Norwegian University
of Life Sciences

Master's Thesis 2016 30 ECTS
Faculty of Social Sciences
School of Economics and Business

The Weekend's Impact on Norwegian Government Bond Volatility

Stian Haugland
Master of Science in Business Administration

Preface

This thesis does not just mark the end of a two-year master's degree; it marks the end of a five-year adventure at NMBU and Ås that has contributed to some of my best moments, both educationally and social. I have somehow managed to complete a three-year bachelor's degree and a two-year master's degree with major in finance and investment and minor in environmental- and resource economics during this time.

I want first of all thank my supervisor Espen Gaarder Haug for proposing the topic, close supervision, good advice and many interesting discussions along the way. I also want to thank the Oslo Stock Exchange for providing the necessary data.

Lots of gratitude to family and friends for spellchecking and a big thanks to Sindre Haugland for his help and support with illustrations.

Any errors and omissions are my sole responsibility.

Abstract

The objective of this thesis is to explore how the weekend affects the general trading day in the Norwegian government bond market in the period 2000 - 2015. The empirical analysis consists of closing prices based on seven different government bonds traded on the Oslo Stock Exchange. When comparing the weekend variance with identical calendar and trading time, the results reflected a deviation from the Calendar-Time Hypothesis and a consistency with the Trading-Time Hypothesis. The Trading-Time Hypothesis is found be the best describing price behaviour for bonds with lesser than five years to maturity.

These results cause evident implications for Value at Risk analysis. When approaching the Calendar-Time Hypothesis in favour of acknowledging the weekend's effect on volatility, the results lead to a risk overestimation during the weekend and risk underestimation during weekdays. The Trading-Time Hypothesis is generally a better fit, where the over- and underestimations are relatively centred around zero. The same implications apply for option valuation in the Norwegian government bond market. When approaching the Calendar-Time Hypothesis in favour of acknowledging the weekend's effect on volatility, the results lead to a pricing overvaluation during the weekend and pricing undervaluation during weekdays. In terms of percentage over- and undervaluation, out-of-the-money options show a stronger sensitivity to misinterpret the weekend's volatility compared to in-the-money options. The significance of this misinterpretation decreases as maturity increases and almost completely vanish after one year.

Sammendrag

Denne masterutredningen undersøker hvorvidt helgen påvirker handledager i det norske markedet for statsobligasjoner i løpet av perioden 2000-2015. Den empiriske analysen består av close priser fra syv ulike statsobligasjoner som handles på Oslo Børs. Når variansen over helgen sammenlignes med identisk kalender- og handletid, viser resultatet et avvik fra Kalendertid Hypotesen og en tilnærming til Handletid Hypotesen. Handletid Hypotesen blir sett på som best beskrivende for prisutviklingen til obligasjoner med mindre enn fem år til forfall.

Disse resultatene skaper tydelige utfordringer for Value at Risk analyse. En tilnærming til Kalendertid Hypotesen, som positivt anerkjenner helgens påvirkning på volatilitet i ukedagene, resulterer i en overestimering av risiko over helgen og en underestimering av risiko i ukedager. Handletid Hypotesen gir en bedre risiko beskrivelse, hvor over- og underestimeringen av risiko er relativt sentrert rundt null. De samme utfordringene gjelder for opsjonsprising i det norske markedet for statsobligasjoner. En tilnærming til Kalendertid Hypotesen, med sin anerkjennelse av helgens påvirkning på volatilitet i ukedagene, resulterer i en overprising over helgen og en underprising i ukedager. Når det gjelder prosentvis over- og underprising, så viser out-of-the-money opsjoner en mye større sensitivitet enn in-the-money opsjoner, i forhold til feiltolking av helgens påvirkning på volatilitet i ukedagene. Betydningen av denne feiltolkningen reduseres når løpetiden øker og er nesten helt borte etter et år.

Table of Contents

1 Introduction

The objective of this thesis is to explore how the weekend affect the general trading day in the Norwegian government bond market in the period 2000 - 2015. Seven chosen government bonds traded on the Oslo Stock Exchange forms basis for the analysis.

This thesis builds on two central hypotheses, the Trading-Time Hypothesis and the Calendar-Time Hypothesis. According to the Trading-Time Hypothesis, the non-trading days does not affect trading prices. On the other hand, the Calendar-Time Hypothesis opposes this and implies that only the passage of time dives prices. These hypothesises argue two different price return variances during the weekend relative to the general trading day, because the weekend consist of two non-trading days. Previous research as presented in chapter 3, finds a slightly higher variance associated with the weekend, thus placing financial markets somewhere in-between the Calendar- and Trading-Time hypothesis. The question is if this also represents the Norwegian government bond market.

Government bonds are regarded as safe haven for investors, because of the low default risk in investment grade bonds. However, volatility in the bond market affect financial player's risk and an accurate estimate of bond's volatility as the basis for risk management is of great interest. The bonds long-term characteristics are generally described by the pull-to-par effect presented in chapter 4, and the uncertainty regarding short-term characteristics is therefore of greater interest to financial players and the subject of this thesis. The negative relationship between interest rate and bond prices makes the current interest rate level[1] historically low and limit potential losses in the bond market. This makes the subject a relevant and recent topic of research.

This thesis' primary analysis consists of testing the Norwegian government bond market's volatility and how it is affected by a closed market. The weekend's impact on seven bonds is tested in accordance with the Trading-Time Hypothesis and the Calendar-Time Hypothesis. An analysis of how the news influence trading day volatility is also conducted to provide a

[1] 0,50 percent from 17.03.2016

complementary extension of the Calendar-Time Hypothesis. With the intent to examine implications of the weekend's effect, the results are applied in Value at Risk estimation and option valuation. Then the results from Value at Risk and option valuation form the basis for an assessment of risk management in the Norwegian bond market.

The thesis is structured as follows; Chapter 2 presents the theory of the Weekend Volatility Effect, while chapter 3 presents previous research. Chapter 4 provides a general overview of the Norwegian bond market. The theories of Value at Risk and option valuation in context with bonds are presented in the respective chapters 5 and 6. Chapter 7 presents the different bonds, of which the analysis is based on. Chapter 8 presents the methodology used for testing the weekend's impact on trading after the Trading-Time Hypothesis and the Calendar-Time Hypothesis. Thereafter, the methodology used to calculate Value at Risk and option prices is presented in chapter 9. All statistical results and implications to Value at Risk and option pricing is presented in chapter 10, and the conclusion and scope for further analysis are in final chapter 11.

2 The Weekend Volatility Effect

Trading days for financial securities are usually Monday to Friday with no active trading during the course of the weekend. This leads to interesting questions to what degree the weekend affect volatility in financial securities. Is price fluctuation affected by trading, time or both? In conjunction with testing the weekend's effect on trading day volatility, K. R. French (1980) conducted two opposing hypothesis; "The Calendar-Time Hypothesis" and "The Trading-Time Hypothesis".

2.1 The Calendar-Time Hypothesis

The Calendar-Time Hypothesis states that only the passage of time, cause price fluctuation. This hypothesis was first discussed, though not named, by Fama (1965). He argued that public political and economic news occurs continuously and makes price fluctuation proportional to the number of days elapsed. Hence, price fluctuation occurs regardless whether trading is active or not and is only affected by the passage of time and randomly occurring news. The Monday variance with the associated Saturday and Sunday variance should therefore be three times higher than any other given day of the week's variance. This hypothesis hinge on the random occurrence of news assumption and a rejection of Calendar-Time Hypothesis does not disprove news as a price fluctuating factor. The methodology behind testing the Calendar-Time Hypothesis and a complementary influence of news test are presented in respectively section 8.4.2 and 8.4.3.

2.2 The Trading-Time Hypothesis

The Trading-Time Hypothesis states that only trading cause price fluctuation. K. R. French (1980) describes this hypothesis with a linear relationship between the price return variance and the random occurrence of trades when the market is open for trading. The Oslo Stock Exchange closes the bond market during the weekend. Therefore, the Monday variance with no associated Saturday and Sunday variance should be equal other trading day variances. A rejection of the Trading-Time Hypothesis does not necessarily disprove trading and validate news as a price fluctuating factor. This rejection can reflect different trading volumes between the comparable trading days. The methodology behind testing the Trading-Time Hypothesis is presented in section 8.4.1.

3 Previous Research

The “weekend effect” term has a variety of definitions, and the financial market frequently use the term to describe relatively large price returns on Fridays compared to those on Mondays. However, this thesis uses the term to describe the weekend’s impact on trading day volatility and no consideration will be given to price returns. Previous research in contrast is considerably more devoted in studying the weekend’s impact on trading day price returns. Stocks are also the generally preferred subject over other financial securities and the following presented previous research is a description of the stock market.

Fama (1965) used a sample set of daily closing prices from thirty stocks of the Dow-Jones Industrial Average from 1957 to 1962. Eleven randomly selected stocks from the sample showed a 22% higher weekend variance than the general trading day. K. R. French (1980) used a sample set of daily closing prices from the Standard and Poor’s index of the 500 largest firms in US, from 1953 to 1977. The sample showed a 19% higher weekend variance than the general trading day. K. R. French and Roll (1986) used a sample set of daily closing prices from all common stocks listed on the New York and American Stock Exchanges, from 1963 to 1982. The sample showed a 10,7% higher weekend variance than the general trading day. Hence, the three researches estimates the weekend’s volatility to be, respectively, 22%, 19% and 10,7% higher than the general trading day. It is important to emphasize that the weekend variance includes Monday trading consequently from the usage of daily closing prices. The Calendar-Time Hypothesis suggest that the weekend volatility is three times higher than the general trading day, which is far from the case in these results.

One compelling argument against the random occurrence of news, and thus the Calendar-Time Hypothesis, is that most public information arrives during normal business hours. Roll (1984) did a similar analysis as the three mentioned above, but with a greater focus on the influence of news. The analysis consisted of orange juice futures traded on the New York Exchange, from 1975 to 1981. The weather is the main influence on juice production and because the weather do not distinguish between weekend and weekday, it meets the random occurrence of news assumption. Roll (1984) found a 54% higher weekend variance than the general trading day. Again, the Calendar-Time hypothesis is not validated despite the weather providing a random occurrence of news. Thus, the stock and orange juice market is found to be somewhere in-between the Calendar- and Trading-Time hypothesis. This leads to the obvious question whether the volatility in any of these markets can be assumed equal for the bond market. Campbell and Ammer (1993) found a low correlation between the unconditional stock and bond price returns. However, Fleming, Kirby, and Ostdiek (1998) used the S&P500 stock index futures and the Treasury bond futures to find a strong volatility linkage between the two markets. This makes it reasonable to expect similar weekend volatility effects in the bond market.

4 The Norwegian Bond Market

The Norwegian bond market distinguishes between newly issued bonds in the primary market and exchanging previously issued bonds in the secondary market.

Newly issued bonds in the primary market are issued through auction or other methods determined by Norges Bank[2]. The type of auction used in this market is the uniform price (Dutch) auction where the bidders bid on price and volume is sealed. The consequential accepted price is an equilibrium between the demanded and offered volume and the winning bidders are issued their demanded volume. Norges Bank announces the offered volume in advance and if the demanded volume is lower than offered volume, the auction cancels out. In the case of bond NST477's auction 11.05.2015, the lowest accepted price was 101,50. The bidders who bid above 101,50 does not need to pay the exceeding bidding amount but bidders who bid below 101,50 are not issued any bonds.

After being issued in the primary market, the bonds are freely tradeable in the secondary market. Bonds are traded on both Oslo Stock Exchange and Nordic ABM[3], but government bonds are only traded at the former. Options on government bonds are not listed on Oslo Stock Exchange but E. G. Haug (1995) describes an over-the-counter (OTC) trading for Norwegian government bonds and a similar situation is expected to exist today. The secondary market yields liquidity benefits as well as regular information about the bonds value. Furthermore, it brings together interested parties and thereby reducing costs related to searching for buyers and sellers (Frank J. Fabozzi & Anson, 2007). The par value of the bonds is 1000 NOK while in the market, bond prices are quoted in percentage. Thus, in the NST477 auction stated above, the quoted price was 101,50 but the cash bond price was 1015 NOK. The relatively low par value of 1000 NOK provides the opportunity for bond investors to divide the borrowed amount into smaller parts, and makes it easier for smaller investors to enter the market.

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[2] The Norwegian central bank issue government bonds and treasury bills on behalf of the Ministry of Finance.

[3] A separated market place for bonds and certificates and not regulated under the terms of the Stock Exchange Act.

With the intent to promote sales in the primary market and turnover in the secondary market, Norges Bank enters into agreements with primary dealers. These dealers are large banks and financial institutions and consist of Danske Bank, DNB, Nordea and Skandinaviska Enskila Banken (Norges Bank, 2016). The primary dealers are the only ones who are allowed to submit bids in the primary market auctions and investors must submit bids through one of them. In the secondary market, the primary dealers act as market makers where they are obliged to quote bid and ask prices on the Oslo Stock Exchange in addition to report all trade transactions. Norwegian government bonds are more frequently traded than corporate bonds. Ødegaard (2012) found an average of 45 trading days in the fourth quarter of 2011 for government bonds traded on the Oslo Stock Exchange, while corporate bonds only showed an average of 4 days in the same period. Despite the relatively high government bond liquidity, they do not trade on a daily basis as each quarter has more than 60 trading days.

The two main factors influencing bonds value and volatility, are the market interest rate and the pull-to-par effect. Figure 1 illustrates the phenomenon known as the pull-to-par.

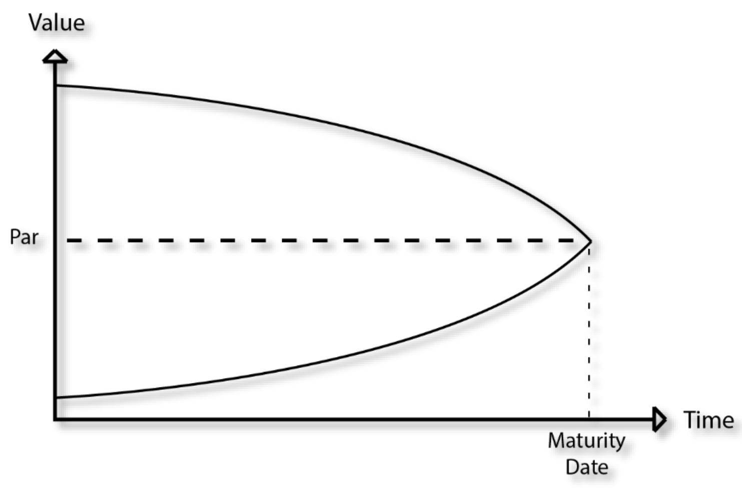

Figure 1: Illustration of bonds pull-to-par effect towards maturity

The consistently downward spiralling volatility and convergence to par at maturity date is a key representation of the long-term volatility characteristic for bonds and is frequently referred throughout this thesis.

5 Value at Risk - Theory

The chapter provide the theoretical background for analysing the weekend's implications for Value at Risk estimation. The VaR estimate provides a single number that summarizes the total risk in a portfolio of financial assets (Hull, 2012). The number expresses maximum loss exposure to a portfolio, given it is held over some period of time and consist of two basic elements: time period and confidence level. An example of 99% one-day VaR = -1%, means that we are 99% confident that an investment will not lose more than one percentage from holding the investment one day. 99% and 1% VaR are used interchangeably to explain the same tail risk but for this thesis, 100% - 50% VaR is used to describe the lower tail risk, while 50% - 0% VaR is used to describe the upper tail risk. 99% and 1% VaR will therefore represent the same risk, but for the respectively lower and upper tail distribution. The three main VaR methods are the parametric method, historic method and Monte Carlo method. Due to time considerations, this thesis only focuses on the parametric and historic method.

5.1 The Parametric Method

The parametric method contains an analytic formula based on an assumed parametric distribution to calculate VaR estimates (Alexander, 2009). The most basic assumption behind the parametric method is that the distribution follows normal distribution, and the formal definition of the parametric method is:

$$VaR_{\propto} = N^{-1}(\propto)\sigma - \mu$$

where μ is the mean price return, σ is the volatility, N^{-1} is the inverse of a normal density function, and α is the significance level. The mean price return is assumed constant over time for this thesis. The purpose of the VaR analysis is to estimate future risk, and the assumption of zero daily price return exclude potential arbitrage.

The commonly used significance levels for the lower tail, and subjects for this thesis, are 0,01 and 0,05. These significance levels provides two standard deviations from the inverse normal density function as follows:

$$N^{-1}(0{,}01) = -2{,}32635, \qquad N^{-1}(0{,}05) = -1{,}64485$$

The two significance levels, express a 99 and 95 percentage certainty that a normal distributed variable will not decrease more than respectively 2,33 and 1,645 standard deviations from its mean value. By the symmetry of the normal distribution function, this also applies to increase on the upper tail. The VaR estimates for the different significance levels are calculated as follows:

$$95\%VaR = (1{,}645 * \sigma) - 0, \qquad 5\%VaR = (1{,}645 * \sigma) + 0$$
$$99\%VaR = (2{,}33 * \sigma) - 0, \qquad 1\%VaR = (2{,}33 * \sigma) + 0$$

As a complementary element, an investment loss value is added to the analysis, and the investment loss is simply calculated by multiplying the VaR estimate with the investment value.

5.2 The Historical Method

The historical method produces a VaR estimate that is calculated directly from the data sample. By sorting the data from lowest to highest price return, one can cut off the worst and best price return for the respectively lower and upper tail. The lower tail 99% and 95% confidence levels are estimated as the 1st and 5th percentile of the price returns distribution. Equivalently, for the upper tail 1% and 5% confidence levels are estimated as the 99st and 95th percentile of the price returns distribution. The term "historical" VaR can be somewhat confusing as the parametric method also use historical data. Some authors therefore use the term "non-parametric VaR" model (Alexander, 2009). Compared to the parametric method, the historical method contains few distributional assumptions. The collected historic price returns from the sample, takes into account skewed and heavy tailed distributions, and assumes all past fluctuations to represent the future. Therefore, the main limitation of the historical method comes from the sample size. In order to assume the historical distribution to be identical to the price return distribution in the approaching risk horizon, the sample size needs to be large enough with a "stable distribution" (Alexander, 2009). The Basel Committee on Banking Supervision recommends a period of three to five years to satisfy the sample constraint (Basel Committee, 2012). Again, the monetary investment loss is calculated for the historic method by multiplying the VaR estimate with the investment value.

5.3 VaR critic and Conditional Value at Risk

The main weakness of VaR is the normal distribution assumption. Numerous papers on financial instruments find price distributions with typically high peaks and fat tails, dating back to the early 1900s[4]. Distributions that fail to meet the normal distribution assumption will undervalue the real risk, which leads to investors undertaking more risk than estimated by VaR. Other distributions may be more suitable to describe different price distribution in cases where the normal distribution does not. Student t distribution is leptokurtic, which often is the case for low time horizons (Alexander, 2009). With a case of positive excess kurtosis, a student t distribution is more likely to produce VaR estimates representing historical behaviour. Other examples of distributions that can be implemented in the parametric method are the Johnson SU distribution, the Cornish-Fisher expansion, generalized Pareto and other extreme value distributions. Non-parametric methods have the possibility to implement Epanechnikov kernel and Gaussian kernel. (Alexander, 2009).

Basel Committee (2012) recognizes the associated weakness with VaR estimates and instead propose the use of Conditional Value at Risk (CVaR) [5] to capture tail risk. CVaR is the mean loss, given that the VaR estimate is exceeded. It is simply calculated by averaging all observations exceeding the VaR estimate and producing greater absolute values. Despite the associated VaR weakness, it is still a popular measurement and this thesis will present both VaR and CVaR in the analysis.

[4] See Haug (2007) for more details on non-normal distribution

[5] Also known as Expected Tail Loss (ETL) and Expected Shortfall (ES)

6 Bond Option Valuation - Theory

This chapter provides the theoretical background to analyse the weekend's implications for option valuation. The arguably most common option pricing model was created by Black and Scholes (1973) and was intended for option valuation on stocks. Although the model has been applied to value options on bonds, its applicability is limited. Frank J. Fabozzi and Anson (2007) points out three of the underlying assumptions in the Black-Scholes model that limits it applicability on valuating bond options. Firstly, the probability distribution assumes that the price can take any positive value, even though the probability is low. Unlike stocks, bond prices have a maximum price value. For example, consider a 5-year 5% coupon bond with a maturity value of 100 NOK. The price cannot be greater than 125 (5 coupons of 5 NOK plus a maturity value of 100 NOK). Secondly, the Black-Scholes model assumes the short-term interest rate to be constant over the life of the option. A bond option price change in conjunction with the interest rate and makes this an unrealistic assumption. Thirdly, the Black-Scholes formula assumes constant variance of returns over the life of the option. The pull-to-par effect described in chapter 4 violates this assumption.

Black (1976) later published a model for valuating European options on forward contracts, which is also used for valuating futures options and bond options. Together with the Black-Scholes model, the Black-76 model also fails to take into account the pull-to-par effect. The term to maturity of the option being evaluated, should therefore not be longer than one fifth of the term to maturity of the underlying bond and is considered a rule of thumb by some traders (E. G. Haug, 2007). Given this rule, options on Norwegian government bonds should not be valuated with maturity longer than two years from the start of the bonds maturity.

The Arbitrage-Free Binomal Model is theoretically more correct for valuating bond options, and is stated by Frank J. Fabozzi and Anson (2007) to be the only proper way of valuating bond options. The Binomal Model divides the option's life into short time periods, and each period is assumed to only be able to do two price movements. This model can be used on American or Bermuda options, while Black-76 can only be used on European options. Despite limitations, the Black-76 formula is the most commonly used model for valuating bond options. Mainly due to speed and simplicity, the Black-76 formula is the chosen valuation method further in the analysis and is calculated as follows:

$$C = e^{-rT}[FN(d_1) - KN(d_2)]$$

$$P = e^{-rT}[KN(-d_2) - FN(d_1)]$$

where

$$d_1 = \frac{\ln\left(\frac{F}{K}\right) + \frac{\sigma^2 T}{2}}{\sigma\sqrt{T}} \text{ and } d_2 = d_1 - \sigma\sqrt{T}$$

where F is the forward price of the bond at expiration of the option, K is the strike price of the bond option, r is the continuously compounded risk free interest rate and T is the time in years to maturity. The forward price is given by:

$$F = \frac{B_0 - I}{e^{-rT}}$$

where B_0 is the bond price at time zero and I is the present value of the coupons paid during the life of the option. The forward price (F) substitutes the bond price and includes risk neutral expectations about future price behaviour.

6.1 The Greek letters

The following Greeks are the main measures of interest for understanding the implications of a changing volatility on the value of an option. In this section and hereafter; in-the-money, at-the-money and out-of-the-money options will be referred to by their respective abbreviations: ITM, ATM and OTM.

6.1.1 Delta

The delta (Δ), measures the rate of change of the option price with respect to the price of the underlying asset. Delta therefore estimates the option's sensitivity to fluctuation in the underlying asset price. Figure 2 illustrates the variation of delta with the bond price for call option.

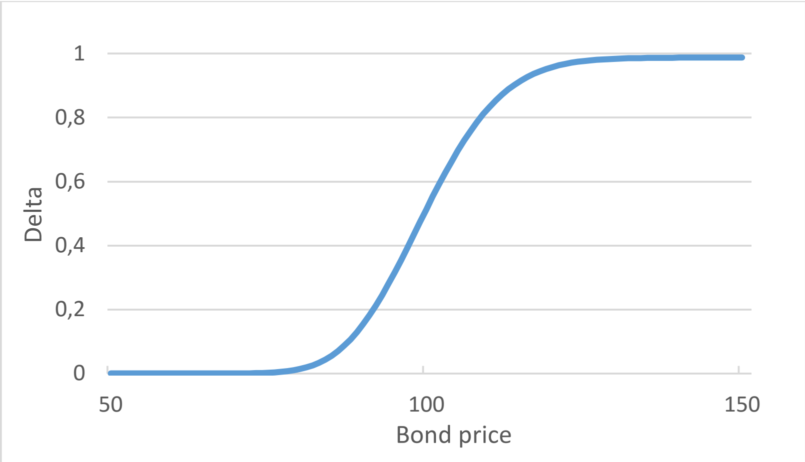

Figure 2: Delta of an bond call option with K=100, r =5%, σ =20%, T =90/365

Call positions have positive delta because a price increase in the underlying asset will increase the option value. Put positions have negative delta because a price increase in the underlying asset will decrease the option value. This is the case for long positions, while short positions have the opposite features. In absolute values, the delta increases as an option moves from OTM to ITM (Hull, 2012). DdeltaDvol is the change in delta with respect to changes in the volatility, and delta's sensitivity to volatility changes is negative for ITM options and positive for OTM options (E. Haug, 2003).

6.1.2 Vega

The vega (ν), measures the rate of change in an option value with respect to the volatility of the underlying asset. Vega therefore estimates the option's sensitivity to volatility changes in the underlying asset. Figure 3 illustrates the variation of vega with the stock price for option.

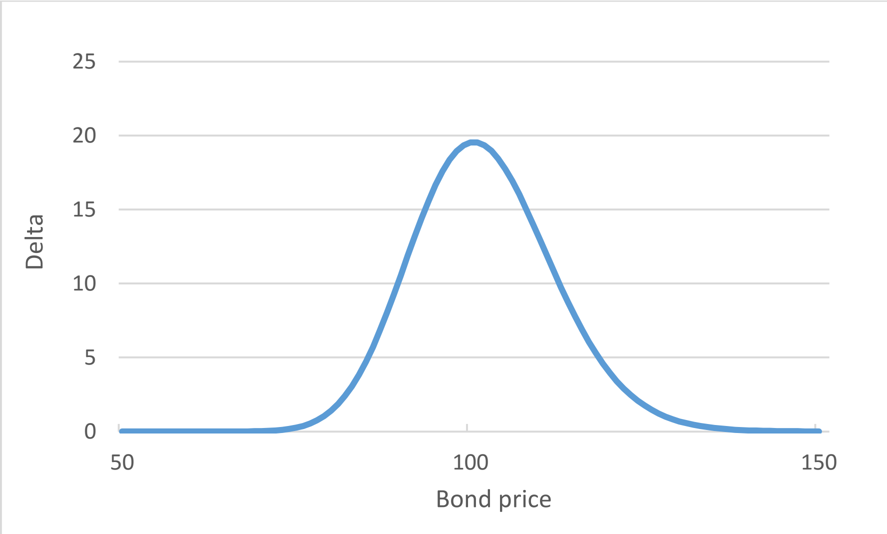

Figure 3: Vega of call option with K=100, r =5%, σ =20%, T =90/365

The vega value peaks at ATM options and decreases nearly symmetrically as the option moves towards ITM and OTM (Hull, 2012). Vega leverage[6] is the percentage change in the option value with respect to percentage point changes in volatility (E. Haug, 2003). Rather than the value change in the option price, the vega leverage shows the percentage change in the investment value. Given the low investment value for OTM options, these options experience a greater sensitivity to changes in volatility than ITM options. DvegaDvol[7] is the change in vega with respect to changes in the volatility, and vega's sensitivity to volatility is lowest for ATM options and increases as the option moves towards ITM and OTM (E. Haug, 2003).

As described previously in this chapter, the Black-76 formula assumes constant volatility. Calculating vega from the Black-76 formula therefore seems questionable. However, Hull and White (1987) found the calculated vega from a stochastic volatility model to be very similar to the Black-Scholes vega, which is also assumed to apply for Black-76.

[6] Or vega elasticity

[7] Also known as Vomma, Vega convexity and Volga

6.1.3 Theta

The theta (Θ), measures the rate of change in an option value with respect to the passage of time with all else remaining constant. Theta therefore estimates the option's sensitivity to change in time to maturity. Options usually have negative theta because, as time passes with all else remaining constant, options loose value as time moves closer to maturity (Hull, 2012). In contrary to the underlying asset price, there is no uncertainty about the passage of time. However, the inability to hedge against the passage of time makes theta have more of a conceptual parameter rather than a practical one.

7 Data Sources

Bond prices from seven different government bonds listed at the Oslo Stock Exchange were selected for analysis, and

Table 1 presents these various bonds.

Table 1: Seven Norwegian government bonds on the Oslo Stock Exchange selected for analysis.

Bond	Period	Maturity	Coupon
NST469	2000 – 2011	10 years and 341 days	6 %
NST470	2002 – 2013	10 years and 350 days	6,50 %
NST471	2004 – 2015	10 years and 347 days	5 %
NST472	2006 – 2017	11 years	4,25 %
NST473	2008 – 2019	11 years	4,5 %
NST474	2010 – 2021	11 years	3,75 %
NST475	2012 – 2023	11 years	2 %

The bonds NST469, NST470 and NST471 did not have identical lifespan as the others with 11 years. All these bonds are however treated equally despite the three with fewer observations. Because bonds changes by aging they are generally categorized into different maturity categories: short term (1 to 5 years), intermediate term (5 to 12 years) and long term (12 to 30 years). The selected bonds do not live longer than 11 years, and can only be separated into short term and intermediate term. Therefore, for the sake of this thesis, higher than 7 years to maturity is considered as long-term bonds and lesser than 3 years to maturity are considered as short-term bonds. In order to capture characteristics related to the bonds aging, Table 2 divide the bonds 11-year maturity into different years-to-maturity periods.

Table 2: Seven Norwegian government bonds on the Oslo Stock Exchange categorized into different years-to-maturity periods.

Time indicator	Years to Maturity	Bonds included in the specific period
11 – 9	10 + 9	NST469, 470, 471, 472, 473, 474, 475
9 – 7	8 + 7	NST469, 470, 471, 472, 473, 474
7 – 5	6 + 5	NST469, 470, 471, 472, 473
5 – 3	4 + 3	NST469, 470, 471, 472
3 – 0	2 + 1 + 0	NST469, 470, 471
3 – 1	2 + 1	NST469, 470, 471
2 – 0	1 + 0	NST469, 470, 471

Given that 11 years is a prime number; it is rather difficult to divide the study period into identical periods. The 3-0 period contains data from 3 years compared with 2 years in all the other periods. Period 3-1 and 2-0 are therefore created as “control periods” to see if they complement any effects shown in the 3-0 period. Price data from all bonds cannot be included in all years-to-maturity periods simply because they have not been active long enough to contribute price data for all periods. The specific bonds represented in each period are specified in the third column. For example, NST475 has a term to maturity of 7 years and 8 months. The price data from this bond can only be included in the 11-9 time series, and not 9-7 time series, because the bond have not been active long enough to contribute data from the entire seventh year left to maturity.

Since price data from all bonds are not included in all periods, this might impose a problem and making the time periods incomparable. One possible solution is to only use price data from NST469, NST470 and NST471, because these bonds have completed their maturity and can provide price data to all periods. Using price data from all seven bonds, compared to three, is simply preferred because it provides more data. The comparison between the three and seven bonds is presented in the appendix section 2. The price data consist of daily prices, ranging from listing day for the different bonds to 15.09.2015. In addition to the seven chosen bonds, there are three active bonds[8] issued by the Norwegian government that are not included in this thesis. These bonds have not been active long enough to produce three years of price data to be included in the 3-0 period at the collection date. As described in chapter 4, government bonds are not traded on a daily basis and daily closing bid and ask prices have therefore been used to create a synthetically closing price[9]. The entire dataset is holiday adjusted, meaning that days following a holiday have been eliminated.

7.1 Bonds price path and returns

The long-term characteristics for bonds price path and returns are very predictable to a certain extent. This section therefore only contains the historic price path and returns for bond NST469 that also illustrates the general behaviour in the other bonds.

[8] From 17.02.2016

[9] $\frac{bid+ask}{2}$

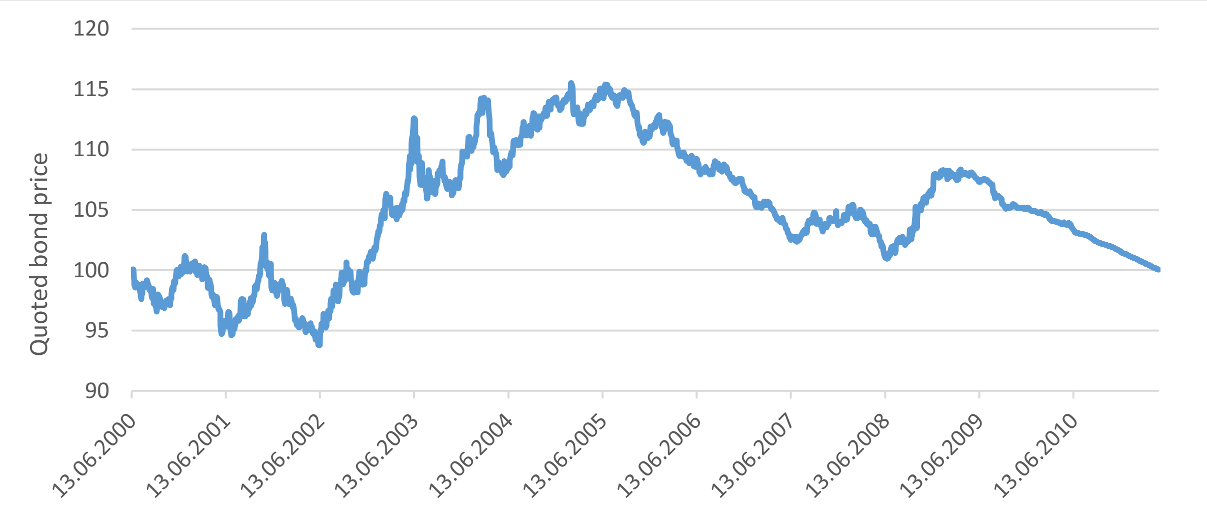

Figure 4: Historic daily close price for bond NST469 traded at Oslo Stock Exchange.

