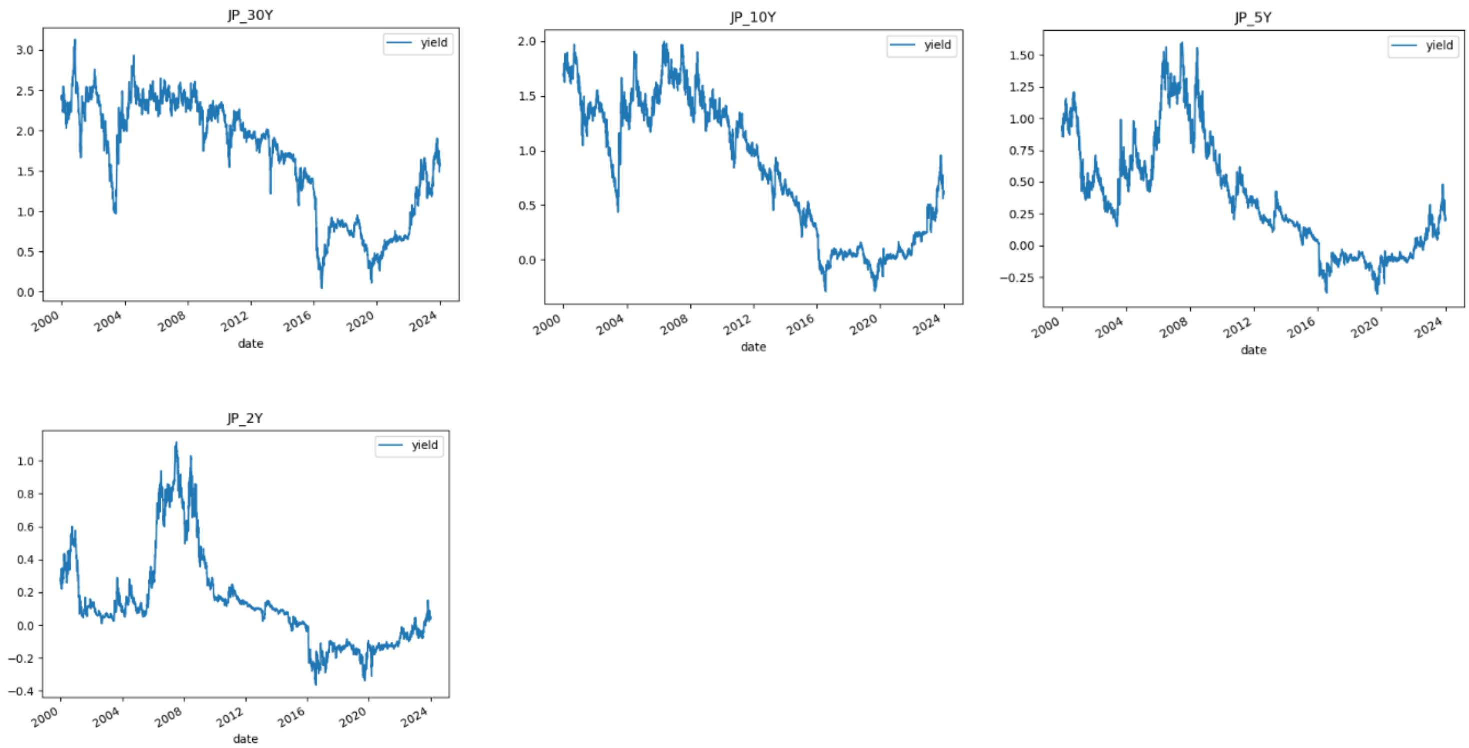


Figure 11. UK Bond Yield Series

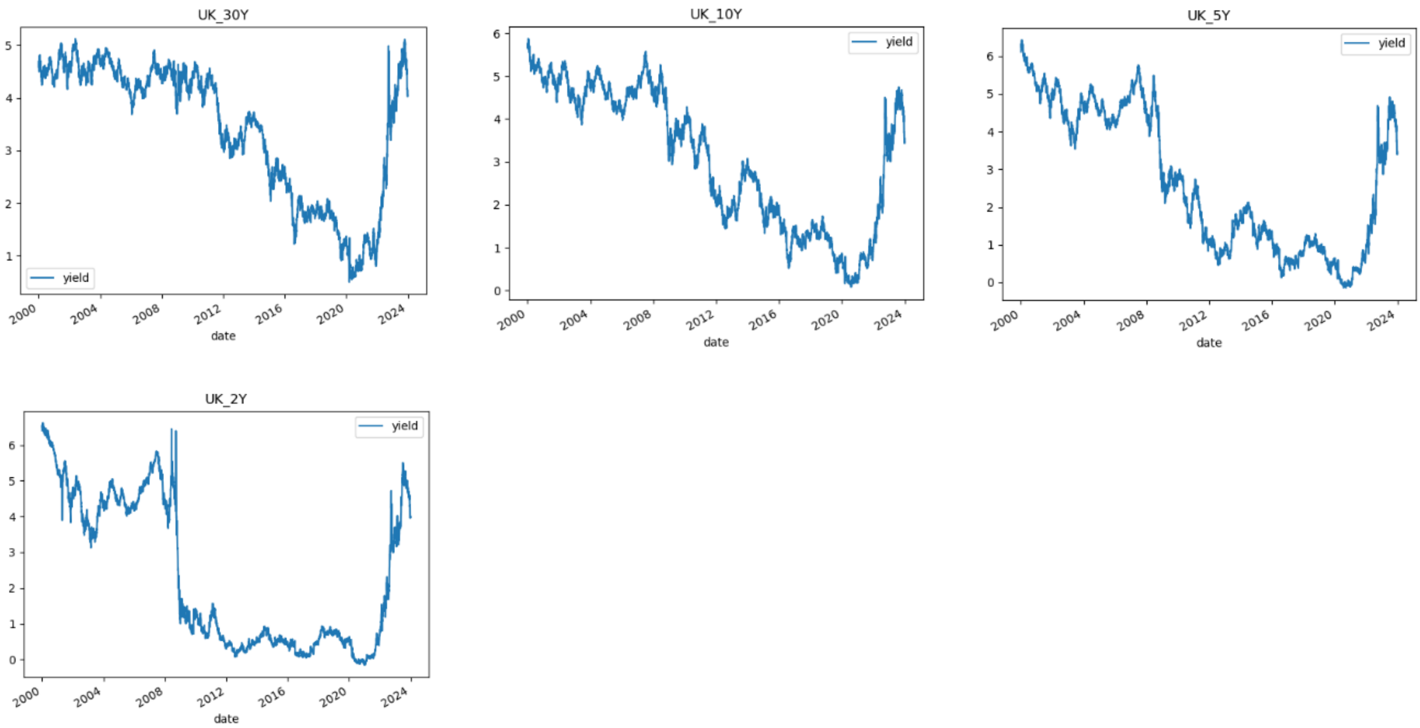


Figure 12. Apple Bond Yield Series

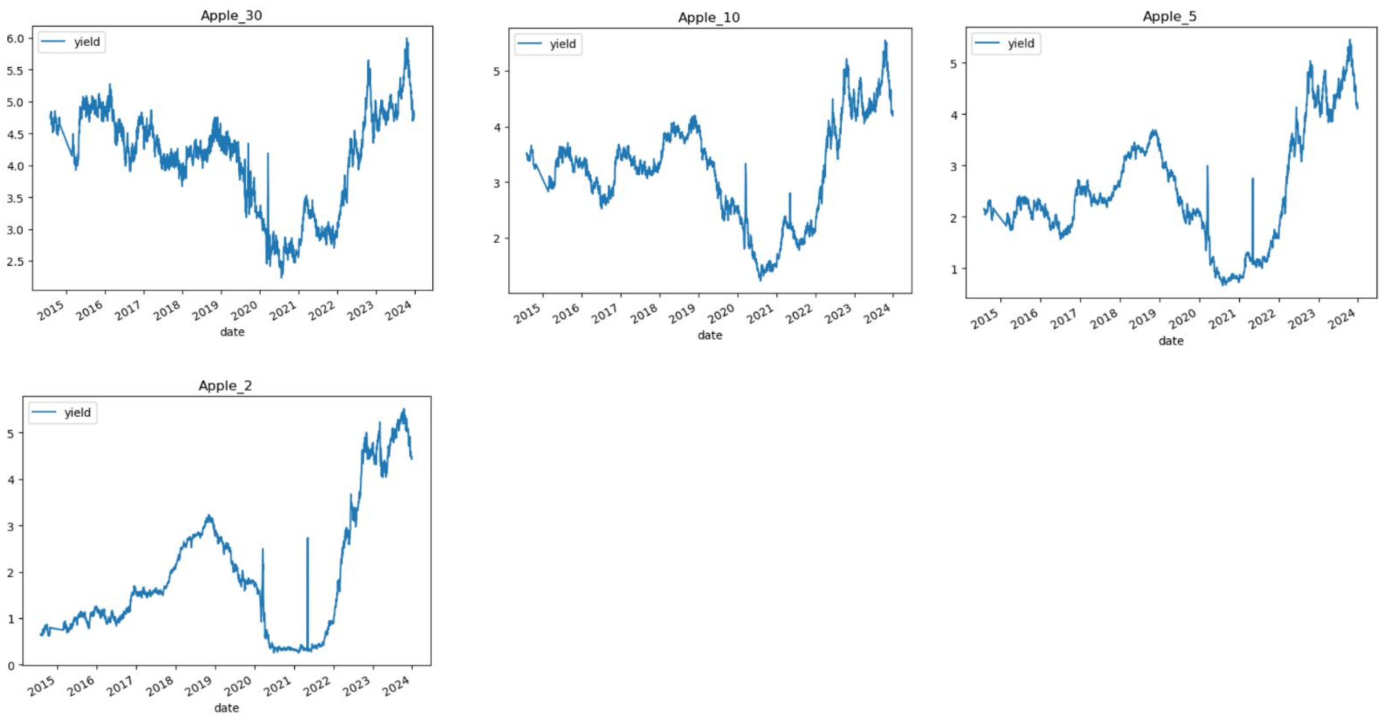


Figure 13. Citigroup Bond Yield Series

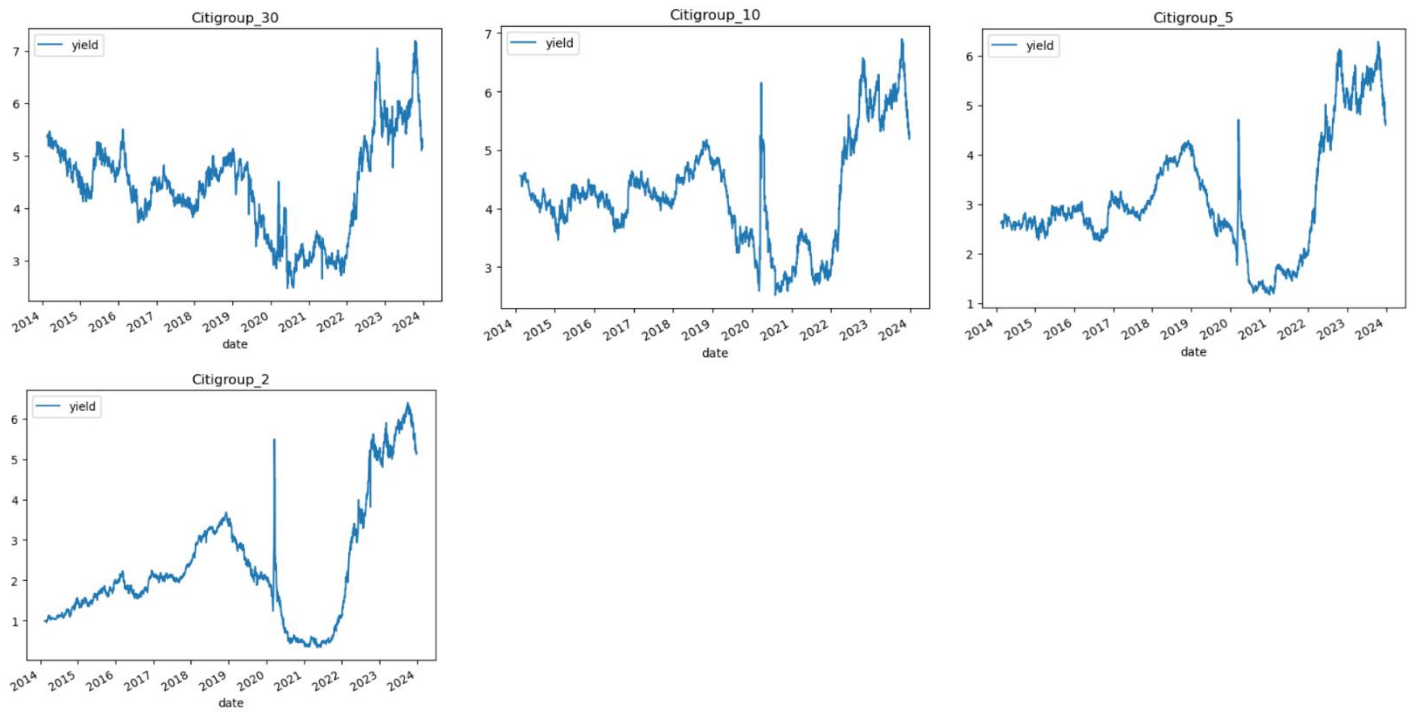


Figure 14. Pfizer Bond Yield Series

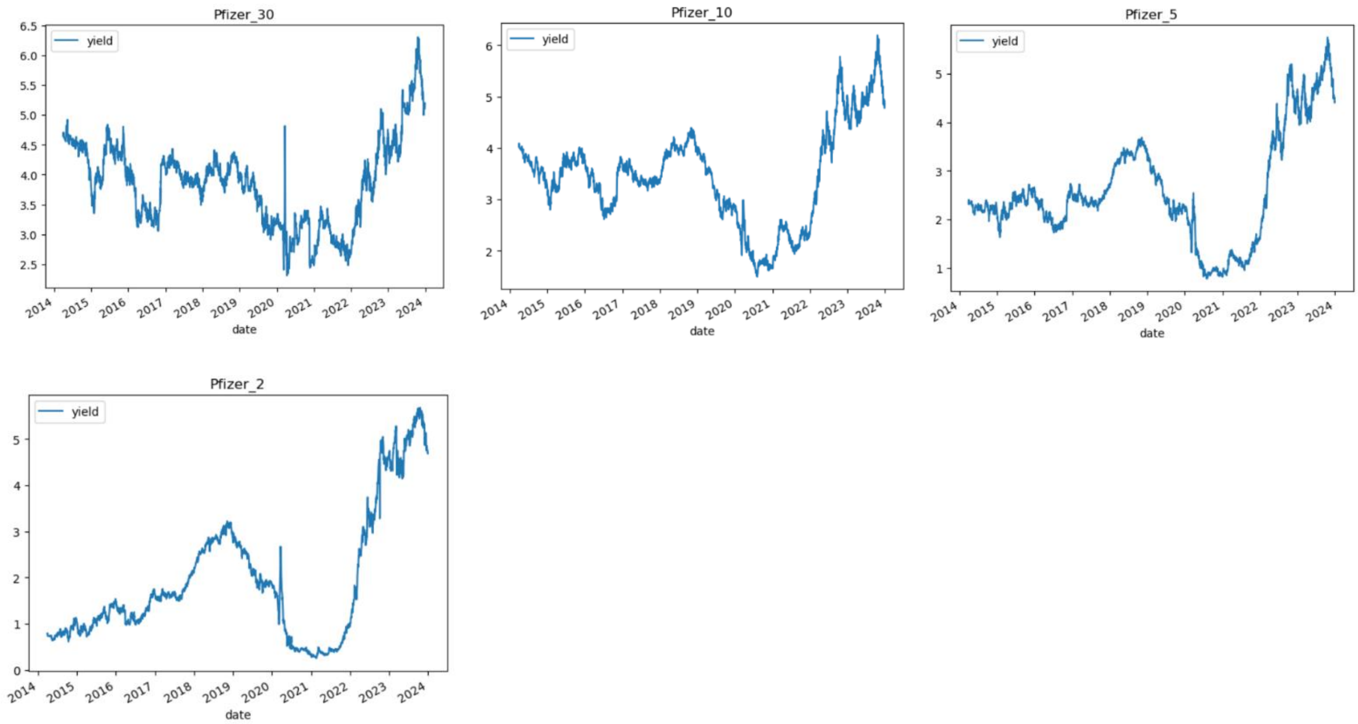


Figure 15. Shell Bond Yield Series

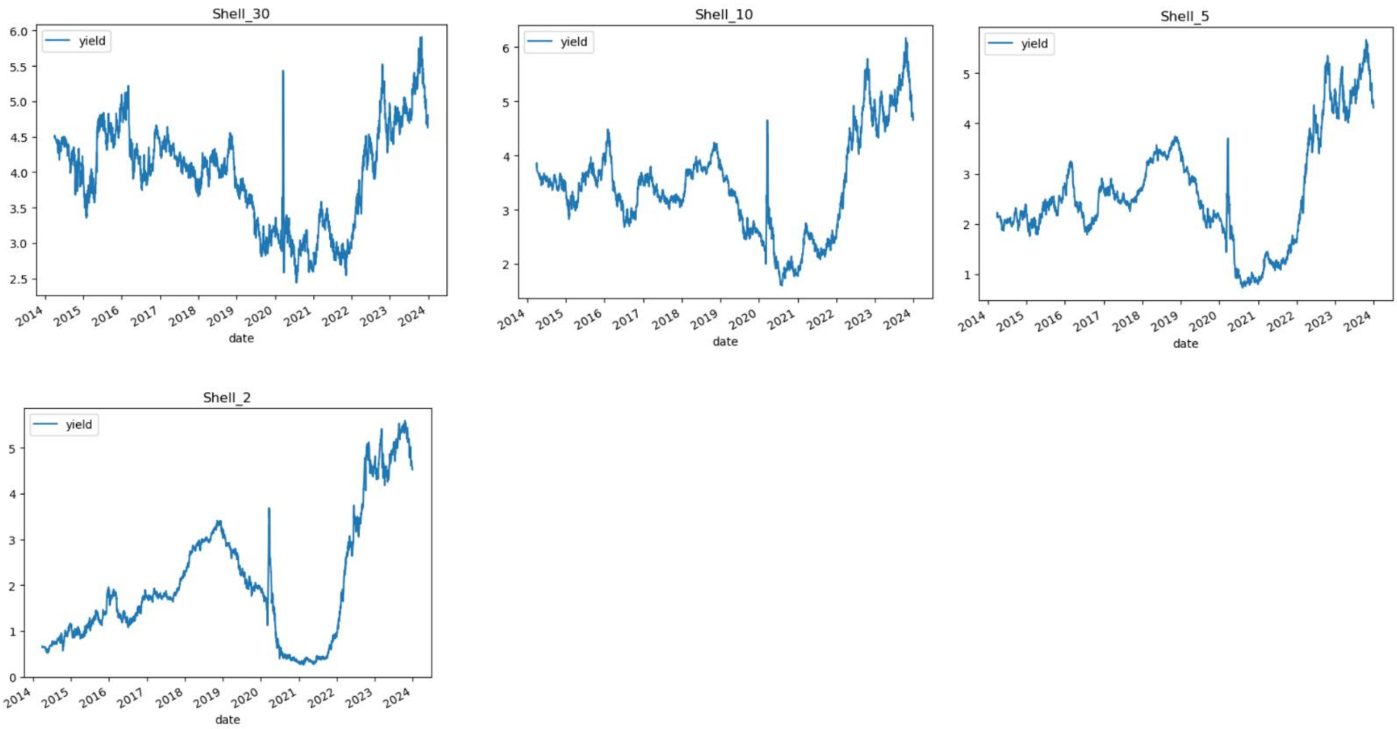


Figure 16. China Bond First Differenced Yield Series

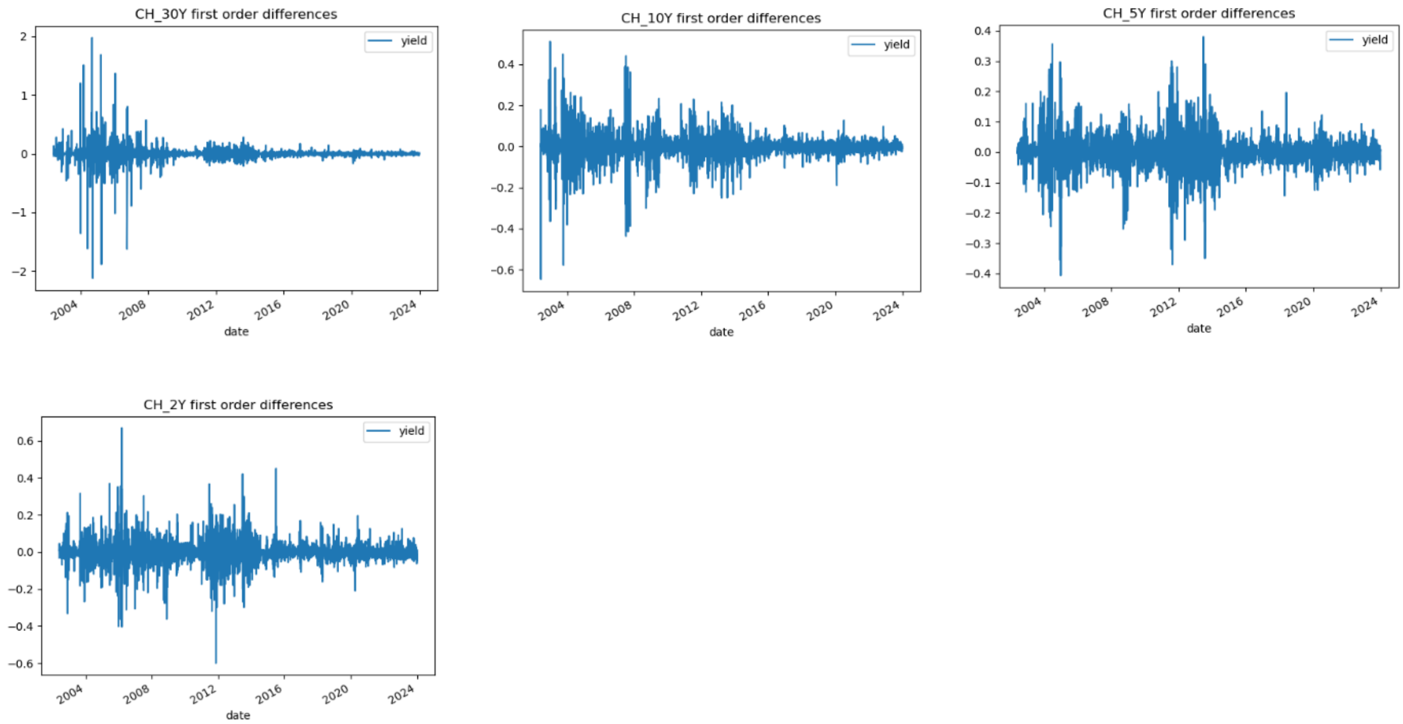


Figure 17. Canada Bond First Differenced Yield Series