NST469, and the other bonds, are listed with a quoted price close to 100 and after a consistently downward spiralling volatility; they expire at par value (100). Because of the thesis' main interest in volatility and risk, the price paths are therefore of little interest and the other bonds price path are omitted. The following historic price returns in Figure 4, gives a better illustration of the pull-to-par effect presented in chapter 4, disregarding the two relatively high volatility periods in 2003 and 2008. The maturity date is not presented on the x-axis to emphasize that this bonds maturity was not fully 11 years, as pointed out in Table 1. Unlike the other bond price paths, the price returns are included in the appendix section 1.

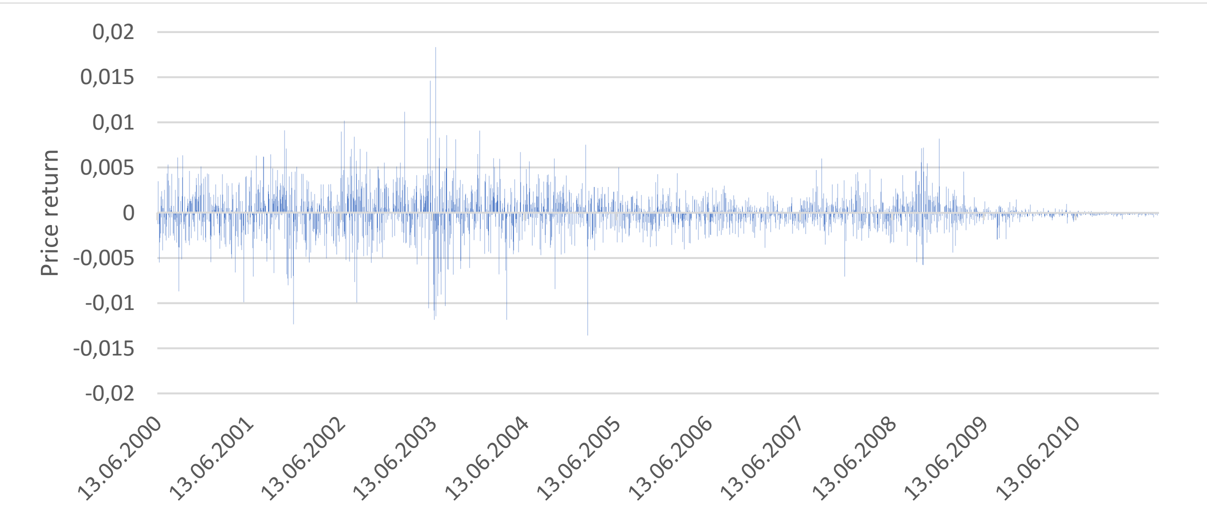

Figure 5: Close-to-close returns for bond NST469 traded at Oslo Stock Exchange from 2000 to maturity in 2011.

8 Weekend Volatility Effect - Methodology

This chapter describes the statistical methods behind the testing of the weekend's impact on Norwegian government bond market volatility according to the Trading-Time Hypothesis and the Calendar-Time Hypothesis.

8.1 The Price Returns

The price returns are estimated as natural logarithmic price changes, and is calculated as follows:

$$R_t = \ln \frac{P(close)_t}{P(close)_{t-n}}$$

where t refers to the current day, and t-n refers to the start of the calculating period. Monday's return is consequently included in the weekend price return, because of the use of close-to-close prices. Thus, there are only four ordinary trading days during the week. All price returns are calculated in the same manner, but differ in associated trading and calendar time. Price returns with associated seven trading hours are calculated as follows:

$$R_{Weekend} = \ln \frac{P(close)_{monday}}{P(close)_{friday}}$$

$$R_{Trading\ days} = \ln \frac{P(close)_t}{P(close)_{t-1}}$$

where t refers to the current day, and t-1 refers to the previous day. Price returns with associated 72 calendar hours are calculated as follows:

$$R_{Weekend} = \ln \frac{P(close)_{monday}}{P(close)_{friday}}$$

$$R_{Mon-Thu} = \ln \frac{P(close)_{thursday}}{P(close)_{monday}}$$

$$R_{Tue-Fri} = \ln \frac{P(close)_{tuesday}}{P(close)_{friday}}$$

The different logarithmic price changes are simply referred to as price returns later in the thesis.

8.2 Volatility

Volatility refers to the degree of price fluctuations in a bond or other securities, and commonly refers to variance and standard deviation. The variance measures how far each observation in the sample is from the mean and is defined as:

$$\sigma^2 = \frac{\sum_{t=1}^{T}(R_t - \bar{R})^2}{T-1}$$

where R_t is the return for day t, $\bar{R}$ is the average total return and T is the number of observations. The standard deviation measures the dispersion of a set of data from its mean, and is the squared root of the variance:

$$\sigma = \sqrt{\sigma^2}$$

8.2.1 Annualized volatility

The standard deviation is annualized for comparing purposes, and this thesis estimates the annualized volatility as follows:

$$\sigma_{annum} = \sigma_t * \sqrt{\frac{365}{Calender\ days_t}}$$

where σ_{annum} is the estimated annual standard deviation, σ_t is a certain period return's standard deviation and $Calender\ days_t$ is the number of calendar days in σ_t.

The scaling of 365 days in the annualizing formula credits the Calendar-Time hypothesis for describing price behaviour. The average number of trading days during a year is about 252 days, and the use of 252 days over 365 days, credits the Trading-Time hypothesis for describing price behaviour. Hull (2012) use 252 days and argues that practitioners tend to ignore non-trading days when estimating volatility because research shows that volatility is much higher when the exchange is open for trading than when it is closed. The findings in previous research in section 3, validates this argument. Therefore, it would probably be more accurate to use a number closer to 252 rather than 365 as a scaling number. The 365 scaling number is mainly chosen because the calculated price returns, based on close-to-close prices, results in volatility estimates consisting of both trading time and non-trading time during the entire week. Thus, scaling with 365 days rather than 252 days is easier to relate to and arguably provides a better description. Annualizing standard deviation is done for the purpose of a common measure for comparison between the different price returns, and the use of 365 poses no threat for the conclusions.

Depending on which one of the two hypothesis that better describes the government bond market, it might be misleading to call it an annualized volatility, and could just have been called scaling volatility.

8.3 Data Distribution

Various measurements like variance and standard deviation are based on the assumption of normally distributed price returns. Skewness and kurtosis are two measures that describes the data sample relative to a normal distribution. Skewness describes asymmetry in a distribution, and is calculated as follows:

$$Skew = \frac{1}{T}\frac{\sum_{t=1}^{T}(R_t - \bar{R})^3}{[\sum_{t=1}^{T}(R_t - \bar{R})^2]^{3/2}}$$

where T is the number of observations, R_t daily return and $\bar{R}$ is average return. A skewness of zero implies perfect symmetric distribution and characterizes a normal distribution, although most financial assets are skewed (Alexander, 2009).

Kurtosis describes the height and width of a distribution. The alternative excess kurtosis, where the number three is subtracted from the kurtosis, is often preferred and is calculated as follows:

$$EKurt = \frac{1}{T}\frac{\sum_{t=1}^{T}(R_t - \bar{R})^4}{[\sum_{t=1}^{T}(R_t - \bar{R})^2]^2} - 3$$

where T is the number of observations, R_t daily return and $\bar{R}$ is average return. An excess kurtosis equal to zero indicates a normal distribution and named mestokurtic distribution. Excess kurtosis higher than zero indicates heavy tails and high peak and named leptokurtic distribution. Excess kurtosis lower than zero indicates heavy tails and low peak and named platykurtic distribution. Though dependent on the sampling frequency and the market in question, most financial securities are leptokurtic (Alexander, 2009).

The Jarque-Bera test for normality determines if the sampled data have the skewness and/or kurtosis matching a normal distribution and is calculated as follows:

$$JB = \frac{T}{6}\left(Skew^2 + \frac{EKurt^2}{4}\right)$$

The Jarque-Bera test is chi-squared distributed with two degrees of freedom, and a null hypothesis stating the sampled data to be normally distributed.

8.4 Testing for Equal Variance

In order to test the weekend's effect on ordinary trading days, a comparison of the weekend variances with the trading days of the week is required. The weekend variance will be compared individually against the trading days of the week, in addition to test for joint significance to validate the Trading-Time Hypothesis or Calendar-Time Hypothesis. Choosing the appropriate statistical method to test for equal variance is a matter of selecting between a parametric and nonparametric test.

Parametric tests assumes the underlying distributions to be based on a certain set of parameters like the mean and standard deviation. As mean and standard deviation rest on the normal distribution assumption, parametric tests like the F-test rest on these assumptions for their validity. Nonparametric tests, in contrast, make minimal assumptions about the underlying distribution and parameters is determined by the data sample. The nonparametric Levene's test is a non-normality robust test by Nordstokke and Zumbo (2010) based on the Levene's test by Levene (1960). The test performs well on data samples with kurtosis and skewed distribution. Nordstokke and Zumbo (2010)'s own notations are as follows:

$$ANOVA\left(\left|R_{ij} - \bar{X}_j^R\right|\right)$$

wherein a one-way analysis of variance is conducted on the absolute value of the mean of the ranks for each group, denoted $\bar{X}_j^R$, subtracted from each individual's rank R_{ij}, for individual i in group j. Nordstokke and Zumbo (2010) focused on a two-group case, but the notation is applicable for more than two independent groups. This test is essentially a classical Analysis of Variance (ANOVA), but with a transformation on the dependant variable.

Empirically, financial data often deviate from the normal distribution assumption. Frank J Fabozzi (2001) states that "government bond returns exhibit fat tails and a peakness greater than predicted by the normal distribution". The testing for equal variance in this thesis will therefore focus on the nonparametric Levene's test over any parametric tests, given that the statistical results disproves the normal distribution assumption.

8.4.1 Testing the Trading-Time Hypothesis

The weekend variance is individually tested against the trading day variances to detect any weekend effect. All variances consist of seven trading hours and are tested after the following null and alternative hypothesis:

$$H_0 : \sigma^2_{weekend,trading-time} = \sigma^2_{t,trading-time}$$

$$H_1 : \sigma^2_{weekend,trading-time} \neq \sigma^2_{t,trading-time}$$

where t refers to all the different trading days. The results from this test only validates or rejects the weekend's effect on volatility. In order to test for equal variance across all periods, the weekend variance and the different trading days are jointly tested as a group after the following null and alternative hypothesis:

$$H_0 = \sigma^2_{weekend,} = \sigma^2_{Mon-Tue} = \sigma^2_{Tue-Wed} = \sigma^2_{Wed-Thu} = \sigma^2_{Thu-Fri}$$

$$H_1 = Variances\ are\ not\ all\ equal$$

8.4.2 Testing the Calendar-Time Hypothesis

The weekend variance is individually tested against the variances of periods with identical calendar hours to detect any weekend effect. All variances consist of 72 calendar hours and are tested after the following null and alternative hypothesis:

$$H_0 : \sigma^2_{weekend,calendar-time} = \sigma^2_{t,calendar-time}$$

$$H_1 : \sigma^2_{weekend,calendar-time} \neq \sigma^2_{t,calendar-time}$$

where t is the periods with equal calendar time as the weekend. The results from this test only give validation or rejection to the weekend's effect on volatility. In order to test for equal variance across all periods, the weekend variance and the periods with identical calendar time are jointly tested as a group after the following null and alternative hypothesis:

$$H_0 = \sigma^2_{weekend,} = \sigma^2_{Mon-Thu} = \sigma^2_{Tue-Fri}$$

$$H_1 = Variances\ are\ not\ all\ equal$$

An alternative approach to testing the Calendar-Time Hypothesis is to divide the weekend variance by three. This makes it possible to test the weekend variance against the same trading day variances from the Trading-Time Hypothesis testing. Since the weekend consist of three days, dividing by three would result in identical calendar time as the other trading days. Due to a desire to alter the price returns as little as possible, this alternative approach is excluded from this thesis.

8.4.3 Testing the influence of news

As described in section 2.1, the Calendar-Time Hypothesis hinge on the random occurrence of news and a rejection of the hypothesis does not disprove news as a price fluctuating factor. Therefore, an additional testing of the influence from news reaching the Norwegian bond market is included in this thesis. The interest rate decisions from Norges Bank’s monetary policy meetings are the main news reaching the Norwegian bond market and likely the main news affecting the bond prices. In contrary to Fama (1965)’s random occurrence of news assumption, the monetary policy meeting does not occur randomly. Information about Norges Bank’s monetary policy meetings is public information on their own website. The interest rate decisions are publicly released at 10 am, which is during ordinary trading hours. Norges Bank holds six meetings per year[10] and these dates are publicly known months in advance. There have been 120 meetings during the data sample’s period between 2000 and 2015. From these 120 meetings, news from 95 of them reached the public on a Wednesday and the last 25 on a Thursday.

In order to test the importance of news, the variance of meeting days is compared to ordinary trading days, i.e. Wednesdays and Thursdays. The variances are close-to-close price returns, as described in section 8.1, and are tested after the following null and alternative hypothesis:

$$H_0 : \sigma^2_{t,Monetary\ policy\ meeting\ day} = \sigma^2_{t,Ordinary\ \ trading\ days}$$
$$H_1 : \sigma^2_{t,Monetary\ policy\ meeting\ day} \neq \sigma^2_{t,Ordinary\ \ trading\ days}$$

[10] From 2012

9 Value at Risk and Option Pricing – Methodology

In order to capture the implications of different interpretations about the weekend's effect on volatility, this chapter compare periods that acknowledges and ignores any weekend volatility effect. The acknowledging period is created by a variation-acknowledging week variance. This total week's variance is used as the basis for creating variances after the Trading-Time Hypothesis and the Calendar-Time Hypothesis. There are several possible ways of creating this variation-acknowledging week variance, whilst this thesis focuses on two main methods:

I. The total week's return variance consist of weekend variance and specific day-of-the-week variance, named the day-of-the-week method.
II. The total week's return variance consist of weekend variance and a general trading day variance for the weekdays, named the trading-week method.

The further daily VaR analysis is conducted with (I), the day-of-the-week method. Because the VaR analysis is a day-by-day risk measurement during the course of a week, makes it more natural to distinguish between the different trading days. The further option valuation is conducted with (II), the trading-week method. The option valuation examines prices over the course of longer maturities, and therefore justifies the use of a general trading day volatility as opposed to the VaR analysis. Thus, the option pricing valuation creates a more direct isolation of the weekend volatility.

9.1 Value at Risk

The VaR analysis consists of three comparable parametric methods, the historical method and historical CVaR. The simple methodology behind the historical method and historical CVaR is described in chapter 5, and this section will therefore only consist of the methodology behind the parametric methods only. Figure 6 illustrates the creation of the three comparable parametric methods.

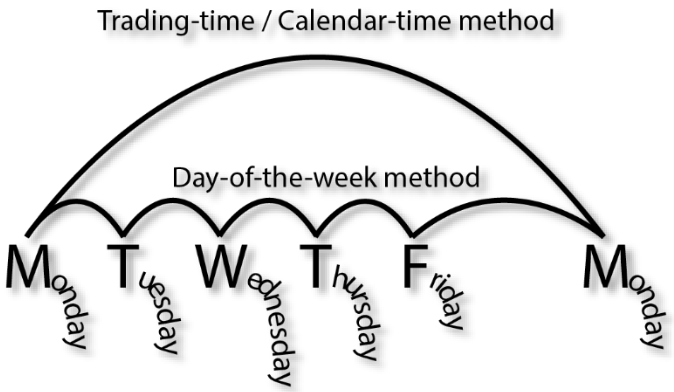

Figure 6: Illustration of the day-of-the-week, trading-time and calendar-time method for VaR analysis

The aggregated day-of-the-week method creates the basis for the two parametric methods after the Trading-Time Hypothesis and the Calendar-Time Hypothesis, named trading-time and calendar-time method. The parametric trading-time method assumes equal variance between weekend and trading days. Consequently, the weekend and trading days are equally weighted and divided by five from the aggregated day-of-the-week's variance. The parametric calendar-time method assume the weekend to yield three times higher variance. Consequently, weekend and trading days are unequally weighted and divided by the associated calendar days from the aggregated day-of-the-week's variance.

Figure 6 illustrates the calculation of the day-of-the-week variance, but the formal notation is as follows:

$$\sigma_{week}^2 = \sum \sigma_t^2$$

where t refers to both weekend and the specific trading day within a week. All variances are squared to a standard deviation estimate for parametric VaR analysis as follows:

$$\sigma = \sqrt{\sigma^2}$$

As discussed in section 5.2, the Basel Committee's recommendation of a three to five years sample size for the historical method is not satisfied for a single bond's return contribution to the different years-to-maturity periods. The different years-to-maturity periods consist of two years, except for the 3-0 period. The individual added bond returns as presented in Table 2, does obviously not stretch the years to maturity, but the amount of data in the different years-to-maturity periods is significantly increased.

9.2 Option pricing

The methodology behind option pricing is similar to the VaR analysis, with some differencing points. Figure 7 illustrates the two comparable methods for option pricing.

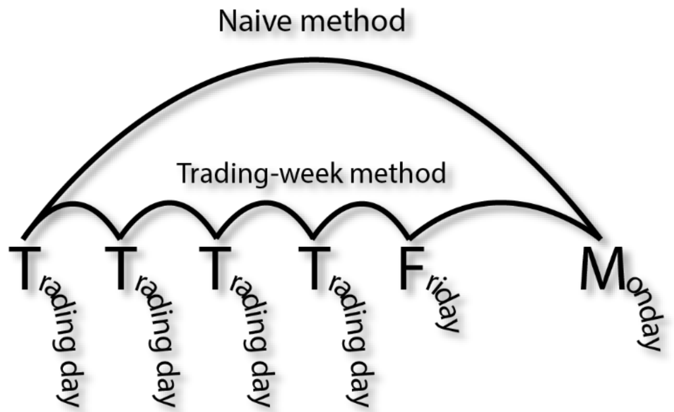

Figure 7: Illustration of the trading-week method and the naive method applied on one week from Monday to Monday

The aggregated trading-week method creates the basis for a method after the Calendar-Time Hypothesis, named the naive method. This naive method assumes the weekend to yield three times higher variance and consequently divide the weekend and trading days by associated calendar time from the aggregated trading week's variance. The naive method is essentially the same method as the calendar-time method. However, since the method is based on a different variation-acknowledging method, the method is given a different name to avoid mix-ups. Because the trading-week method consist of four general trading day variances, a method after the Trading-Time Hypothesis will only show the difference between the weekend variance and one trading day variance. The previous research in chapter 3, found the weekend volatility to be considerably closer to the Trading-Time Hypothesis than the Calendar-Time Hypothesis. Thus, including a method after the Trading-Time Hypothesis is assumed to show little deviation from trading-week method, and is omitted from the option valuation. Though Figure 7 only illustrates a one-week maturity, the same principle applies for longer maturities and the aggregated trading week variance in a given period is estimated as follows:

$$\sigma_T^2 = \sum \sigma_t^2$$

where t refers to weekend and general trading days within the period T. In order to be implemented in the Black-76 formula, the various variances are annualized and transformed to standard deviation in the following manner:

$$\sigma_{annum} = \sqrt{\sigma^2 * \frac{365}{Calendar\ days}}$$

where calendar days is the number of days within the period.

The option valuation analysis consists of both call and put options with various maturities ranging from one day to one year. In addition to varying in maturity, the analysis distinguishes between three different expiration days: Monday close, Wednesday close and Friday close. The calculated bond price in the Black-76 formula is described in chapter 6, but for the sake of simplicity, it is set to 100 for all maturities. 10-year government bonds are generally used as risk-free rate in the Norwegian financial market (pwc, 2016), and the risk free rate of 1,31% is collected from Norges Bank at 09.02.2016. Because of the unrealistic assumption that option trading only consists of ATM options, various deltas are used to create comparable ITM and OTM scenarios. Five different strikes are set to the deltas equal to +/-90%, 75%, 50%, 25% and 10%. As pointed out in Hull (2012), practitioners tend to ignore days when the exchange is closed, and the trading-week method is therefore set as reference for the various deltas. The naive method’s delta will therefore vary from the trading-week’s delta in accordance with DdeltaDvol as described in section 6.1.1.

Delta from the Black-76 formula in chapter 6, is calculated as follows:

$$\Delta_{call} = e^{-rt}N(d_1)$$

$$\Delta_{put} = e^{-rt}[N(d_1) - 1]$$

As mentioned in chapter 4, there is no organized option trading on the Oslo Stock Exchange. The strikes and valuated option prices in this thesis are therefore strictly hypothetical.

9.2.1 Theta and Vega

An extension to the option pricing analysis is given to the two Greeks: theta and vega. Variations in vega and theta as bond prices move towards OTM and ITM are well documented, and section 6.1 provides both a descriptions and illustrations. Therefore, the variations of interest in this thesis are with respect to volatility changes. The vega and theta analysis and comparisons are conducted in the same manner as for the option pricing.

The calculation of vega from the Black-76 formula in section 6.1.2 is calculated as follows:

$$\nu_{call,\ put} = Fe^{-rt}N(d_1)\sqrt{T}$$

Moreover, the calculation of theta from the Black-76 formula in section 6.1.3 is calculated as follows[11]:

$$\Theta_{call} = -\frac{Fe^{-rt}N'(d_1)\sigma}{2\sqrt{T}} + rFe^{-rt}N(d_1) - rKe^{-rt}N(d_2)$$

$$\Theta_{put} = -\frac{Fe^{-rt}N'(d_1)\sigma}{2\sqrt{T}} + rFe^{-rt}N(-d_1) - rKe^{-rt}N(-d_2)$$

[11] These formulas provides a yearly theta, but are frequently expressed daily or in trading days.

10 Results and Discussion

This chapter presents the statistical results from the various test and methods in chapter 8 and 9. All the statistical calculations are done in Excel, while graphical visualizations of the different price return distributions have been obtained through the econometrical software Stata.

As described in chapter 7, bonds behave differently depending on their age, hence the necessity of dividing the bonds maturity into different years-to-maturity periods. The practical implications from this are seven additional analysis to capture characteristics in all years-to-maturity periods. As a result, this thesis is presented with an extensive empirical analysis and in pursuit of finding a balance between quality and quantity; the appendix is largely used and referred to. Moreover, some analyses and methods included in either chapter 10 or the appendix have omitted certain years-to-maturity periods.

10.1 Trading-Time Hypothesis

The following section presents the analysis results regarding the Trading-Time Hypothesis testing. Table 3 presents the descriptive statistic based on price returns from periods including seven trading hours as described in section 8.1.

Table 3: Descriptive statistic of weekend and trading day returns including seven trading hours for bonds entire 11-year maturity.

	Weekend	Mon-Tue	Tue-Wed	Wed-Thu	Thu-Fri	Dataset
Calender hours	72	24	24	24	24	
Trading hours	7	7	7	7	7	7
Variance (upscaled)	7,81	6,01	8,11	8,75	7,36	7,62
Standard Deviation	0,28 %	0,25 %	0,28 %	0,30 %	0,27 %	0,28 %
per annum	3,08 %	4,69 %	5,44 %	5,65 %	5,18 %	5,27 %
Min	-0,020	-0,013	-0,017	-0,013	-0,016	-0,020
Max	0,014	0,017	0,020	0,021	0,013	0,021
Observations	2554	2569	2665	2584	2577	12949
Excess Kurtosis	7,87	5,44	6,25	4,31	4,13	5,68
Skewness	-0,64	0,06	0,13	0,04	-0,45	-0,17
Jarque-Bera	6763	3166	4344	2002	1919	17471
p-value	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000

The weekend's variance of 7,81 is above the whole dataset's 7,62 variance, which implies a slightly higher volatility during the weekend. When comparing the weekend to the other trading days, this impression weakens. Mon-Tue's and Thu-Fri's variance were lower than the weekend's, while both Tue-Wed's and Wed-Thu's variances are higher. Within the period of the data sample, the decisions from Norges Bank's monetary policy meetings have consistently been announced on Wednesdays and Thursdays. This could provide an explanation for Tue-Wed's and Wed-Thu's higher volatility, and will be discussed further in section 10.2.1. The various excess kurtosis and skewness does not indicate normally distributed price returns and is complimented by the Jarque-Bera test. The p-values reject the normal distribution hypothesis for the weekend and all trading days. Monday to Thursday's skewness is fairly close to zero compared to Friday and the weekend. This indicates a somewhat symmetrical price return distribution before the week reaches Friday. Thus, it is reasonable to assume that kurtosis with fat tails and high peak is the primary cause behind the rejection of the normal distribution hypothesis. For the sake of visual presentation, the variance in Table 3 and all further variances are multiplied with one million. The unaltered weekend variance is 0,00000781, while the upscaled variance is 7,81. All standard deviations are however unaltered and is presented in normal scale.

Table 3 presents volatility from the bonds entire 11-year maturity, and is unable to capture any years-to-maturity characteristics. Table 4 therefore divide the bonds 11-year maturity into different periods as described in chapter 7.

Table 4: Variance (upscaled) for weekend and trading days with seven trading hours for different years-to-maturity periods.

Years-to-maturity:	Weekend	Mon-Tue	Tue-Wed	Wed-Thu	Thu-Fri	Dataset
11-9	12,71	10,35	13,98	14,37	12,55	12,82
9-7	10,63	8,08	10,85	12,17	10,16	10,40
7-5	7,05	4,89	6,51	7,63	6,24	6,48
5-3	3,87	2,96	3,87	4,26	2,97	3,60
3-0	0,79	0,56	0,96	0,77	0,57	0,74
3-1	1,17	0,84	1,43	1,14	0,85	1,09
2-0	0,21	0,23	0,28	0,19	0,13	0,21

The bond variances decreases as maturity approaches, and from the 9-7 years-to-maturity period, the variances is roughly reduced by half every new period. These results are consistent with the pull-to-par effect described in chapter 4. The control periods also compliment these results with a variance increase in the 3-1 period and thereafter declining in the 2-0 period.

The rejection of the normal distribution hypothesis in Table 3 validates the use of the nonparametric Levene's test for the equal variance testing. Table 5 presents the individual and joint significance test for equal variance between the weekend and the other trading days.

Table 5: Individual and joint significance test for equal variance between price returns including seven trading hours with 0,01 alpha level for bonds entire 11-years maturity.

	Weekend	**Mon-Tue**	**Tue-Wed**	**Wed-Thu**	**Thu-Fri**	**Jointly**
Variance (upscaled)	7,81	6,01	8,11	8,75	7,36	
Nonparametric Levene's test		5,85	4,59	16,53	2,81	12,47
p-value		0,02	0,03	0,00	0,09	0,00

The weekend's variances were generally not significantly different from the other trading days with the exception of the high Wed-Thu variance. Thus, the individual testing rejects the equal trading time hypothesis and the joint significance testing in the grey column rejects the Trading-Time Hypothesis. Since the Wed-Thu variance is significantly higher than the weekend, this result implies some day-of-the-week volatility effect in this market. These results for the bonds entire 11-year maturity are not necessarily reflected in all years-to-maturity periods. Table 7 therefore presents the joint significance test for equal variance with different years to maturity. The continued practice of the nonparametric Levene's test is justified in the appendix section 3.2, where all maturity periods reject the normal distribution hypothesis.

Table 6: Joint significance test for equal variance between price returns including seven trading hours with 0,01 alpha level for different years-to-maturity periods.

Years-to-maturity periods	**11-0**	**11-9**	**9-7**	**7-5**	**5-3**	**3-0**	**3-1**	**2-0**
Nonparametric Levene's test	12,47	4,57	3,80	3,46	2,09	1,70	1,46	1,91
p-value	0,00	0,00	0,00	0,00	0,08	0,15	0,21	0,11

The previous rejection of the Trading-Time Hypothesis for bonds entire 11-year maturity appears to be due to similar results in long term to maturity bonds. However, the 5-3 and 3-0 years to maturity periods are not significantly different between weekend and the various trading days. The control groups compliment these results. Thus, the Trading-Time Hypothesis is found to be the best describing price behaviour for bonds with lesser than five years to maturity. Individual testing between the weekend and other trading days with different years-to-maturity periods are omitted from this chapter, but can be found in the appendix section 4.1.

The Trading-Time Hypothesis testing has some potential weakness and limitations. Because of the incapability of separating Monday's intraday returns, there is a degree of uncertainty related to the weekend's inclusion of Monday trading. If the market experiences a low Monday volatility, the weekend will have a higher impact on trading days than shown in this thesis. The observed unexplainable low Mon-Tue variance could be an extension of a low Monday variance. It is also worth mentioning that the periods closer to maturity has fewer bonds contributing data as presented and discussed in the appendix section 2. The equal variance for short term to maturity bonds could also be a result from the pull-to-par effect. As shown in Table 4, the weekend variance and trading day variances are very small, but still differ as maturity approaches. Keep in mind; these variances are multiplied by one million. Thus, alternatively to trading being the sole cause of price behaviour, the pull-to-par to effect could be pulling any visible day-of-the-week volatility effect or weekend volatility effect to be insignificant as they approach maturity. This can be an interesting topic for further research.

10.2 Calendar-Time Hypothesis

The following section presents the analysis results regarding the Calendar-Time Hypothesis testing. Table 7 presents the descriptive statistic based on price returns from periods with 72 calendar hours as described in section 8.1.

Table 7: Descriptive statistic of weekend and weekday periods including 72 calendar hours for bonds entire 11-year maturity.

	Weekend	**Mon-Tue**	**Tue-Fri**
Calender hours	72	72	72
Trading hours	7	21	21
Variance (upscaled)	7,81	30,34	32,18
Standard Deviation	0,28 %	0,55 %	0,57 %
per annum	3,08 %	6,08 %	6,26 %
Min	-0,020	-0,034	-0,032
Max	0,014	0,028	0,028
Observations	2554	2435	2518
Excess Kurtosis	7,87	4,86	3,88
Skewness	-0,64	-0,12	0,05
Jarque-Bera	6763	2399	1585
p-value	0,0000	0,0000	0,0000

Despite the equal calendar hours, the weekend and weekday periods highly differ. The two weekday period variances are fairly similar, but are close to four times larger than the weekend variance of 7,81. As observed for the Trading-Time Hypothesis testing, it seems that kurtosis with fat tails and high peaks are the primary cause behind rejecting the normal distribution hypothesis by the Jarque-Bera's p-value. Again, to capture any time period characteristics, Table 8 divide the bonds 11-year maturity into different periods as described in chapter 7.

Table 8: Variances (upscaled) for weekend and weekday periods with 72 calendar hours divided into different years to maturity periods.

Years-to-maturity:	**Weekend**	**Mon-Thu**	**Tue-Fri**
11-9	12,71	50,47	53,82
9-7	10,63	41,02	43,96
7-5	7,05	26,75	28,01
5-3	3,87	14,76	14,40
3-0	0,79	2,76	3,02
3-1	1,17	4,08	4,48
2-0	0,21	1,00	0,76

The weekend's variances are identical to the weekend presented in Table 4 and therefore has the same progression towards maturity. The weekday period variances are roughly halved every new period from 9-7 years to maturity before rapidly declining the three last years before maturity. These results are consistent with the pull-to-par effect described in chapter 4. Because of the obvious unequal variance between the variances from Table 8, the individual comparisons are moved to appendix section 4.1. Table 9 therefore only presents the joint significance test for equal variance with different years-to-maturity periods. The further use of the nonparametric Levene's test is justified and presented in the appendix section 3.3, where all maturity periods reject the normal distribution hypothesis.

Table 9: Joint significance test for equal variance between price returns including 72 calendar hours with 0,01 alpha level for different years-to-maturity periods.

Years-to-maturity periods	**11-0**	**11-9**	**9-7**	**7-5**	**5-3**	**3-0**	**3-1**	**2-0**
Nonparametric Levene's test	256	96	75	53	43	24	23	14
p-value	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Unsurprisingly, the Levene's test rejects the joint significance test for equal variance for all years-to-maturity periods. Thus, rejecting the Calendar-Time Hypothesis to describe price behaviour in the Norwegian government bond market. Alternatively, as stated in section 8.4.2, one possible method to test the Calendar-Time Hypothesis is dividing the weekend variance by three before testing for equal variance with the general trading days. The weekend variance in section 10.1 was found out to not be the highest compared to the other trading days. Therefore, it is unreasonable to assume a third of the weekend variance to be equal to the other trading days.

10.2.1 The news' influence on government bond volatility

As described in section 2.1, the rejection of the Calendar-Time Hypothesis in section 10.2 does not necessarily reject the influence from information and news on government bond volatility. Figure 8 compares monetary policy meeting variance with ordinary Wednesdays and Thursdays variance for different years-to-maturity periods.

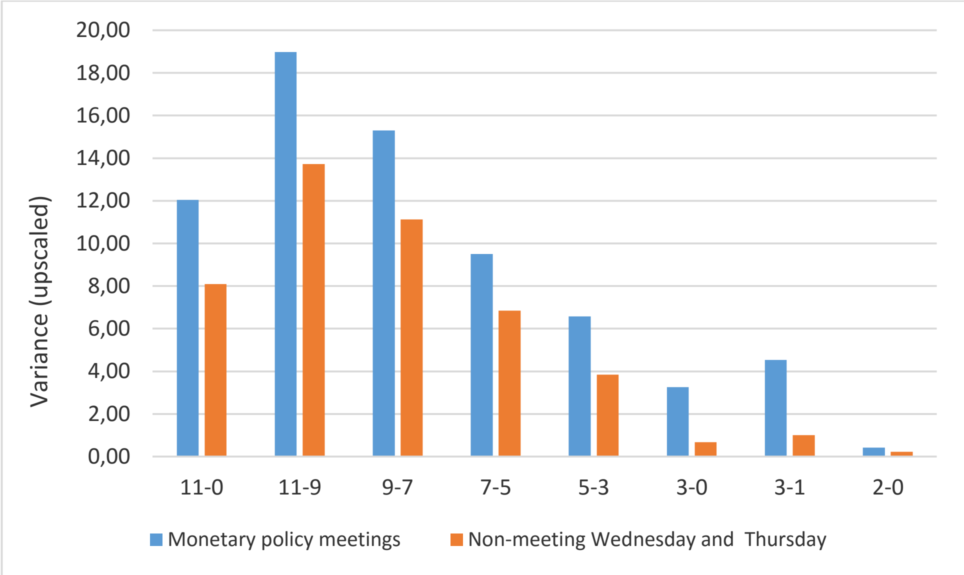

Figure 8: Monetary policy meetings variance (upscaled) and Non-meeting Wednesdays and Thursdays variance (upscaled) in different years to maturity periods

The variances from monetary policy meeting days are consistently higher than ordinary Wednesdays and Thursdays in all years-to-maturity periods. This gives reason to believe that news reaching the market has a positive effect on government bond volatility. In order to test this, Table 10 compares monetary policy meetings variance with ordinary Wednesdays and Thursdays with different years-to-maturity periods. The further use of the nonparametric Levene's test is again justified for all maturity periods and is presented in the appendix section 3.4.

Table 10: Testing for equal variance between returns from Monetary Policy Meetings and non-meeting Wednesdays and Thursdays with 0,01 alpha level for different years to maturity periods.

Years-to-maturity periods:	**11-0**	**11-9**	**9-7**	**7-5**	**5-3**	**3-0**	**3-1**	**2-0**
Nonparametric Levene's test	15,54	1,67	1,21	2,78	5,23	35,40	27,04	8,58
p-value	0,00	0,20	0,27	0,10	0,02	0,00	0,00	0,00

The validation of news positive effect on government bond volatility for the entire 11-year maturity, appear only to be due to the significantly different variances in the 3-0 years-to-maturity period. Thus, the news reaching the market of Norwegian government bonds only has a significant volatility effect on bonds with three years or less until maturity. The 3-0 period was also found in section 10.1 to validate the Trading-Time Hypothesis for describing price behaviour. This sounds intuitively incorrect, but is explained by the monetary policy news reaching the market when the market is open for trading.

There are several weaknesses associated with this particular test on news' influence on government bond volatility. Firstly, the meeting day's volatility does not specify if the interest rate declined, raised or stayed the same. If one does not take into account pre expectations, a changing interest rate will arguably cause higher volatility changes than an unchanged interest rate. The meetings distribution in appendix section 3.4 shows more extreme positive price returns, which indicates a majority of declining interest rates. Secondly, the analysis only measures the announcement day volatility. The days leading up to the meetings are not given any considerations which could yield possible significant patterns. Thirdly, the Wednesday and Thursday variance is equally weighted. From the 120 different monetary policy meetings included in the analysis, 95 of them occurs on Wednesdays and could therefore been weighted greater than Thursdays. Additionally, if we again look at the three extinct bonds in the appendix section 2, the Wed-Thu variance was considerably lower for long-term bonds. This might imply that news had a higher influence on the newer issued long-term bonds, or the interest rate has been changed more frequently. Despite these weaknesses, the results do provide a description of the news influence on bond volatility.

10.3 Value at Risk

The Value at Risk estimate provides a better illustration of the monetary implications from different interoperations of the weekend's effect on government bonds. Table 11 presents the estimated volatility used for VaR analysis. The weekend and the different trading days are aggregated to a day-of-the-week's variance, and create the basis for the trading-time and calendar-time variance.

Table 11: Estimated volatility from the day-of-the-week, trading-time and calendar time method based on price returns from the bonds entire 11-years maturity.

	Weekend	Mon-Tue	Tue- Wed	Wed-Thu	Thu-Fri	Week
Calendar hours	72	24	24	24	24	168
Trading hours	7	7	7	7	7	35
Calendar days	3	1	1	1	1	7
Day-of-the-week variance (upscaled)	7,81	6,01	8,11	8,75	7,36	38,05
Trading-time variance (upscaled)	7,61	7,61	7,61	7,61	7,61	38,05
Calendar-time variance (upscaled)	16,31	5,44	5,44	5,44	5,44	38,05
Day-of-the-week standard deviation	0,28 %	0,25 %	0,28 %	0,30 %	0,27 %	
Trading-time standard deviation	0,28 %	0,28 %	0,28 %	0,28 %	0,28 %	
Calendar-time standard deviation	0,40 %	0,23 %	0,23 %	0,23 %	0,23 %	

In conjunction with the Calendar-Time Hypothesis, the calendar-time variance is three times higher during the weekend than the general trading day. Unsurprisingly, the calendar-time variance therefore overestimates the weekend and gives the weekend credit for over 40% of the week's total variance. In contrast, the trading-time variance is equal across the weekend and general trading days in conjunction with the Trading-Time Hypothesis. The trading-time method provides a much closer depiction of the weekend compared to the day-of-the-week variance, but fail to capture the low Mon-Tue variance, and the high Wed-Thu variance.

Table 12 presents a daily 95% and 99% VaR analysis during the course of the week for a 100-mill NOK investment. The analysis consists of the bonds entire 11-year maturity price returns. Since the parametric method assumes zero mean price return, upper and lower tail will produce symmetrical values. Only the historical method and historical CVaR will provide different VaR estimates for the upper tale. Due to the lack of variety and space considerations, the upper tale is omitted from this section. The four various VaR estimation methods are listed consecutively with the following complementary tail risk capturing CVaR estimate. The differencing methods are presented in percentage and value difference underneath. A positive difference indicates an overestimation of VaR, while a negative difference indicates an underestimation compared to the day-of-the-week estimate. A parametric CVaR estimate has not been included as the difference between parametric and historic method is assumed sufficiently measured by VaR.

Table 12: Daily 95% and 99% VaR analysis for the weekend and trading days, in percentage and value terms for a 100-mill NOK investment based on price returns from the bonds entire 11-years maturity.

	Weekend				**Monday to Tuesday**			
	99% VaR		95% VaR		99% VaR		95% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Loss in %	Loss in NOK
1. Parametric day of the week	-0,65 %	-651 074	-0,46 %	-459 664	-0,57 %	-571 390	-0,40 %	-403 406
2. Parametric trading-time	-0,64 %	-642 720	-0,45 %	-453 766	-0,64 %	-642 720	-0,45 %	-453 766
3. Parametric calendar-time	-0,94 %	-940 846	-0,66 %	-664 245	-0,54 %	-543 198	-0,38 %	-383 502
4. Historical distributional VaR	-0,92 %	-916 617	-0,43 %	-431 031	-0,73 %	-732 382	-0,36 %	-361 619
Historical distributional CVaR	-1,31 %	-1 307 020	-0,72 %	-719 715	-0,94 %	-937 513	-0,57 %	-565 934
Differencing methods:								
Day of the week and trading-time (1-2)	0,01 %	8 354	0,01 %	5 898	-0,07 %	-71 330	-0,05 %	-50 360
Day of the week and calendar-time (1-3)	-0,29 %	-289 772	-0,20 %	-204 582	0,03 %	28 192	0,02 %	19 904
Day of the week and Historic mehod (1-4)	-0,27 %	-265 544	0,03 %	28 632	-0,16 %	-160 992	0,04 %	41 787

	Tuesday to Wednesday				**Wednesday to Thursday**			
	99% VaR		95% VaR		99% VaR		95% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Loss in %	Loss in NOK
1. Parametric day of the week	-0,66 %	-663 506	-0,47 %	-468 441	-0,69 %	-689 264	-0,49 %	-486 626
2. Parametric trading-time	-0,64 %	-642 720	-0,45 %	-453 766	-0,64 %	-642 720	-0,45 %	-453 766
3. Parametric calendar-time	-0,54 %	-543 198	-0,38 %	-383 502	-0,54 %	-543 198	-0,38 %	-383 502
4. Historical distributional VaR	-0,89 %	-889 798	-0,44 %	-439 253	-0,89 %	-886 514	-0,43 %	-434 175
Historical distributional CVaR	-1,12 %	-1 117 971	-0,69 %	-691 882	-1,11 %	-1 110 914	-0,71 %	-709 888
Differencing methods:								
Day of the week and trading-time (1-2)	0,02 %	20 786	0,01 %	14 675	0,05 %	46 544	0,03 %	32 860
Day of the week and calendar-time (1-3)	0,12 %	120 309	0,08 %	84 939	0,15 %	146 066	0,10 %	103 124
Day of the week and Historic mehod (1-4)	-0,23 %	-226 291	0,03 %	29 188	-0,20 %	-197 250	0,05 %	52 451

	Thursday to Friday			
	99% VaR		95% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK
1. Parametric day of the week	-0,63 %	-632 248	-0,45 %	-446 372
2. Parametric trading-time	-0,64 %	-642 720	-0,45 %	-453 766
3. Parametric calendar-time	-0,54 %	-543 198	-0,38 %	-383 502
4. Historical distributional VaR	-0,83 %	-825 304	-0,40 %	-400 528
Historical distributional CVaR	-1,10 %	-1 103 032	-0,66 %	-657 008
Differencing methods:				
Day of the week and trading-time (1-2)	-0,01 %	-10 472	-0,01 %	-7 394
Day of the week and calendar-time (1-3)	0,09 %	89 050	0,06 %	62 870
Day of the week and Historic mehod (1-4)	-0,19 %	-193 056	0,05 %	45 845

From the (1-3) difference columns, the calendar-time overestimates the weekend and underestimate the trading days, compared to the day-of-the-week VaR estimate. The (1-2) difference columns shows that the trading-time both overestimate and underestimate during the week, but are relatively centred around zero percent. Thus, the parametric-time generally provides a better fit than the calendar-time. This is most evident for the weekend's 99% VaR estimate, where the calendar-time method overestimates by 0.29%, while the trading-time method only underestimates by -0.01%. A deviation from these findings is Mon-Tue's low variance, presented in

Table 11, which causes the calendar-time's general underestimation of trading days to be a better fit than the trading-time method. The (1-4) differencing column represents the difference between the parametric method and the historical method due to non-normality. As previously stated in section 5.1, the parametric method assumes normally distributed price returns, and the results in section 10.1 found the distributions to be both leptokurtic and skewed. The high difference between the parametric and historic method is therefore not a surprising result. The highest non-normality difference of 0,27% is observed for the 99% VaR estimate during the weekend. However, The 95% VaR estimates shows a much lower difference due to non-normality by not exceed 0,05% difference. One noteworthy remark is that the 99% VaR weekend estimate shows a relatively high similarity between the historical and parametric calendar-time method. By assuming a market's volatility to move according to the Calendar-Time Hypothesis, the risk assessment over the weekend will actually be closer to the historical because of the non-normality price return distribution. Thus, with a strike of luck, two wrongs can make a right. The differing results in the historic and parametric method due to non-normality give reason to consider other possible distributions for the parametric method. The student t distribution could provide a better fit with the leptokurtic distribution found in section 10.1.

VaR analysis for different years-to-maturity periods, as well as the upper tail risk, is included in the appendix section 5. The different VaR analysis in the appendix show a similar pattern to the entire 11-year maturity, but the overall daily risk decreases as the bonds approaches maturity that is consistent with the pull-to-par effect described in chapter 4.

10.4 Option Valuation

This section compares an acknowledging weekend effect by the trading-week method against the ignoring naive method. To demonstrate option prices dependability on time and the maturity, the following subsections distinguish between short-term and long-term characteristics. The short-term characteristics analysis provides a comprehensive analysis of various option prices and strikes, and will only consider expiration on Monday's close. The long-term characteristics will thereafter only present pricing differences, but will also include Friday's close and Wednesday's close as expiration days.

10.4.1 Short-term characteristics

Table 13 presents the descriptive statistics used in the option valuation analysis as specified in section 9.2. Because the option analysis consists of maturities beyond the course of one day, Table 13 presents the aggregated descriptive statistics for the entire week, in contrast to Table 11 in the VaR analysis.

Table 13: Descriptive statistic for the option pricing with expiration on Monday's close. Estimated volatility from the trading-week method and naive method based on returns from the bonds entire 11-years maturity.

	Weekend	**Thu-Mon**	**Wed-Mon**	**Tue-Mon**	**Mon-Mon**
Bond price	100	100	100	100	100
Strike	100	100	100	100	100
Calendar days	3	4	5	6	7
Risk free rate (annual)	1,31 %	1,31 %	1,31 %	1,31 %	1,31 %
Trading-week variance (upscaled)	7,81	15,43	23,05	30,67	38,30
Naive variance (upscaled)	16,41	21,88	27,35	32,83	38,30
Trading-week standard deviation	0,28 %	0,39 %	0,48 %	0,55 %	0,62 %
per annum	3,08 %	3,75 %	4,10 %	4,32 %	4,47 %
Naive standard deviation	0,41 %	0,47 %	0,52 %	0,57 %	0,62 %
per annum	4,47 %	4,47 %	4,47 %	4,47 %	4,47 %

Despite the changed presentation from Table 11 in the VaR analysis, the naive variance in conjunction with the Calendar-Time Hypothesis is three times higher during the weekend than the general trading day. The equally assumed volatility on trading days is calculated based on price returns from the whole dataset. The decision behind using the whole dataset to create a trading day volatility is reasoned and elaborated in the appendix section 6.

Table 14 presents the difference between the trading-week method's and the naive method's option prices. The analysis consists of call and put prices for bonds entire 11-year maturity. The different absolute delta values 90%, 75%, 50%, 25% and 10% are reported successively from ITM to OTM. Associated strike prices are presented to the right from the option prices in the same column. The strike prices are quoted prices, but the option prices are presented in NOK. The differencing methods are presented in percentage and value difference underneath. A positive difference indicates an overvaluation of option prices, while a negative difference indicates an undervaluation compared to the trading-week estimate.

Table 14: Option prices from the trading week method and naive method with up to one week's maturity and expiration on Monday's close for bonds entire 11-year maturity. Option prices from the trading week method are outlined with a dark blue colour, while the option prices from naive method are outlined with a red colour.

	Weekend		**Thu-Mon**		**Wed-Mon**		**Tue-Mon**		**Mon-Mon**	
Call/Put:	Option price	Strike	Option price	Strike	Option price	Strike	Option price	Strike	Option price	Strike
ATM (Δ = 50%)	1,11 1,62	100	1,57 1,87	100	1,92 2,09	100	2,21 2,29	100	2,47 2,47	100
Call:										
ITM (Δ = 90%)	3,71 4,00	99,64	5,16 5,31	99,50	6,46 6,54	99,38	7,32 7,36	99,29	8,17 8,17	99,21
ITM (Δ = 75%)	2,30 2,73	99,81	3,21 3,45	99,74	3,99 4,12	99,67	4,60 4,66	99,62	5,06 5,06	99,59
OTM (Δ = 25%)	0,42 0,85	100,19	0,59 0,84	100,26	0,70 0,84	100,33	0,80 0,86	100,38	0,92 0,92	100,42
OTM (Δ = 10%)	0,13 0,42	100,36	0,19 0,34	100,50	0,22 0,29	100,63	0,26 0,30	100,71	0,29 0,29	100,80
Put:										
ITM (Δ = 90%)	3,73 4,02	100,36	5,19 5,35	100,50	6,51 6,59	100,63	7,40 7,43	100,71	8,25 8,25	100,80
ITM (Δ = 75%)	2,31 2,74	100,19	3,23 3,47	100,26	4,01 4,15	100,33	4,64 4,70	100,38	5,11 5,11	100,42
OTM (Δ = 25%)	0,42 0,85	99,81	0,59 0,84	99,74	0,70 0,84	99,67	0,81 0,87	99,62	0,93 0,93	99,59
OTM (Δ = 10%)	0,13 0,42	99,64	0,19 0,34	99,50	0,22 0,29	99,38	0,25 0,28	99,28	0,29 0,29	99,21
Method difference	Percentage	NOK	Percentage	NOK	Percentage	NOK	Percentage	NOK	Percentage	NOK
ATM (Δ = 50%)	-45 %	0,50	-19 %	0,30	-9 %	0,17	-3 %	0,08	0 %	0,00
Call:										
ITM (Δ = 90%)	-8 %	0,29	-3 %	0,15	-1 %	0,08	0 %	0,03	0 %	0,00
ITM (Δ = 75%)	-19 %	0,43	-8 %	0,25	-3 %	0,14	-1 %	0,06	0 %	0,00
OTM (Δ = 25%)	-103 %	0,43	-42 %	0,25	-20 %	0,14	-8 %	0,06	0 %	0,00
OTM (Δ = 10%)	-218 %	0,29	-80 %	0,15	-36 %	0,08	-13 %	0,03	0 %	0,00
Put:										
ITM (Δ = 90%)	-8 %	0,29	-3 %	0,15	-1 %	0,08	0 %	0,03	0 %	0,00
ITM (Δ = 75%)	-19 %	0,43	-8 %	0,25	-3 %	0,14	-1 %	0,06	0 %	0,00
OTM (Δ = 25%)	-103 %	0,43	-42 %	0,25	-20 %	0,14	-7 %	0,06	0 %	0,00
OTM (Δ = 10%)	-217 %	0,29	-80 %	0,15	-36 %	0,08	-13 %	0,03	0 %	0,00

By ignoring any acknowledging weekend effect, the naive method overvalues the options due to the overestimation of the weekend volatility. On the course of an options maturity throughout the aggregated week, there is an evident fading away effect, before neither over- nor undervalue options when the maturity reaches a week. This is due to the identical week volatility for the two methods, and is observable in the Mon-Mon column. Vertically comparison between call and put valuations across the different maturities is nearly identical. As stated in section 6.1.2, the value change in the option price from a change in the volatility (vega) is highest for ATM options and decreases as the option moves towards ITM or OTM. Over the weekend, the differencing value for an ATM option is 0,50 NOK while the symmetrical value difference for delta 10% and 90% are 0,29 NOK. The symmetrical value change is not the case for percentage difference. As OTM options are priced much lower than ITM options, symmetrical value difference for delta 10% and 90%, will have a significantly higher percentage difference for the OTM option than the ITM option. The mentioned weekend delta of 10% and 90% have a percentage difference of -218% and -8% respectively for call options. This is consistent with the vega leverage described in section 6.1.2. As mentioned in chapter 6, the two comparing trading-week method and naive method option prices have different deltas. The increased volatility by the naive method in ITM options has a reducing price change effect. While, the increased volatility by the naive method in OTM option have an increasing price effect. This is consistent with the DdeltaDvol, described in 6.1.1 and enhances the percentage differences. Speculating in increased volatility in OTM options therefore yields the largest percentage changes in addition to being cheaper than ITM.

The resulting difference between the trading week method and the naive method reflects the previous expressed deviation from the Calendar-Time Hypothesis. This calls upon a possible extension of the Black-76 formula to distinguish between calendar and trading hours. D. W. French (1984) made such an extension to the Black-Scholes model to utilize a trading-time variance and a calendar-time interest rate. This thesis found the Trading-Time Hypothesis to describe price behaviour for short-term bonds in section 10.18.4.1, and the general results implies that the volatility is higher during trading days than non-trading days. Therefore, a similar trading day adjusted extension provided by D. W. French (1984) could prove valuable to the Black-76 formula.

10.4.2 Long-term characteristics

The long-term analysis only consists of call options. As the previous findings are near to identical for both calls and puts, one can expect the following analysis to apply for put options and therefore omitted from this thesis. All the figures in this section display the differencing percentage between the trading-week method and the naive method. The different days of the week are expressed by the day's initial letter. The differencing percentages are with respect to the delta values of 25%, 50% and 75%. The presentation is a day-by-day basis up to 8 weeks, before jumping up to one-year maturity. As an extension to the short-term characteristics, the long-term characteristics will also include Wednesday's close and Friday's close as expiration days in addition to Monday's close.

Figure 9 presents differencing percentages for option prices up to one-year maturity and expiration on Monday's close.

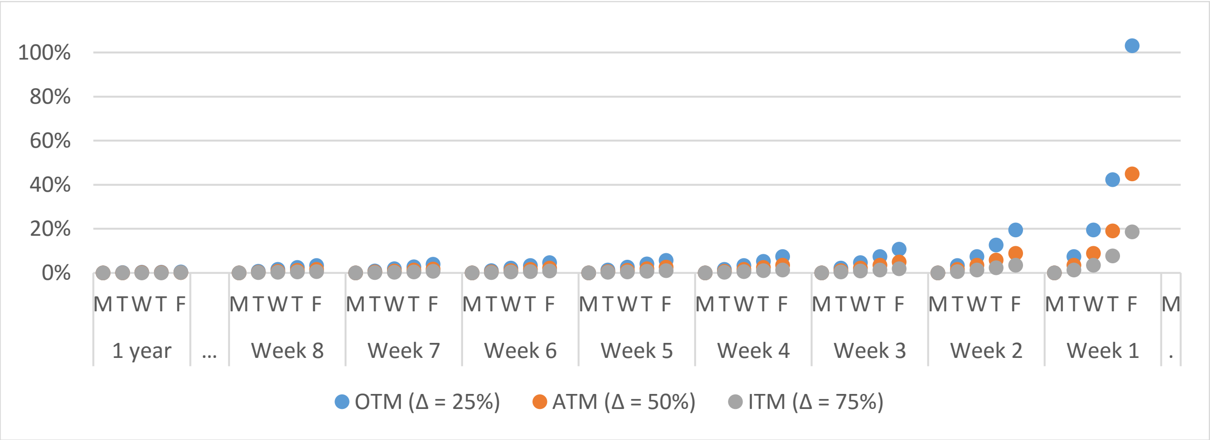

Figure 9: Percentage differences between the trading-week method and the naive method's option valuation for call options with up to one year's maturity and expiration on Monday's close – deltas of 25%, 50% and 75% and based on data from bonds entire 11-year maturity

The first week is a visualisation of the differencing percentages for the respective deltas and the fading away effect found in Table 14. The added weeks before maturity displays the same overvaluation of the weekend by the naive method before the difference fades away on Mondays. The overvaluation of the weekend decreases with a longer maturity, and after a year, it has almost completely vanished. Nearly identical observations are found for long-term and short-term bonds and is presented in the appendix section 7.3.

Figure 10 presents differencing percentages for options prices up to one-year maturity and expiration on Friday's close.

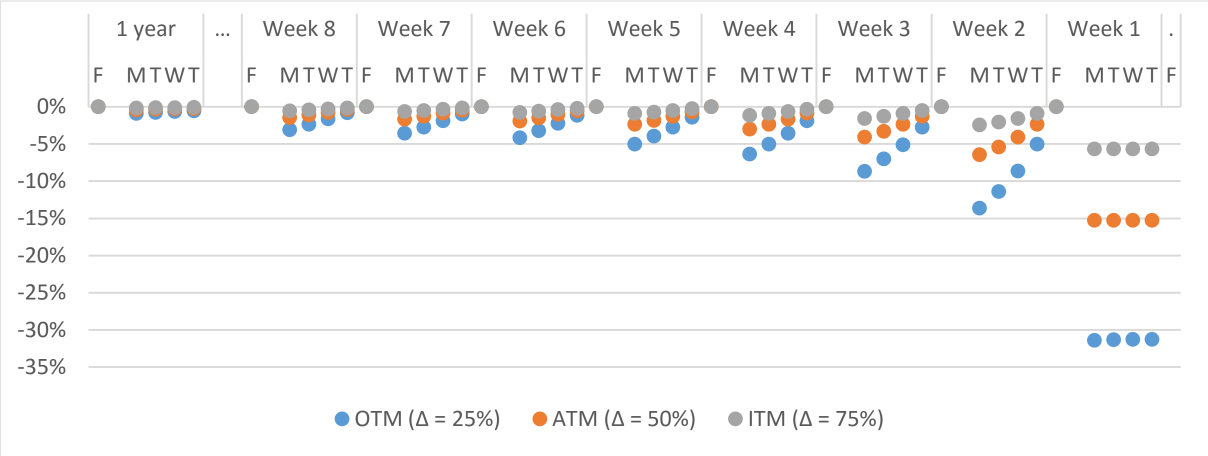

Figure 10: Percentage differences between the trading-week method and the naive method's option valuation for call options with up to one year's maturity and expiration on Friday's close – deltas of 25%, 50% and 75% and based on data from bonds entire 11-year maturity

In contrary to the naive methods overvaluation of the weekend when options expire on Monday's, the Friday expiration day shows an undervaluation of the trading days. The undervaluation is constant for the first week but added weeks before maturity display a higher undervaluation towards the weekend. Due to the identical week volatility for the two methods the percentage difference always vanishes on Fridays and after a year, there is almost no difference regardless of the day of the week. Additionally, the higher percentage difference for OTM as discussed in section 10.4.1 looks to be present regardless of the expiration day. The long-term and short-term bonds located in the appendix section 7.2. shows nearly identical observations.

Figure 11 presents differencing percentages for option prices up to one-year maturity and expiration on Wednesday's close.

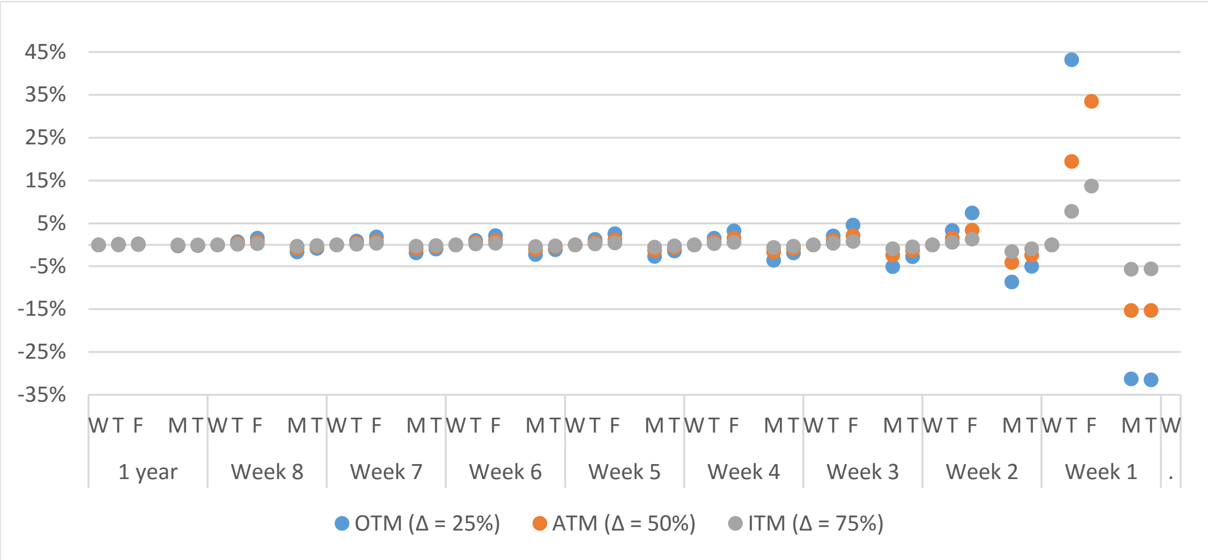

Figure 11: Percentage differences between the trading-week method and the naive method's option prices for call options with up to one year's maturity and expiration on Wednesday's close – deltas of 25%, 50% and 75% and based on data from bonds entire 11-year maturity.

The use of Wednesday as expiration day capture a combination of the naive methods undervaluation during trading days and the overvaluation of the weekend from the two previous figures. Again, this pattern weakens by adding weeks to the maturity and almost vanishes with an added year. The same nearly identical observations for long-term and short-term bonds are also found and presented in the appendix section 7.3.

10.4.3 Theta and Vega

The following section compares the same acknowledging trading week method against the ignoring naive method and its resulting implications on theta and vega. Figure 12 presents differencing percentages for options theta up to one-year maturity and expiration on Wednesday's close.

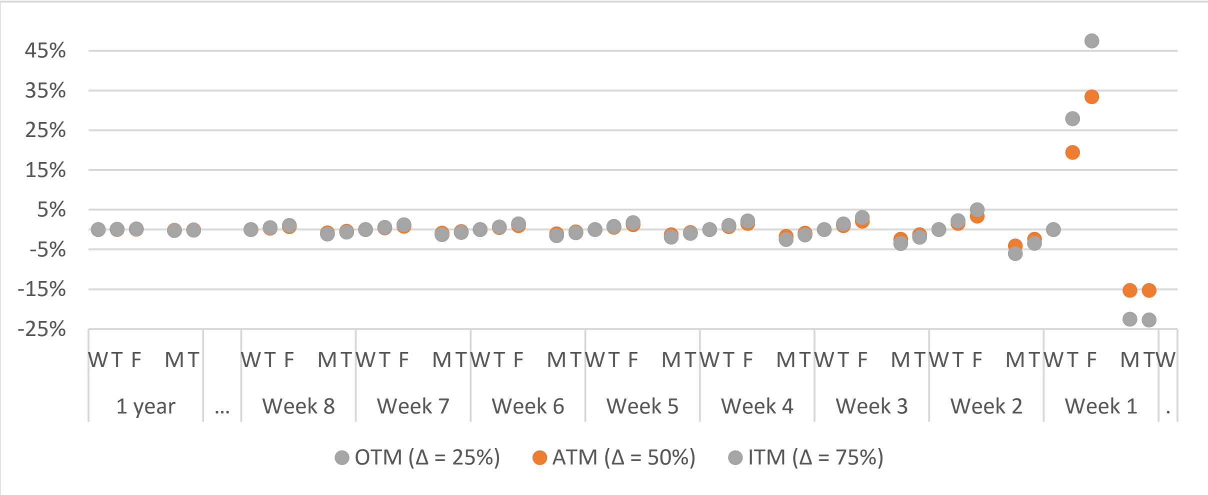

Figure 12: Percentage differences between the trading-week method and naive method's theta for call options with up to one year's maturity and expiration on Wednesday's close – deltas of 25%, 50% and 75% and based on data from bonds entire 11-year maturity.

Theta's sensitivity to volatility changes is similar to those for option pricing. The naive method underestimates the trading days and overestimates the weekend compared to the trading week method. The same one-year fading away effect of the percentage differences is also present here. In contrary to option pricing, the theta estimation for ITM and OTM options show a nearly identical percentage difference, and this is why both OTM and ITM are marked with the same grey colour in Figure 12. Because the Wednesday expiration day captures both the over- and undervaluation by the naive method, theta from expiration on Mondays and Fridays have been omitted from this thesis. Theta sensitivity in long-term and short-term bonds expiration on Wednesday's close is presented in the appendix section 8. and presents nearly identical observations.

Figure 13 presents differencing percentages for options vega up to one-year maturity and expiration on Wednesday's close.

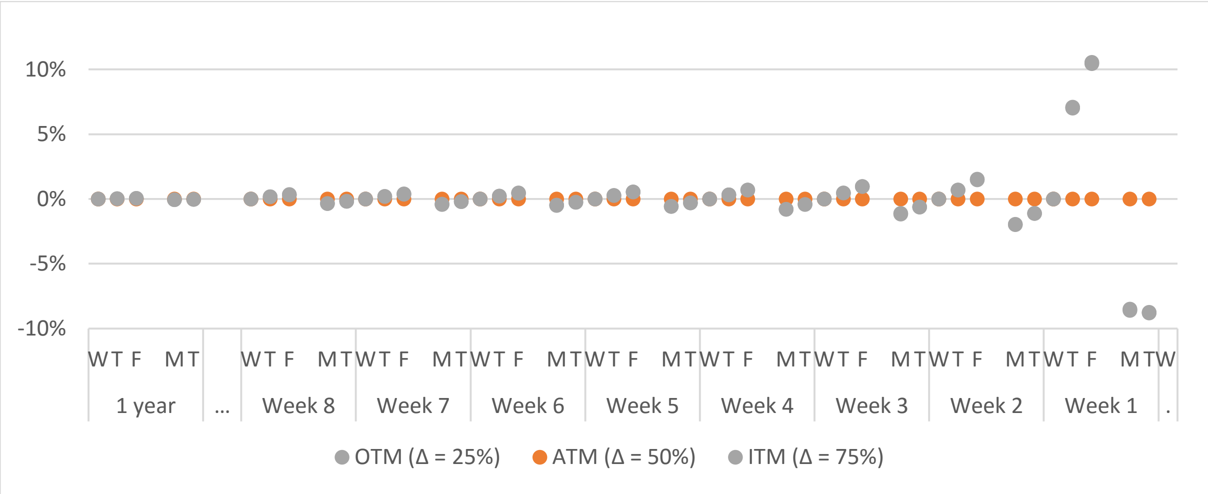

Figure 13: Percentage differences between the trading-week method and naive method's vega for call options with up to one year's maturity and expiration on Wednesday's close – deltas of 25%, 50% and 75% and based on data from bonds entire 11-year maturity

The patterns found in the theta analysis for OTM and ITM option's under-and overestimation, are also found to be the case for vega, and therefore marked by the same colour in Figure 13. However, the major difference in the vega analysis, is ATM options insensitivity to volatility changes. The orange ATM dots in the figure is zero on all maturities and means that the naive method has no effect on vega during the weekend or general trading days. This insensitivity corresponds with the findings in E. Haug (2003). Again, the nearly identical difference in long-term and short-term is presented in the appendix section 9.