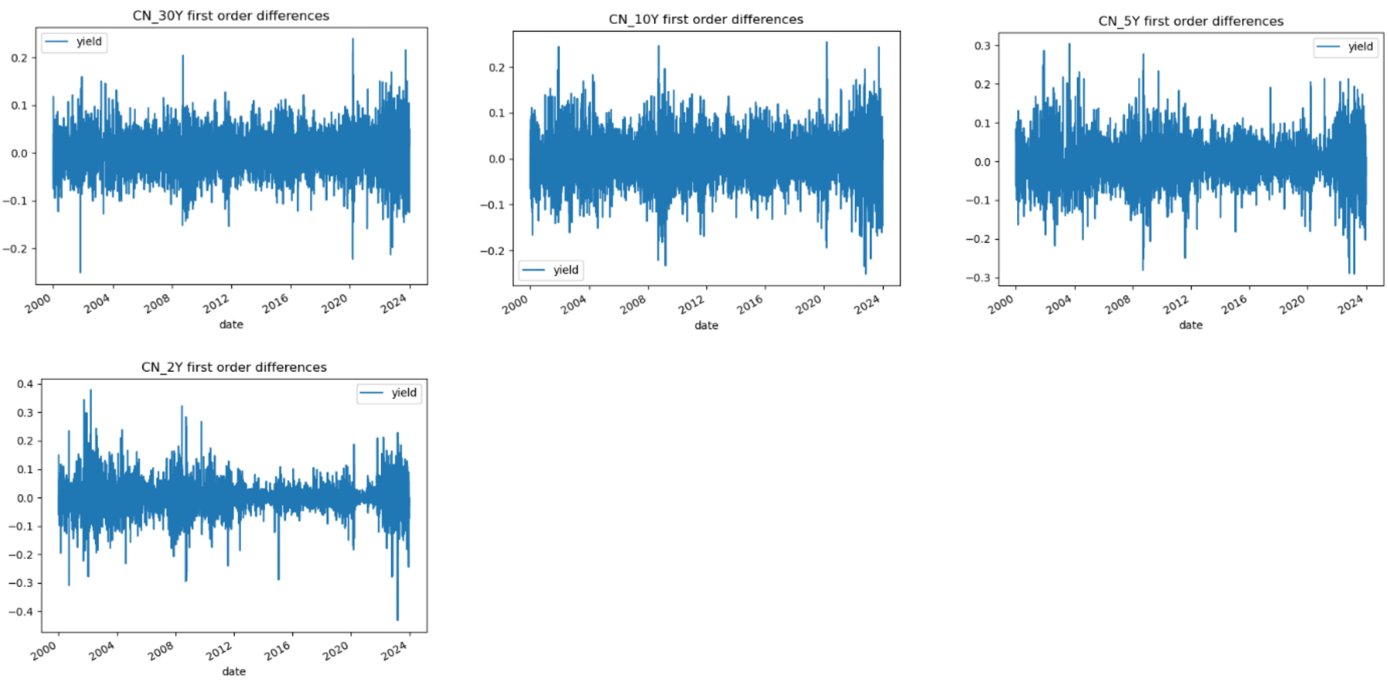


Figure 18. Germany Bond First Differenced Yield Series

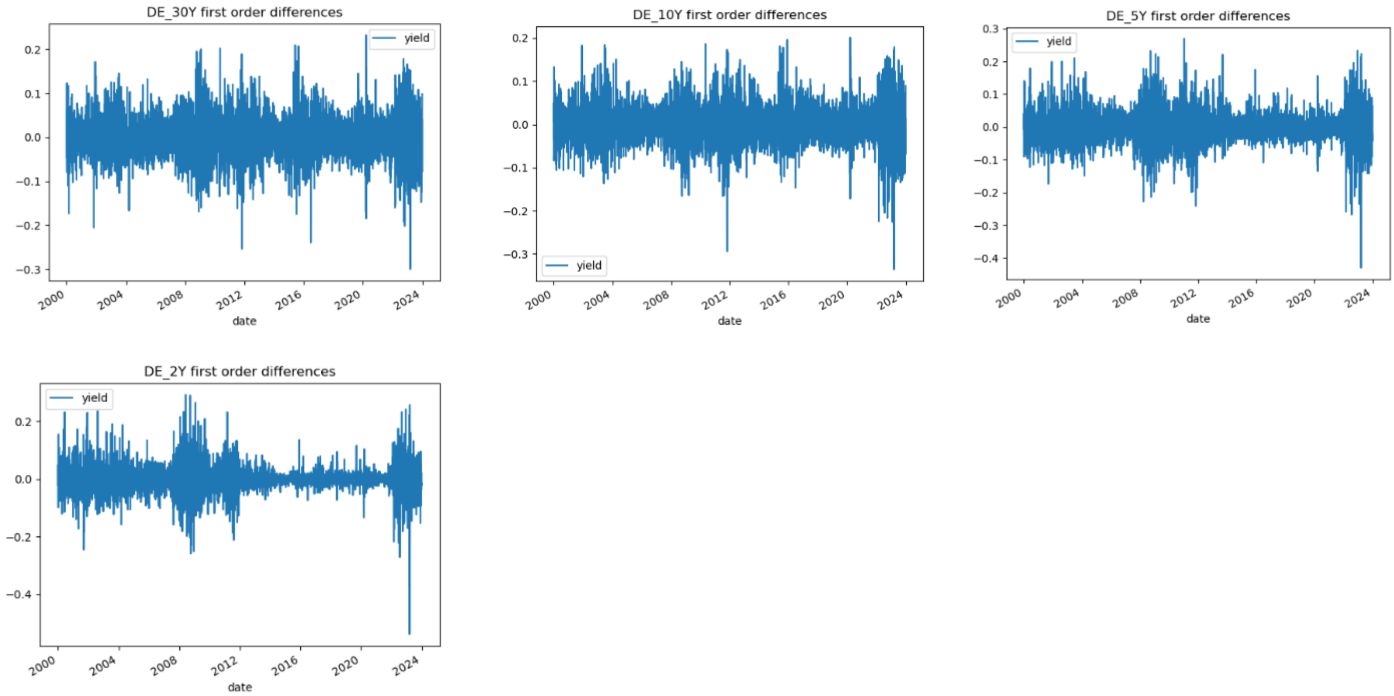


Figure 19. France Bond First Differenced Yield Series

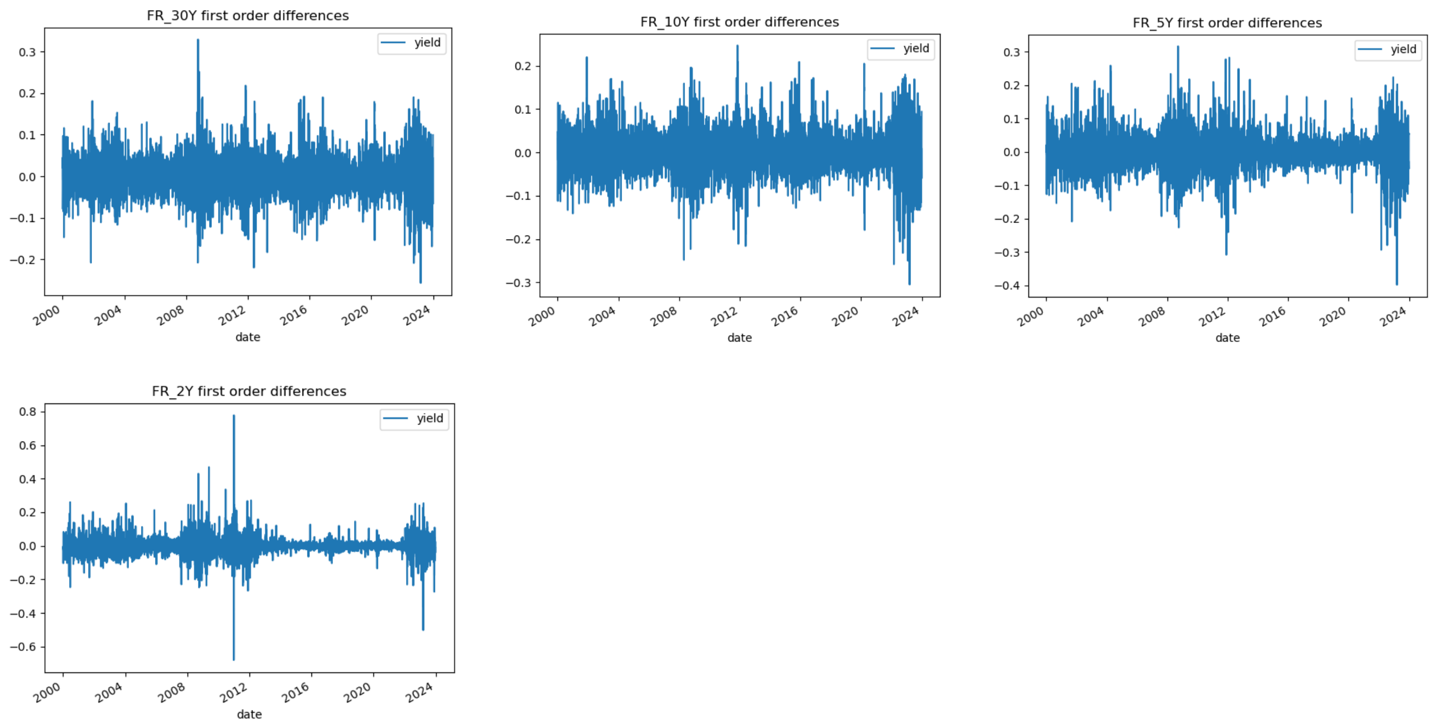


Figure 20. Japan Bond First Differenced Yield Series

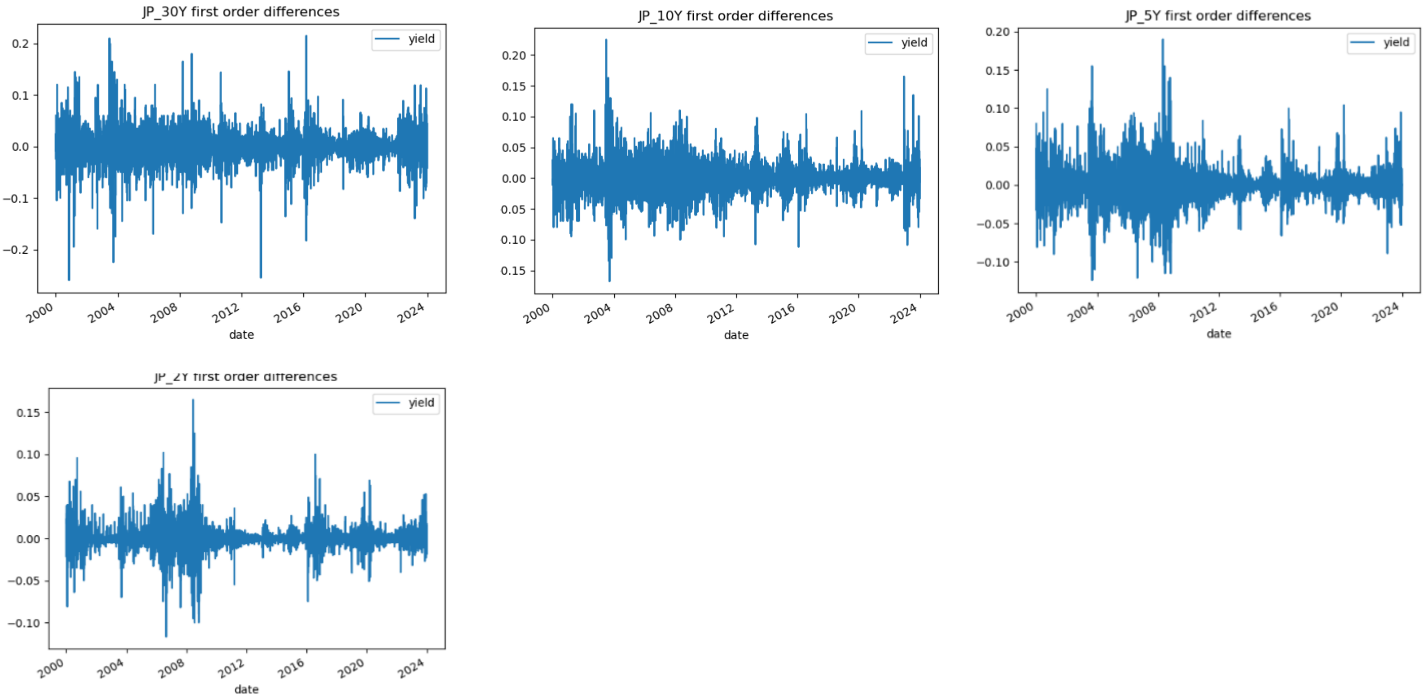


Figure 21. UK Bond First Differenced Yield Series

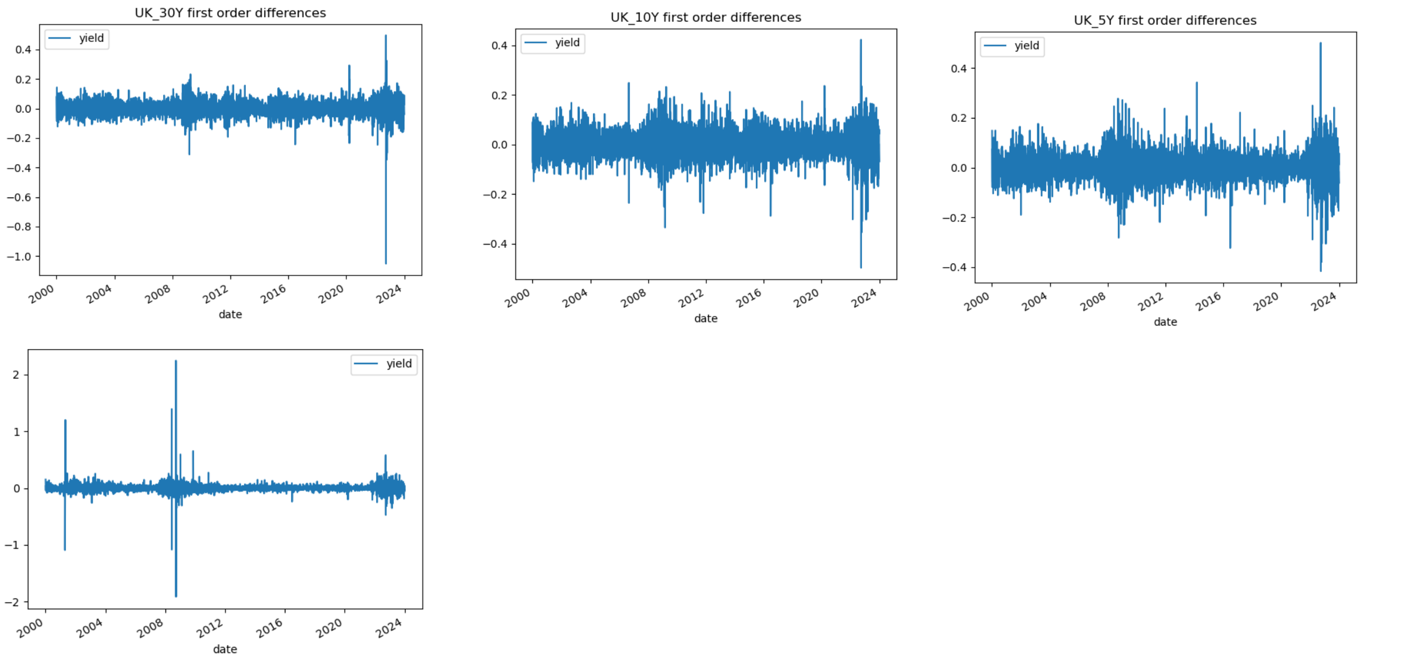


Figure 22. US Bond First Differenced Yield Series

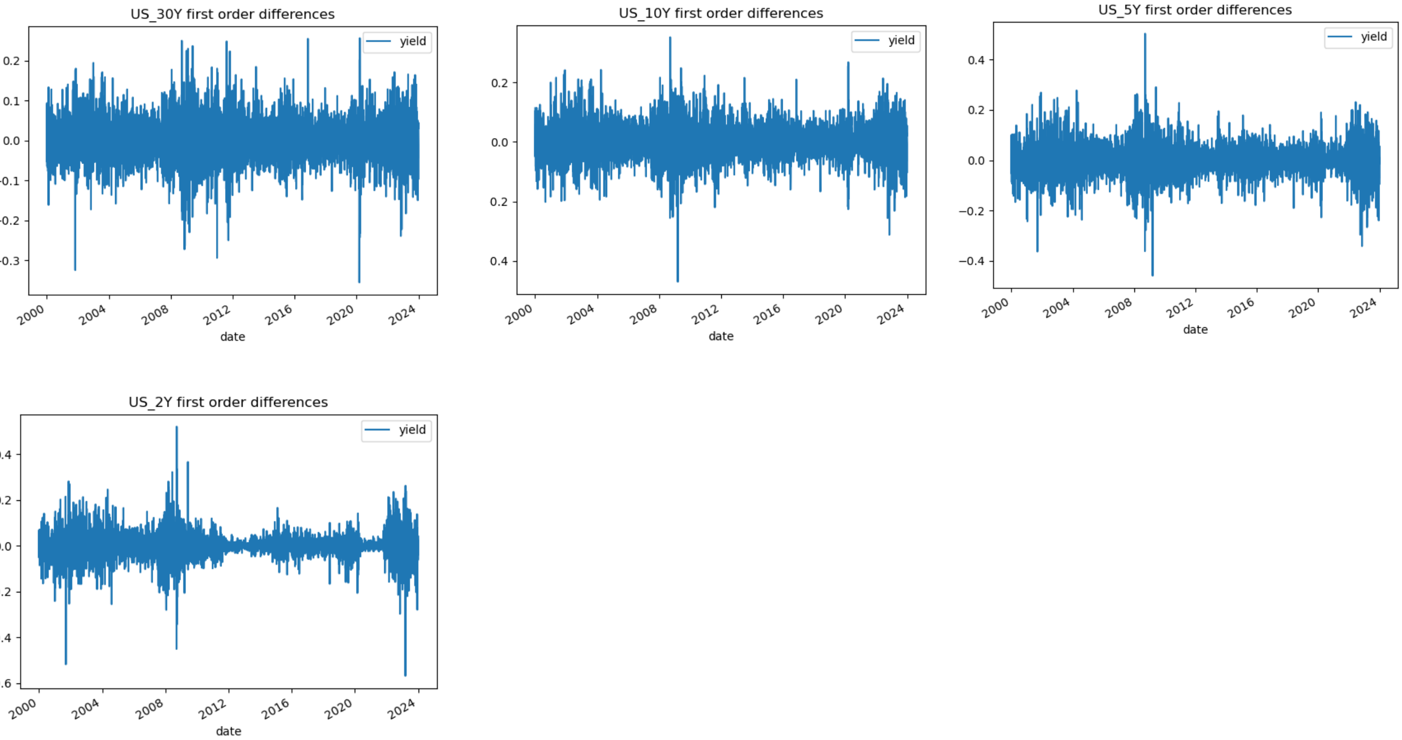


Figure 23. Apple Bond First Differenced Yield Series

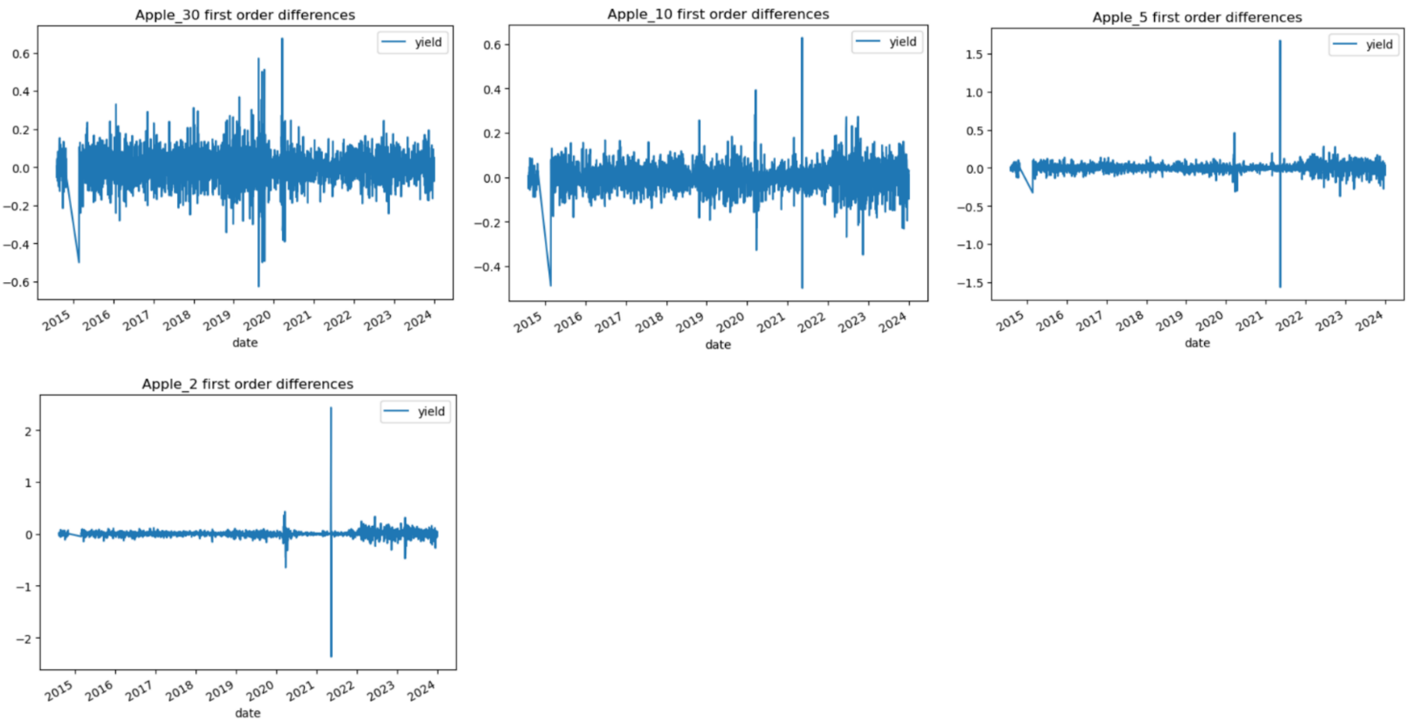


Figure 24. Citigroup Bond First Differenced Yield Series

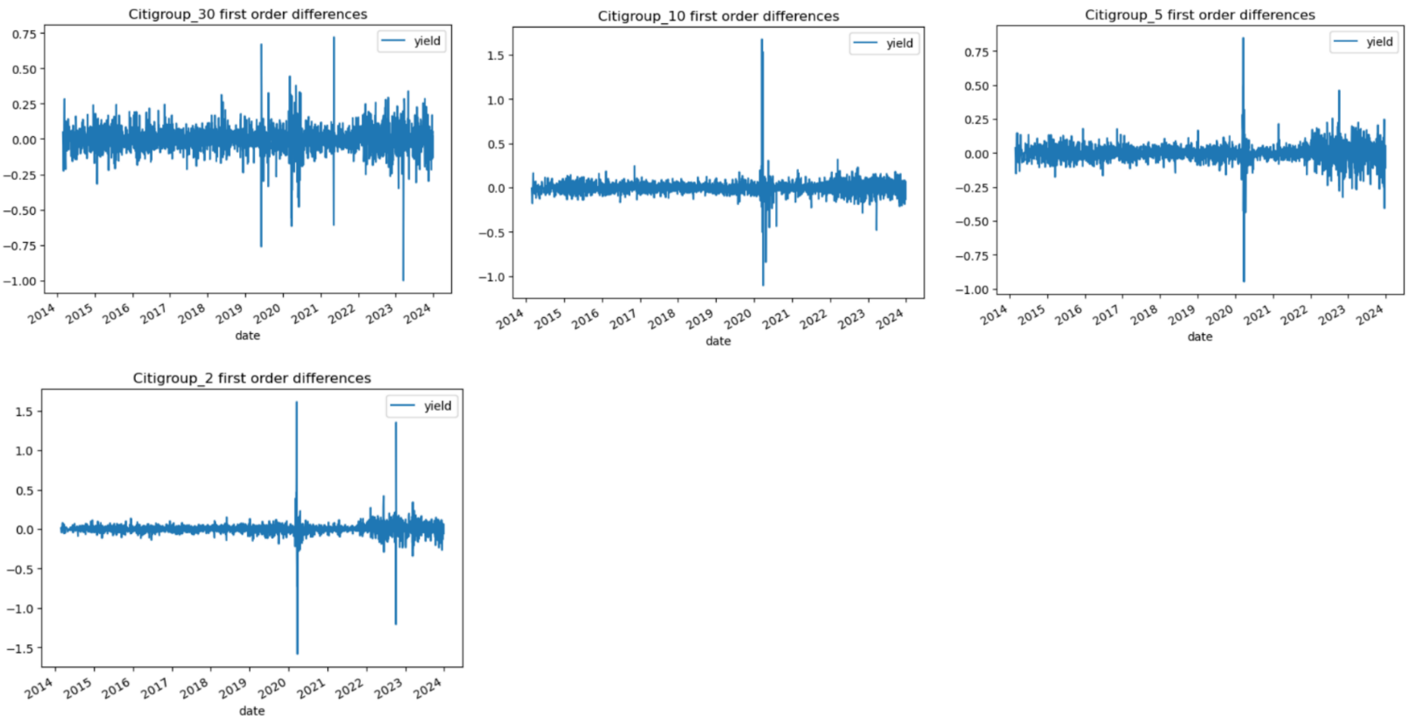


Figure 25. Pfizer Bond First Differenced Yield Series

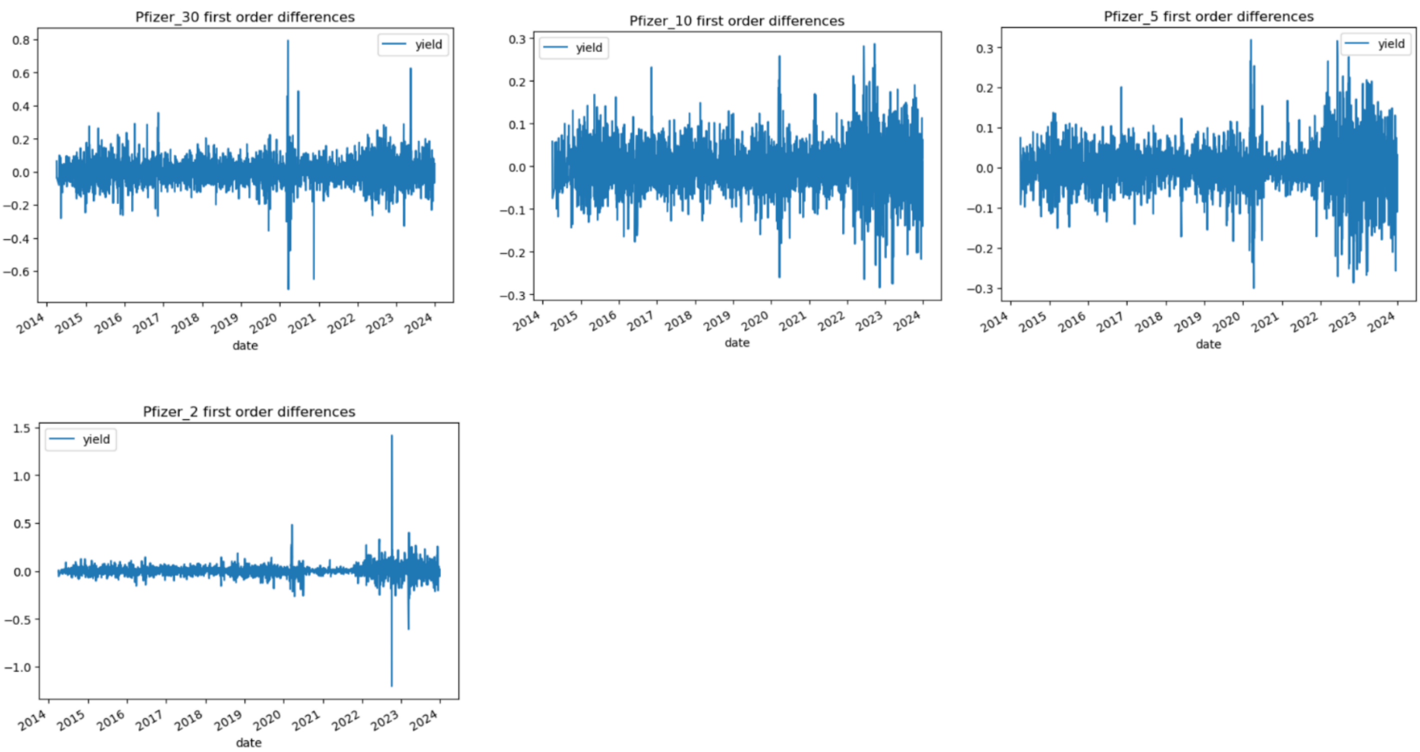
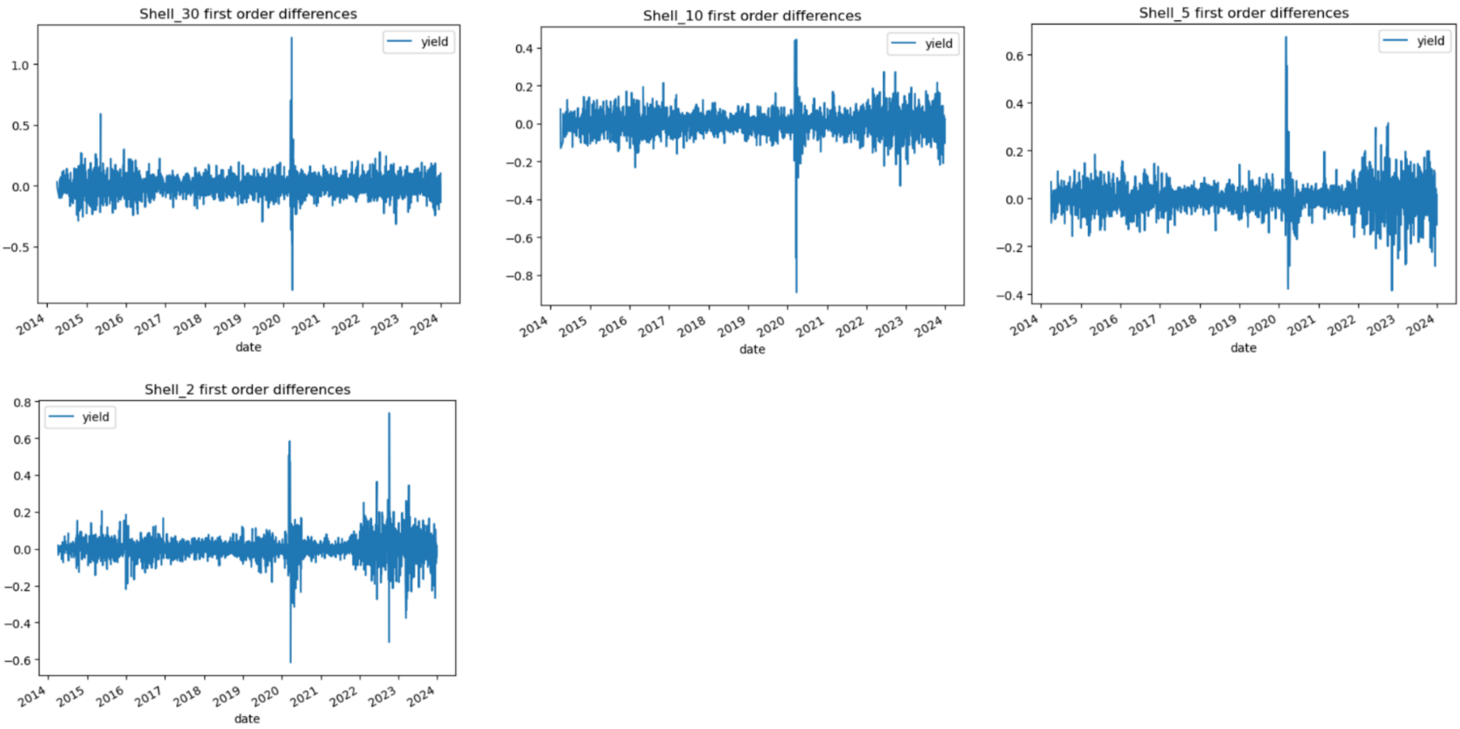


Figure 26. Shell Bond First Differenced Yield Series



Appendix C – Frequency Distributions of Q-values

Figure 27. Frequency Distribution of Q-values of China Government Bonds

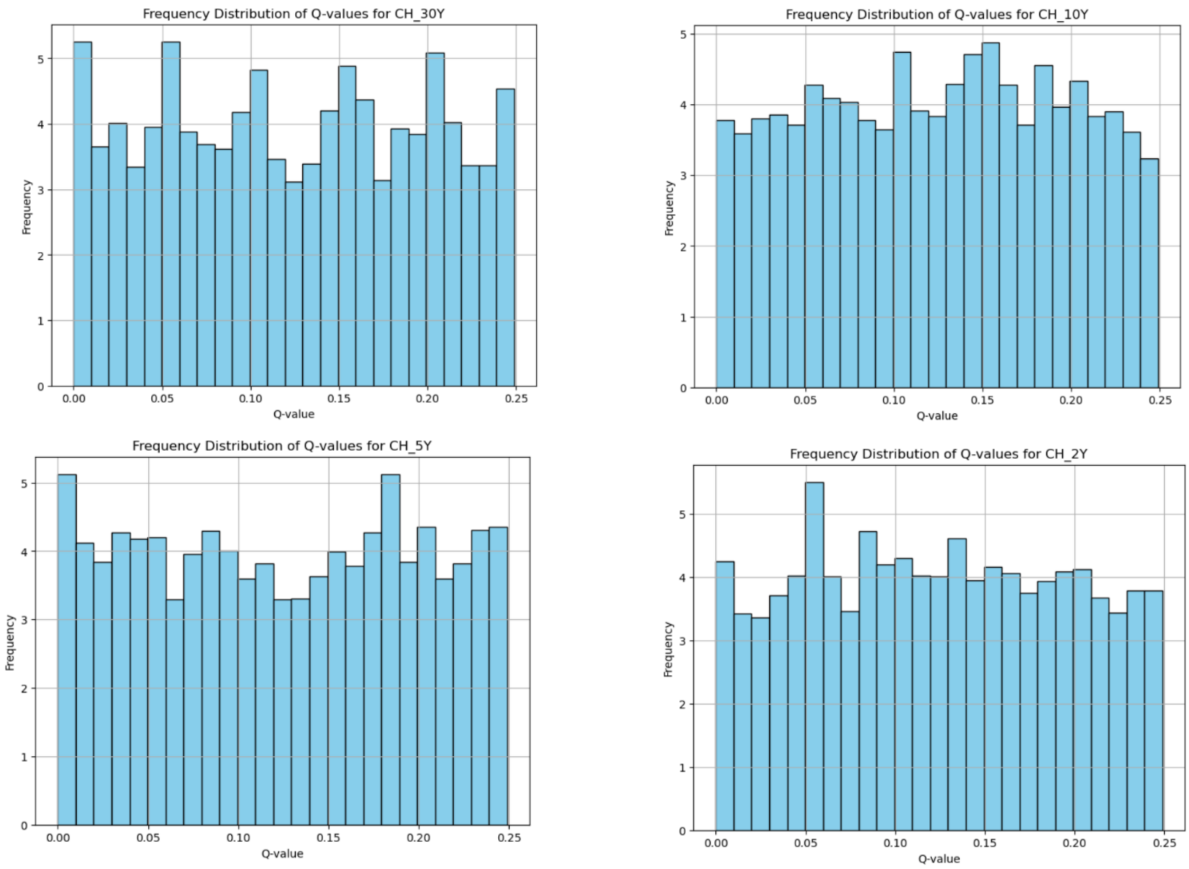
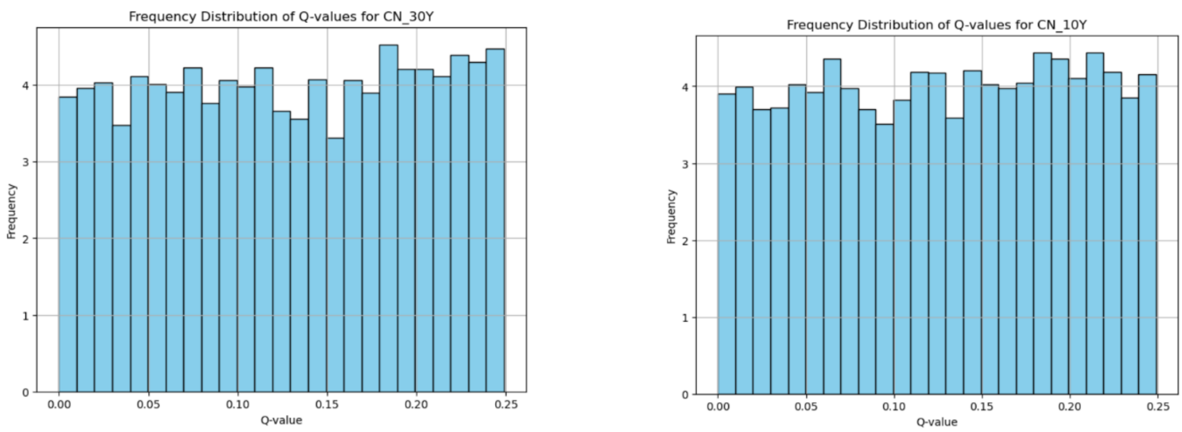