11 Conclusion and scope for further analysis

The analysis of daily closing prices from seven selected Norwegian government bonds traded at the Oslo Stock Exchange during the period between 13.06.2000 to 15.09.2015 shows a deviation from the Calendar-Time Hypothesis and a similarity with the Trading-Time Hypothesis. The weekend variance is lower than one third of the comparing 72-calendar hours for all years-to-maturity periods, which does not support the Calendar-Time Hypothesis. The weekend variance is also found to have significantly equal variance with the other trading days for bonds 5-3 and 3-0 years-to-maturity periods. Thus, the Trading-Time Hypothesis is found to be the best describing price behaviour for bonds with less than five years to maturity. The complementary analysis of the non-random news that reaches the Norwegian government bond market only showed a significant effect on short-term bonds.

From the Value at Risk analysis, it is evident that approaching the Calendar-Time Hypothesis overestimates the weekend risk and underestimates the weekday risk compared to a weekend effect-acknowledging estimate. The Trading-Time Hypothesis generally provides a better fit, where the over- and underestimations are relatively centered around zero. The option valuation results in the same overestimation of the weekend and underestimation of the weekdays by the Calendar-Time Hypothesis. OTM options prove to be considerably more sensitive in terms of percentage over- and undervaluation than ITM options. For a 10% delta call option priced at Friday’s close with expiration on Monday’s close, the Calendar-Time Hypothesis overvalues the option price by 218 percent, and the 90% delta call option is only overvalued by 8 percent. The option value differences in these two scenarios are however identical. The undervaluation of the trading days is presented in the long-term characteristics and shows that both the over- and undervaluation decreases with a longer maturity and before almost completely vanishing after a year. The theta and vega analyses show identical sensitivity in terms of percentage over- and undervaluation for ITM and OTM options, which is one differencing point from the option valuation. However, the primary differencing point is vega’s insensitivity to volatility and maturity changes for ATM options. These findings can have major impacts for financial players that use options as part of risk management in this market. Thus, this thesis strongly advices to take into account the deviation from the Calendar-Time Hypothesis and a similarity with the Trading-Time Hypothesis.

The limitations of the analysis' scope in this thesis are mainly due to time considerations, but also partly to the availability of data. Access to open bid and ask prices would provide a more comprehensive exploration of the weekend's effect by creating intraday and overnight returns. This reduces the weakness associated with testing for the trading time hypothesis as discussed in section 10.1. All price returns in this thesis have been weighted equal despite having different associated trading volumes. Weighting the different price returns with respect to trading volume would give a better understanding of the relevance of trading on volatility. In addition to the discussed weakness with testing the influence of news in section 8.4.3, the test only consider monetary policy meetings as relevant news. No consideration is given to a possible asymmetric occurrence of news, and an inclusion of other news relevant factors would yield added results to the already collected findings. Finally, an extension to the option valuation analysis would be to test the results and to determine which degree the found volatilities are reflected in the market. These suggestions could prove interesting topics for further research.

References

Alexander, C. (2009). *Market Risk Analysis : Value at Risk Models* (Vol. v.4). Chichester: Wiley.

Basel Committee. (2012). Retrieved 12.02.20016, from http://www.bis.org/publ/bcbs219.pdf

Black, F. (1976). The pricing of commodity contracts. *Journal of financial economics, 3*(1), 167-179.

Black, F., & Scholes, M. (1973). The pricing of options and corporate liabilities. *The journal of political economy*, 637-654.

Campbell, J. Y., & Ammer, J. (1993). What moves the stock and bond markets? A variance decomposition for long-term asset returns. *The journal of Finance, 48*(1), 3-37.

Fabozzi, F. J. (2001). *Bond portfolio management* (Vol. 73): John Wiley & Sons.

Fabozzi, F. J., & Anson, M. J. P. (2007). *Fixed income analysis* (2nd ed. ed. Vol. v.31). Hoboken, N.J: J. Wiley.

Fama, E. F. (1965). The Behavior of Stock-Market Prices. *Journal of Business, 38*(1), 34. doi:10.1086/294743

Fleming, J., Kirby, C., & Ostdiek, B. (1998). Information and volatility linkages in the stock, bond, and money markets. *Journal of financial economics, 49*(1), 111-137.

French, D. W. (1984). The weekend effect on the distribution of stock prices: Implications for option pricing. *Journal of financial economics, 13*(4), 547-559.

French, K. R. (1980). Stock returns and the weekend effect. *Journal of financial economics, 8*(1), 55-69.

French, K. R., & Roll, R. (1986). Stock return variances: The arrival of information and the reaction of traders. *Journal of financial economics, 17*(1), 5-26.

Haug, E. (2003). Know Your Weapon, Parts 1 and 2. *Wilmott Magazine, May and August*.

Haug, E. G. (1995, 25.04.2016). OTC Interest Rate Derivatives. Retrieved 24.04.2016, from http://www.espenhaug.com/OTCFixedIncome.pdf

Haug, E. G. (2007). *The complete guide to option pricing formulas*: McGraw-Hill Companies.

Hull, J. (2012). *Options, futures, and other derivatives* (8th ed., global ed. ed.). Boston, Mass: Pearson.

Hull, J., & White, A. (1987). The pricing of options on assets with stochastic volatilities. *The journal of Finance, 42*(2), 281-300.

Levene, H. (1960). Robust tests for equality of variances1. *Contributions to probability and statistics: Essays in honor of Harold Hotelling, 2*, 278-292.

Nordstokke, D. W., & Zumbo, B. D. (2010). A new nonparametric Levene test for equal variances. *Psicológica: Revista de metodología y psicología experimental, 31*(2), 401-430.

Norges Bank. (2016). Retrieved 20.04.2016, from http://www.norges-bank.no/

pwc. (2016, 29.04.2016). Risikopremien i det norske markedet 2015. Retrieved 16.03.2016, from http://www.pwc.no/no/publikasjoner/deals/rapport/risikopremie-2015.pdf

Roll, R. (1984). Orange Juice and Weather. *The American Economic Review, 74*(5), 861-880.

Ødegaard, B. A. (2012). The liquidity of the Secondary Market for Debt Securities in Norway (Vol. 2012/12): University of Stavanger.

Appendix

1. The bonds historical price returns

Following are the individual graphed close-to-close price returns for each of the seven bonds. Because the price returns for the bonds that are still active must be seen in context with their remaining time to maturity, the whole maturity is added to the x-axis. The maturity dates for the three extinct bonds is not presented on the x-axis to emphasize that the bonds maturity was not fully 11 years as pointed out in Table 1

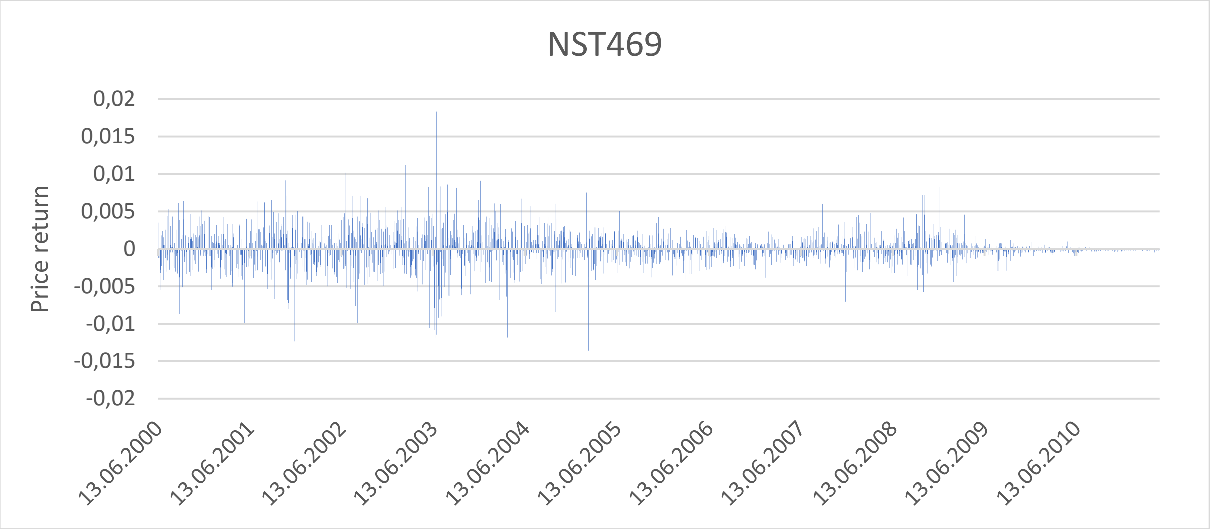

Figure 14: Close-to-close returns for bond NST469 from 2000 to maturity in 2011

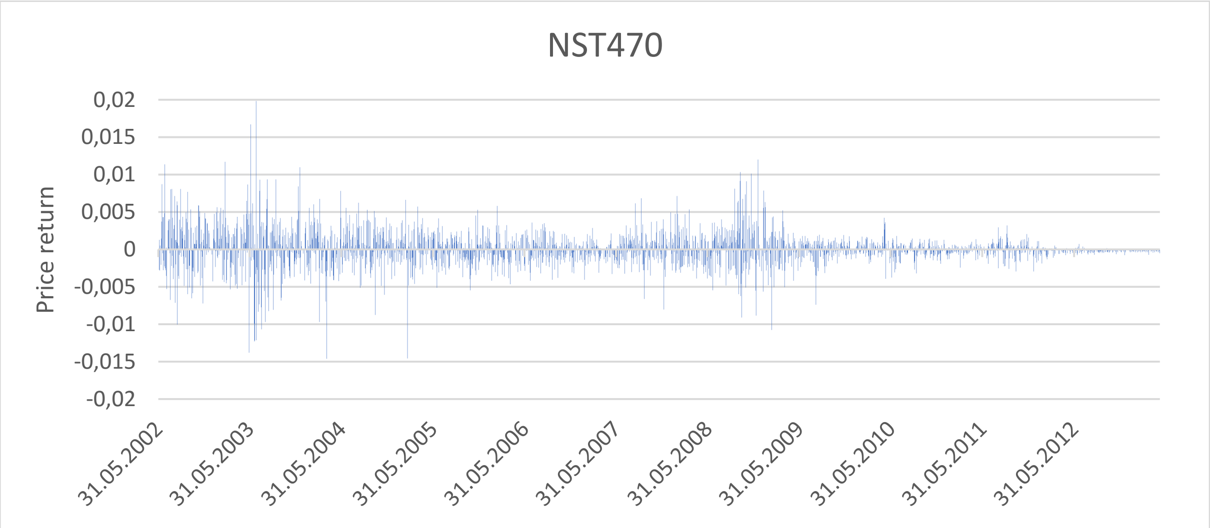

Figure 15: Close-to-close returns for bond NST470 from 2002 to maturity in 2013

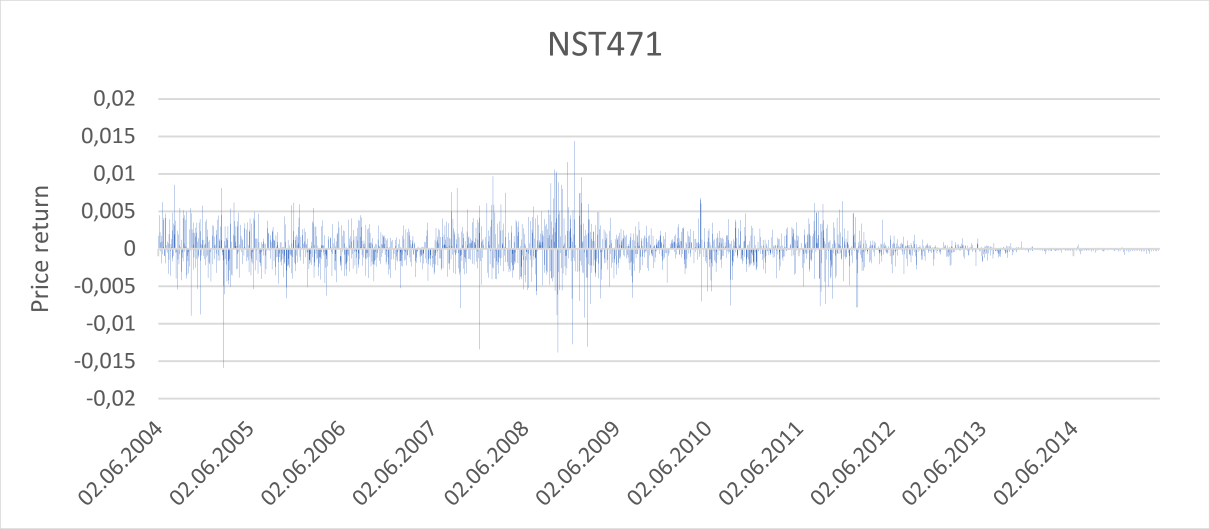

Figure 16: Close-to-close returns for bond NST471 from 2004 to maturity in 2015

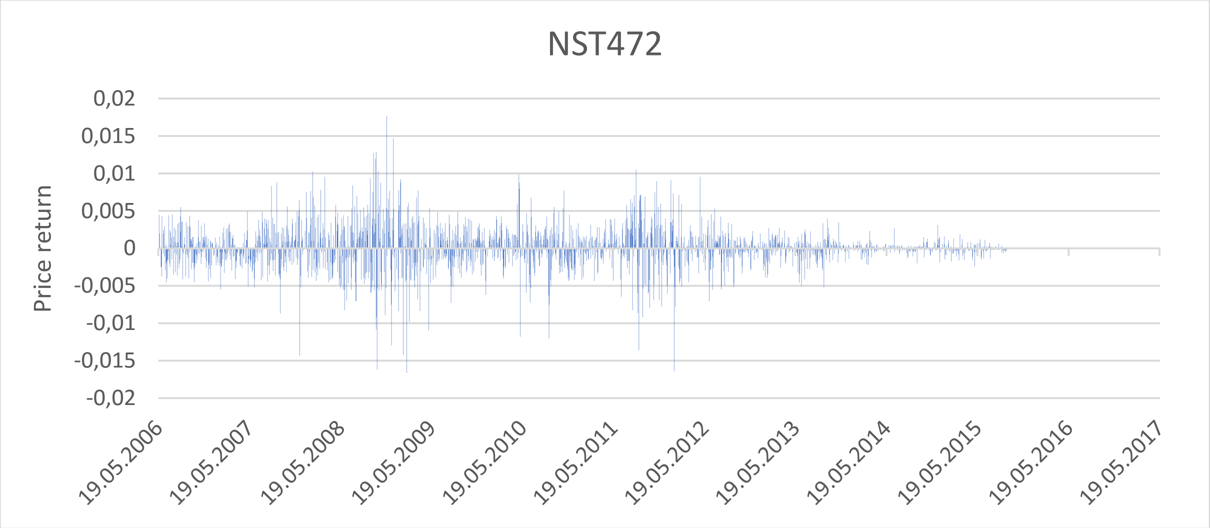

Figure 17: Close-to-close returns for bond NST472 from 2006 to 2015 with maturity in 2017

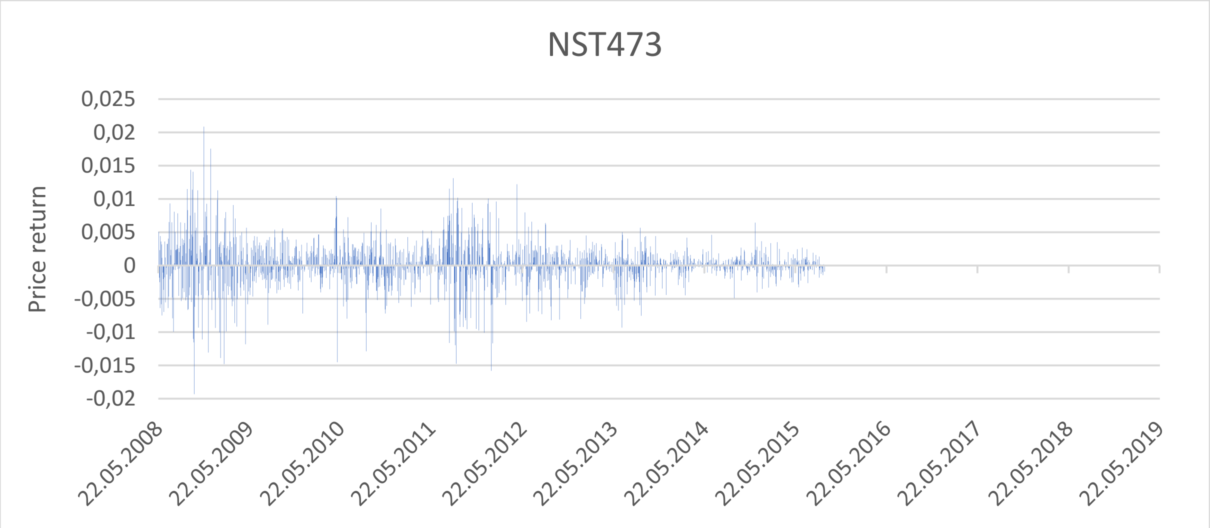

Figure 18: Close-to-close returns for bond NST473 from 2008 to 2015 with maturity in 2019

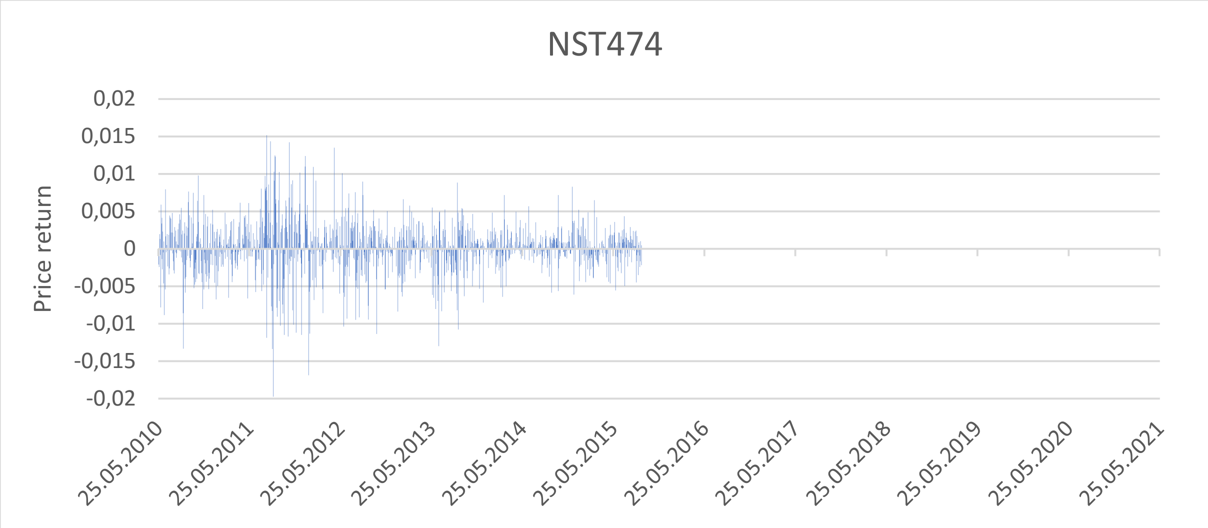

Figure 19: Close-to-close returns for bond NST474 from 2010 to 2015 with maturity in 2021

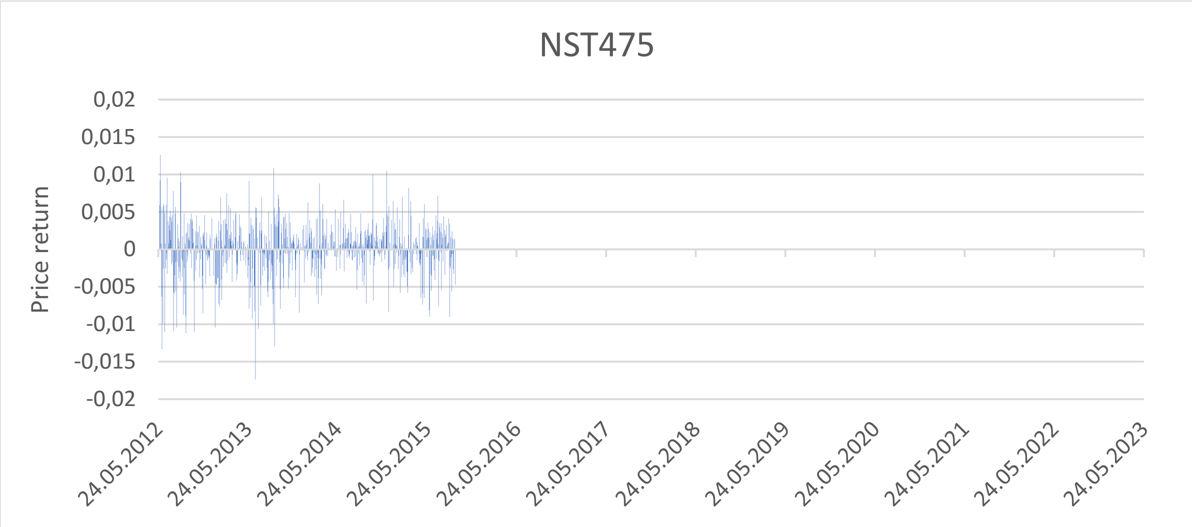

Figure 20: Close-to-close returns for bond NST475 from 2012 to 2015 with maturity in 2023

The three extinct bonds successfully capture the entire pull-to-par effect, while the others gives a good description of the effect up to the years-to-maturity period were they have contributed data. All bonds presents a generally high volatility period during the financial crisis of 2008 independent of the term to maturity.

2. Analyse three or seven bonds?

Following is the discussion of which bonds should be included in the analysis. Table 15 presents the three extinct bonds and Table 16 presents seven bonds after the method explained in chapter 7's Table 2

Table 15: Variances (upscaled) with different years to maturity periods for weekend and trading day returns for the three bonds: NST469, NST470 and NST471

Years to maturity	11-9	9-7	7-5	5-3	3-0	3-1	2-0
Weekend	6,17	5,55	6,70	4,62	0,79	1,17	0,21
Mon-Tue	7,61	5,65	3,92	3,11	0,56	0,84	0,23
Tue- Wed	13,14	8,28	4,92	4,30	0,96	1,43	0,28
Wed-Thu	9,72	7,84	6,44	4,81	0,77	1,14	0,19
Thu-Fri	11,50	9,32	5,95	3,31	0,57	0,85	0,13
Dataset	9,73	7,39	5,59	4,04	0,74	1,09	0,21

Table 16: Variances (upscaled) with different years to maturity periods for weekend and trading day returns for the seven bonds: NST469, NST470, NST471, NST472, NST473, NST474 and NST475

Years to maturity	11-9	9-7	7-5	5-3	3-0	3-1	2-0
Weekend	12,71	10,63	7,05	3,87	0,79	1,17	0,21
Mon-Tue	10,35	8,08	4,89	2,96	0,56	0,84	0,23
Tue- Wed	13,98	10,85	6,51	3,87	0,96	1,43	0,28
Wed-Thu	14,37	12,17	7,63	4,26	0,77	1,14	0,19
Thu-Fri	12,55	10,16	6,24	2,97	0,57	0,85	0,13
Dataset	12,82	10,40	6,48	3,60	0,74	1,09	0,21

Because the three expired bonds are the only ones that have contributed data for the last three years to maturity, 3-0, 3-1 and 2-0 are the same variances in Table 15 and Table 16. There is no straightforward answer behind choosing one dataset over the other. Table 15 presents a generally lower variance but is most significant for the weekend. When taking into account that the weekend contains Monday trading, this might indicate a more recent active Monday trading for long-term bonds, as shown in Table 16. This can be an interesting topic for further research. One noteworthy observation is the weekend's variance increase in period 7-5 in Table 15. This is a deviation from the clear pull-to-par[12] effect in Table 16 and the previous appendix section's graphed returns seemed to resemble the Pull to Par effect. Because Table 16 better illustrates the pull-to-par effect and obvious benefit by having more data, this thesis

[12] Described in chapter 4.

will use all seven bonds in the analysing section. As mentioned, there is no right or wrong choice here and the further use of seven bonds is assumed to not pose any threats for results and conclusion.

3. Data sample return distributions and the normal return distribution

Following are the large collection of 117 data distributions with fitted normal distribution. All data distributions are presented with Excess kurtosis, Skewness, number of observations, Jarque-Bera and associated p-value. Because of the poor visual presentation of the tail distribution, the left and right tail outliers are reported for the various periods and bonds whole dataset. In contrary to this thesis' comma usage, these illustrations uses period as a decimal separator because the graphs are conducted in econometrical software Stata.

3.1 The analysed bonds

This section contains distributions with fitted normal distribution for the seven selected bonds and their aggregated years-to-maturity periods that represents this thesis' data sample.

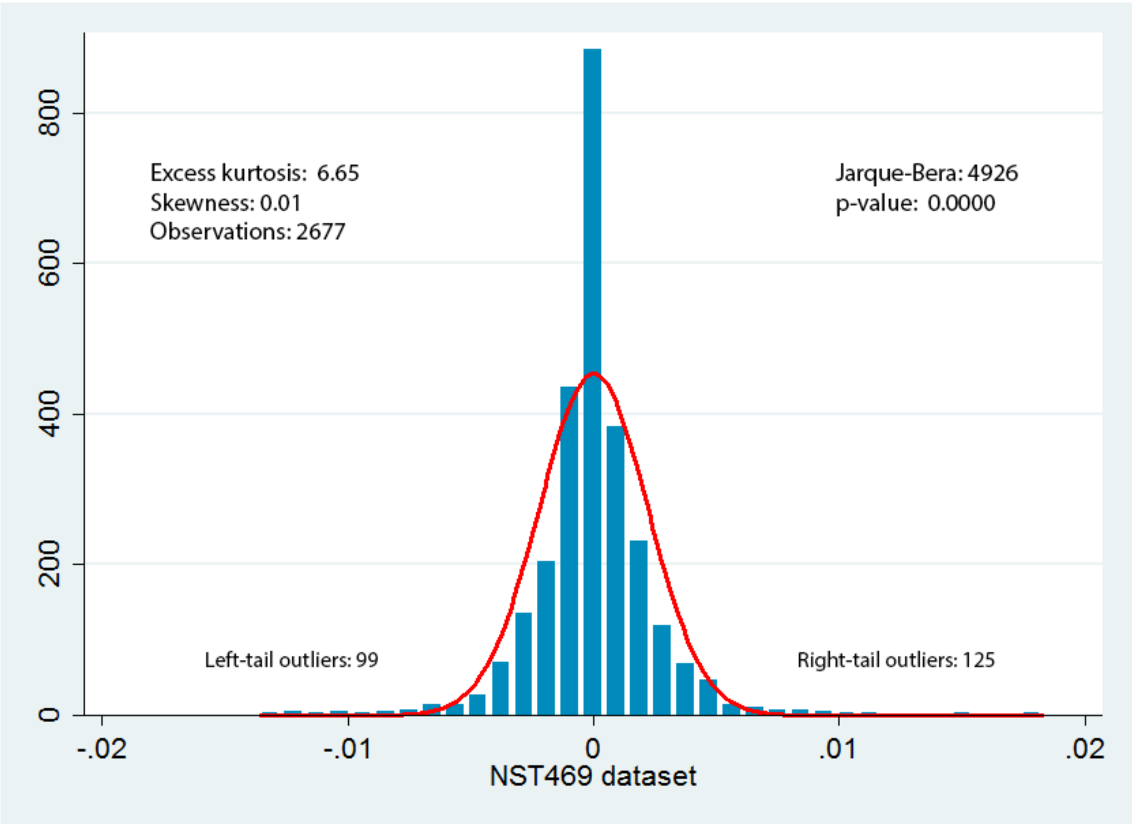

Figure 21: The entire NST469 dataset price returns and fitted normal distribution between 2000 and 2011

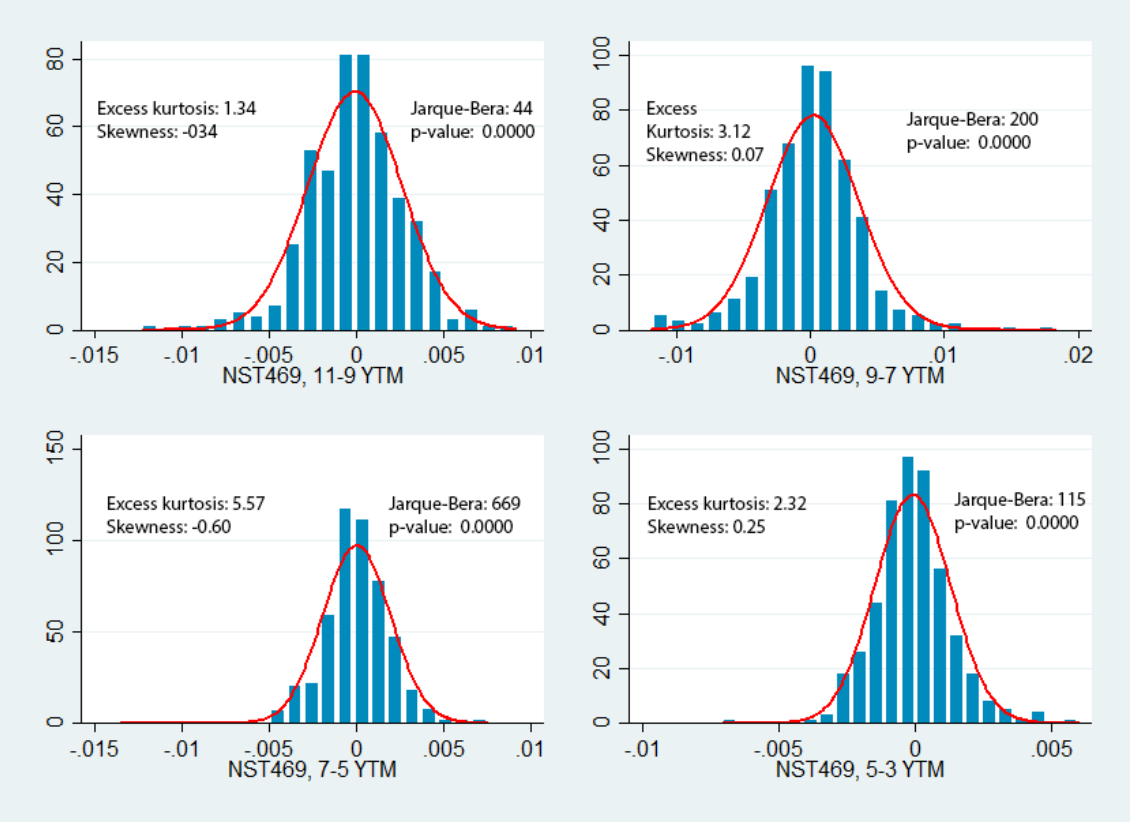

Figure 22: The NST469 price returns and fitted normal distribution for the bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2000 and 2011. The different period's number of observations is respectively 466, 490, 495 and 488.