Figure 28. Frequency Distribution of Q-values of Canada Government Bonds



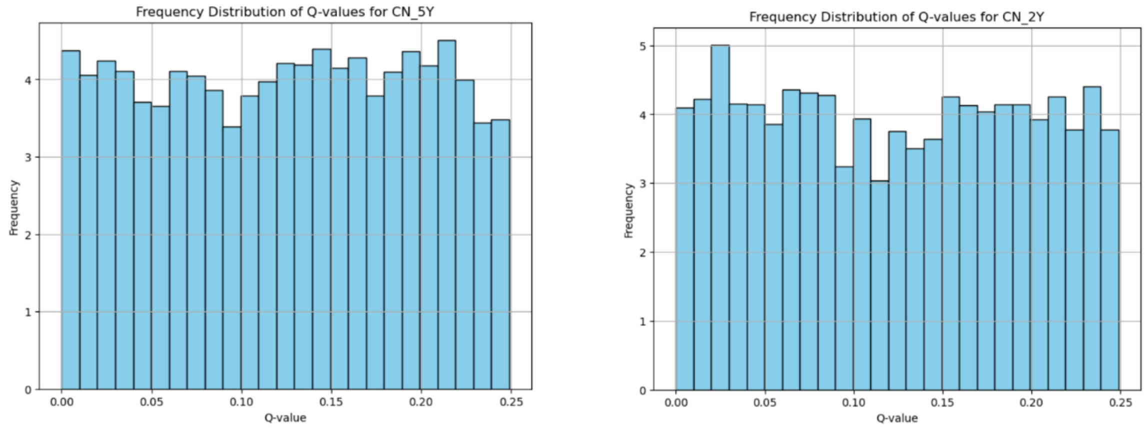


Figure 29. Frequency Distribution of Q-values of Germany Government Bonds

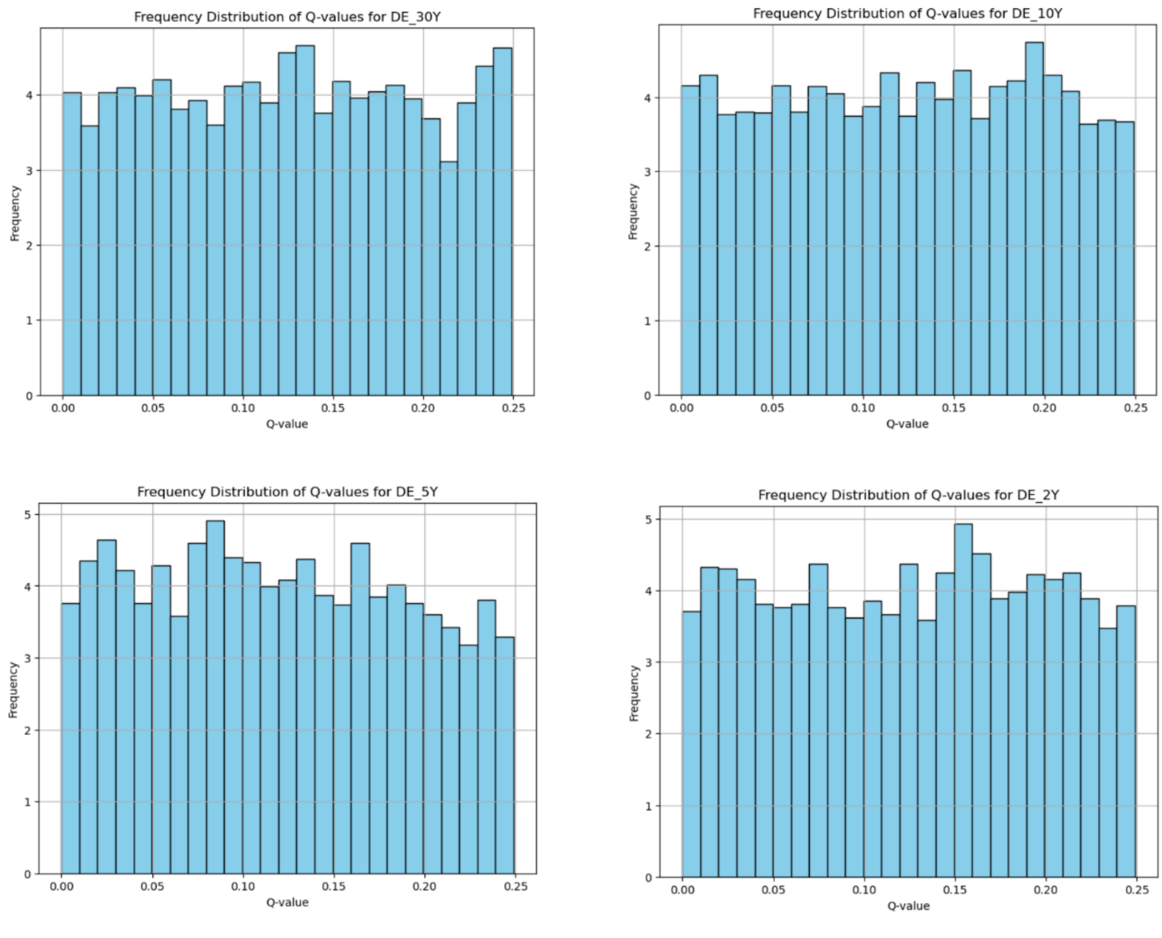


Figure 30. Frequency Distribution of Q-values of France Government Bonds

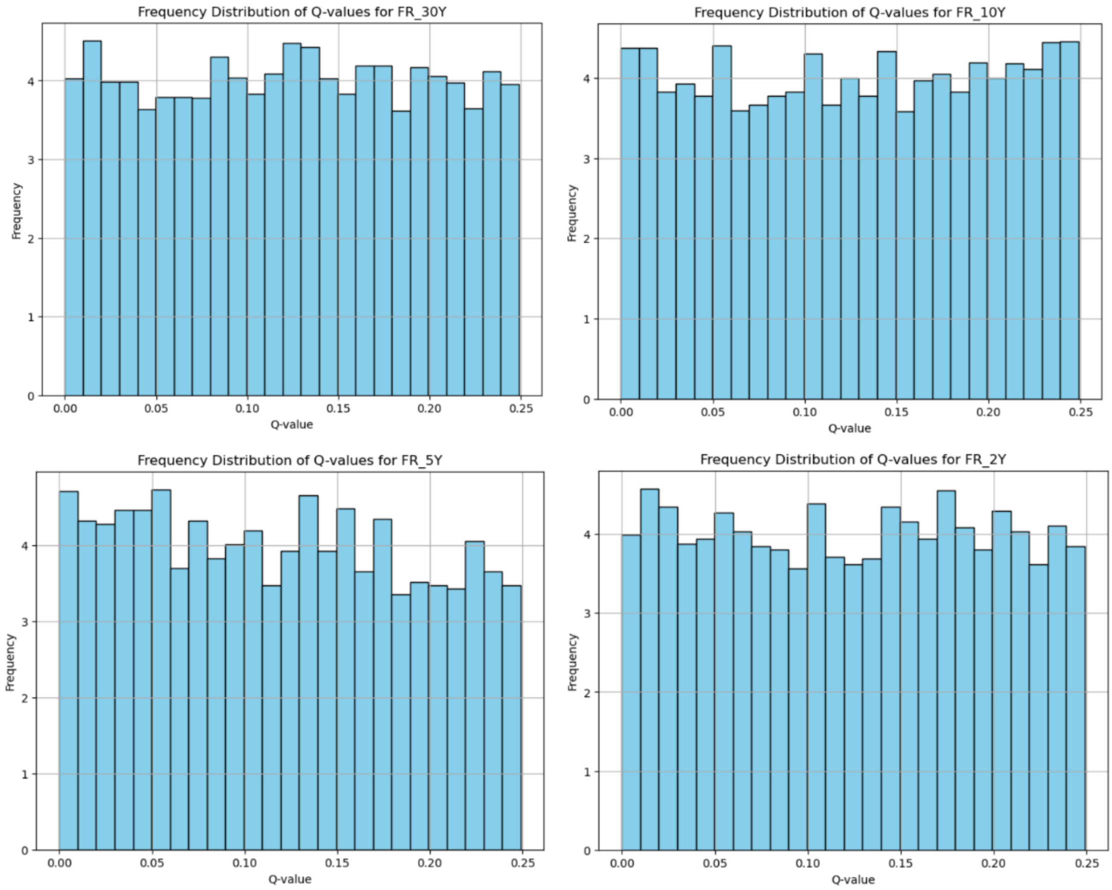
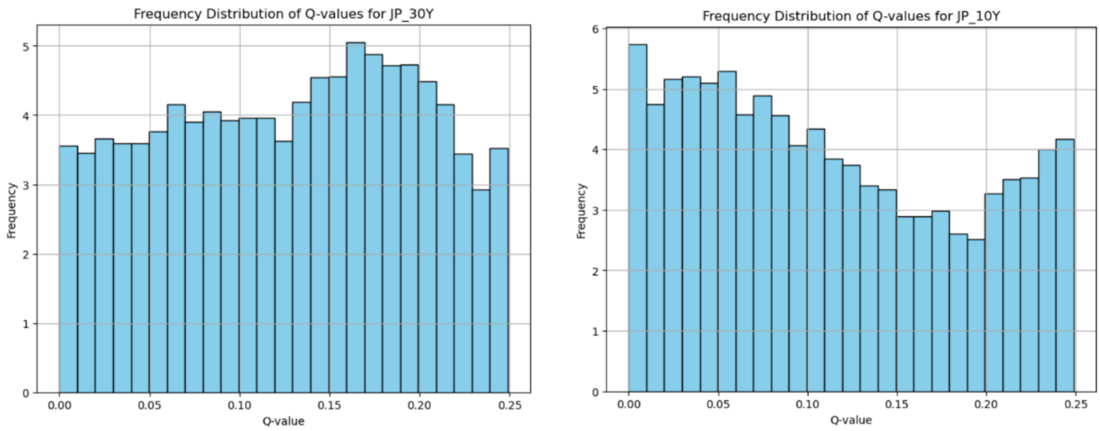


Figure 31. Frequency Distribution of Q-values of Japan Government Bonds



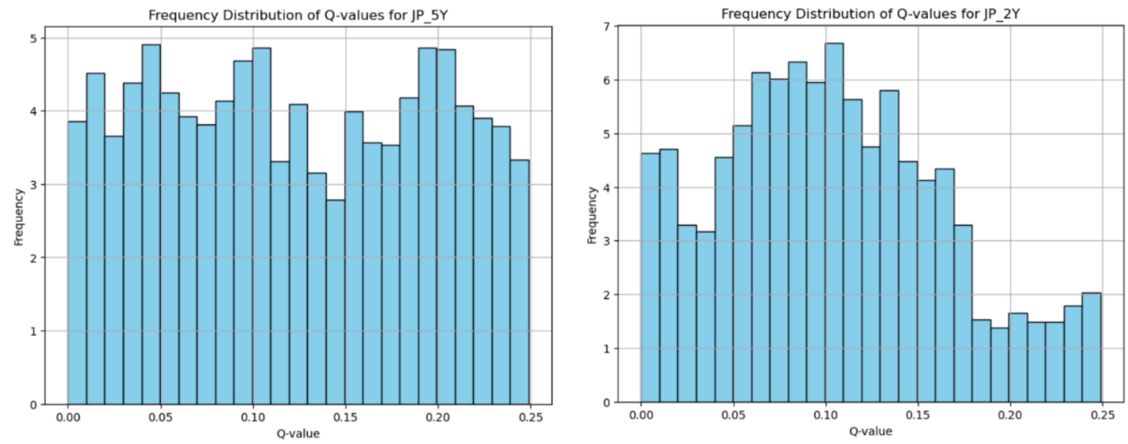


Figure 32. Frequency Distribution of Q-values of UK Government Bonds

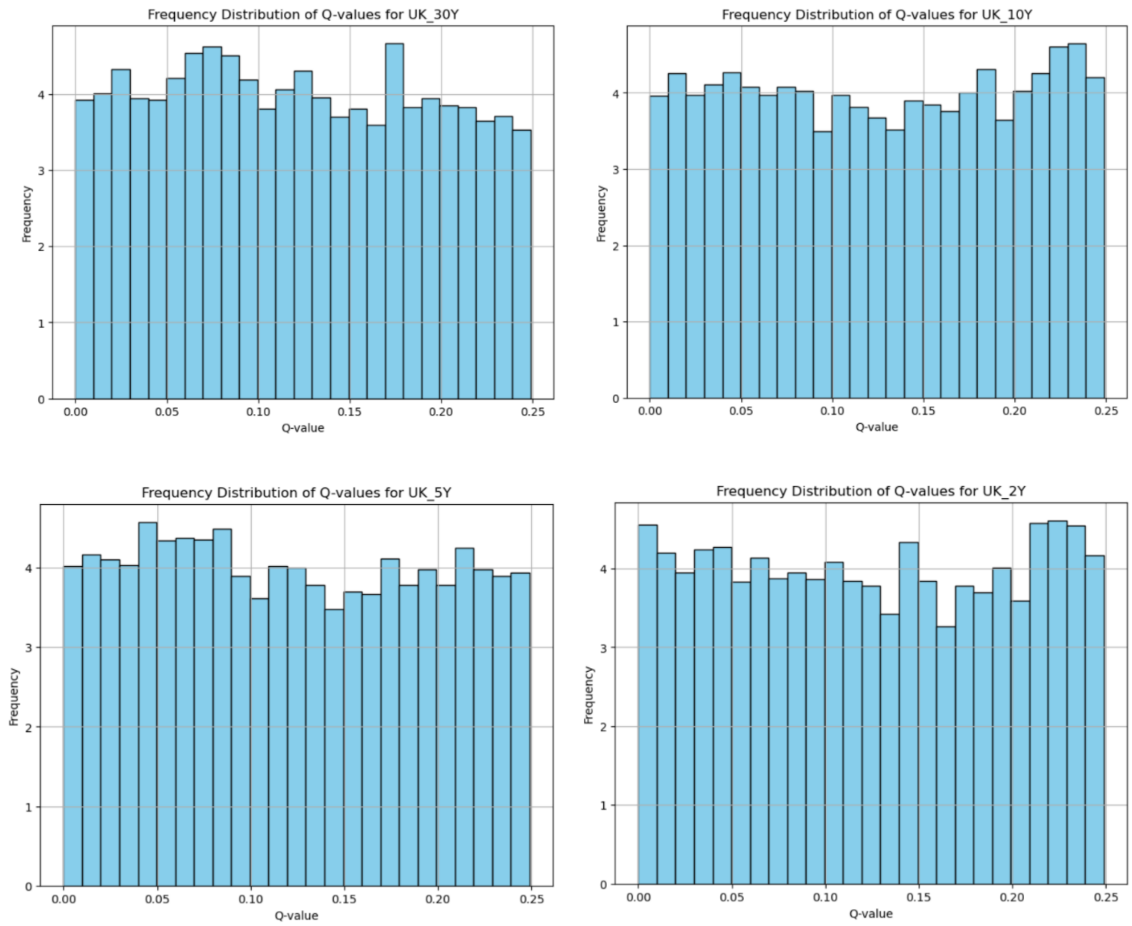


Figure 33. Frequency Distribution of Q-values of US Government Bonds

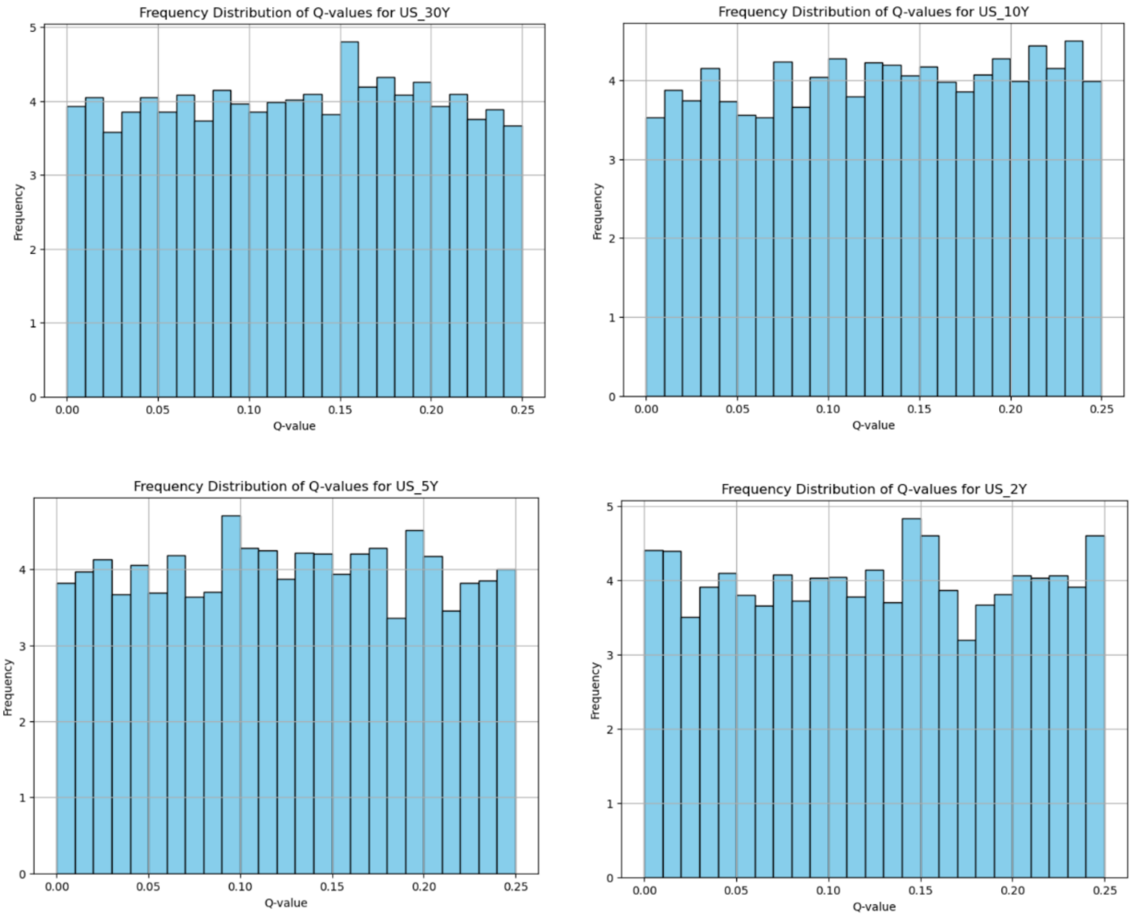
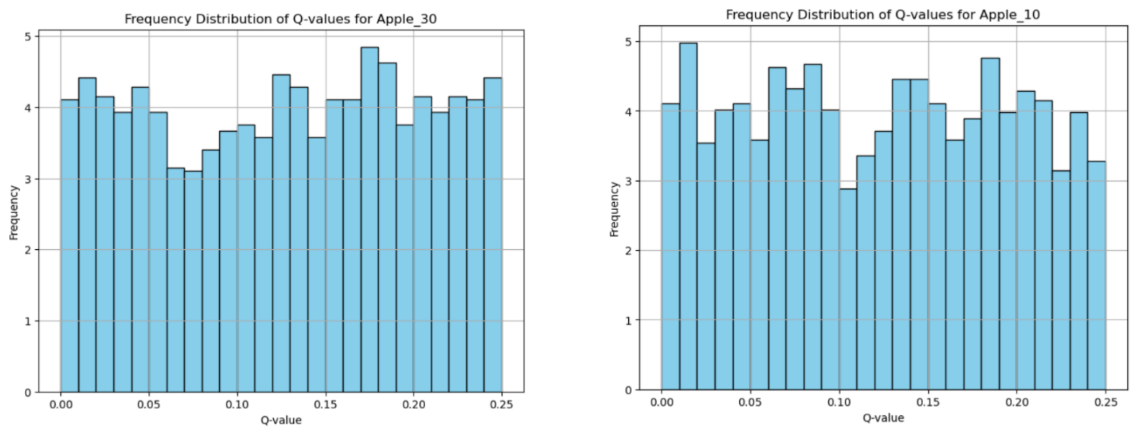
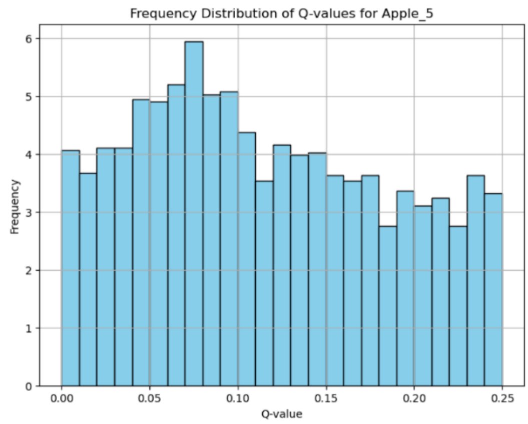


Figure 34. Frequency Distribution of Q-values of Apple Bonds





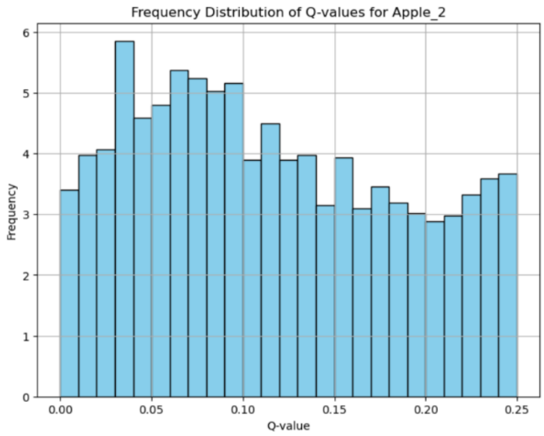
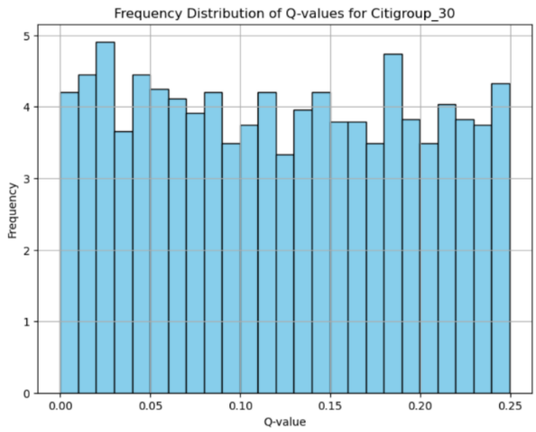
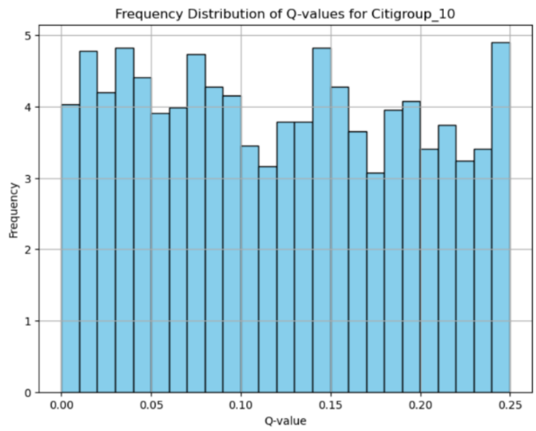
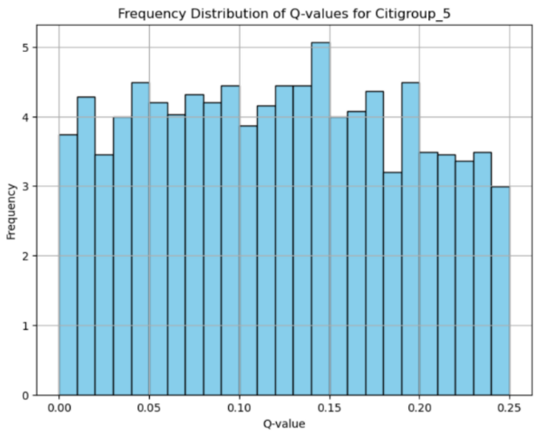