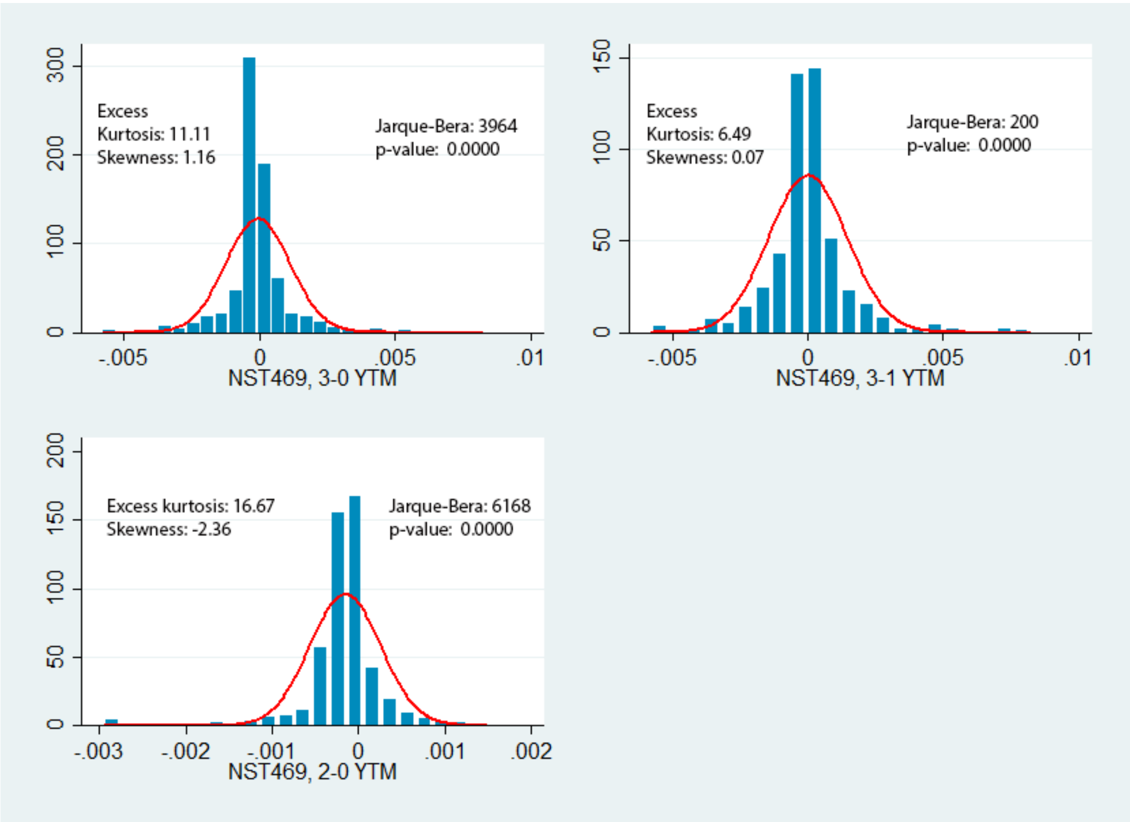

Figure 23: The NST469 price returns and fitted normal distribution for bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2000 and 2011. The different period's number of observations is respectively 738, 492 and 493

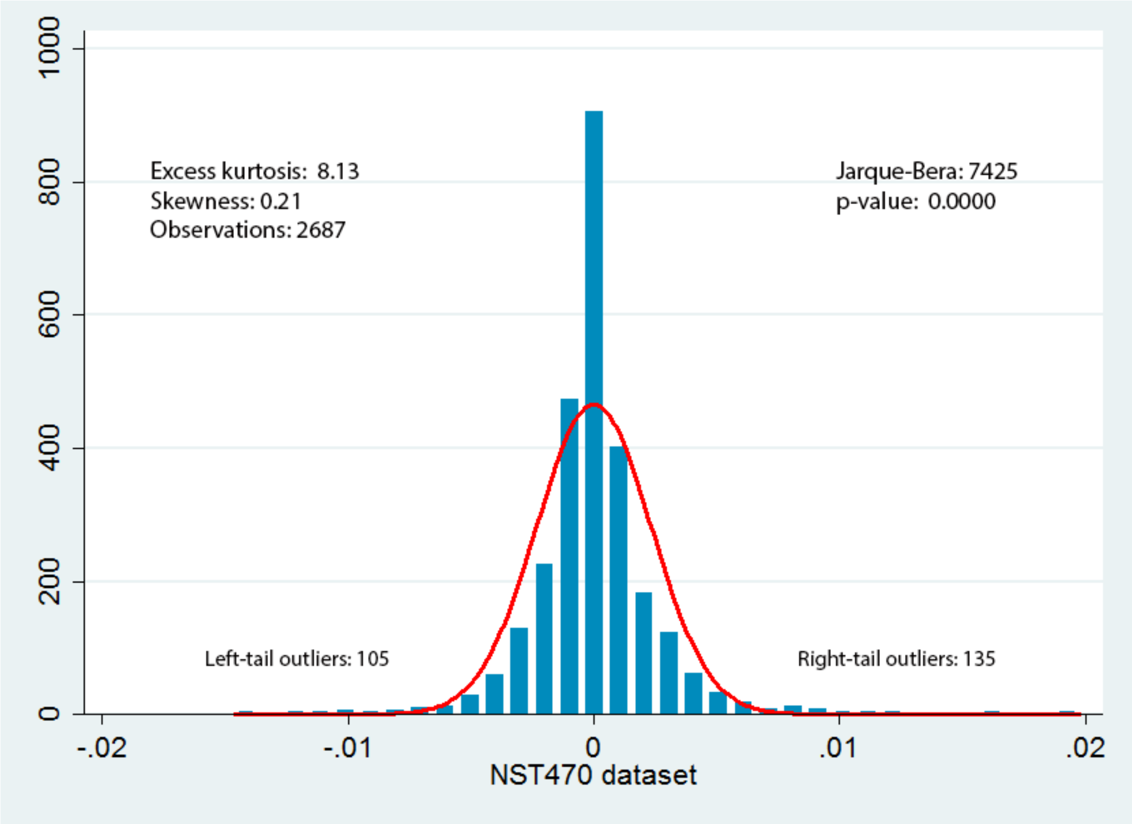

Figure 24: The entire NST470 dataset price returns and fitted normal distribution between 2002 and 2013.

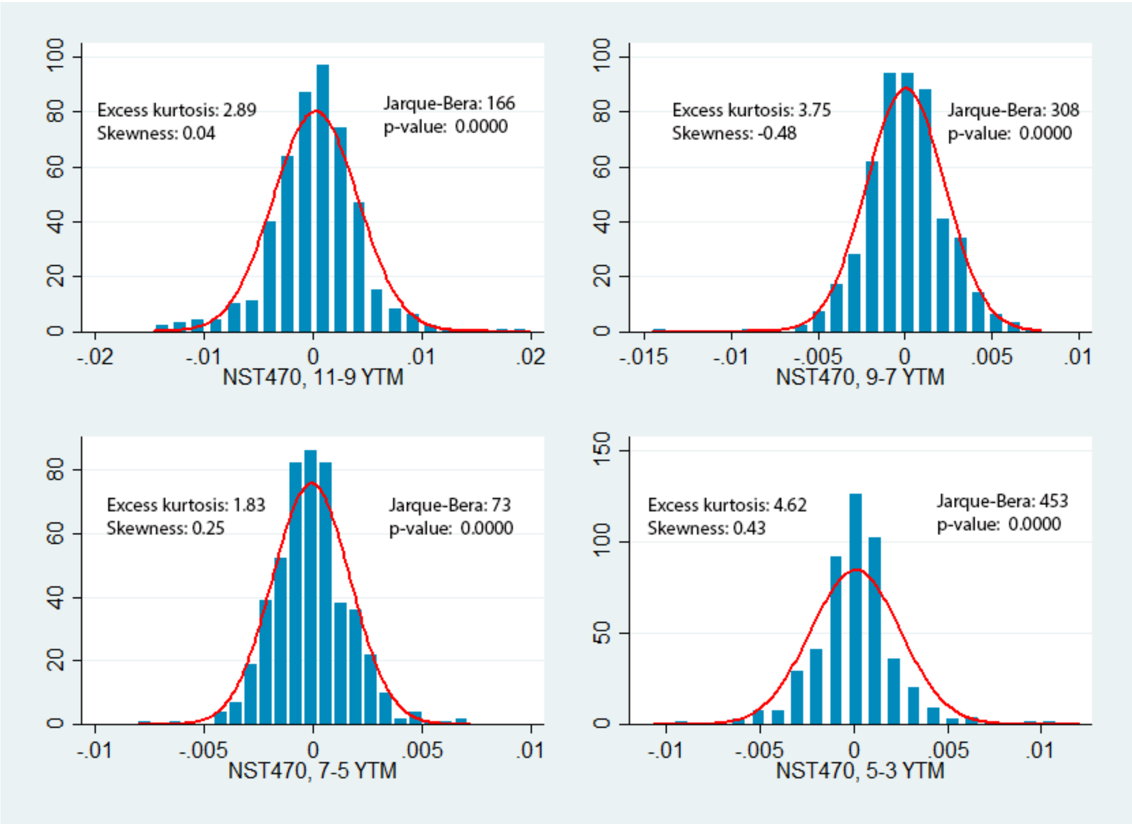

Figure 25: The NST470 price returns and fitted normal distribution for the bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2002 and 2013. The different period's number of observations is respectively 477, 493, 489 and 493.

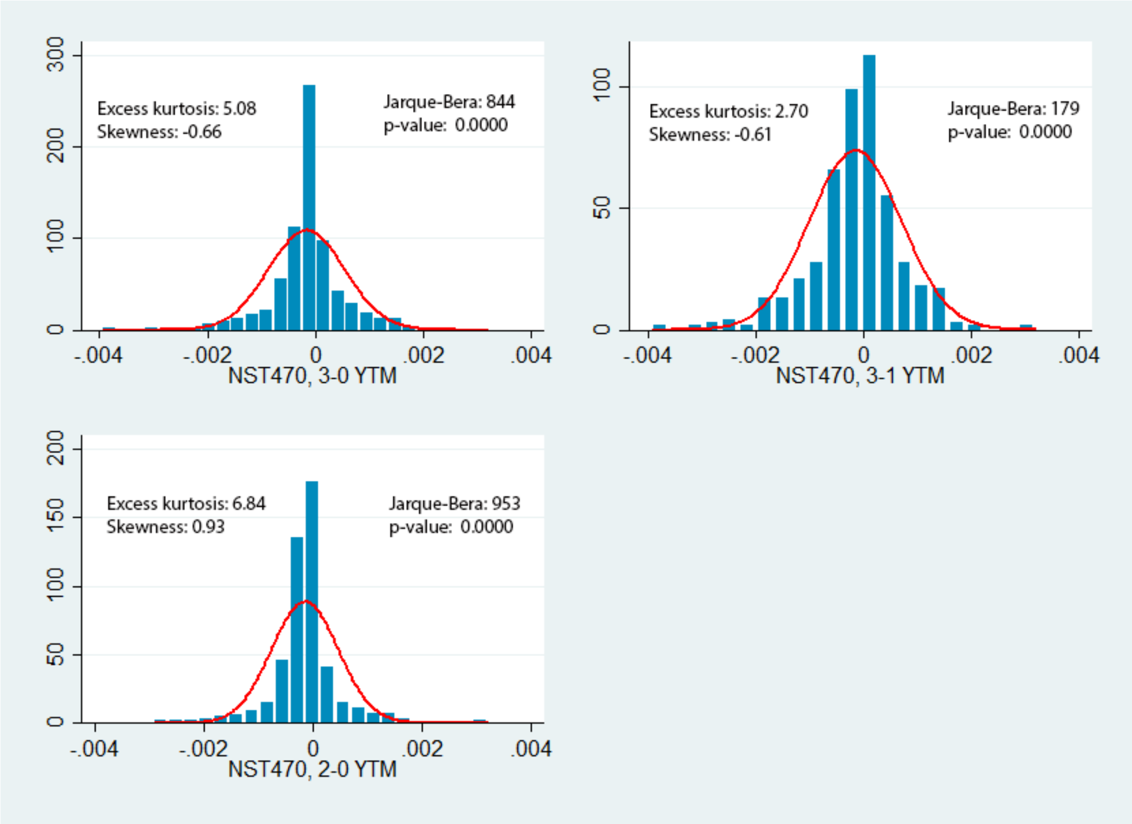

Figure 26: The NST470 price returns and fitted normal distribution for the bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2002 and 2013. The different period's number of observations is respectively 735, 491 and 489.

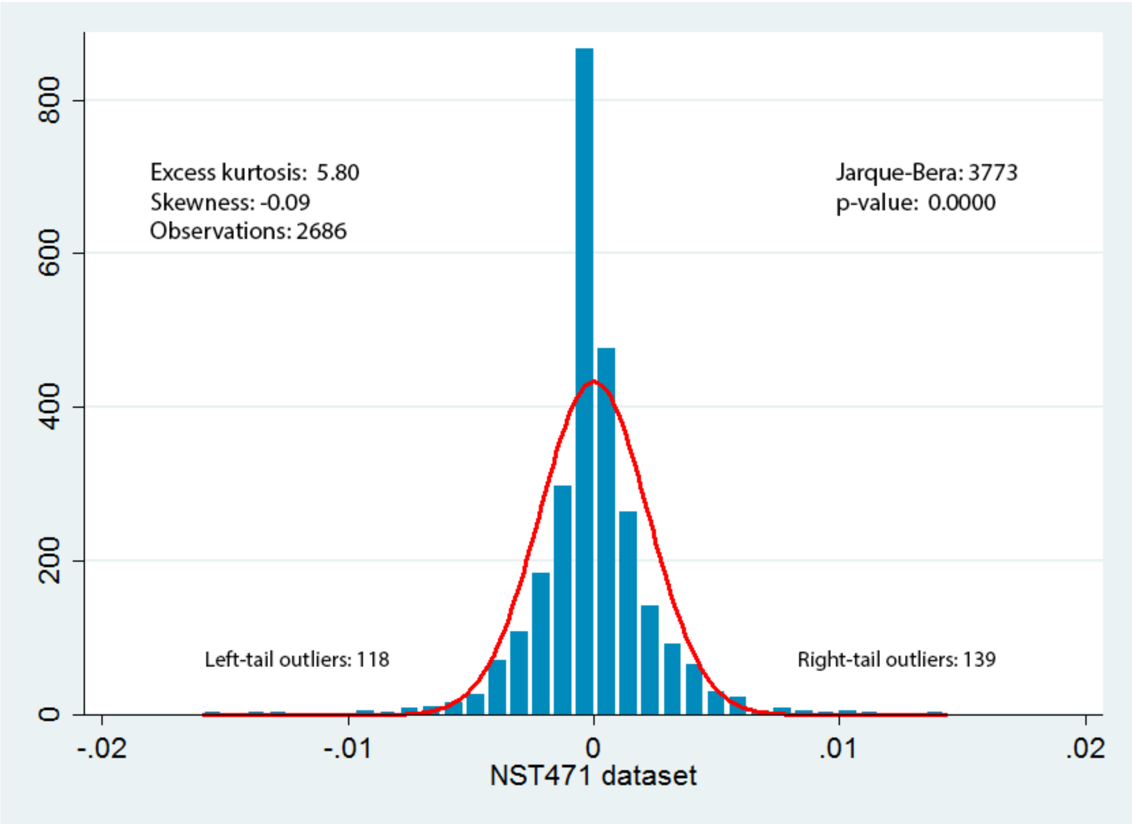

Figure 27: The entire NST471 dataset price returns and fitted normal distribution between 2004 and 2015.

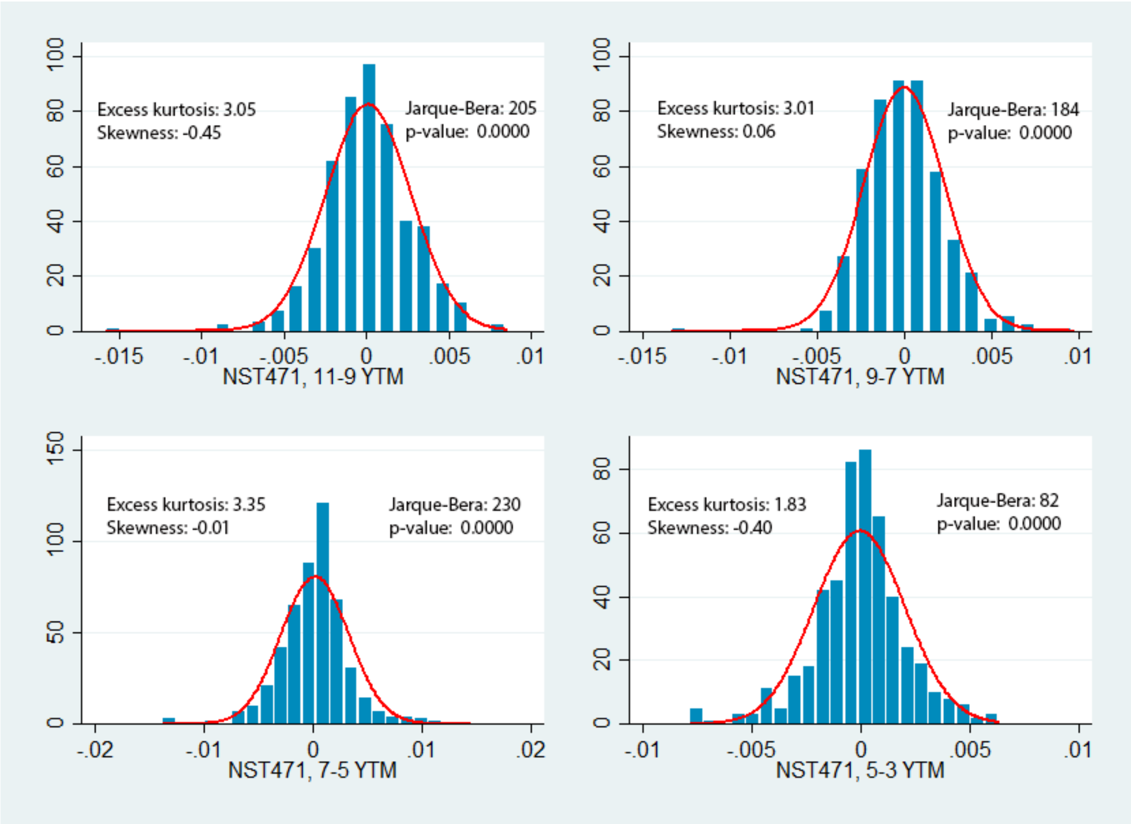

Figure 28: The NST471 price returns and fitted normal distribution for the bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2004 and 2015. The different period's number of observations is respectively 485, 487, 493 and 493.

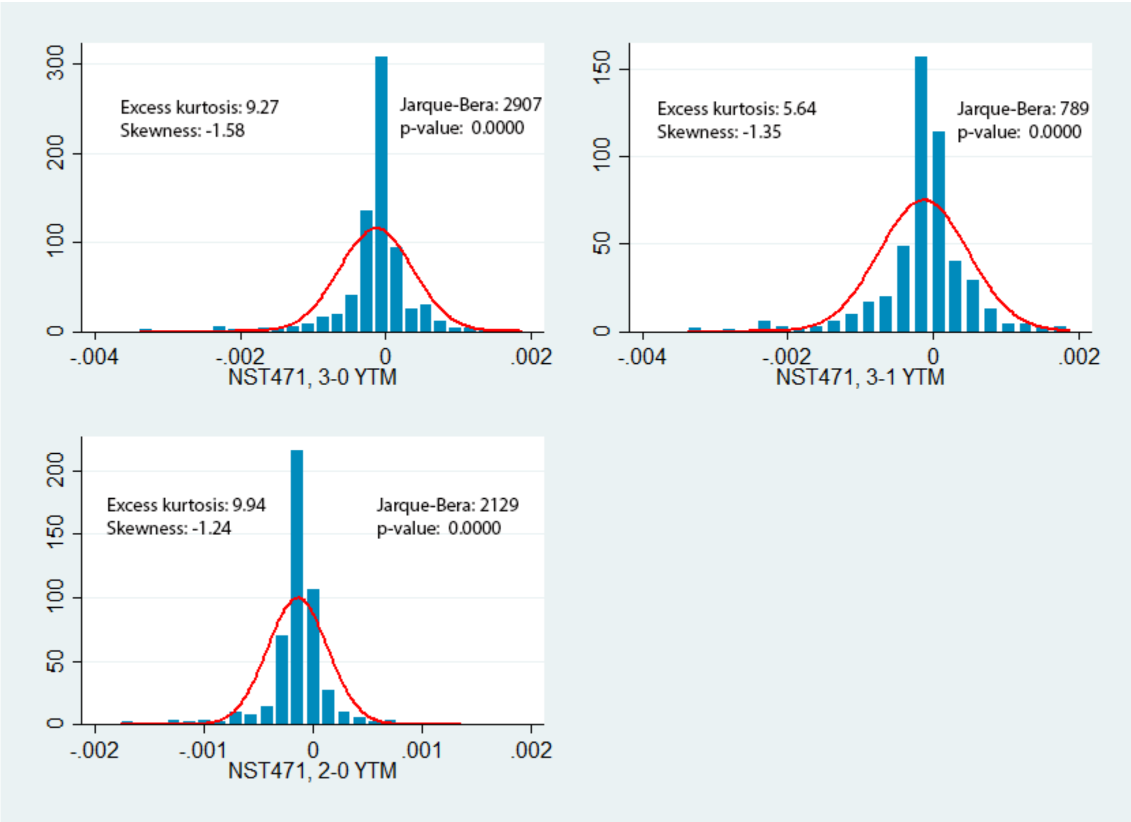

Figure 29: The NST470 price returns and fitted normal distribution for the bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2002 and 2013. The different period's number of observations is respectively 728, 485 and 487.

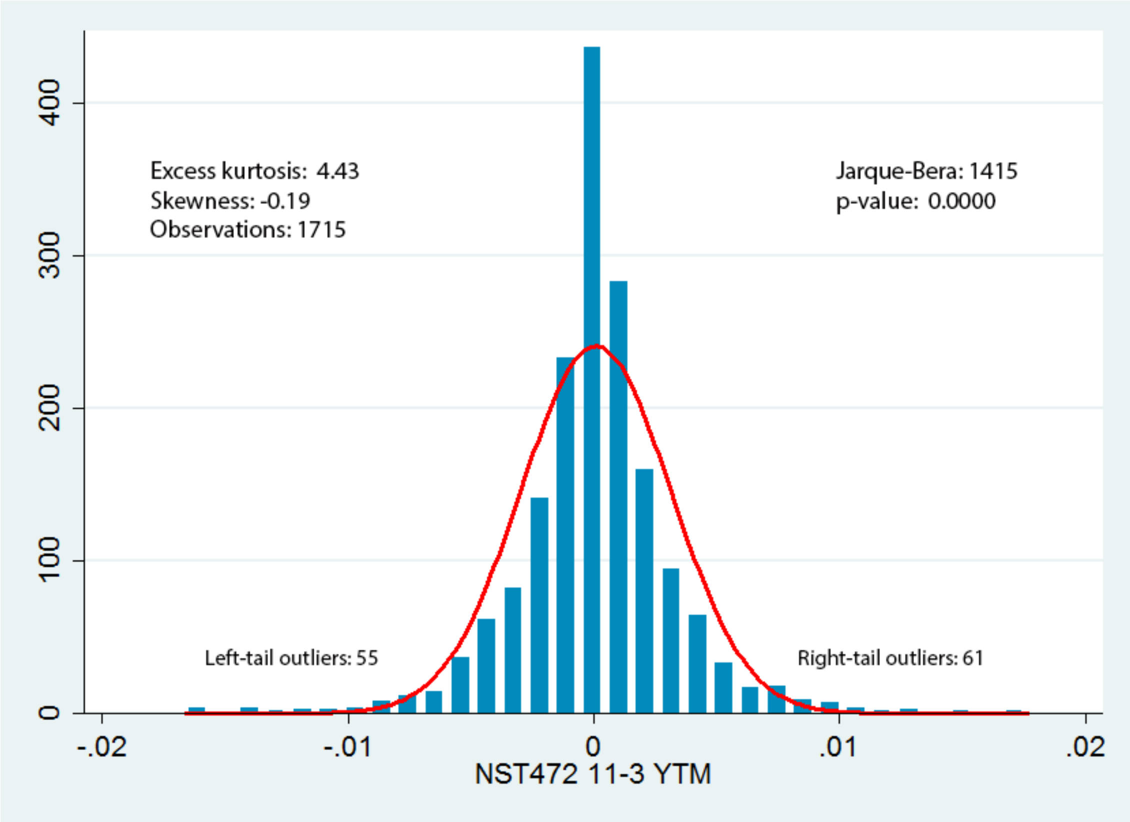

Figure 30: The NST472 price returns and fitted normal distribution for the bonds 11-3 years-to-maturity period between 2006 and 2015.

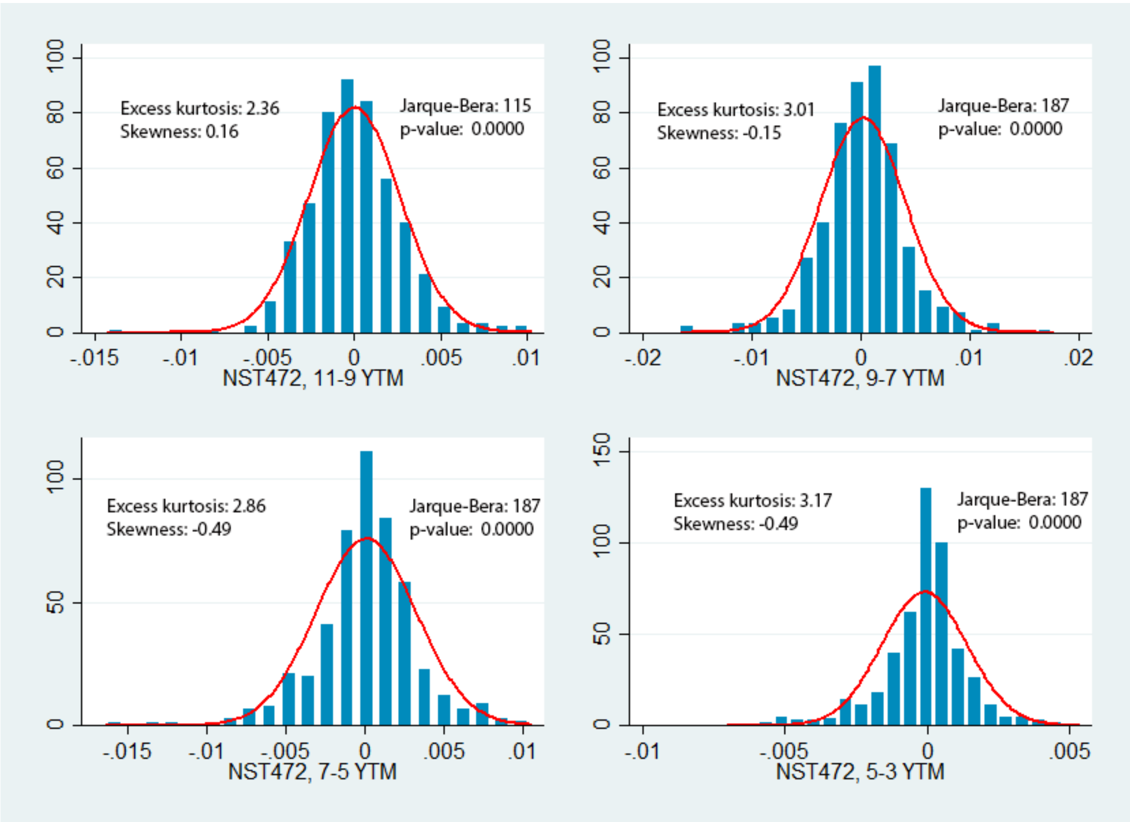

Figure 31: The NST472 price returns and fitted normal distribution for the bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2006 and 2015. The different period's number of observations is respectively 487, 491, 492 and 488.

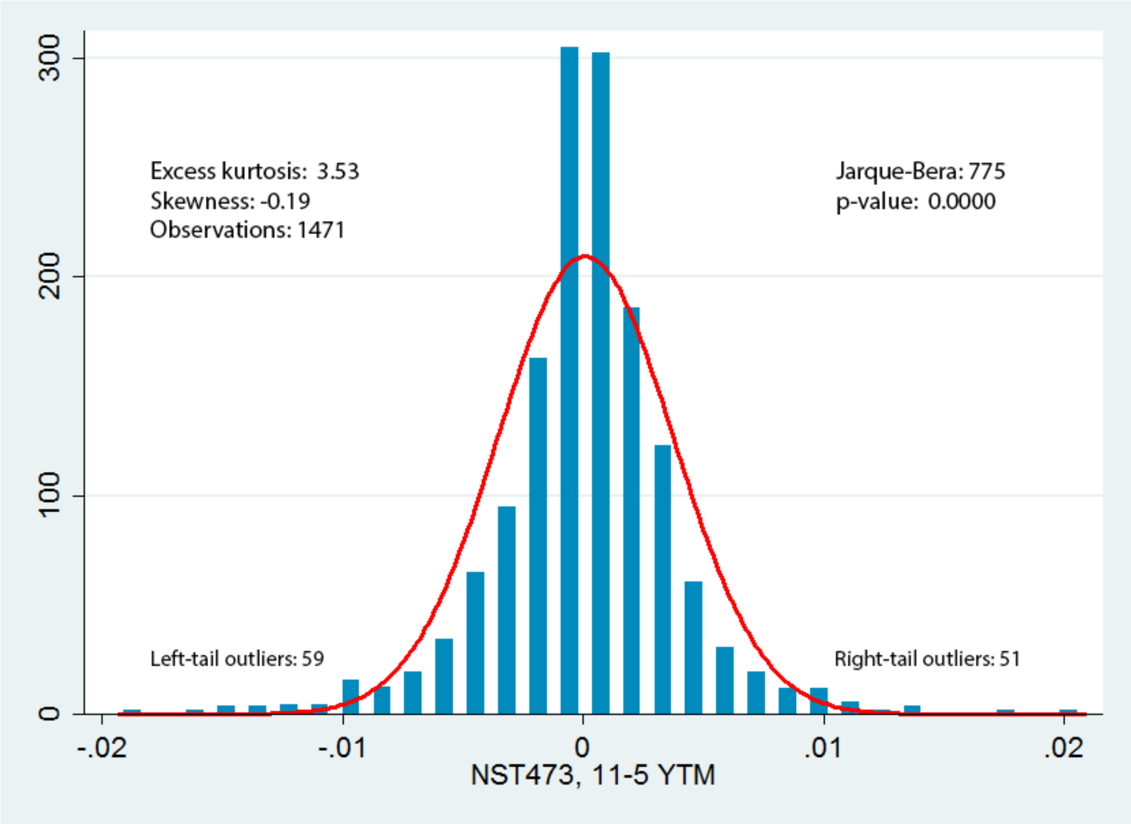

Figure 32: The NST473 price returns and fitted normal distribution for the bonds 11-5 years-to-maturity period between 2008 and 2015.

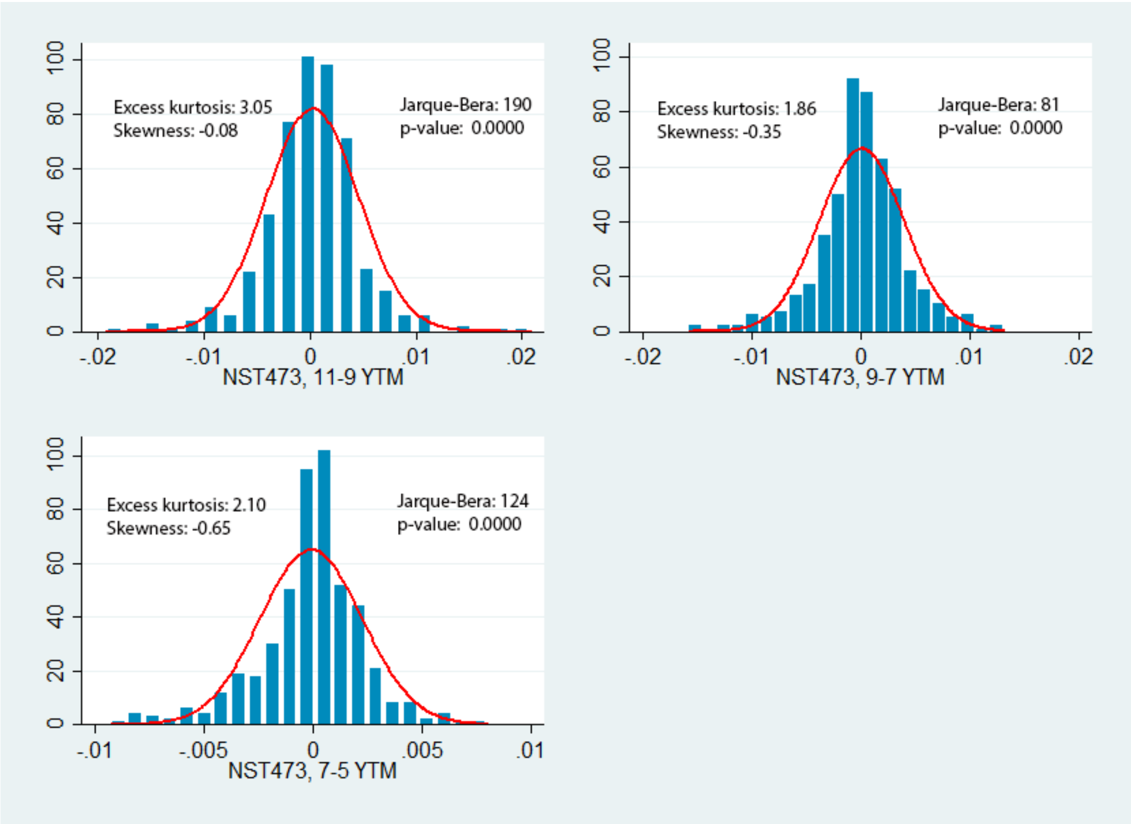

Figure 33: The NST472 price returns and fitted normal distribution for the bonds 11-9, 9-7, 7-5, years-to-maturity periods between 2006 and 2015. The different period's number of observations is respectively 490, 494 and 487.