Figure 35. Frequency Distribution of Q-values of Citigroup Bonds







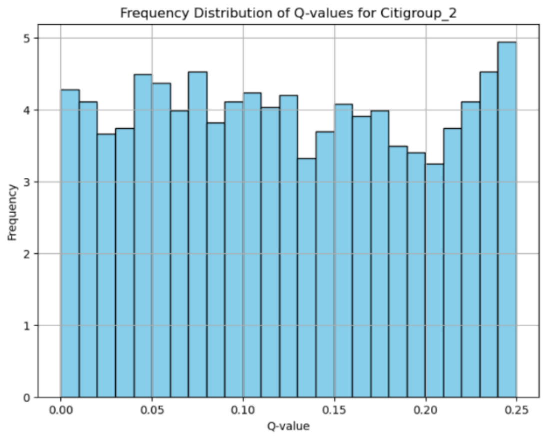


Figure 36. Frequency Distribution of Q-values of Pfizer Bonds

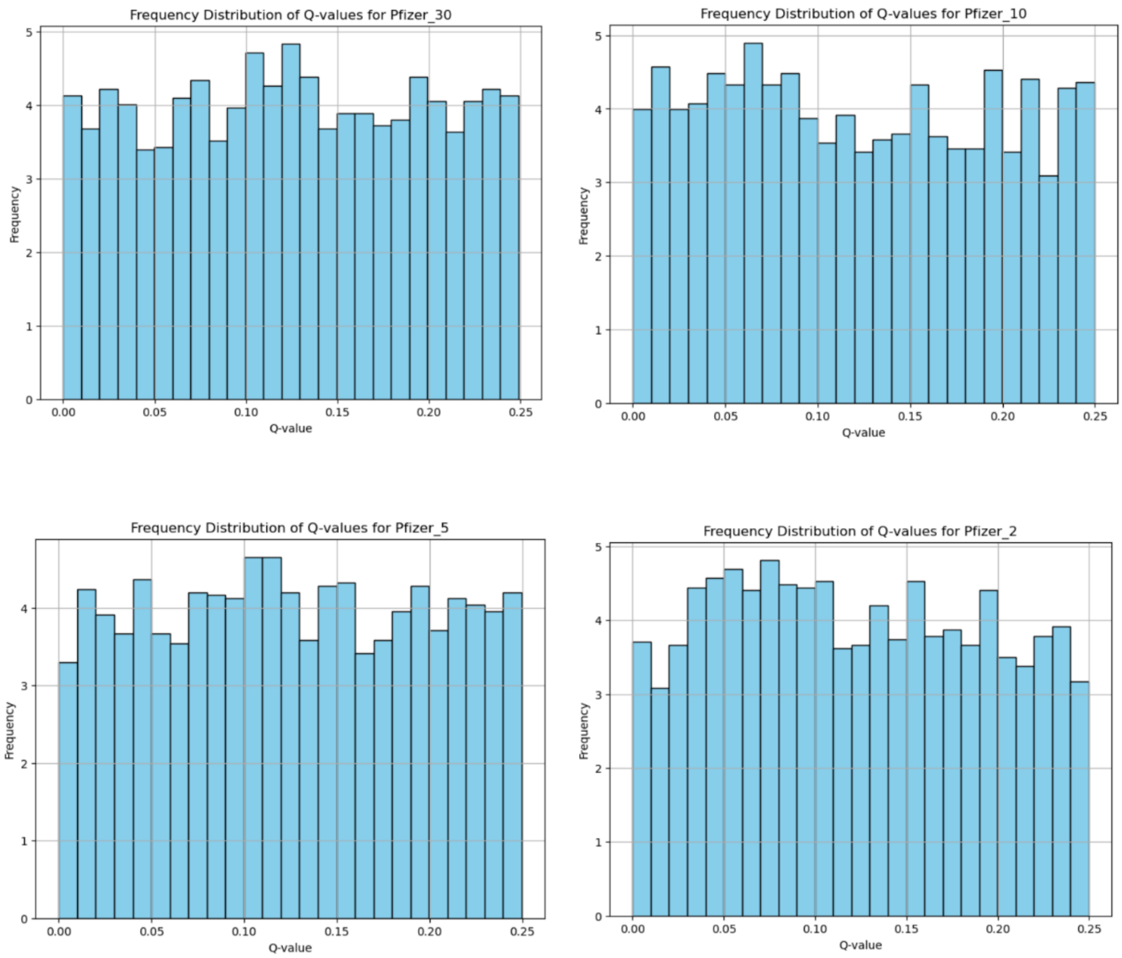
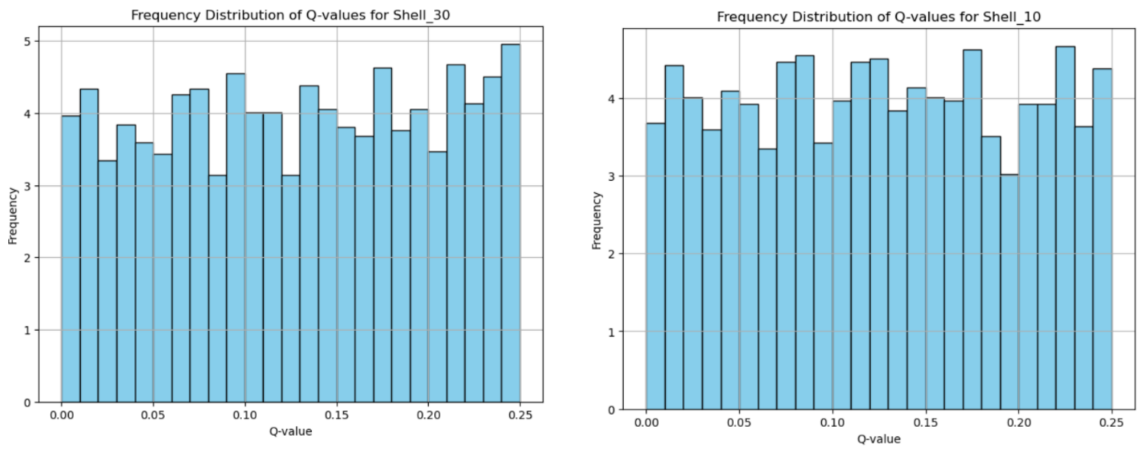
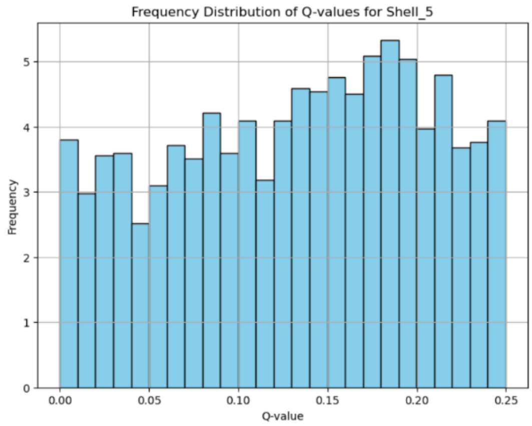
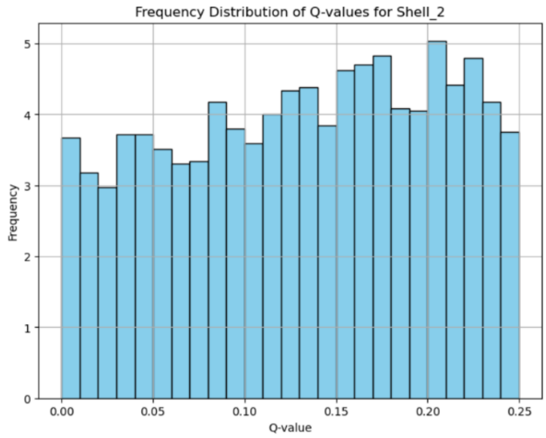


Figure 37. Frequency Distribution of Q-values of Shell Bonds





Frequency Distribution of Q-values for Shell_5
Frequency
Q-value
0
1
2
3
4
5
0.00
0.05
0.10
0.15
0.20
0.25



Frequency Distribution of Q-values for Shell_2
Frequency
Q-value
0
1
2
3
4
5
0.00
0.05
0.10
0.15
0.20
0.25

Appendix D – Frequency Distribution of Q-values – with negative yields

Figure 38. Frequency Distribution of Q-values of Germany Government Bonds with negative yields

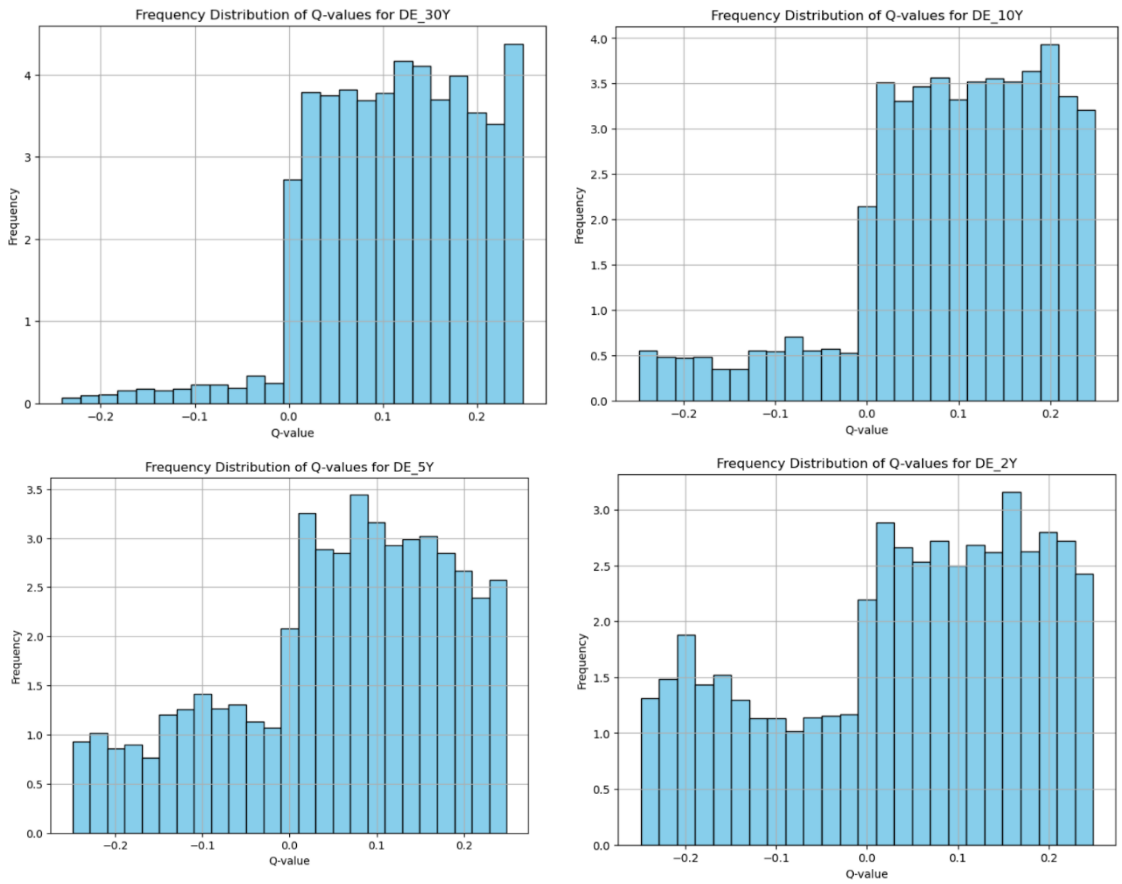
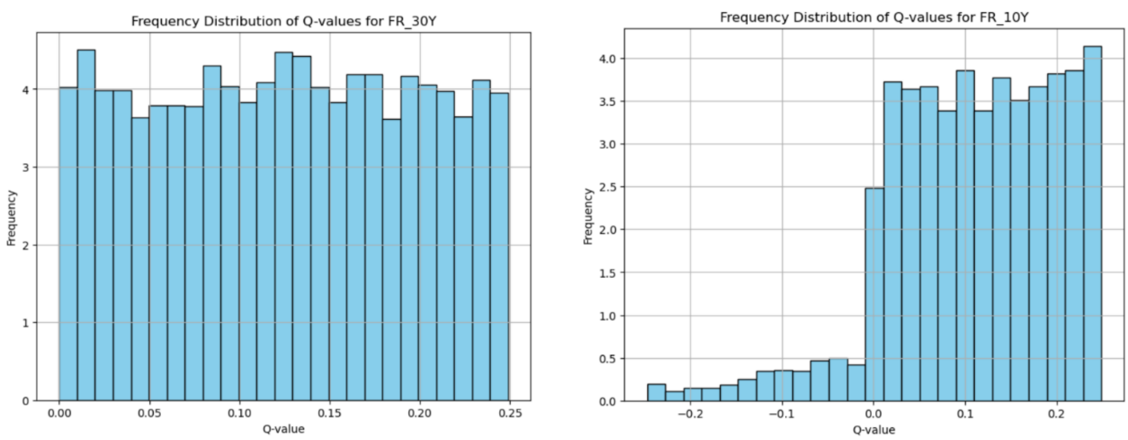


Figure 39. Frequency Distribution of Q-values of France Government Bonds with negative yields



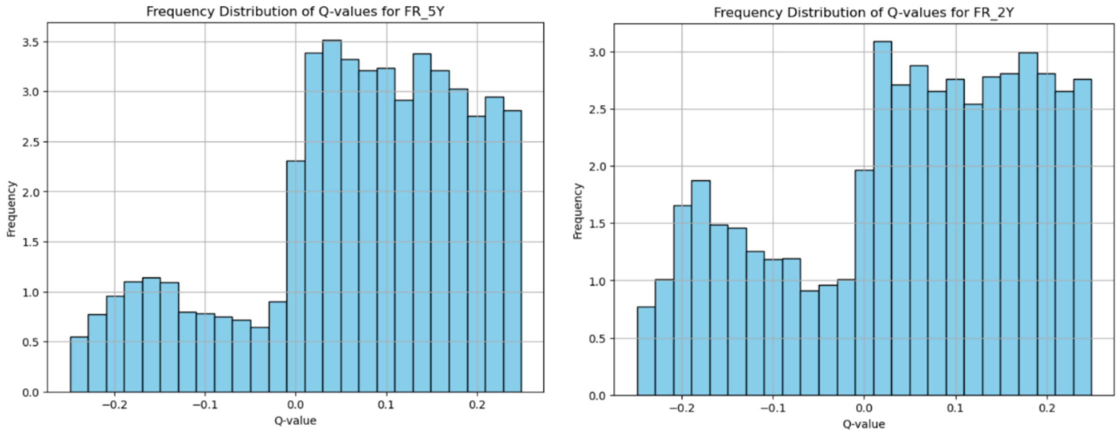
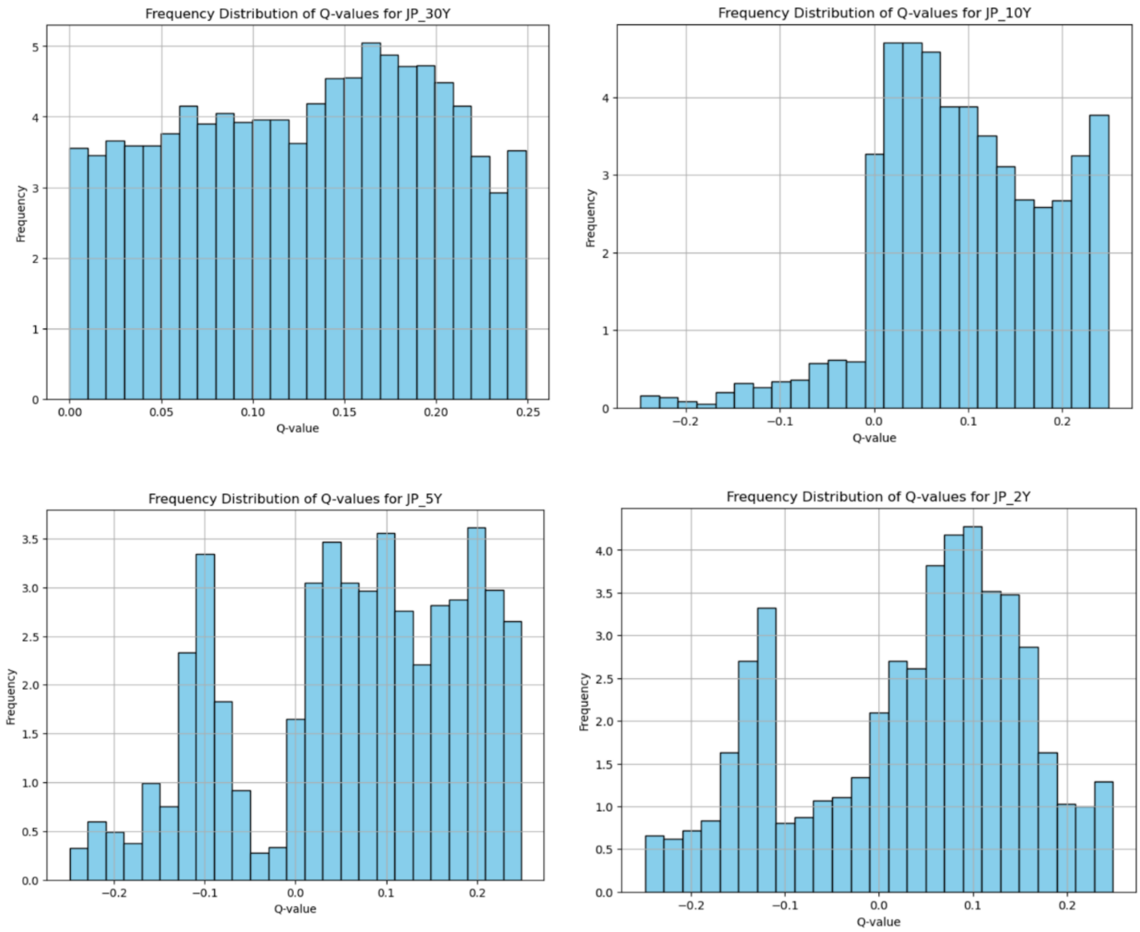


Figure 40. Frequency Distribution of Q-values of Japan Government Bonds with negative yields



Appendix E – Frequency distribution of Q-values with the barrier proximity regression

Figure 41. Frequency distribution of Q-values of China government bond with the barrier proximity regression

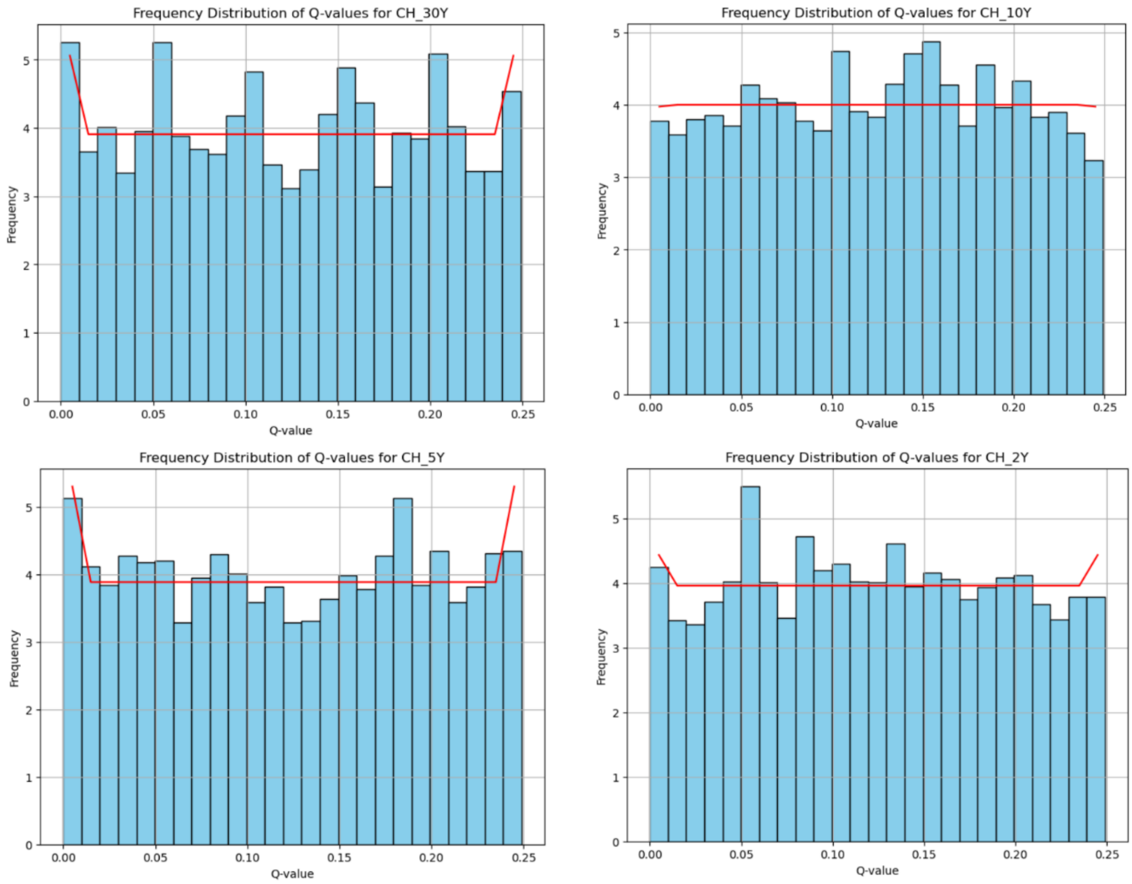


Figure 42. Frequency distribution of Q-values of Canada government bond with the barrier proximity regression

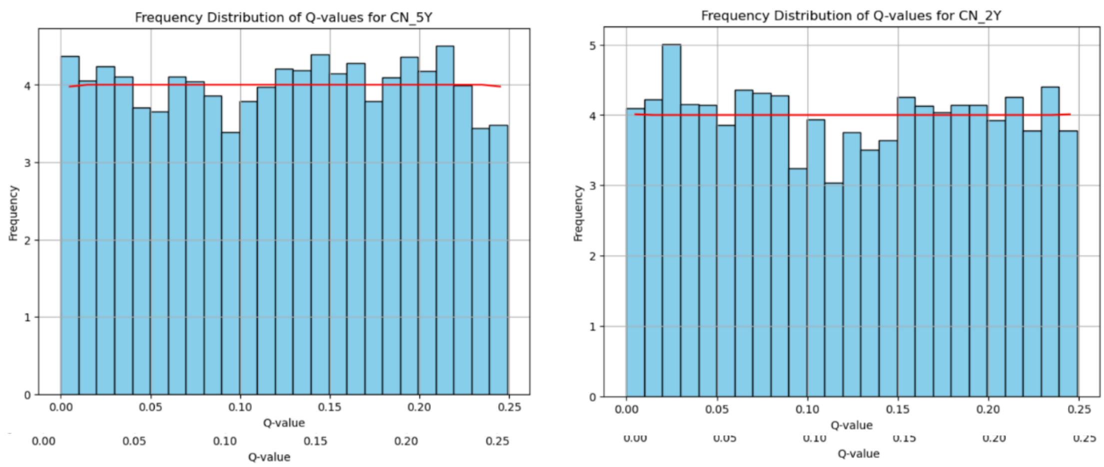


Figure 43. Frequency distribution of Q-values of Germany government bond with the barrier proximity regression

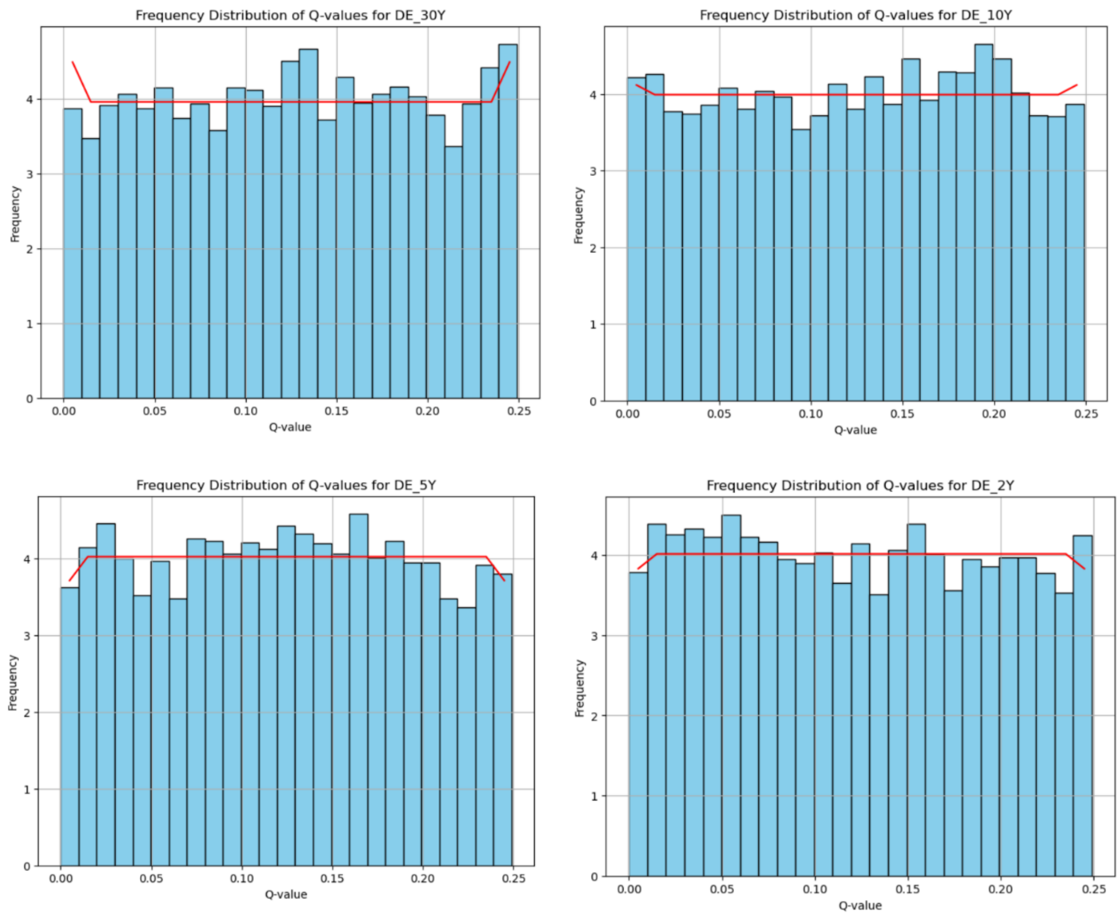
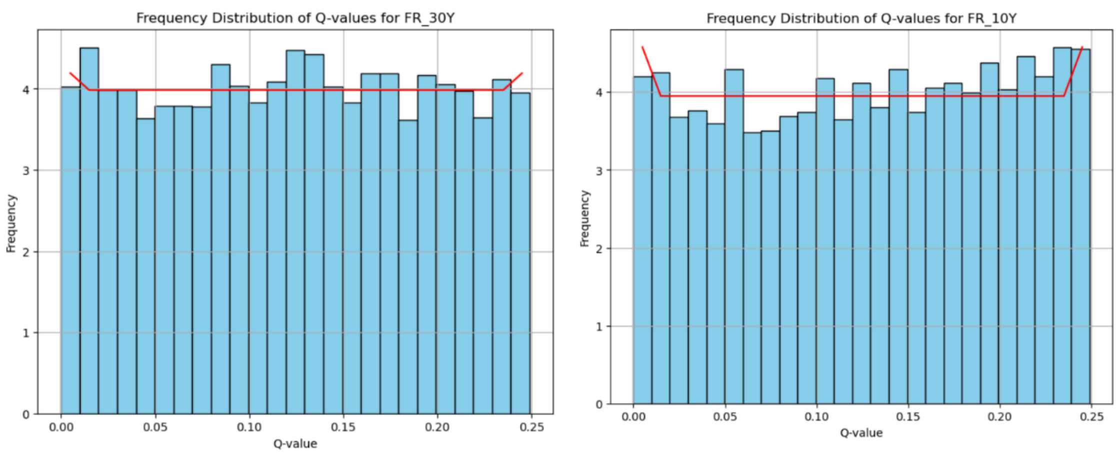


Figure 44. Frequency distribution of Q-values of France government bond with the barrier proximity regression



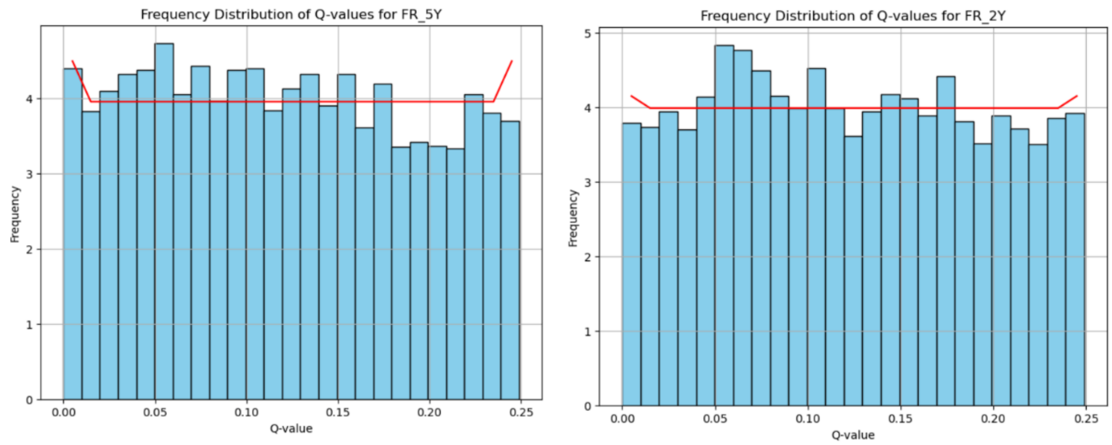


Figure 45. Frequency distribution of Q-values of Japan government bond with the barrier proximity regression

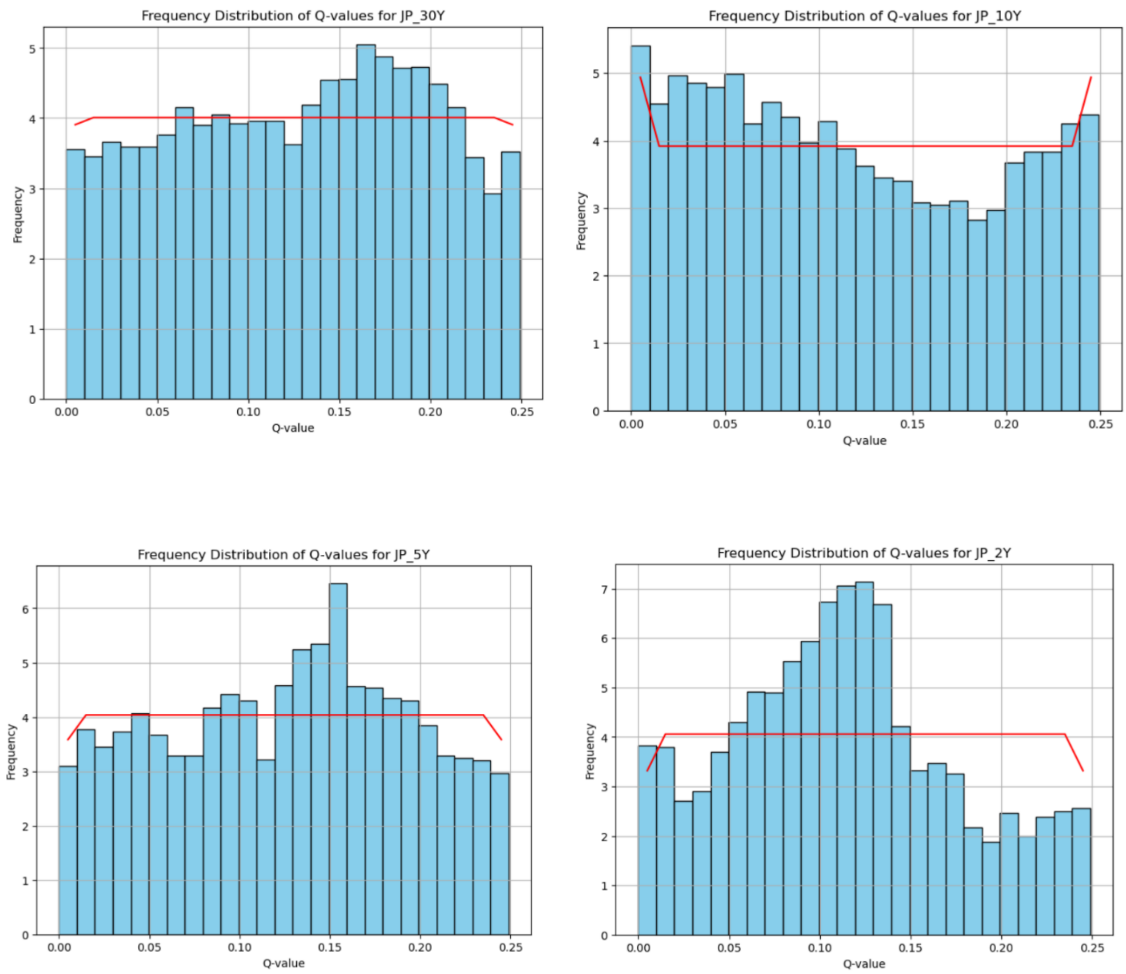


Figure 46. Frequency distribution of Q-values of UK government bond with the barrier proximity regression

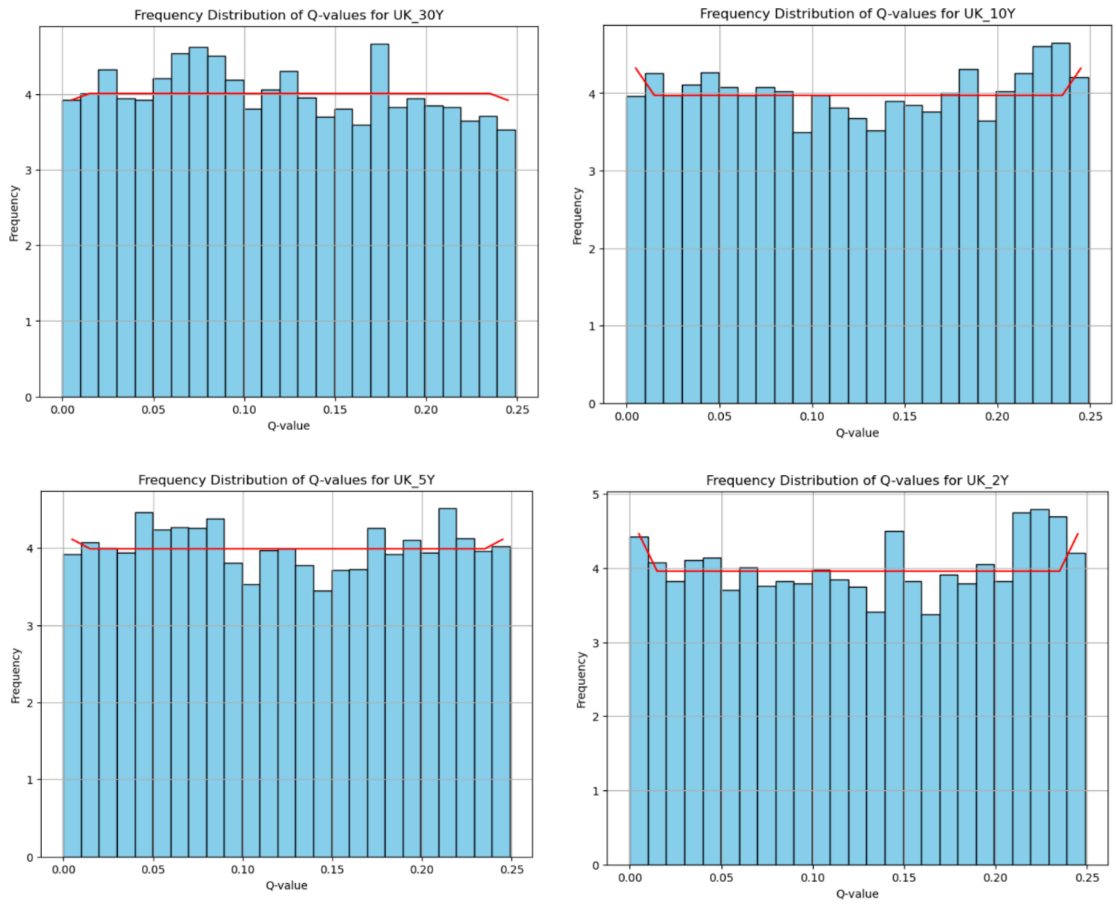
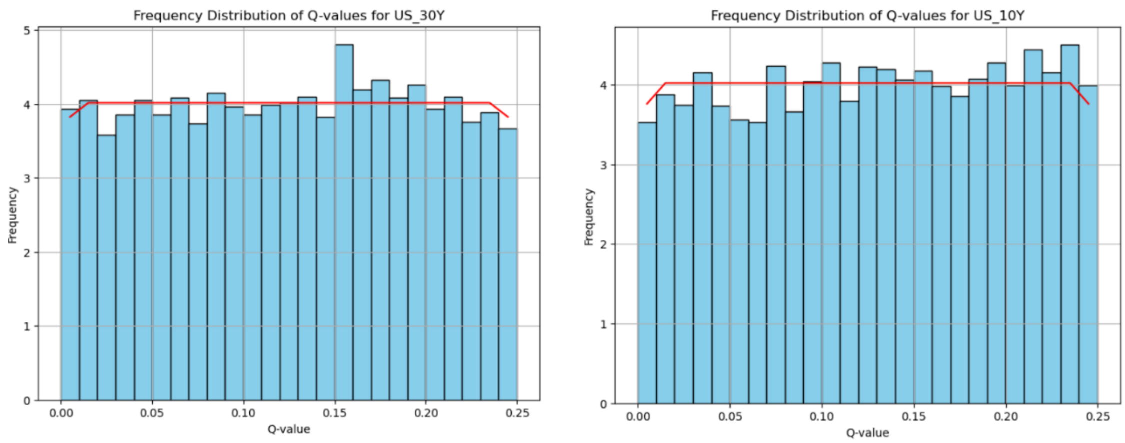


Figure 47. Frequency distribution of Q-values of US government bond with the barrier proximity regression



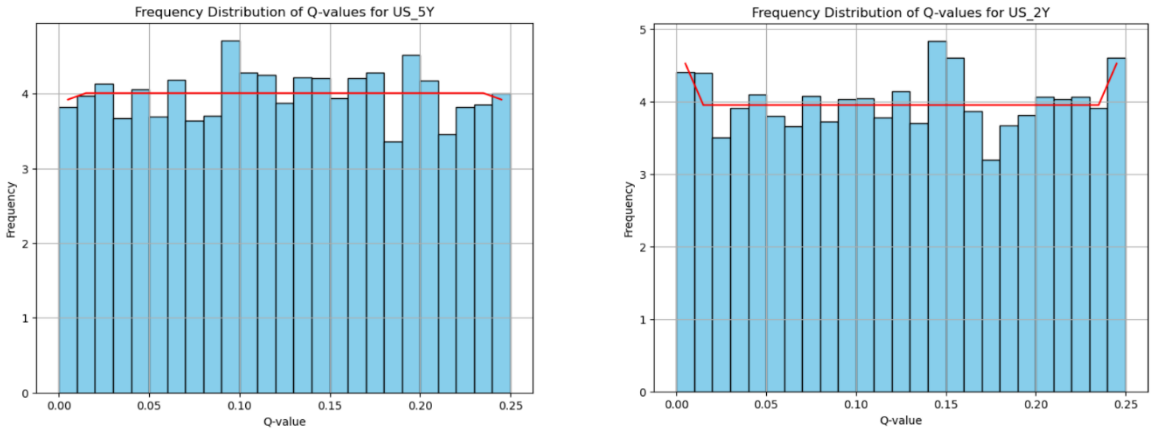


Figure 48. Frequency distribution of Q-values of Apple bonds with the barrier proximity regression

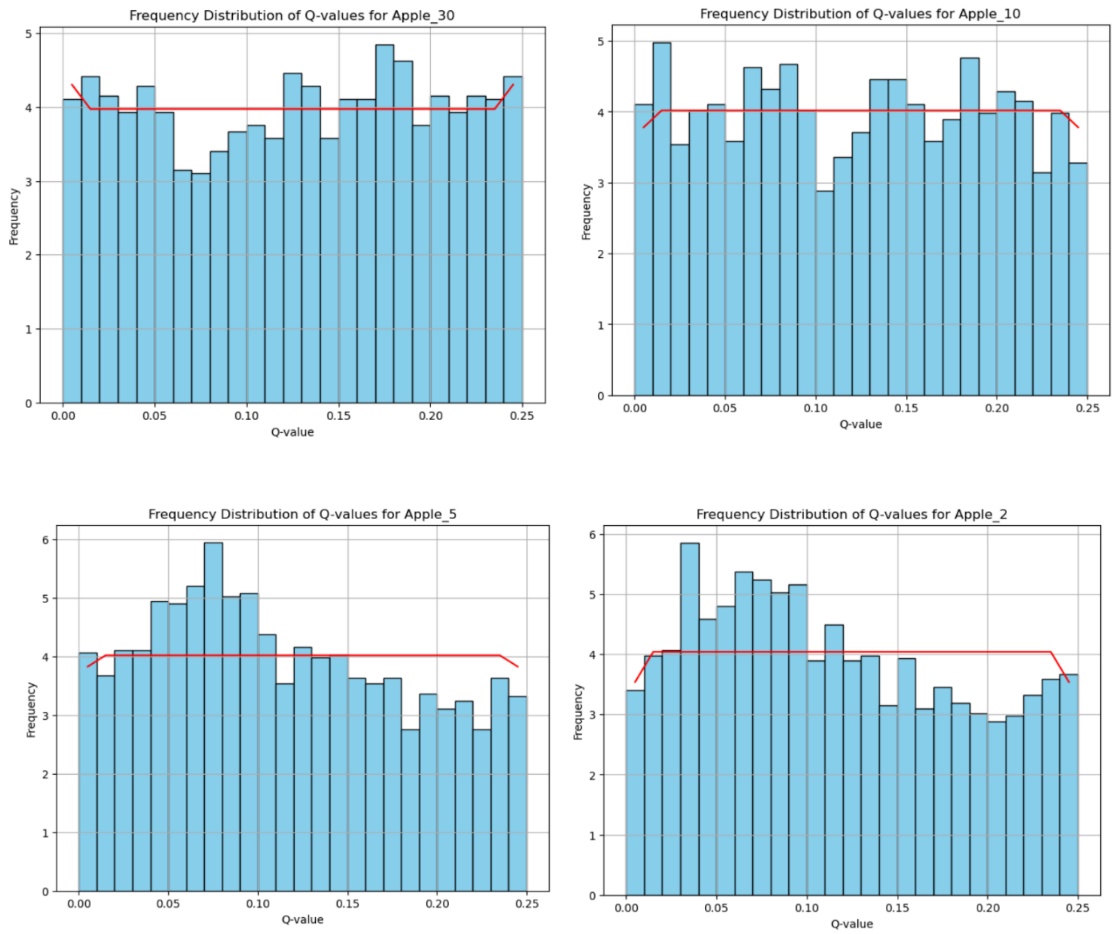


Figure 49. Frequency distribution of Q-values of Citigroup bonds with the barrier proximity regression

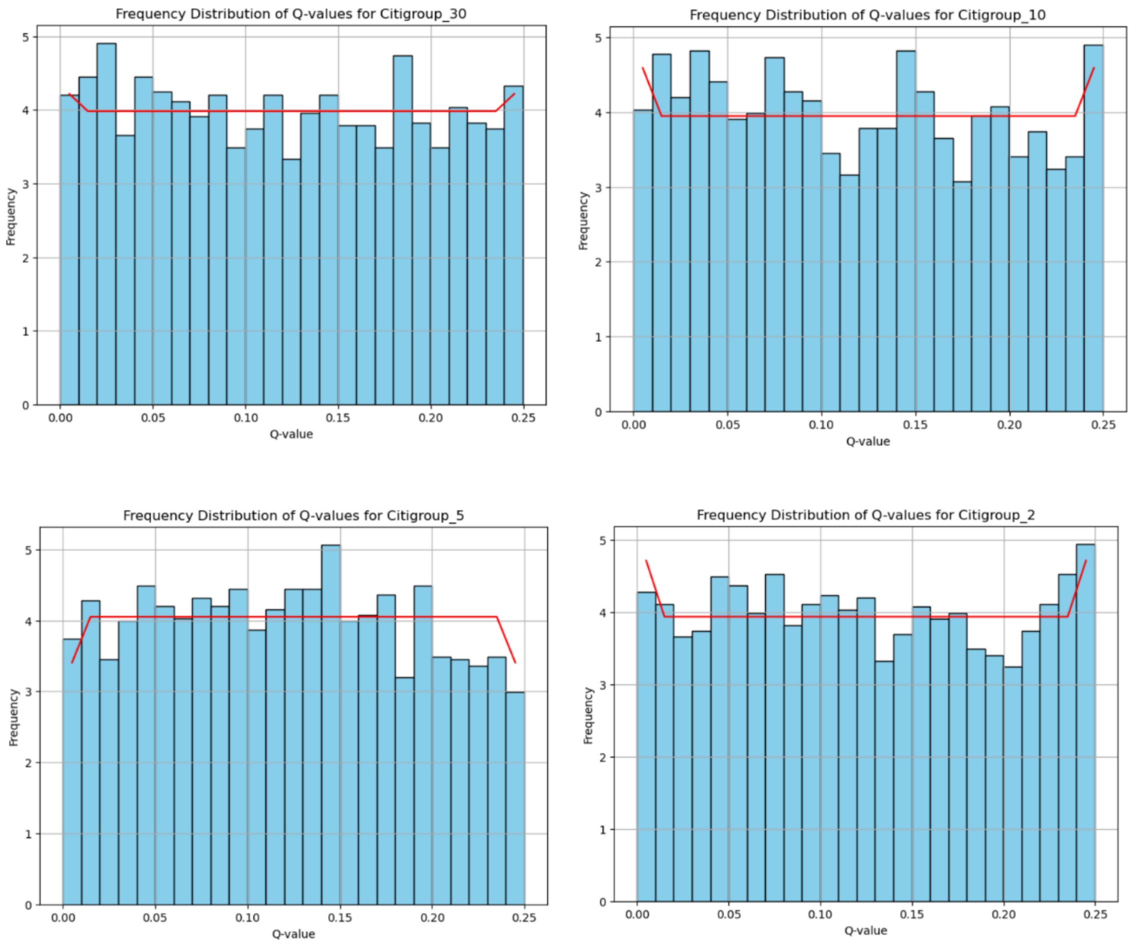
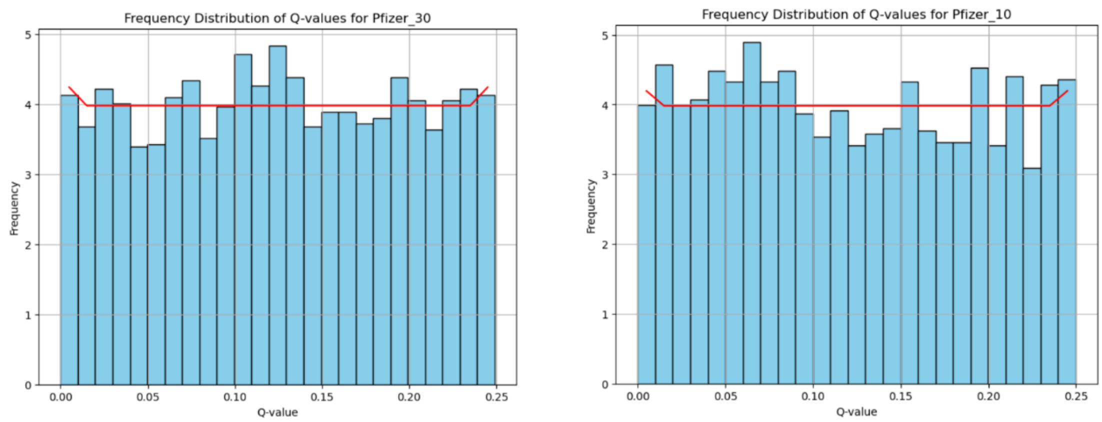


Figure 50. Frequency distribution of Q-values of Pfizer bonds with the barrier proximity regression