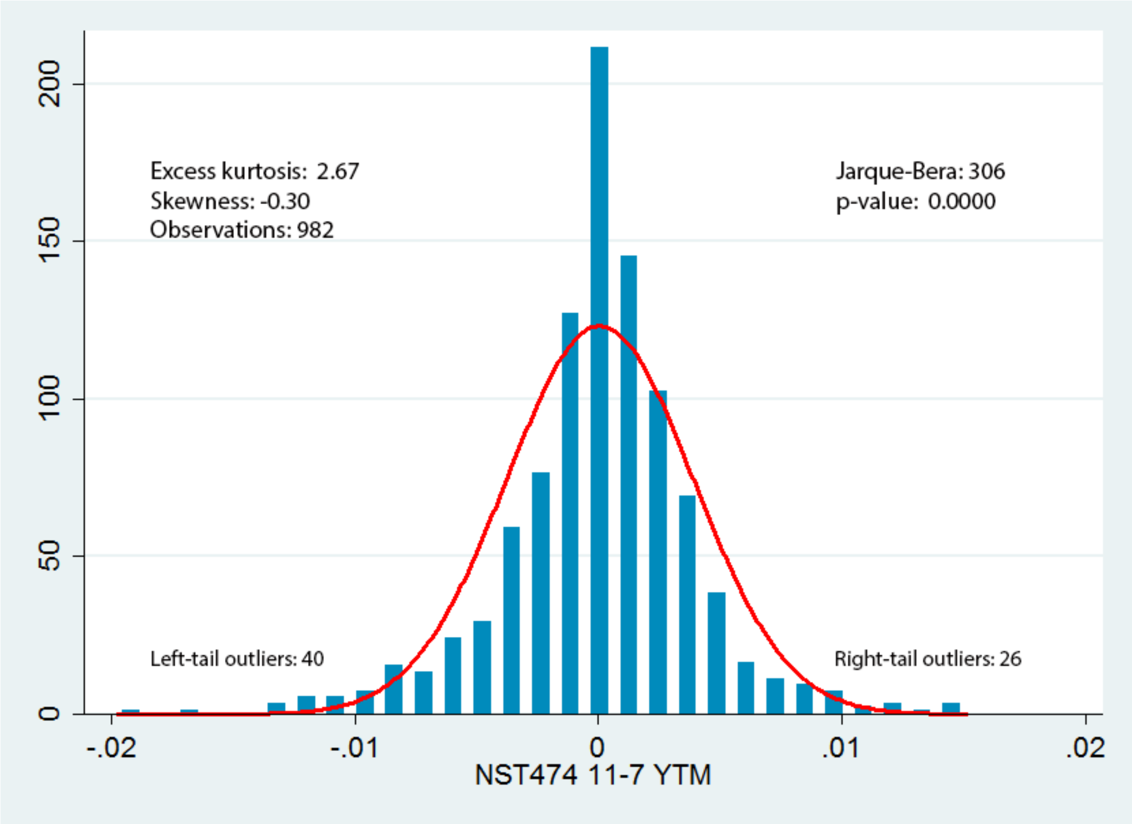

Figure 34: The NST474 price returns and fitted normal distribution for the bonds 11-7 years-to-maturity period between 2010 and 2015.

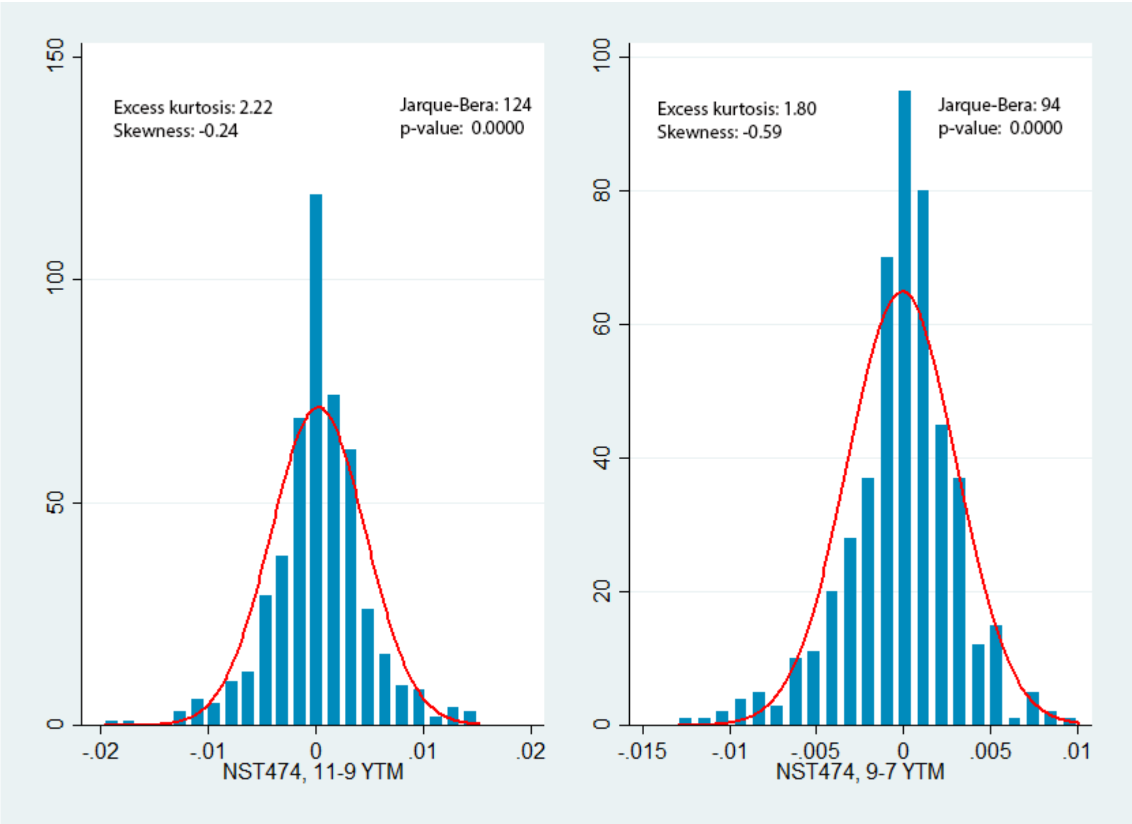

Figure 35: The NST472 price returns and fitted normal distribution for the bonds 11-9 and 9-7 years-to-maturity periods between 2006 and 2015. The different period's number of observations is respectively 499 and 485.

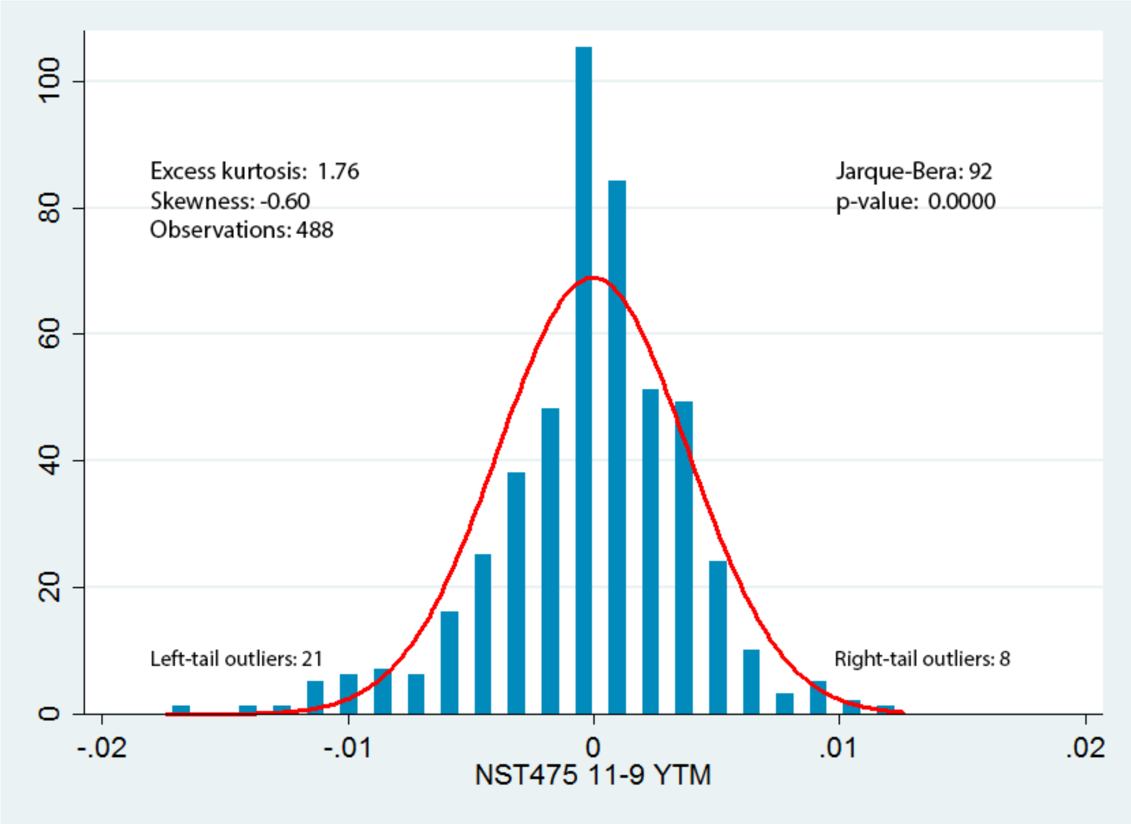

Figure 36: The NST475 price returns and fitted normal distribution for the bonds 11-9 years-to-maturity period between 2012 and 2015.

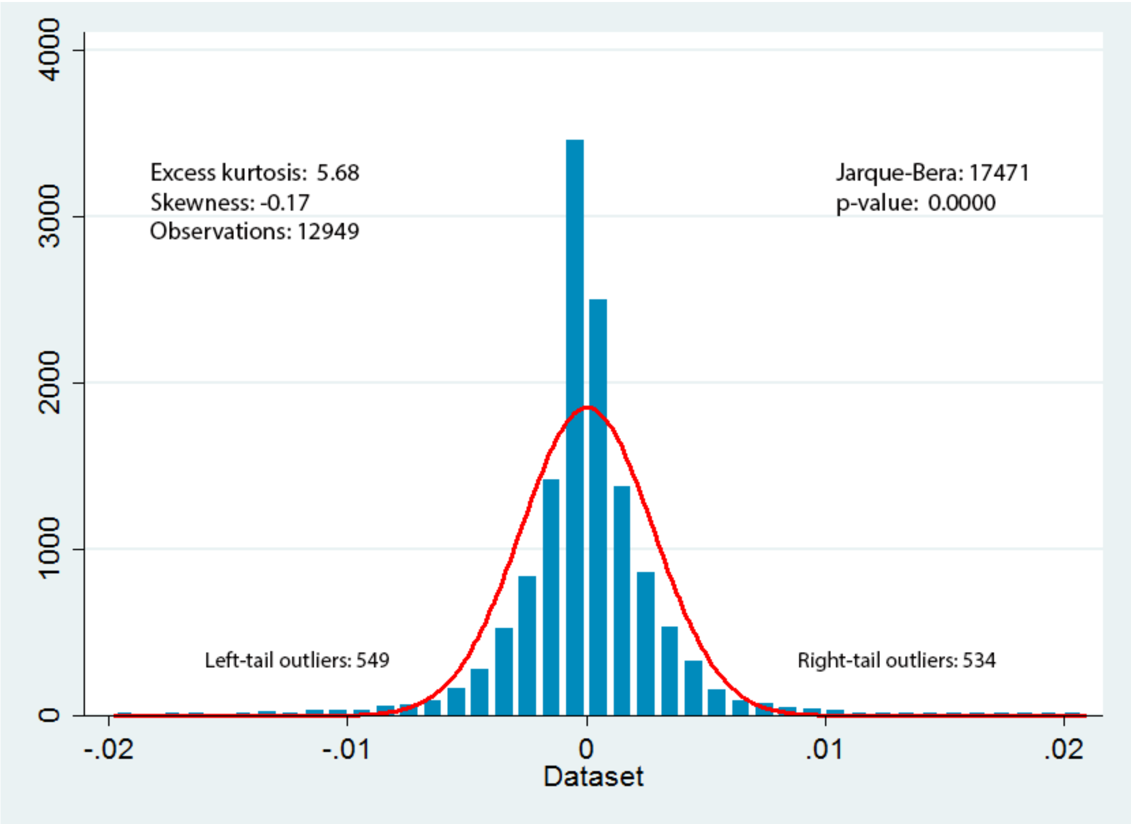

Figure 37: The entire dataset's price returns and fitted normal distribution between 2000 and 2015.

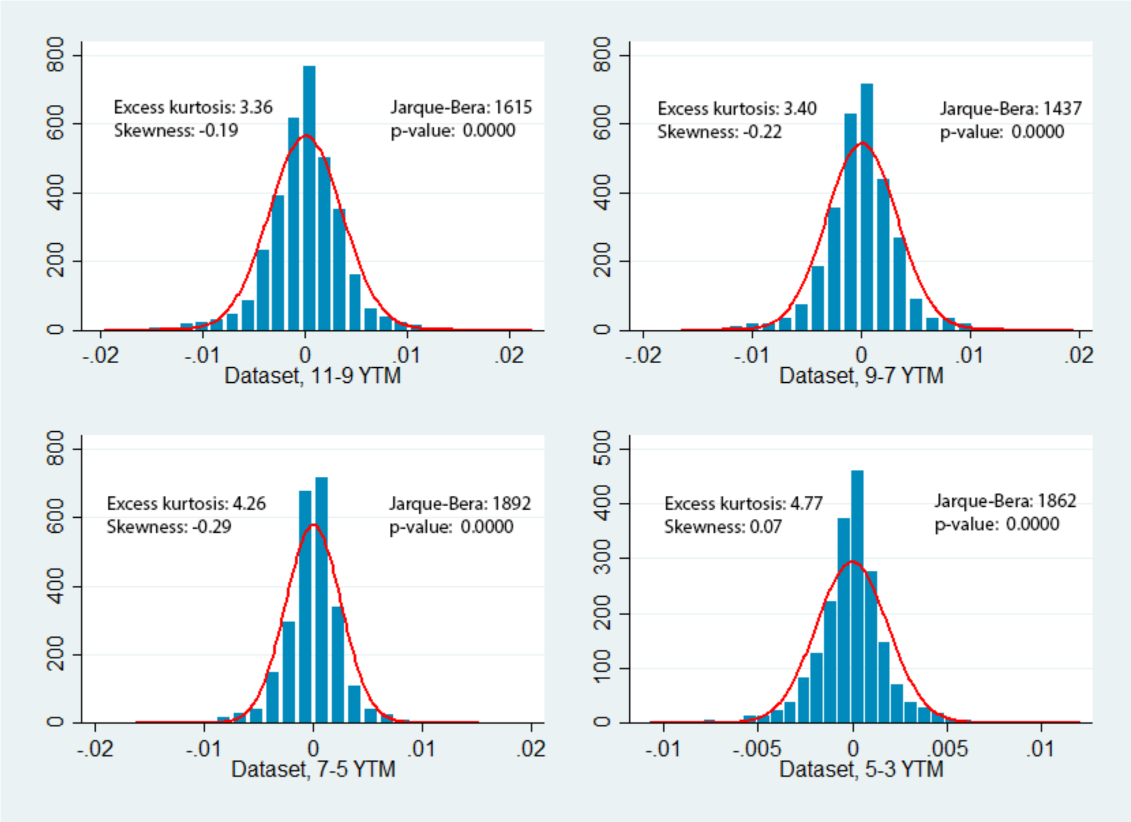

Figure 38: The dataset price returns and fitted normal distribution for bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 3390, 2940, 2456 and 1962.

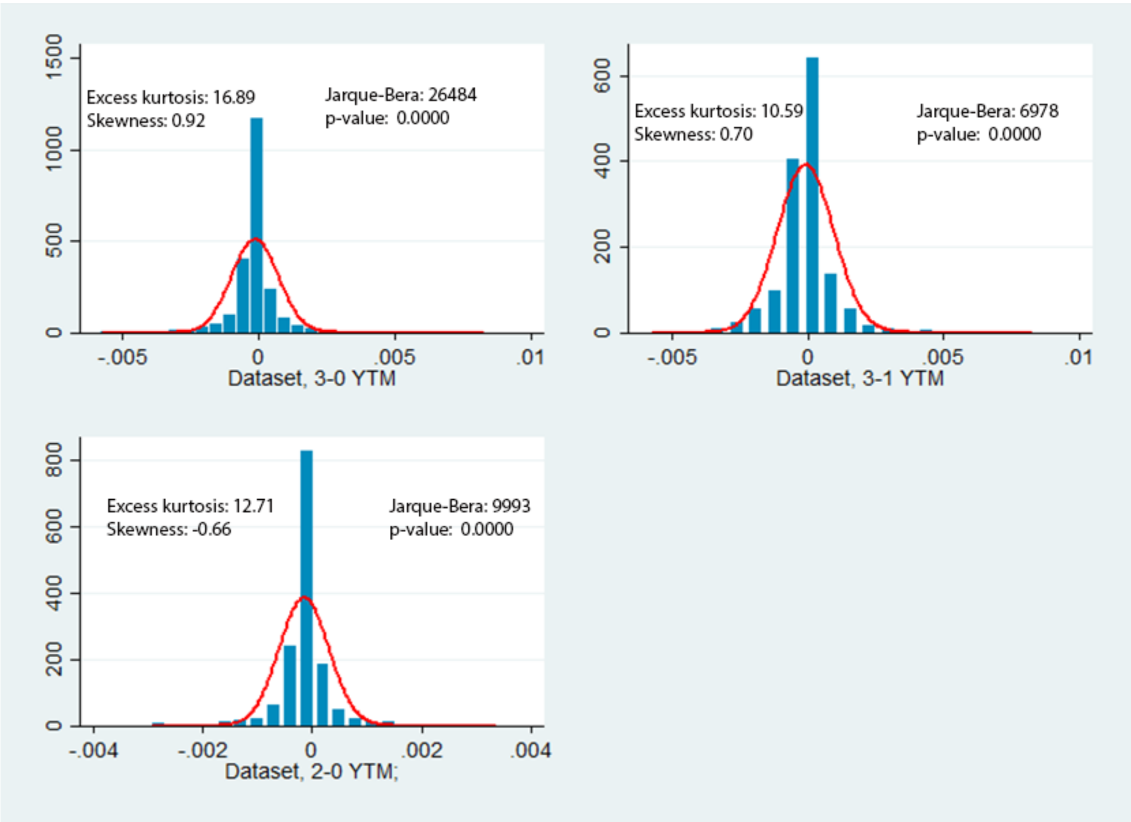

Figure 39: The dataset price returns and fitted normal distribution for bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 2201, 1468 and 1469.

3.2 Trading-Time Hypothesis - Seven trading hours

This section contains the distributions with fitted normal distribution for the weekend price returns and the four trading day's price returns used in the Trading-Time Hypothesis testing. The price return periods contain seven trading hours and are divided up and presented in all years-to-maturity periods.

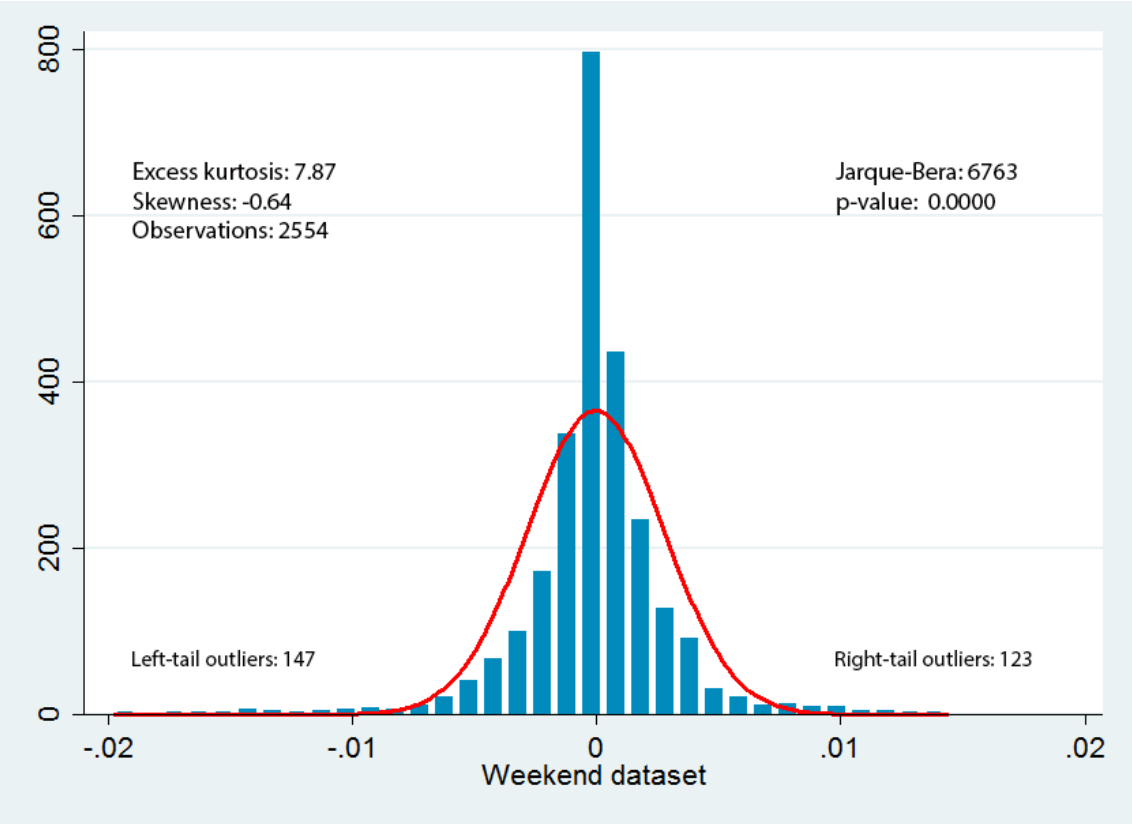

Figure 40: The entire dataset's weekend price returns and fitted normal distribution between 2000 and 2015.

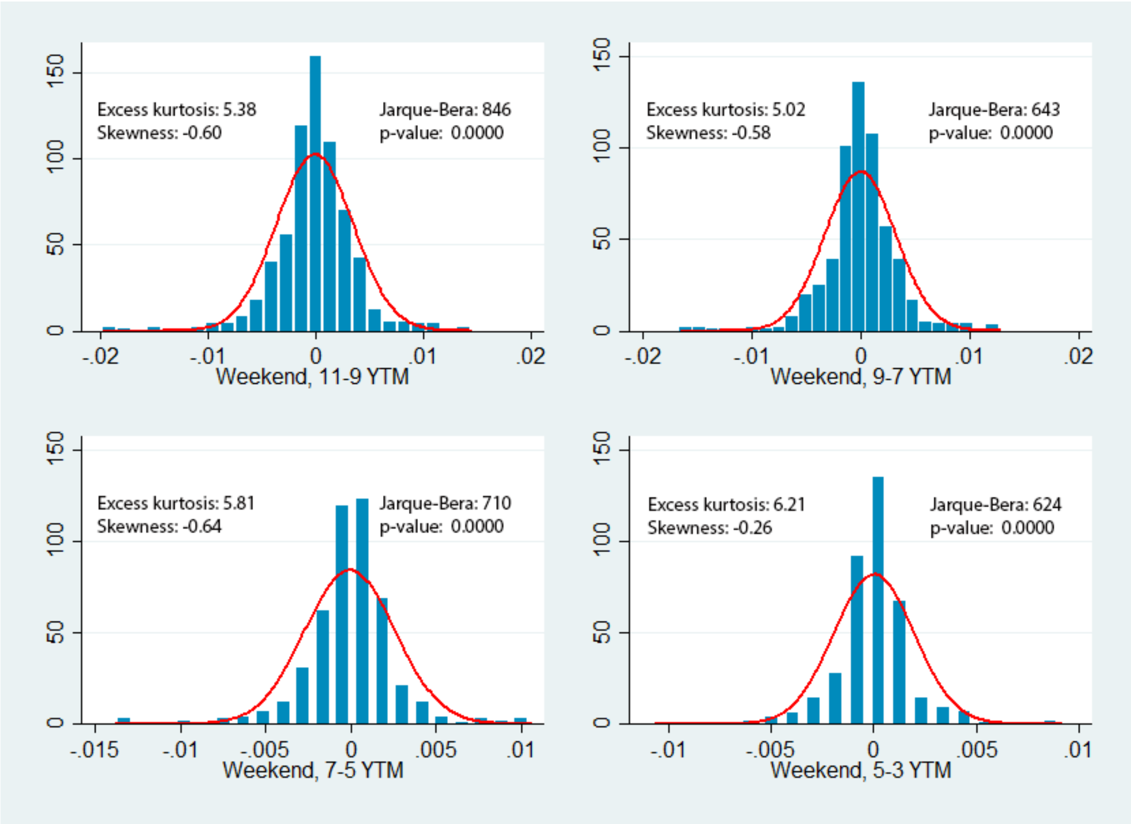

Figure 41: The weekend's price returns and fitted normal distribution for bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 670, 582, 482 and 386.

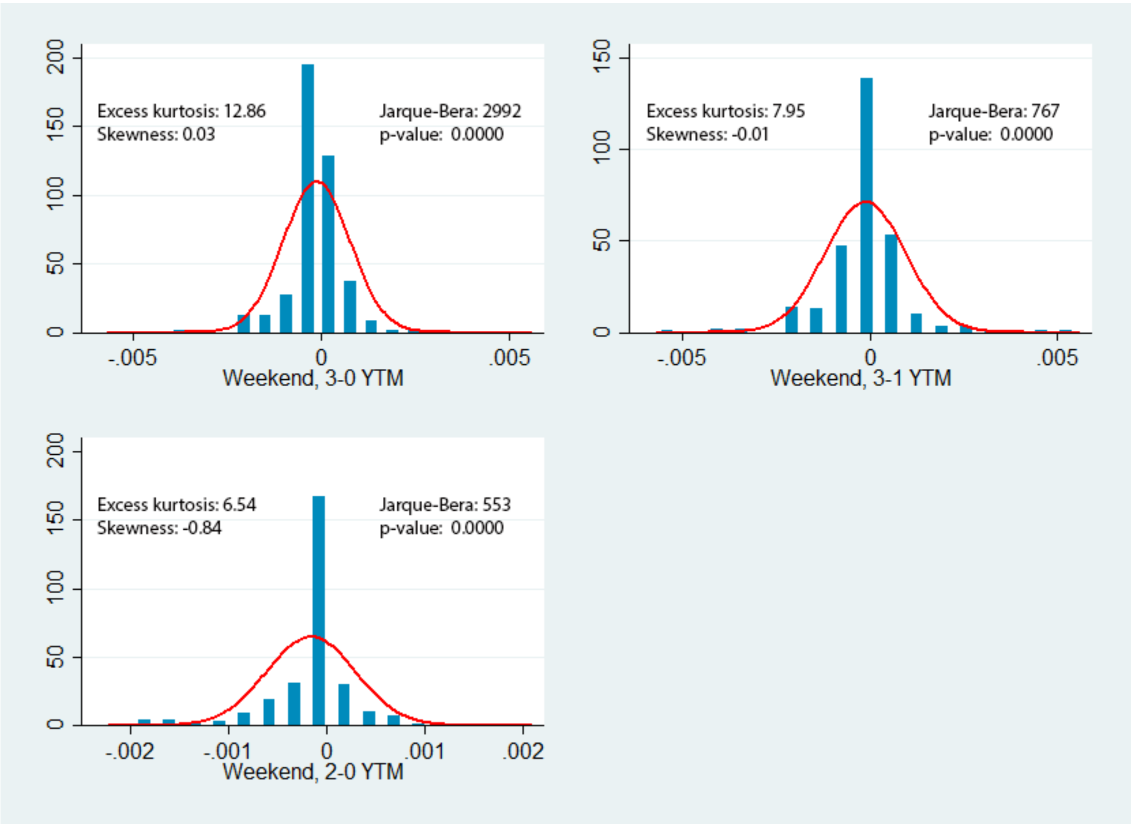

Figure 42: The weekend's price returns and fitted normal distribution for bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 434, 291 and 291.

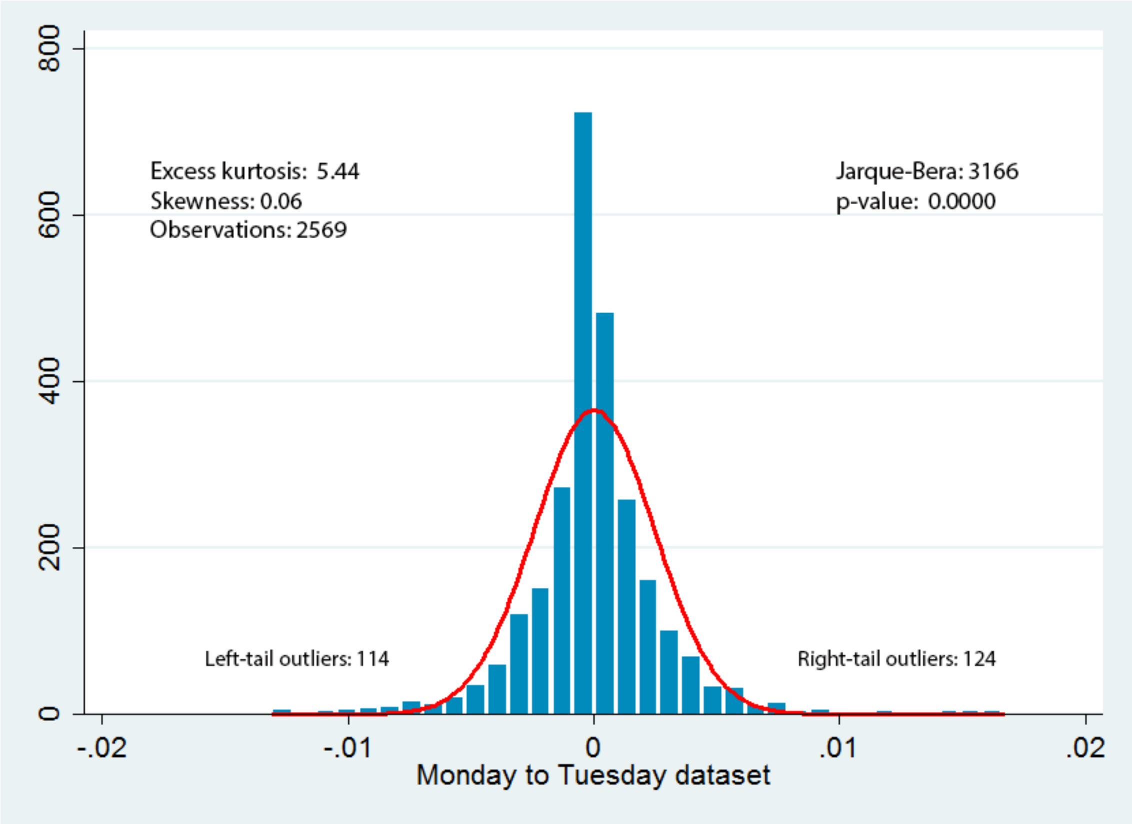

Figure 43: The entire dataset's Monday to Tuesday price returns and fitted normal distribution between 2000 and 2015.

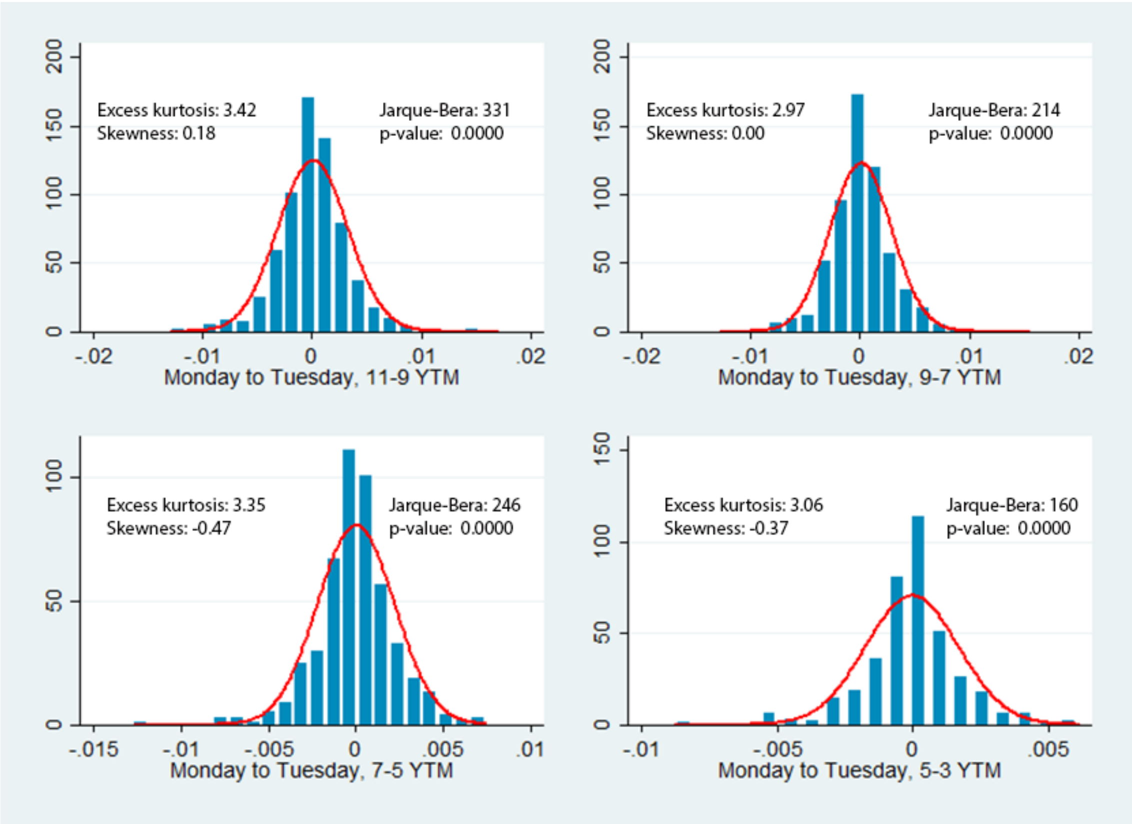

Figure 44: The Monday to Tuesday's price returns and fitted normal distribution for bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 671, 584, 487 and 387.