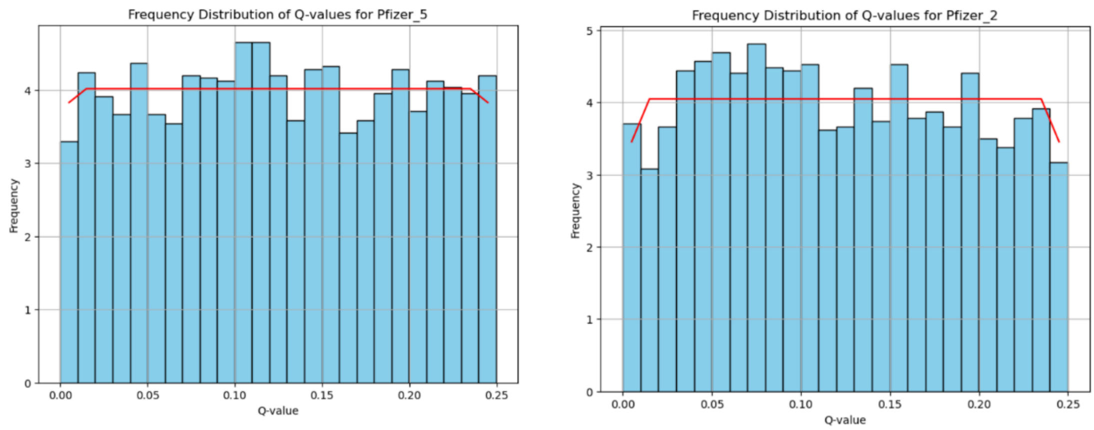
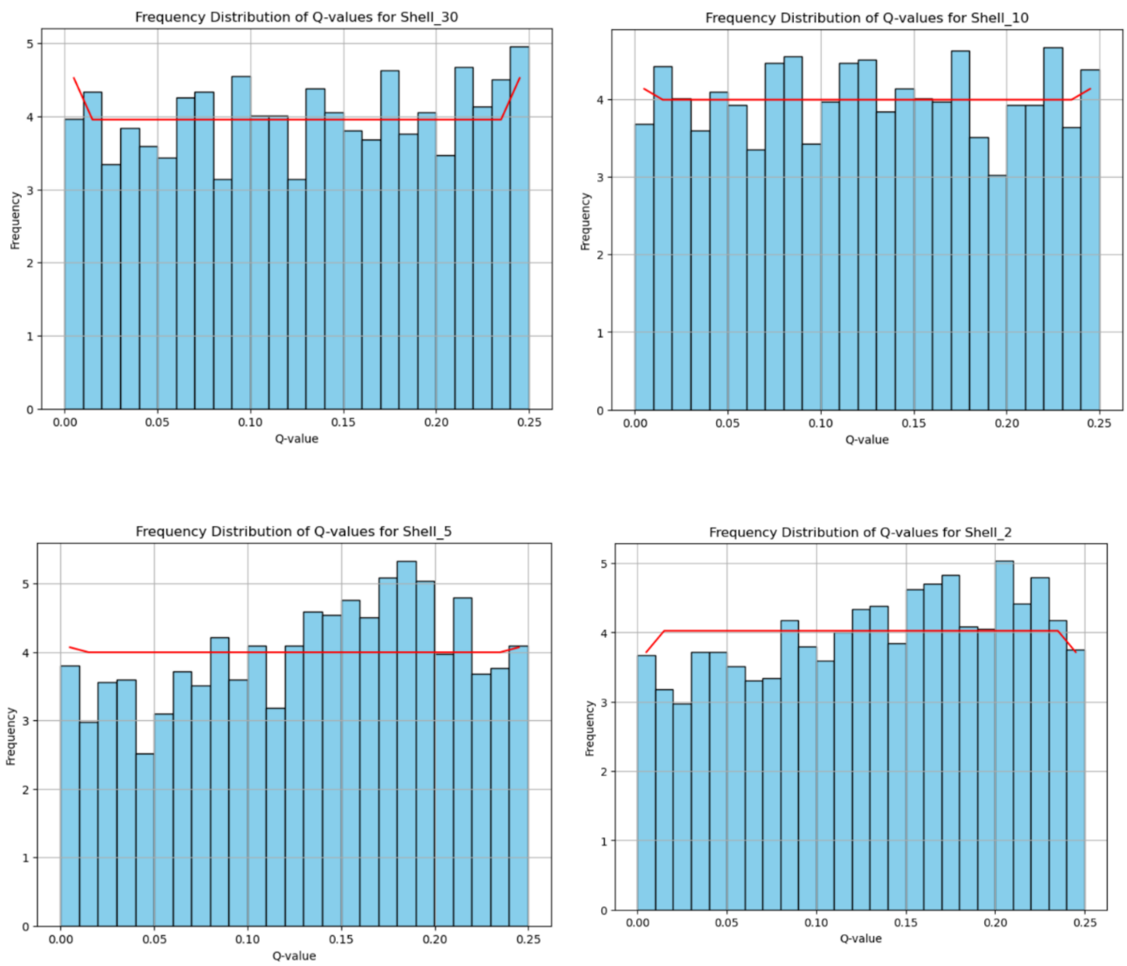


Figure 51. Frequency distribution of Q-values of Shell bonds with the barrier proximity regression



Appendix F – Frequency distribution of Q-values with the barrier hump regression

Figure 52. Frequency distribution of Q-values of China government bonds with the barrier hump regression

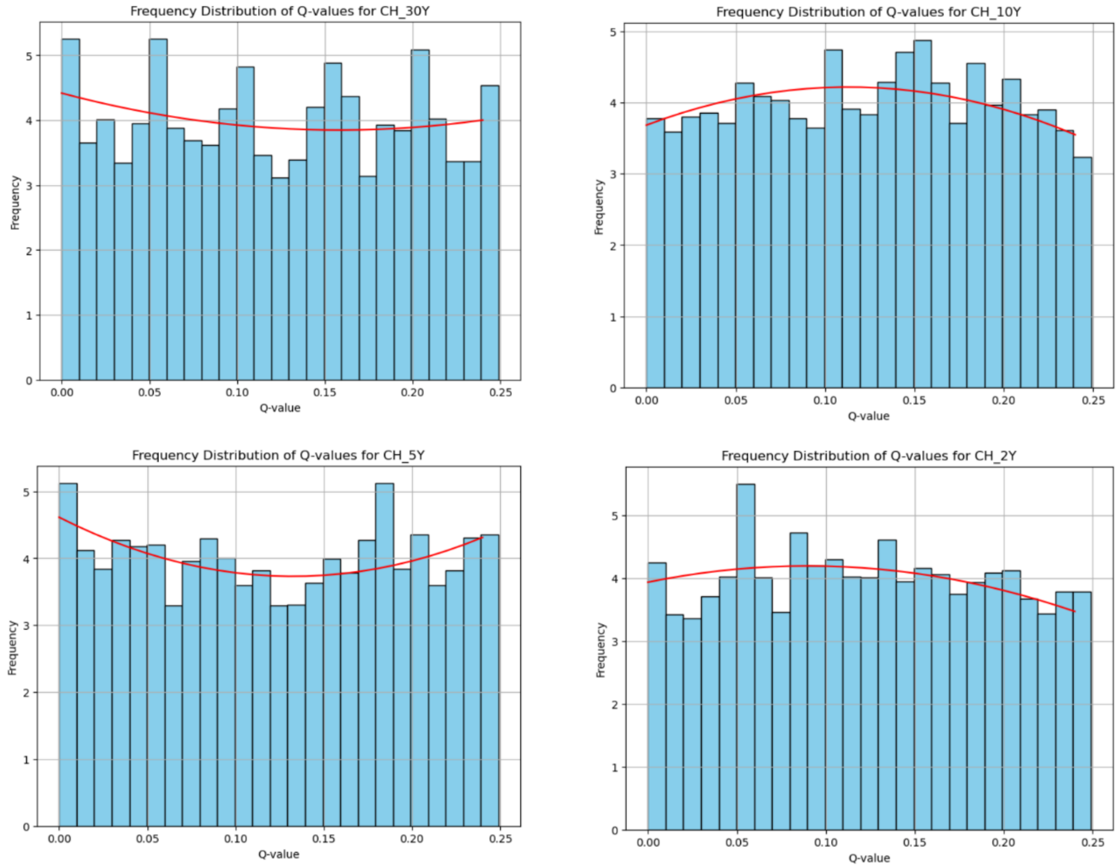
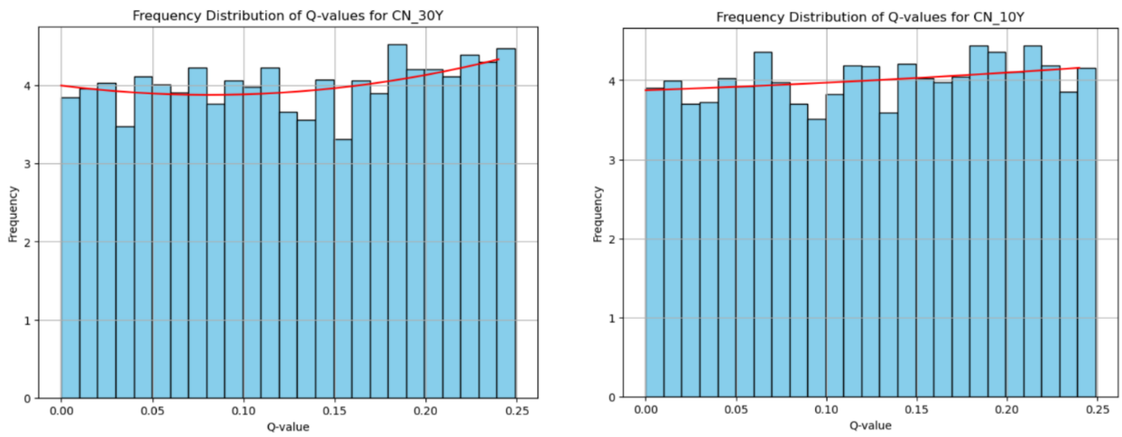
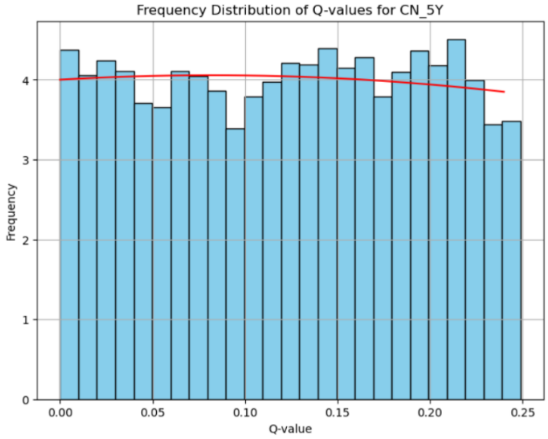


Figure 53. Frequency distribution of Q-values of Canada government bonds with the barrier hump regression





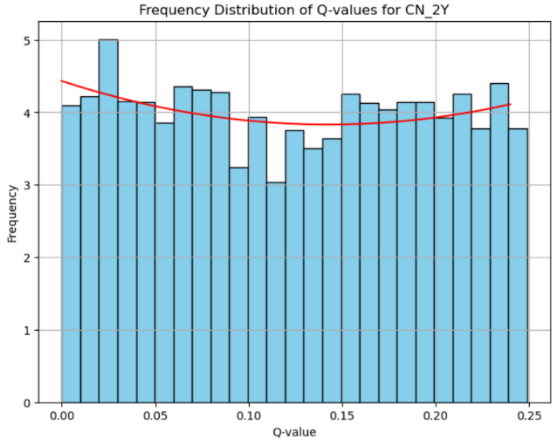
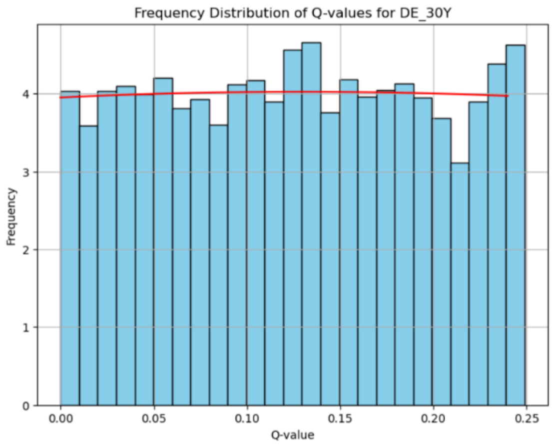
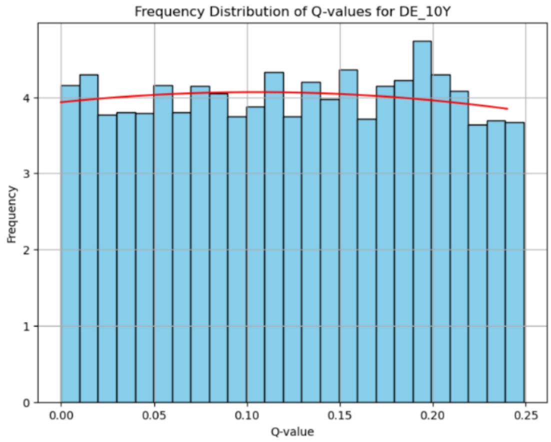
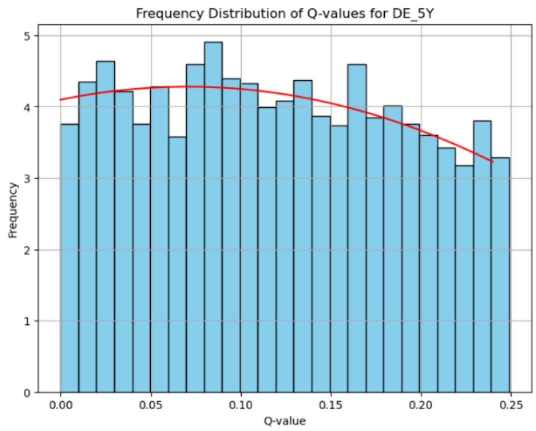


Figure 54. Frequency distribution of Q-values of Germany government bonds with the barrier hump regression







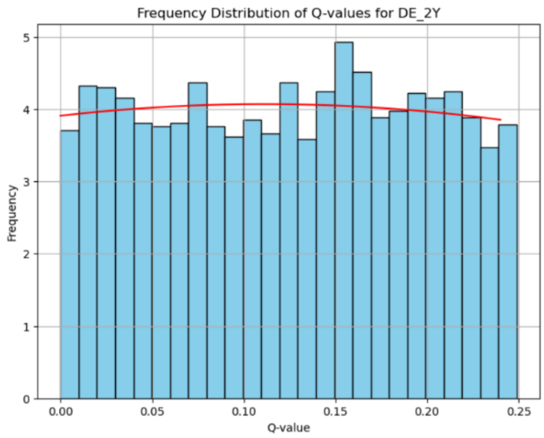


Figure 55. Frequency distribution of Q-values of France government bonds with the barrier hump regression

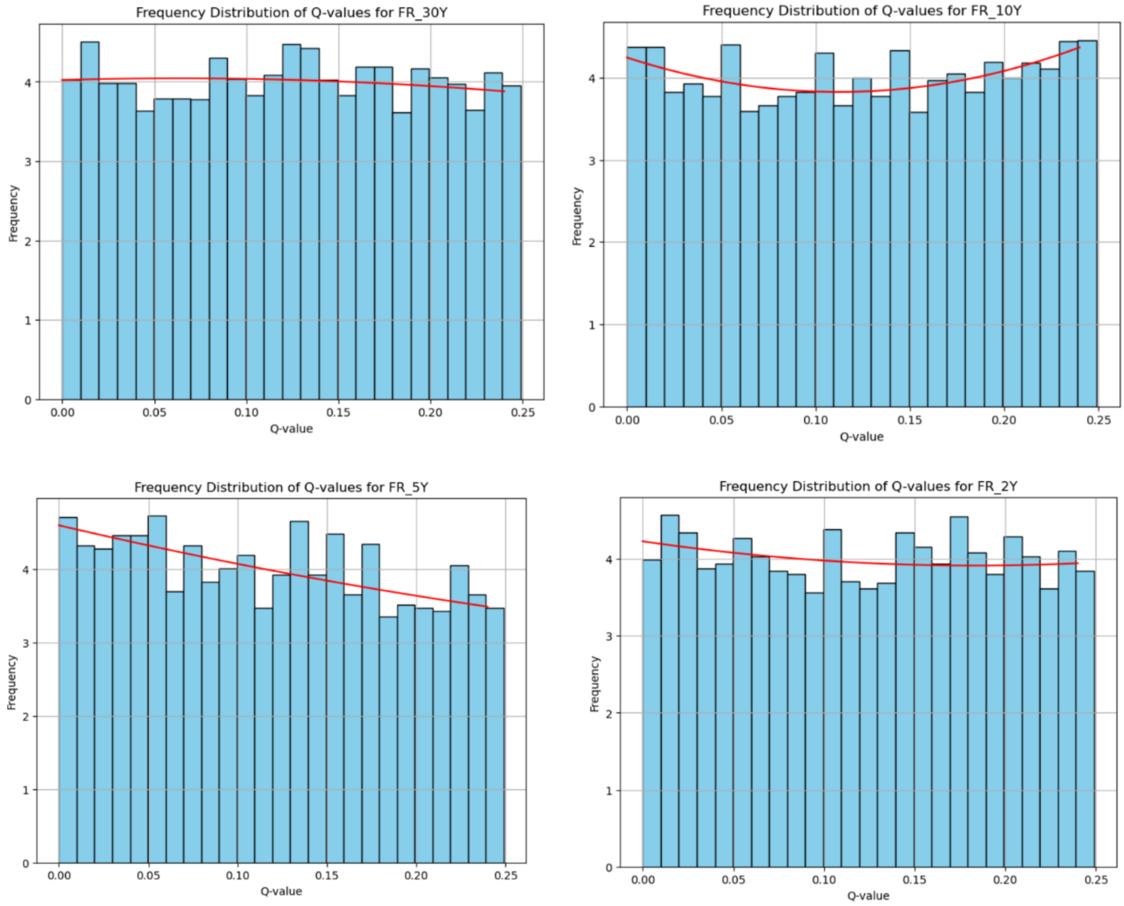
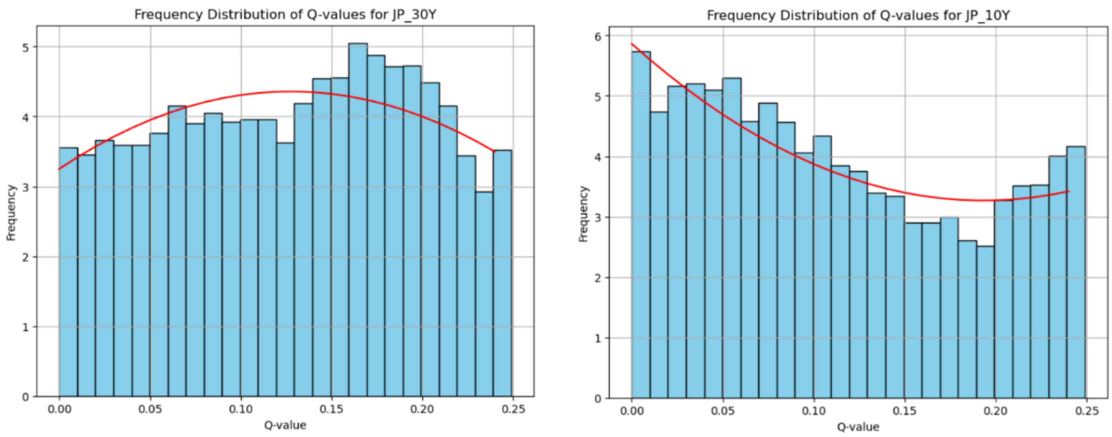


Figure 56. Frequency distribution of Q-values of Japan government bonds with the barrier hump regression



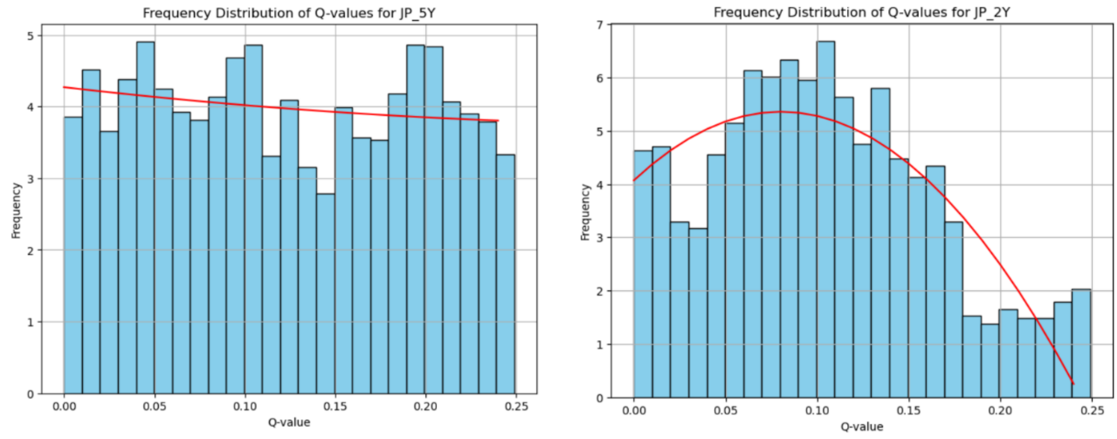


Figure 57. Frequency distribution of Q-values of UK government bonds with the barrier hump regression

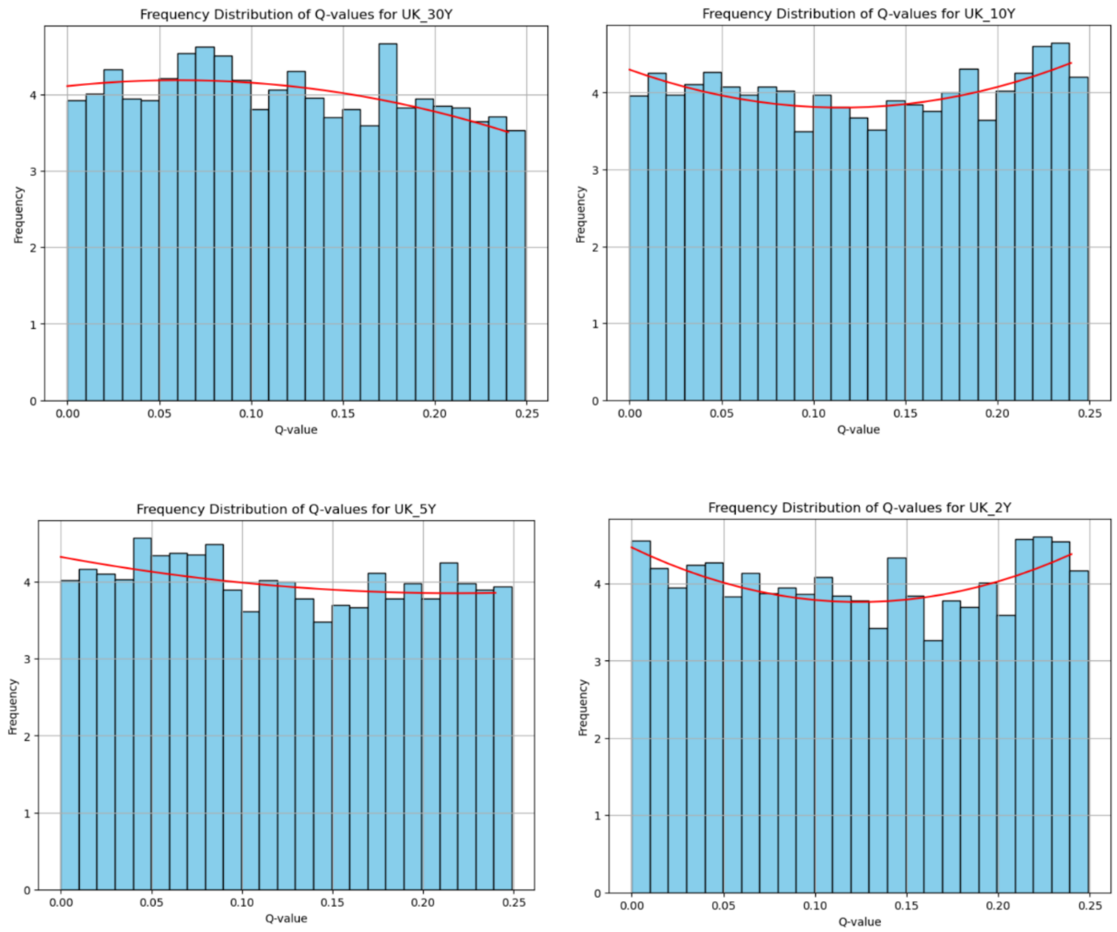


Figure 58. Frequency distribution of Q-values of US government bonds with the barrier hump regression

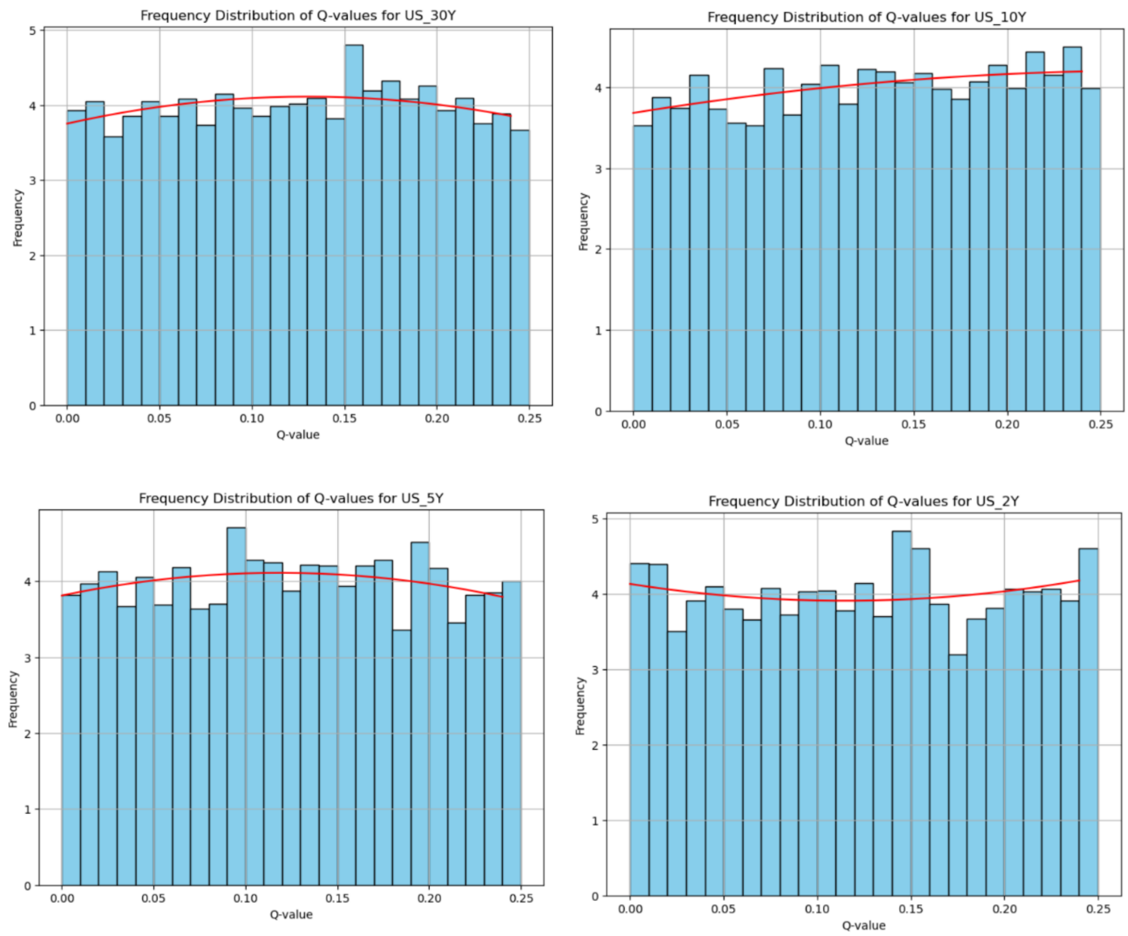
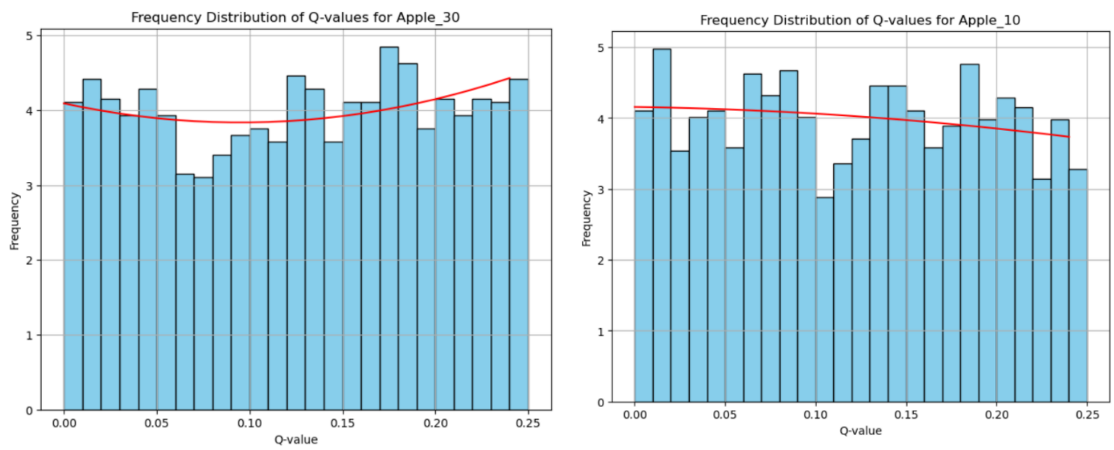


Figure 59. Frequency distribution of Q-values of Apple bonds with the barrier hump regression



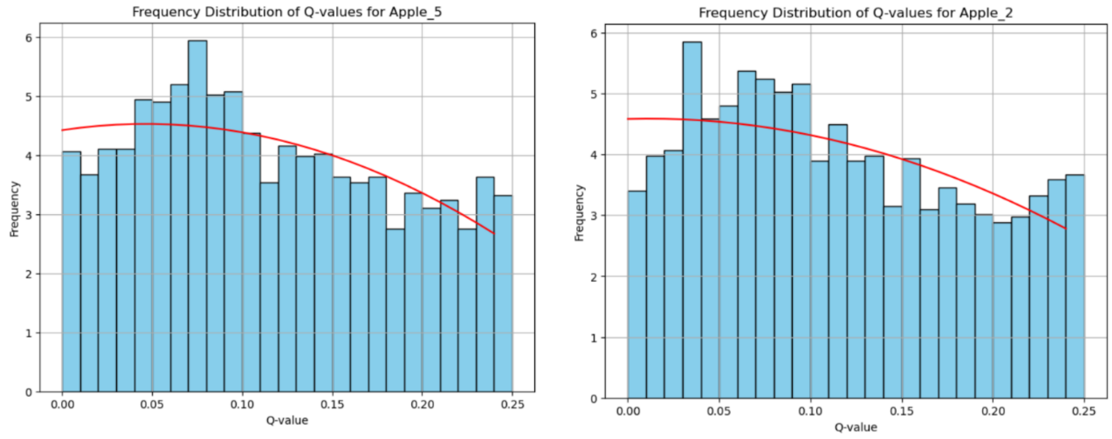


Figure 60. Frequency distribution of Q-values of Citigroup bonds with the barrier hump regression

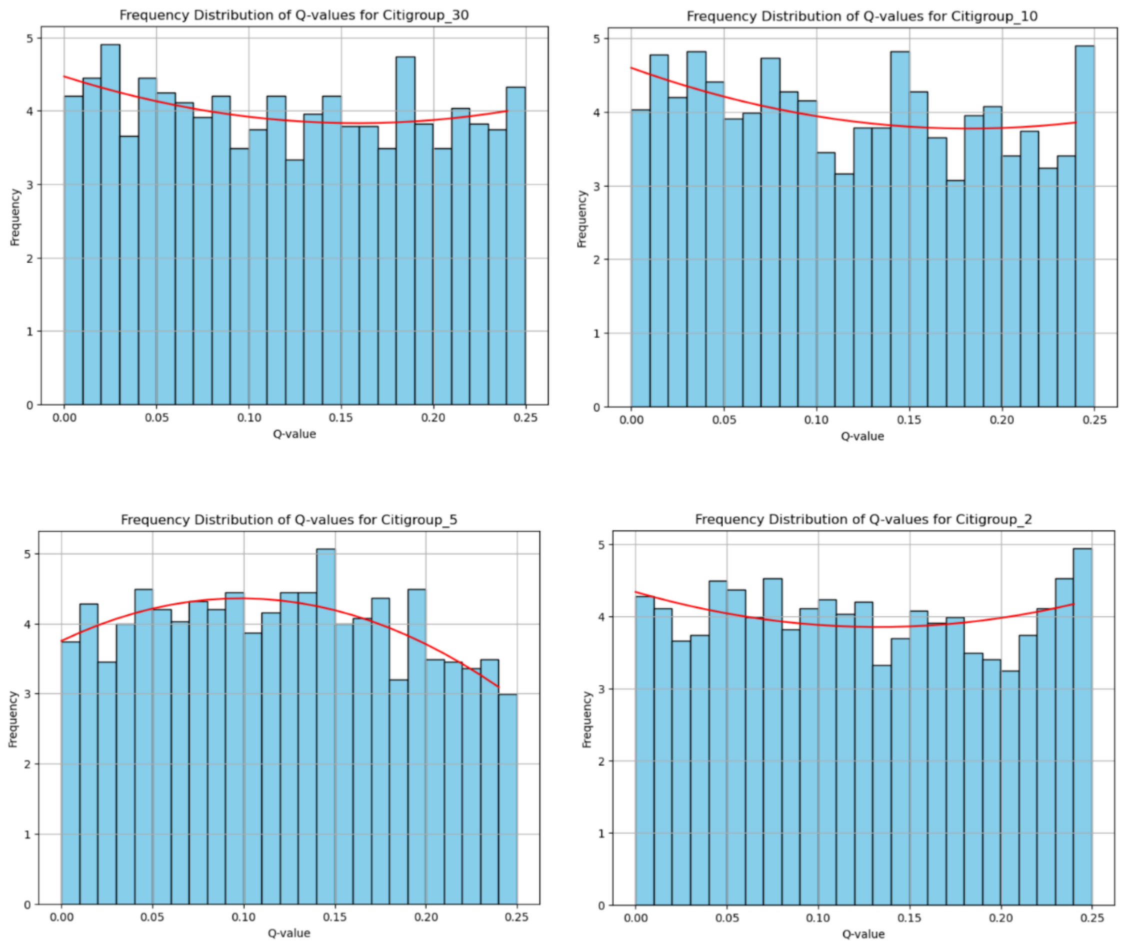


Figure 61. Frequency distribution of Q-values of Pfizer bonds with the barrier hump regression

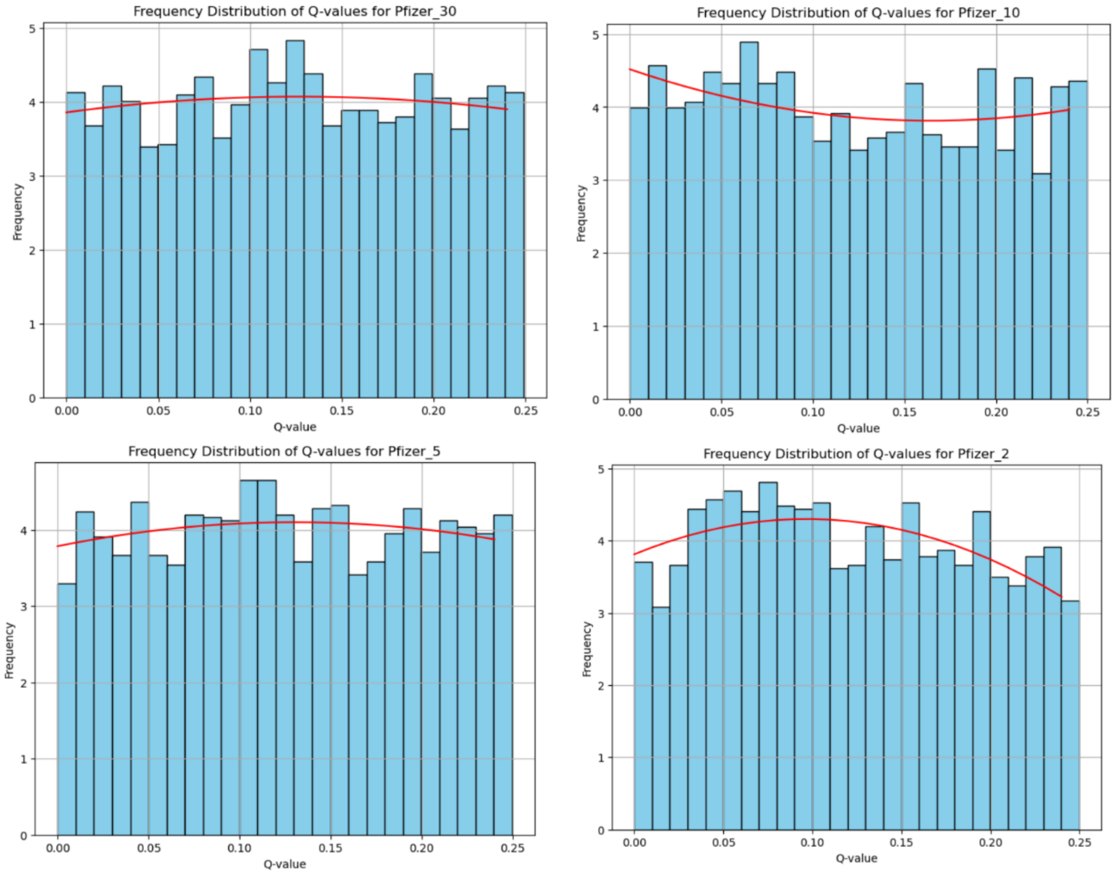
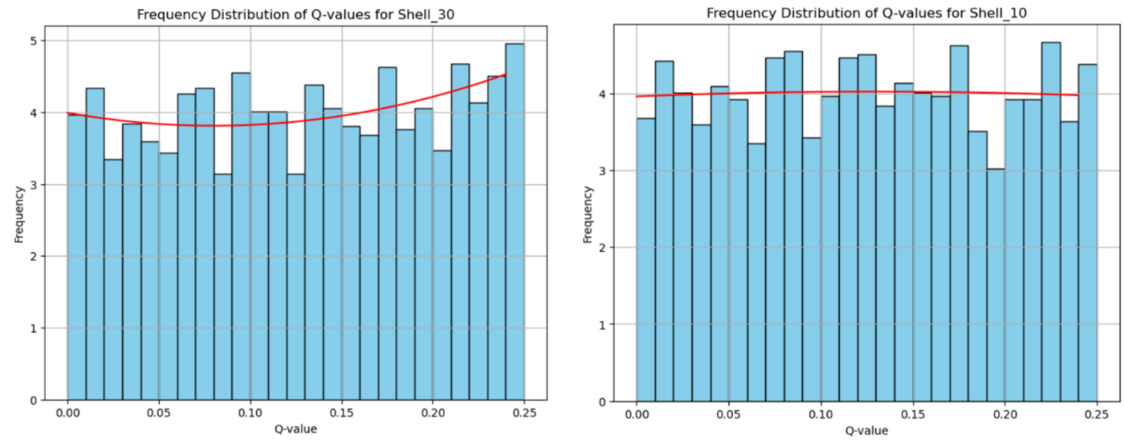
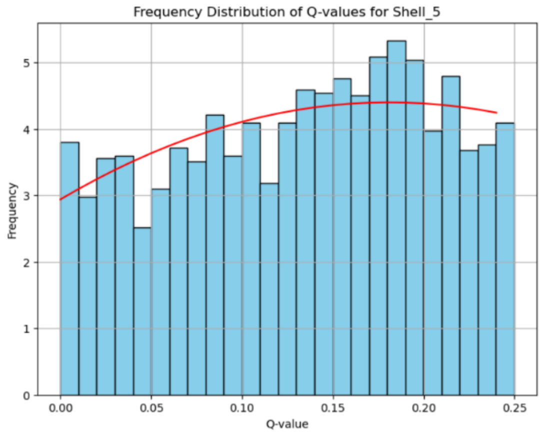
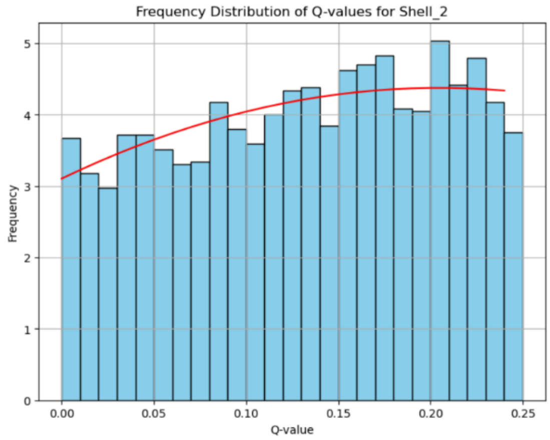


Figure 62. Frequency distribution of Q-values of Shell bonds with the barrier hump regression




Frequency Distribution of Q-values for Shell_5
Frequency
Q-value


Frequency Distribution of Q-values for Shell_2
Frequency
Q-value

Appendix G – First differenced yield series with the market prediction regressions

(Note: only US bonds are presented, as regressions are extremely similar among every other bond since the regression's slope is approximately 0 to every bond)

Figure 63. First differenced yield series of the US government bond with the conditional mean regression

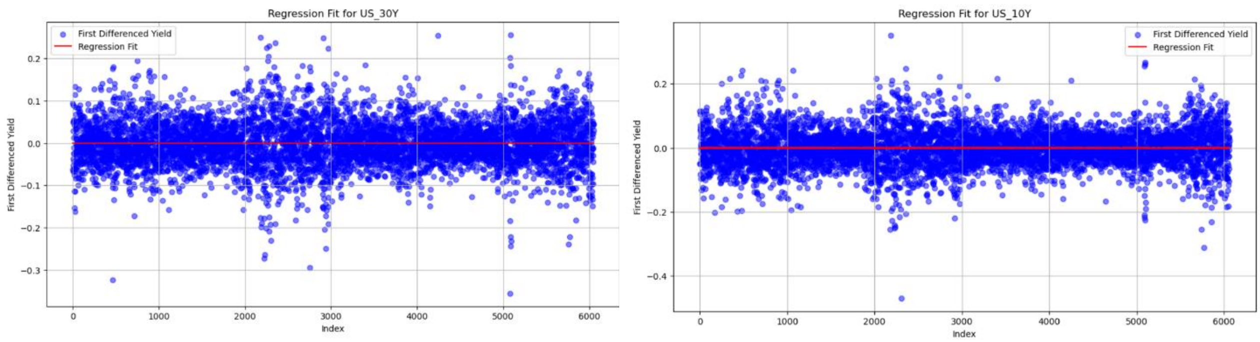
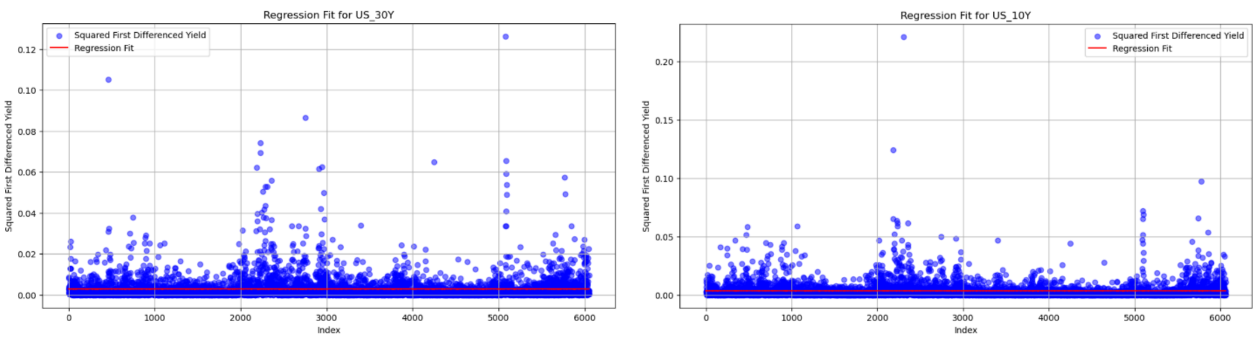


Figure 64. First differenced yield series of the US government bond with the conditional volatility regression



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