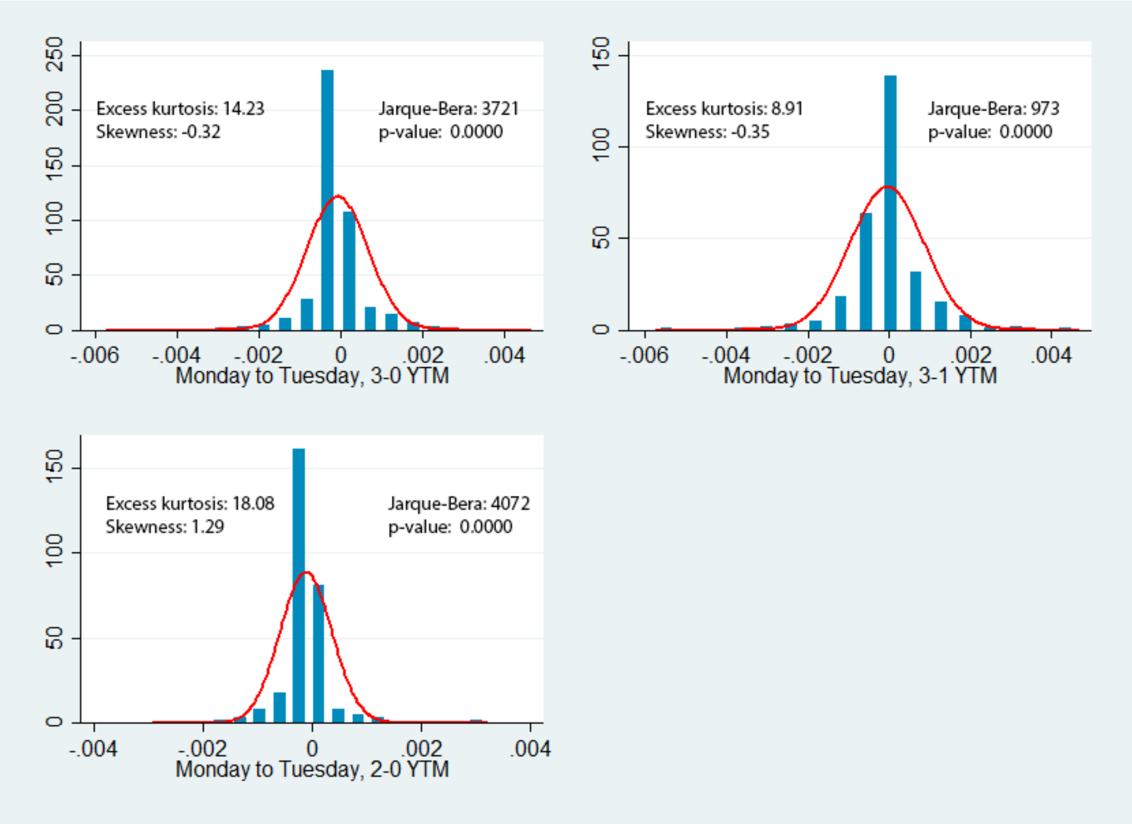

Figure 45: The Monday to Tuesday's price returns and fitted normal distribution for bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 440, 292 and 293.

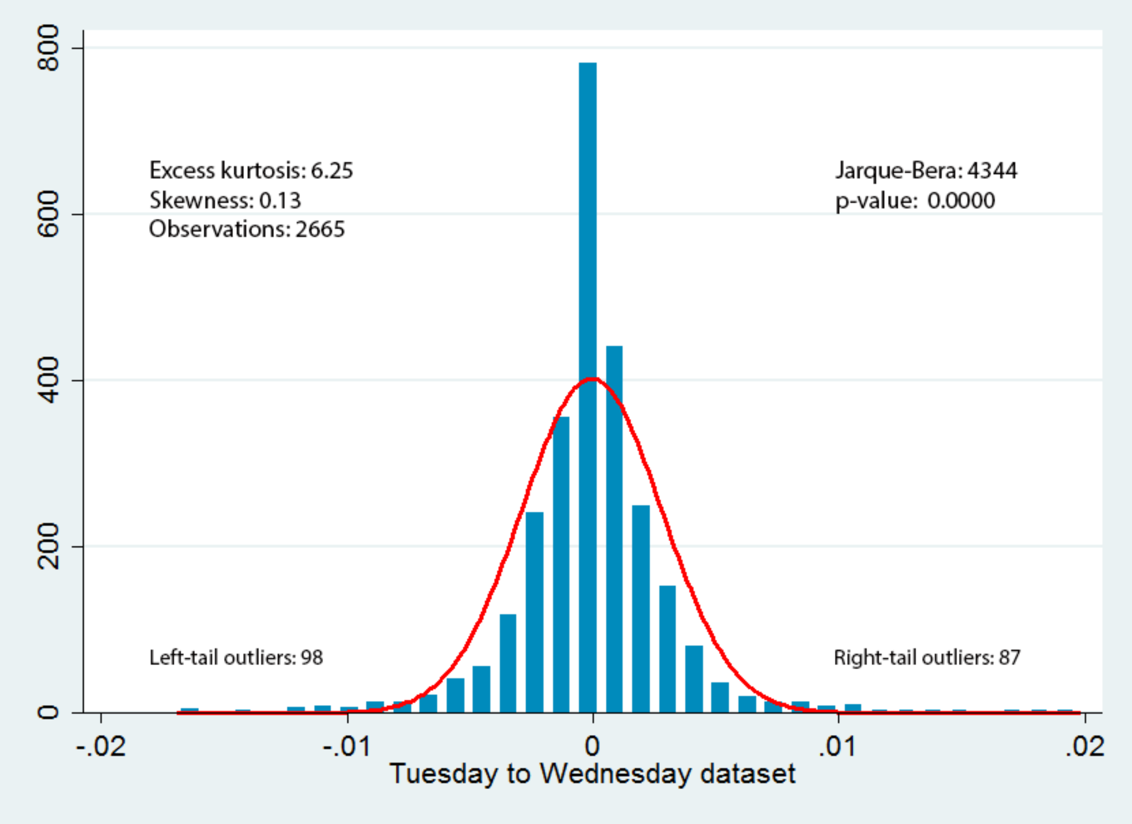

Figure 46: The entire dataset's Tuesday to Wednesday price returns and fitted normal distribution between 2000 and 2015.

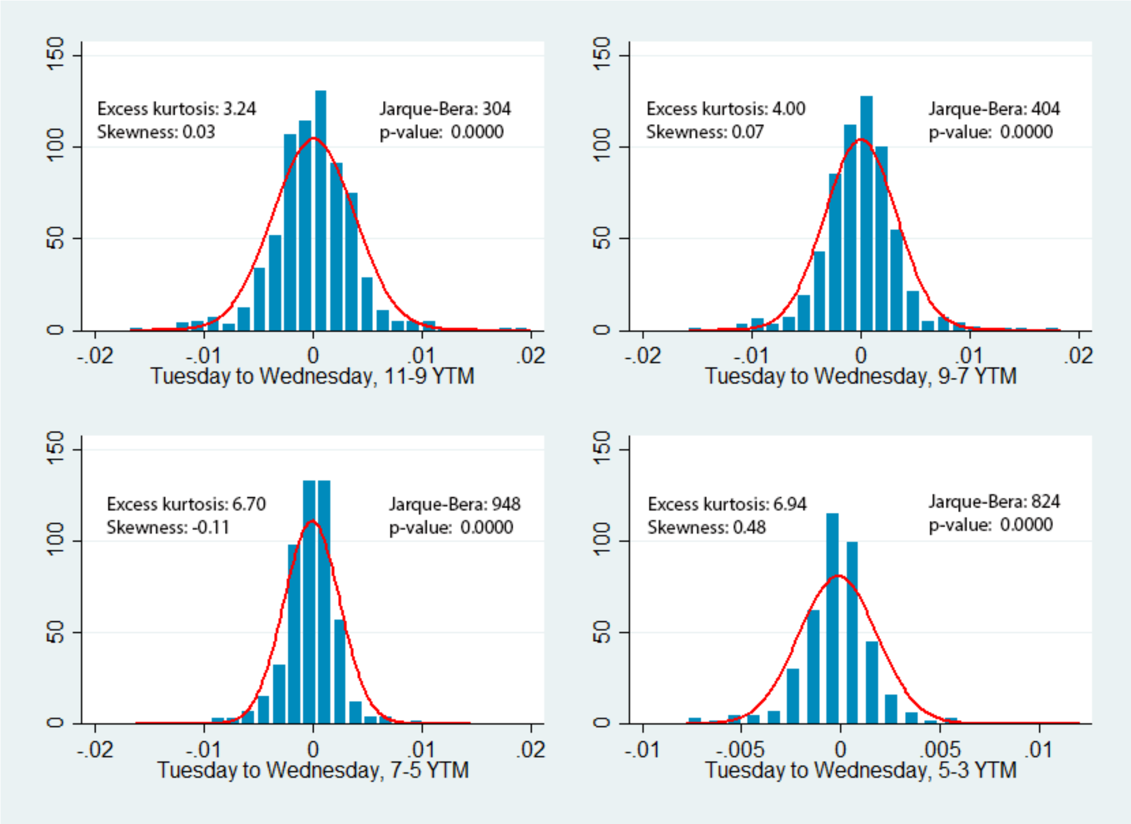

Figure 47: The Tuesday to Wednesday's price returns and fitted normal distribution for bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2000 and 2015. The period's number of observations is respectively 696, 605, 507 and 403.

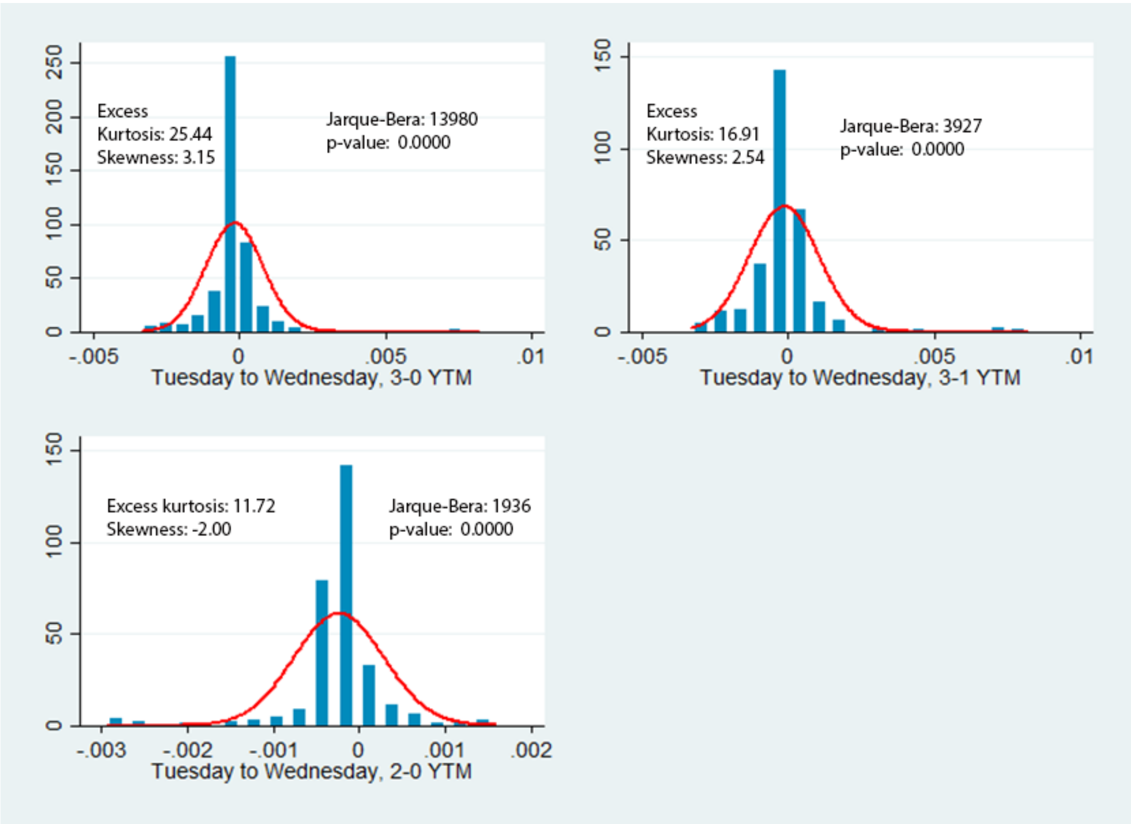

Figure 48: The Tuesday to Wednesday's price returns and fitted normal distribution for bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 454, 303 and 303.

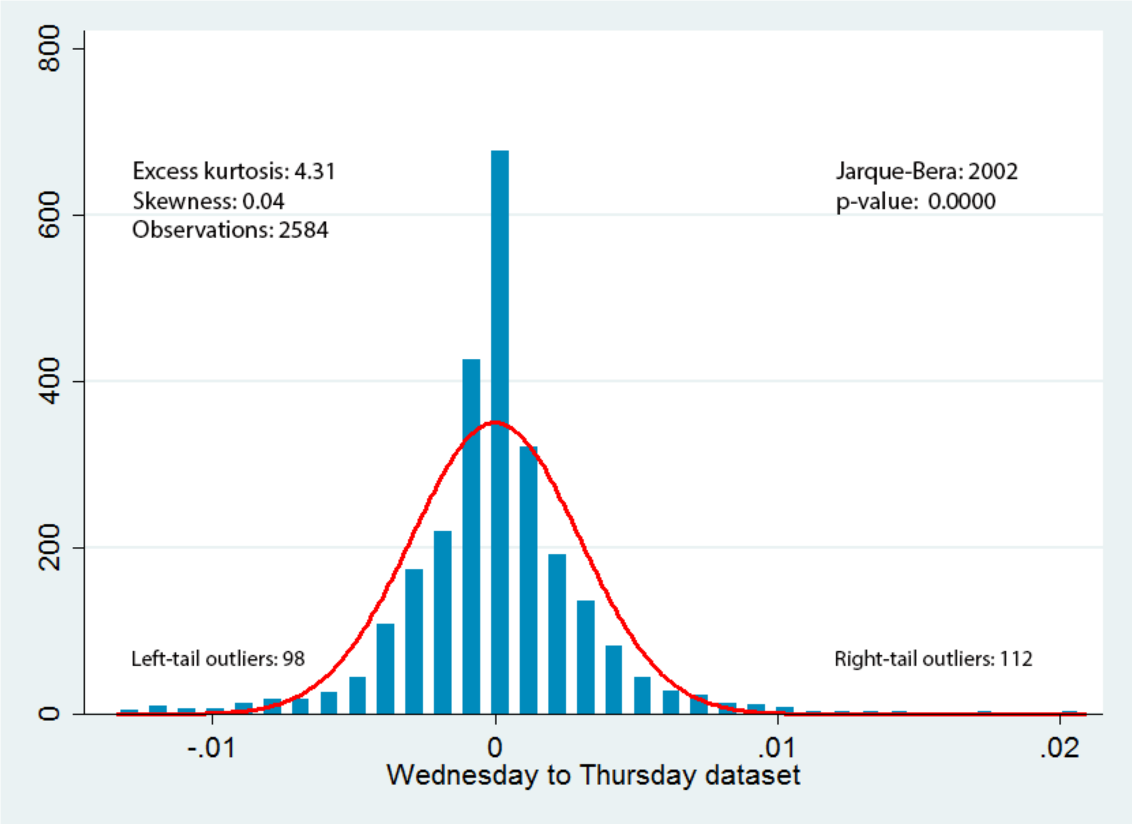

Figure 49: The entire dataset's Wednesday to Thursday price returns and fitted normal distribution between 2000 and 2015.

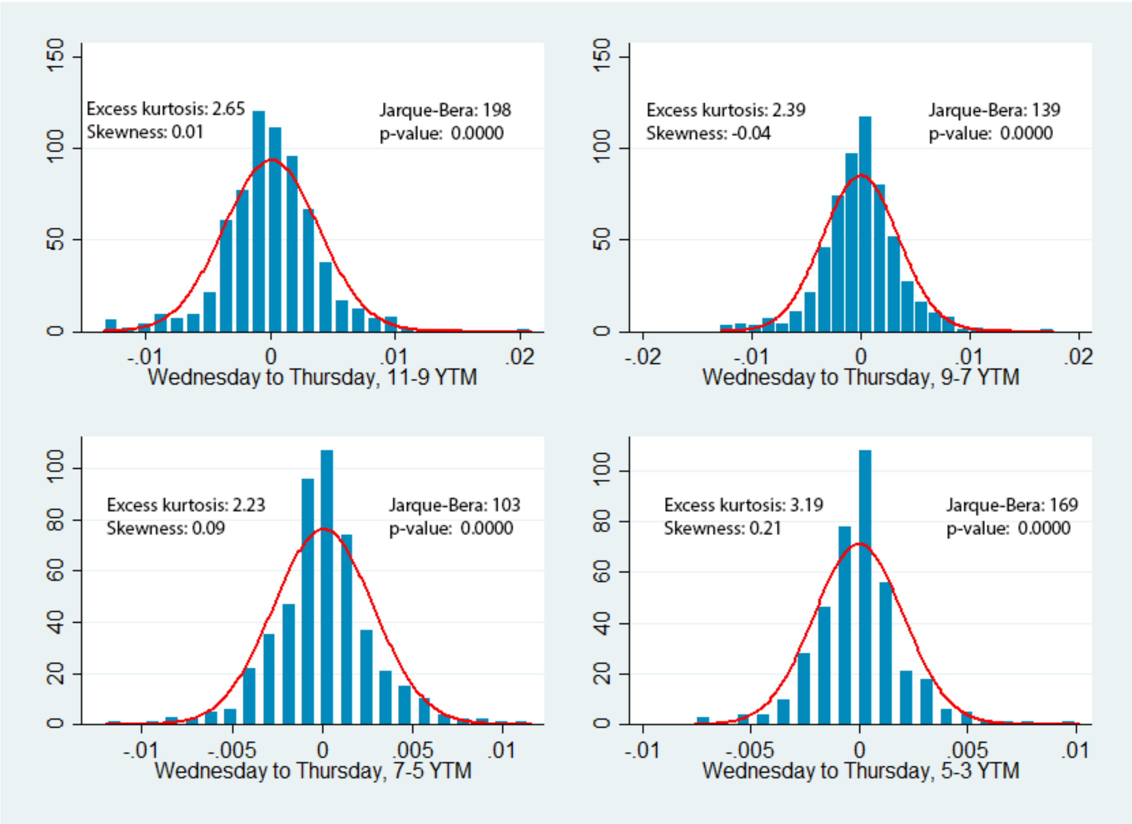

Figure 50: The Wednesday to Thursday's price returns and fitted normal distribution for bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2000 and 2015. The period's number of observations is respectively 676, 585, 492 and 393.

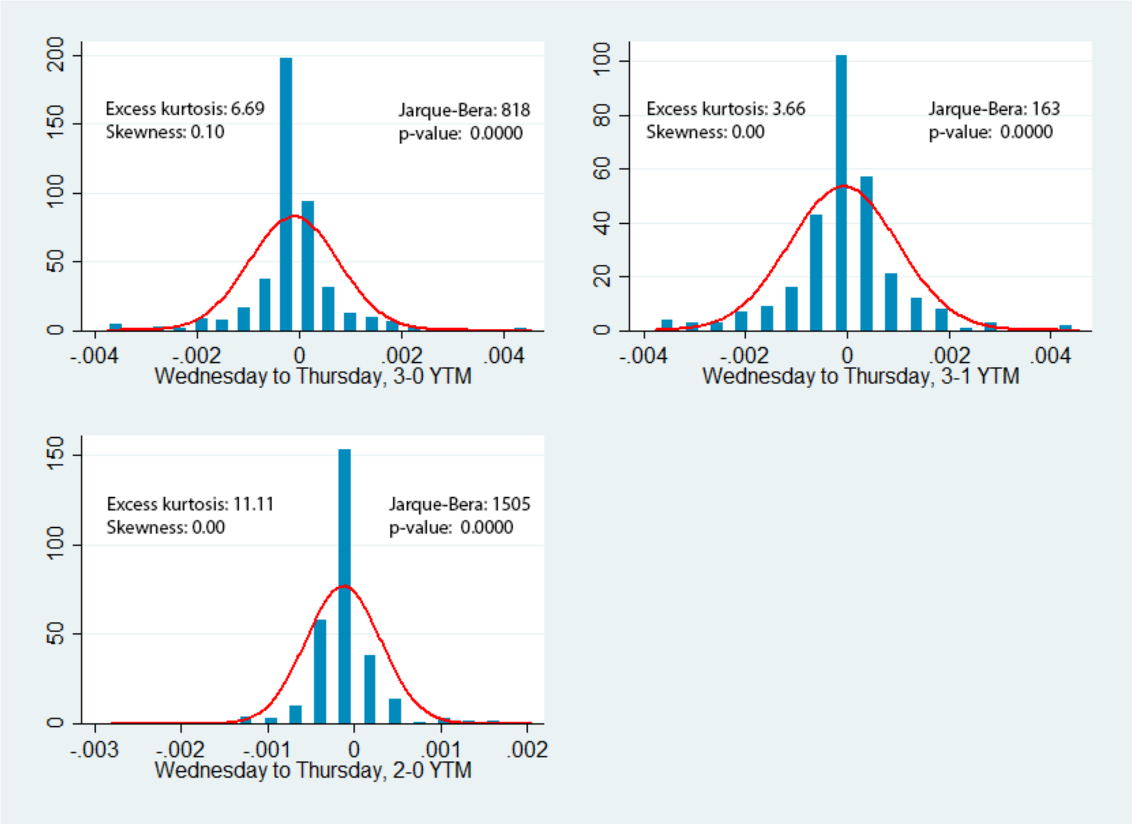

Figure 51: The Wednesday to Thursday's price returns and fitted normal distribution for bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 438, 292 and 292.

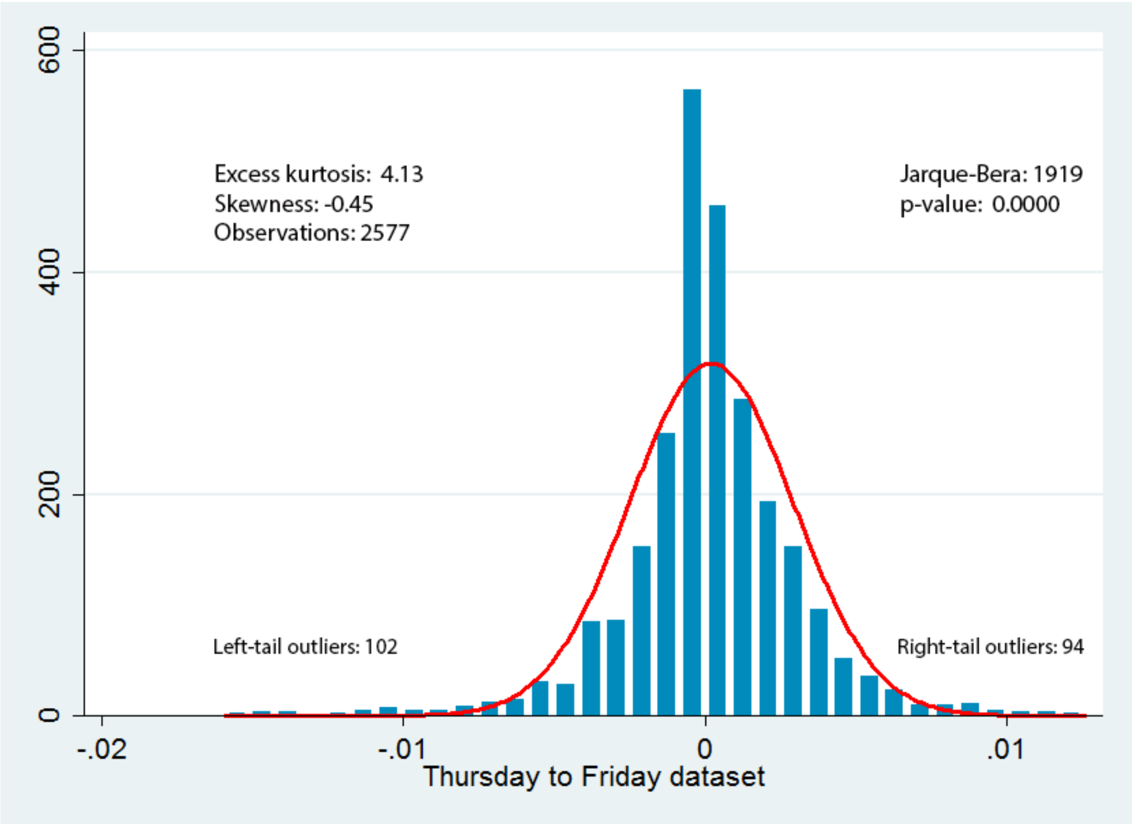

Figure 52: The entire dataset's Thursday to Friday price returns and fitted normal distribution between 2000 and 2015.

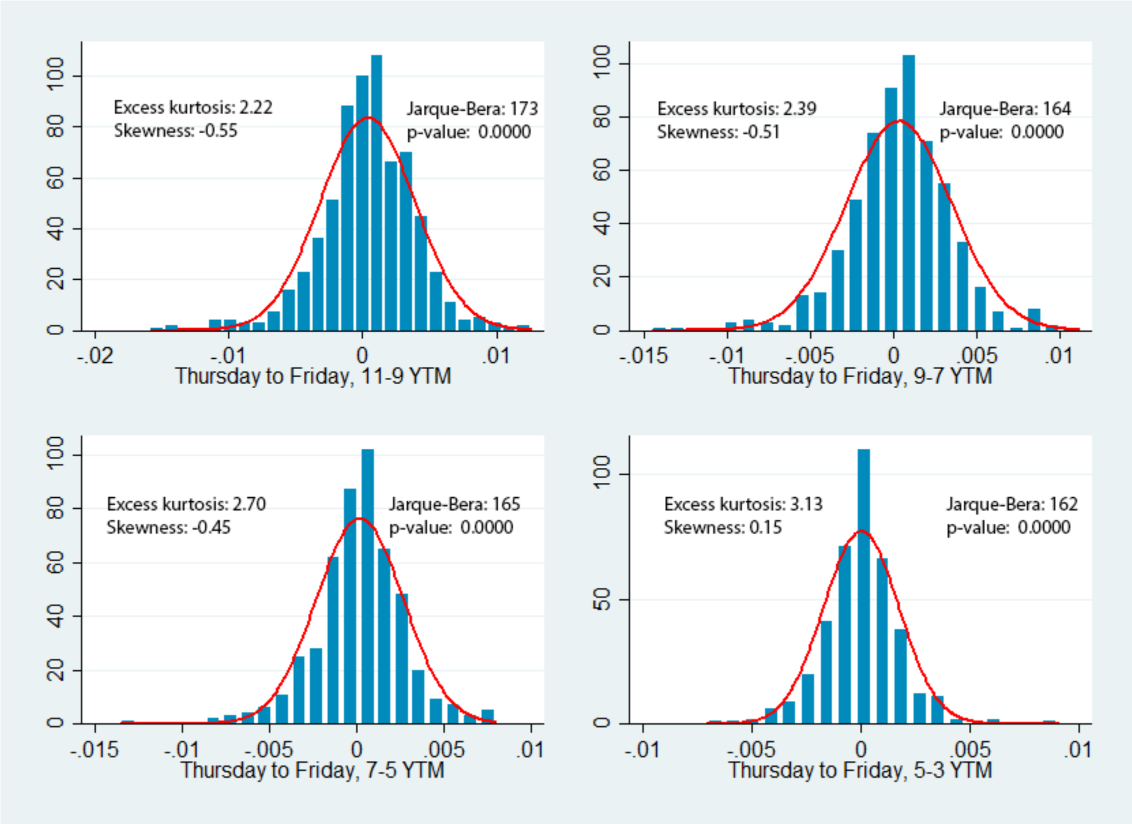

Figure 53: The Thursday to Friday's price returns and fitted normal distribution for bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2000 and 2015. The period's number of observations is respectively 677, 584, 488 and 393.

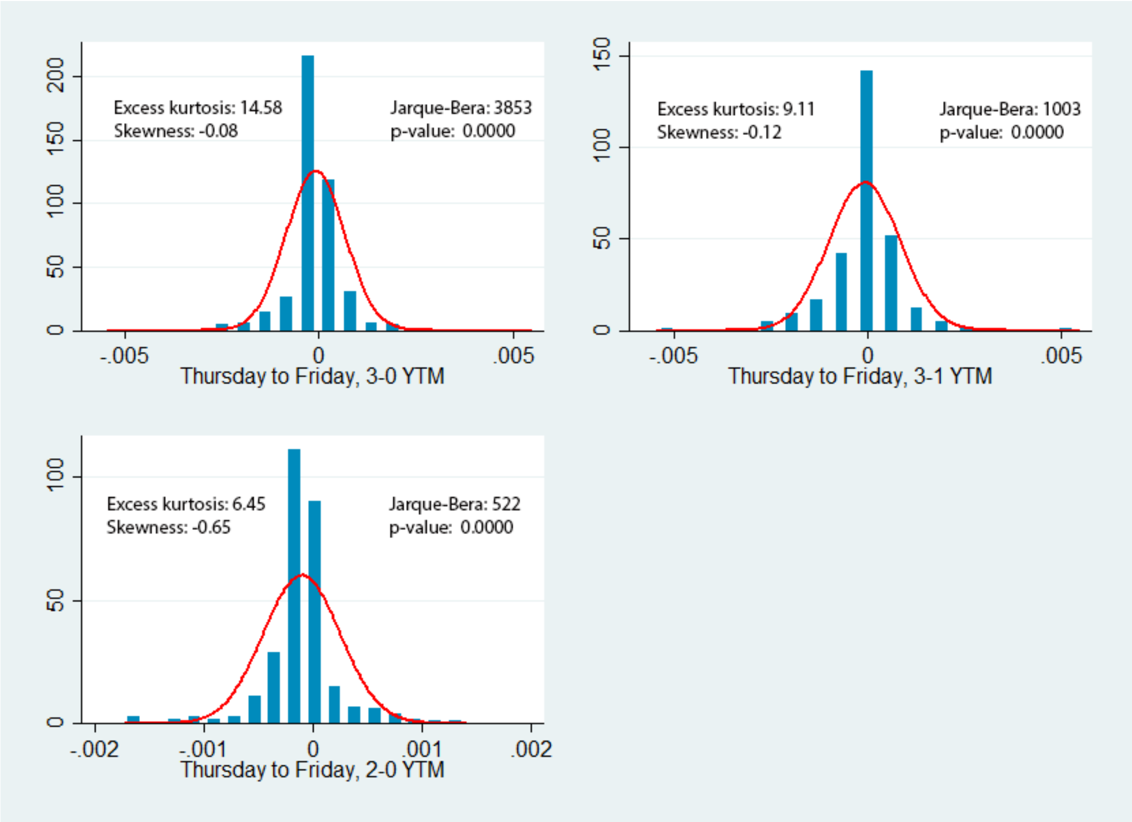

Figure 54: The Thursday to Friday's price returns and fitted normal distribution for bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 435, 290 and 290.

3.3 Calendar-Time Hypothesis - 72 calendar hours

Following are the distributions for the comparing price return periods used for testing the Calendar-Time Hypothesis. The price returns periods contain 72 calendar hours and are divided up and presented in all years-to-maturity periods. The weekend data sample is included in the previous section and therefore omitted from this section.

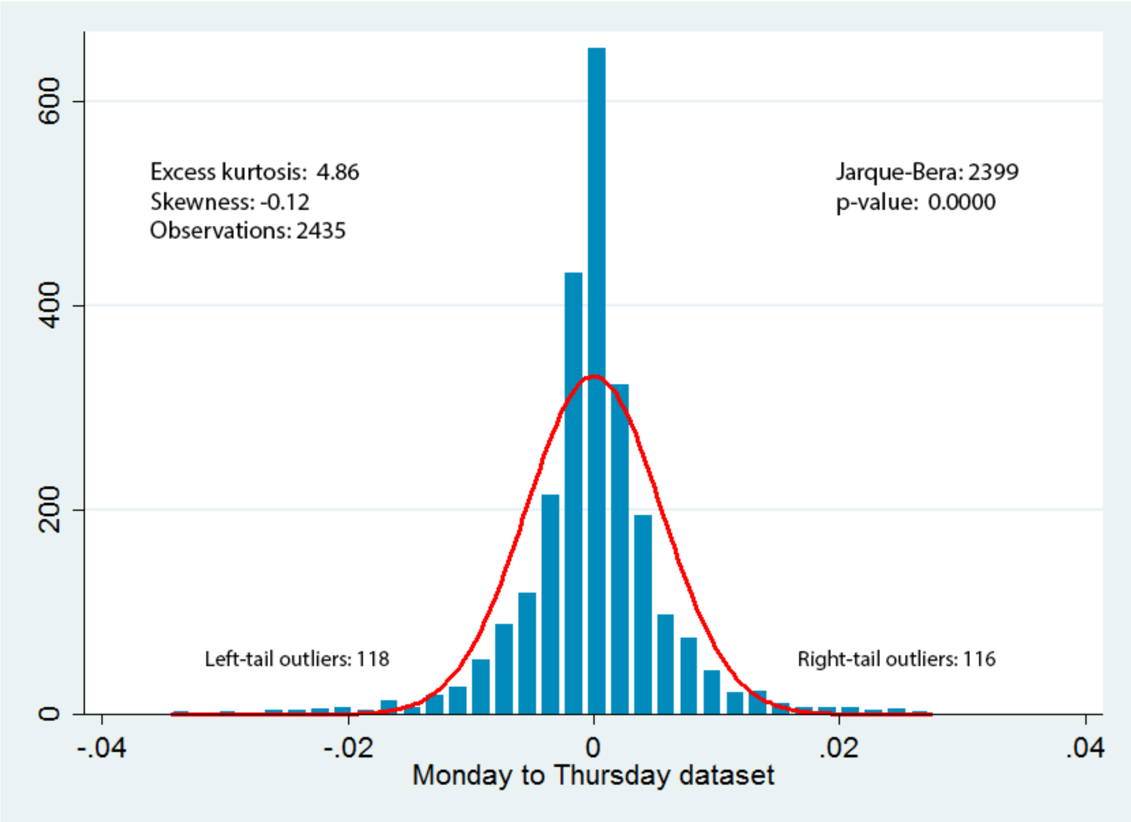

Figure 55: The entire dataset's Monday to Thursday price returns and fitted normal distribution between 2000 and 2015.

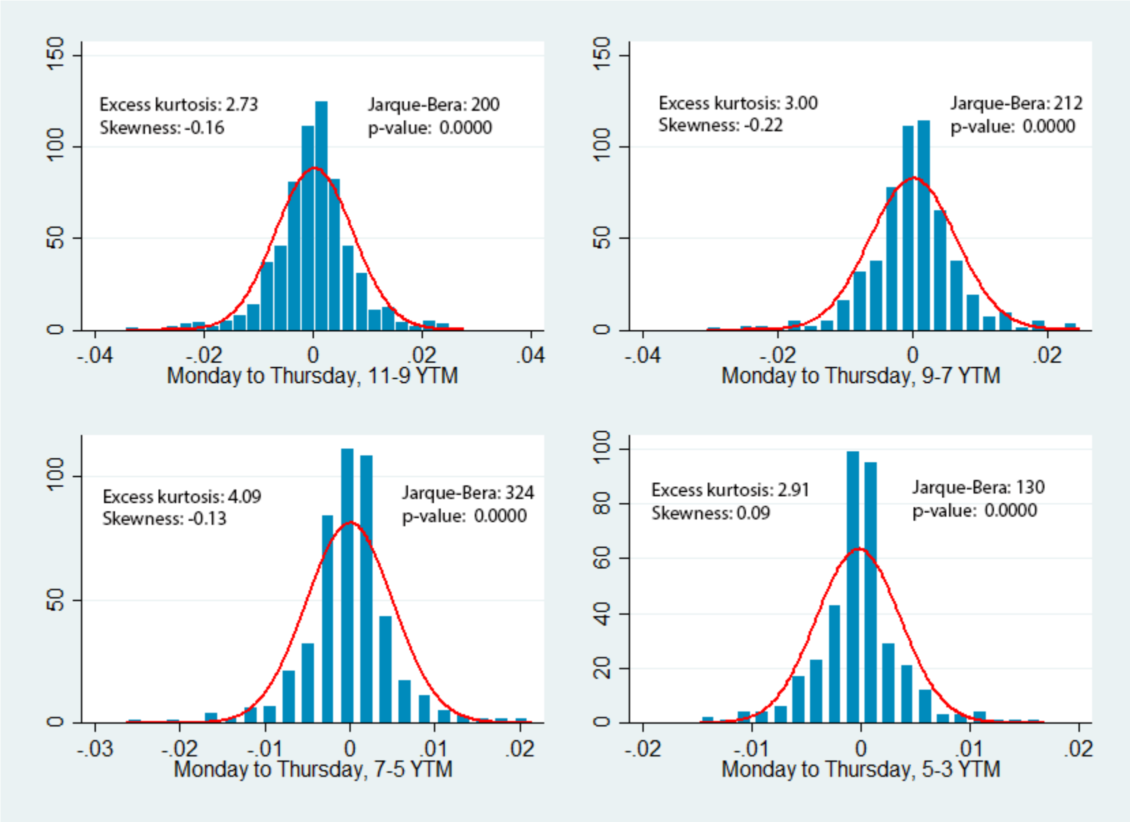

Figure 56: The Monday to Thursday's price returns and fitted normal distribution for bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2000 and 2015. The period's number of observations is respectively 636, 554, 462 and 369.

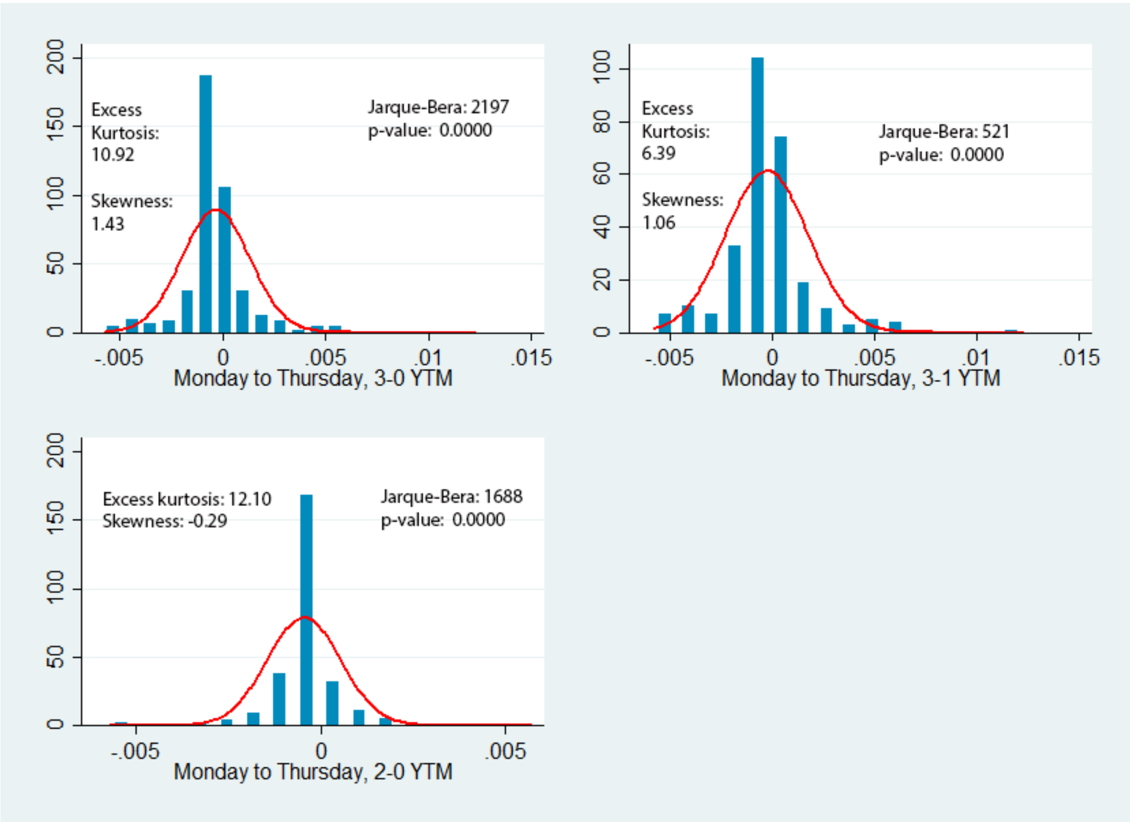

Figure 57: The Monday to Thursday's price returns and fitted normal distribution for bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 414, 276 and 276.

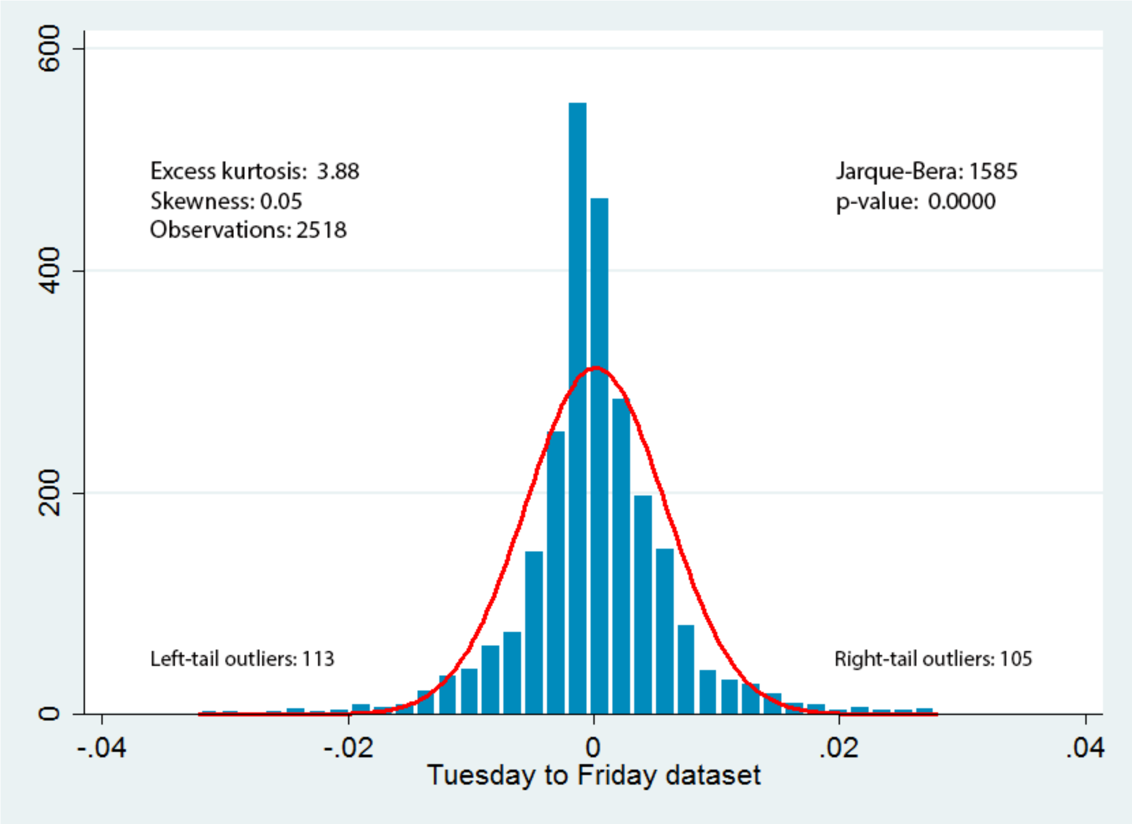

Figure 58: The entire dataset's Tuesday to Friday price returns and fitted normal distribution between 2000 and 2015.

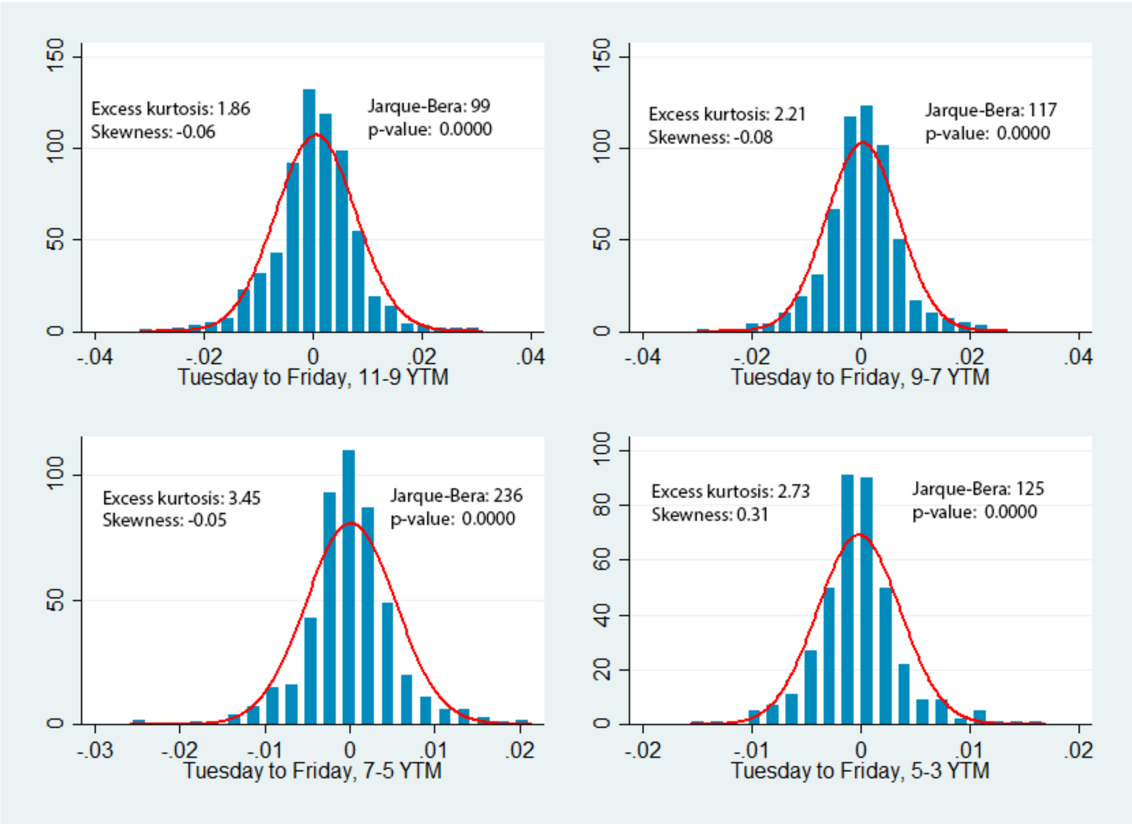

Figure 59: The Tuesday to Friday's price returns and fitted normal distribution for bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2000 and 2015. The period's number of observations is respectively 659, 572, 476 and 383.

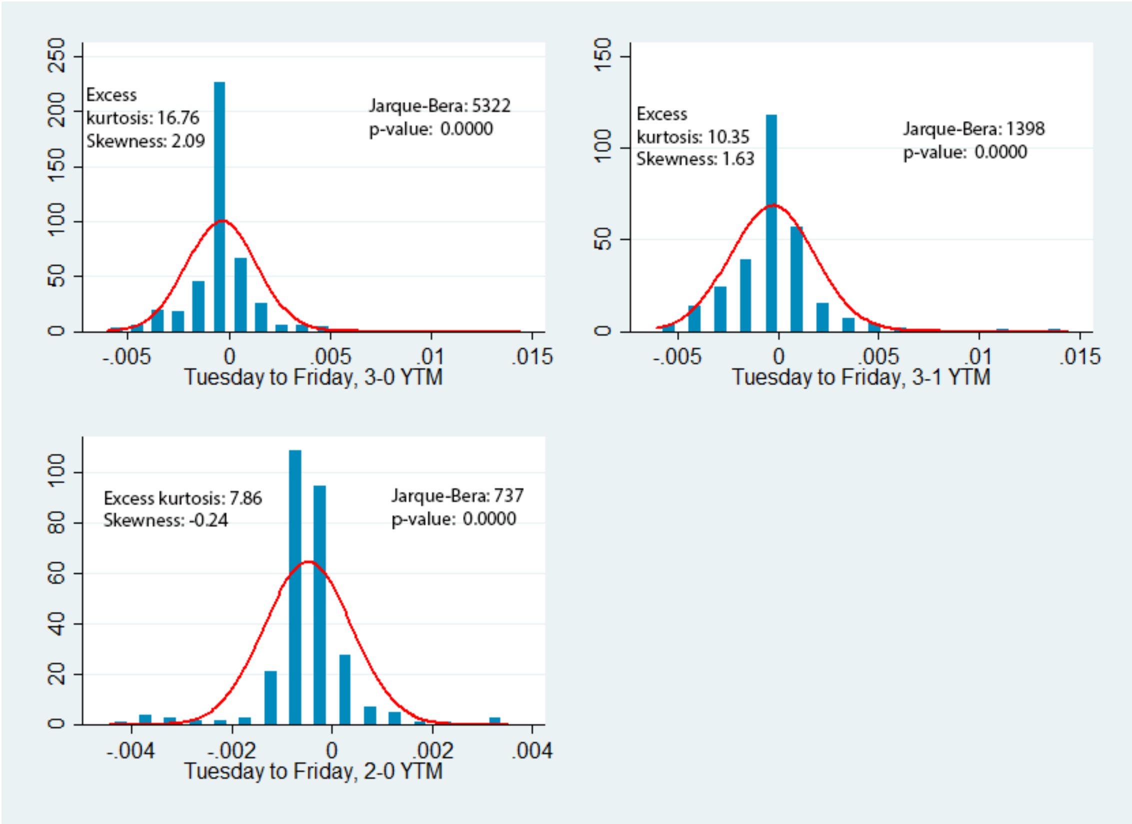

Figure 60: The Tuesday to Friday's price returns and fitted normal distribution for bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 428, 285 and 285.

3.4 The importance of news - Wednesdays and Thursdays

Following are the distributions for the comparing price return periods used for testing the news influence on government bond volatility.

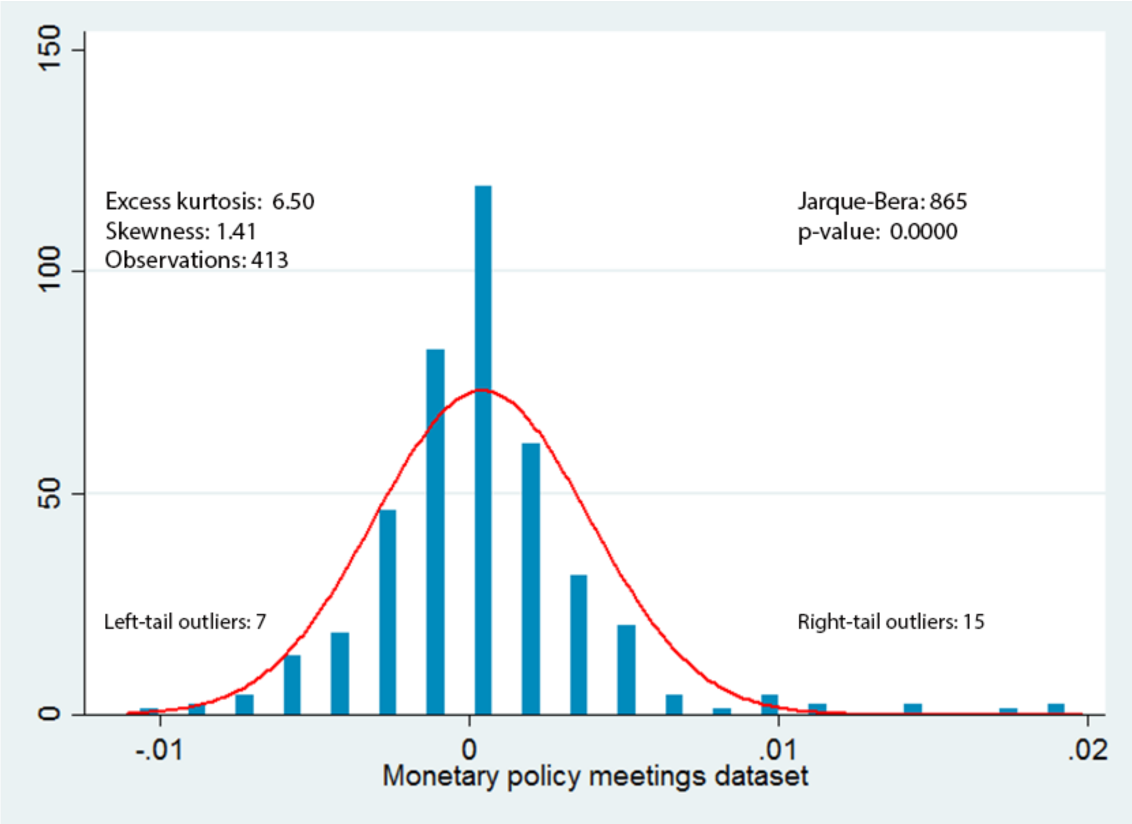

Figure 61: The entire dataset's monetary policy meeting day price returns and fitted normal distribution between 2000 and 2015.

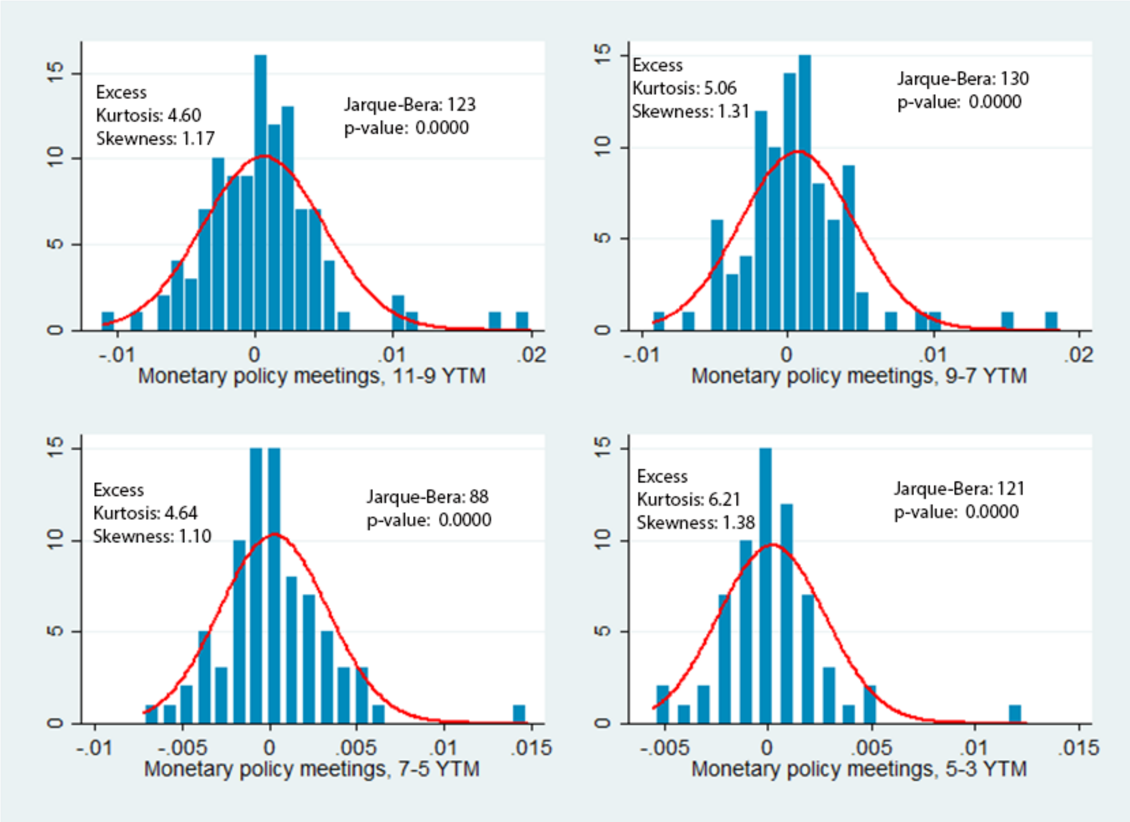

Figure 62: The monetary policy meeting day price returns and fitted normal distribution for bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2000 and 2015. The period's number of observations is respectively 111, 96, 80 and 63.

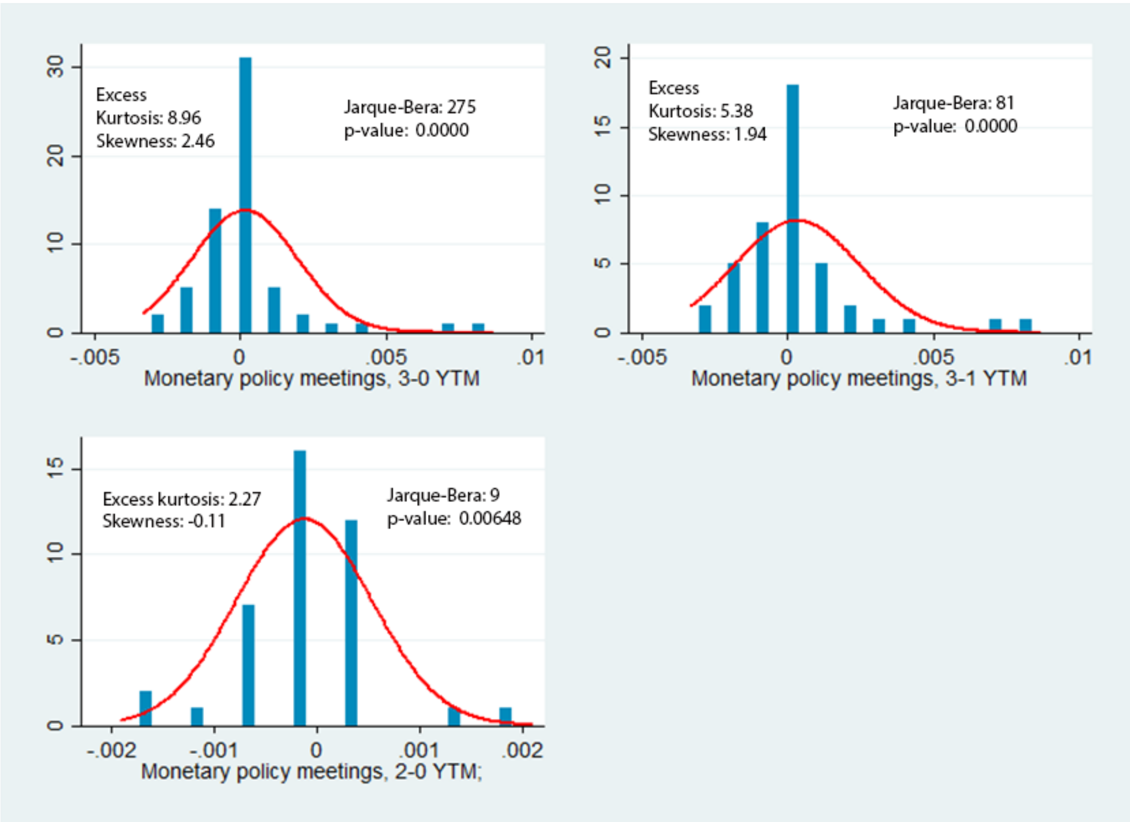

Figure 63: The monetary policy meeting day price returns and fitted normal distribution for bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 63, 44 and 40.

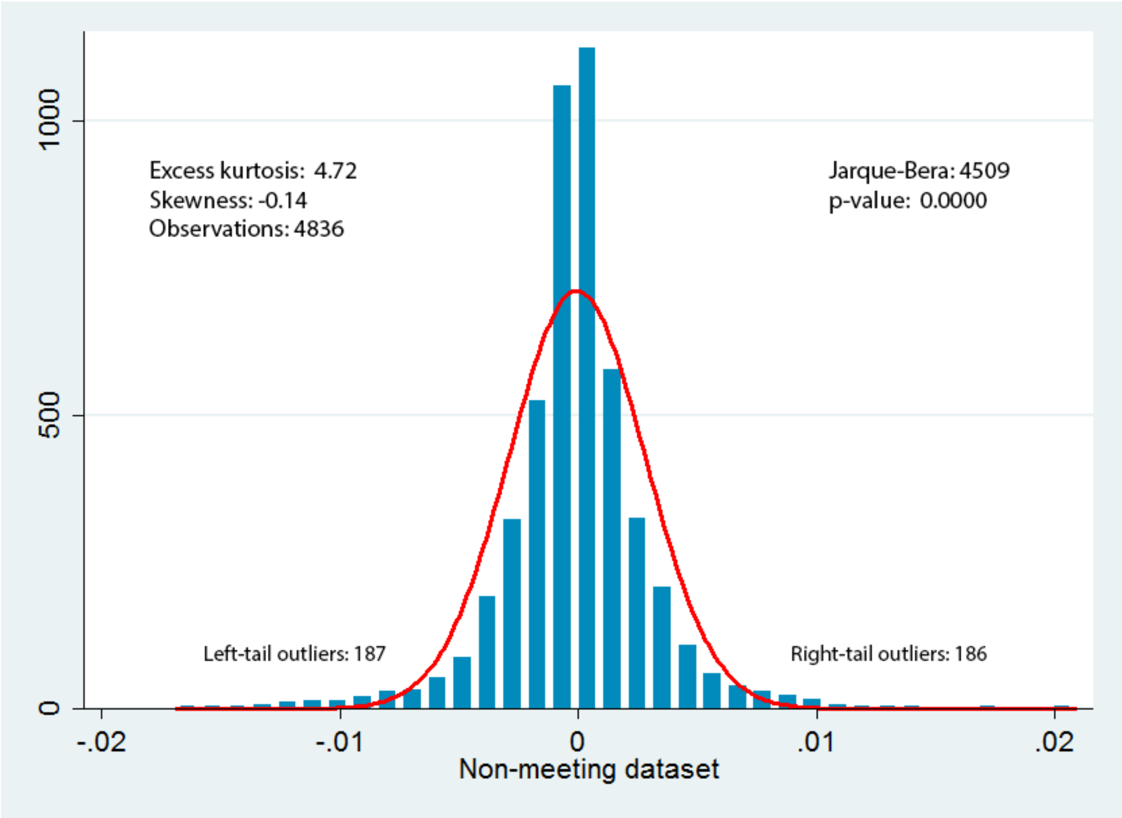

Figure 64: The entire dataset's non-monetary policy meeting (Wednesday and Thursday) price returns and fitted normal distribution between 2000 and 2015.

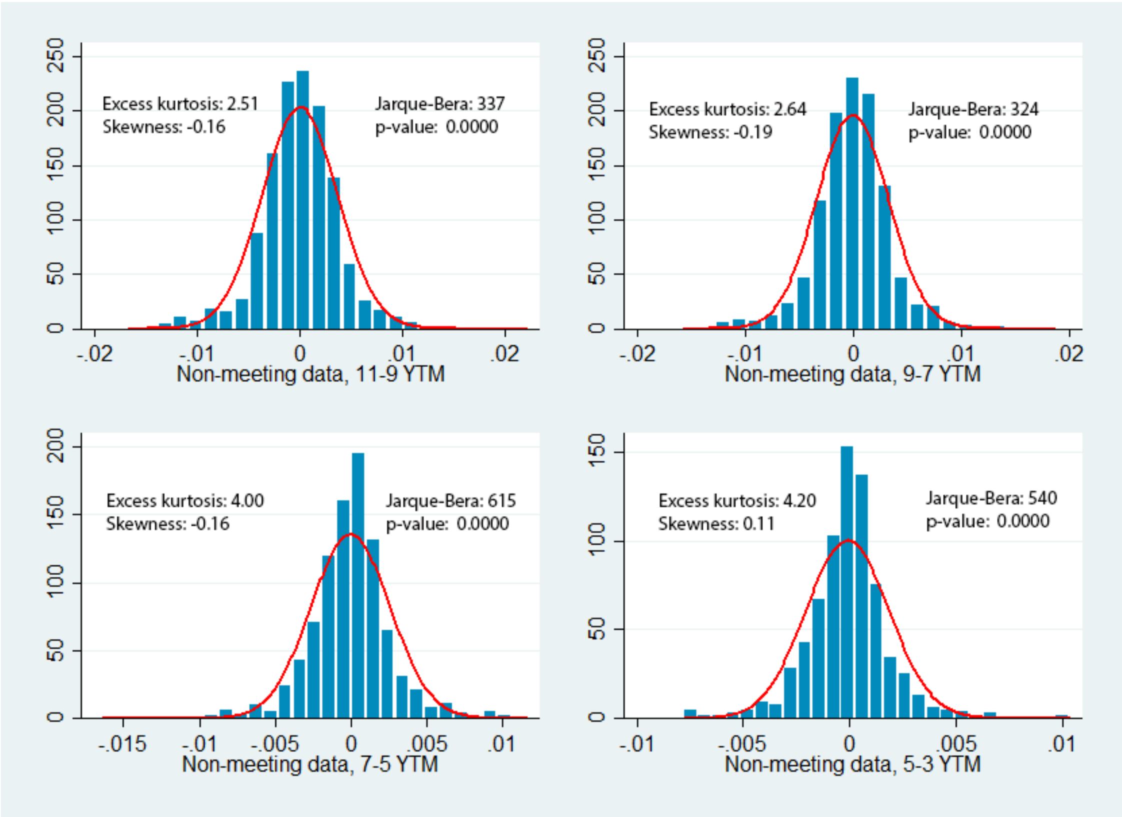

Figure 65: The non-monetary policy meeting (Wednesday and Thursday) price returns and fitted normal distribution for bonds 11-9, 9-7, 7-5, and 5-3 years-to-maturity periods between 2000 and 2015. The period's number of observations is respectively 1261, 1094, 919 and 733.

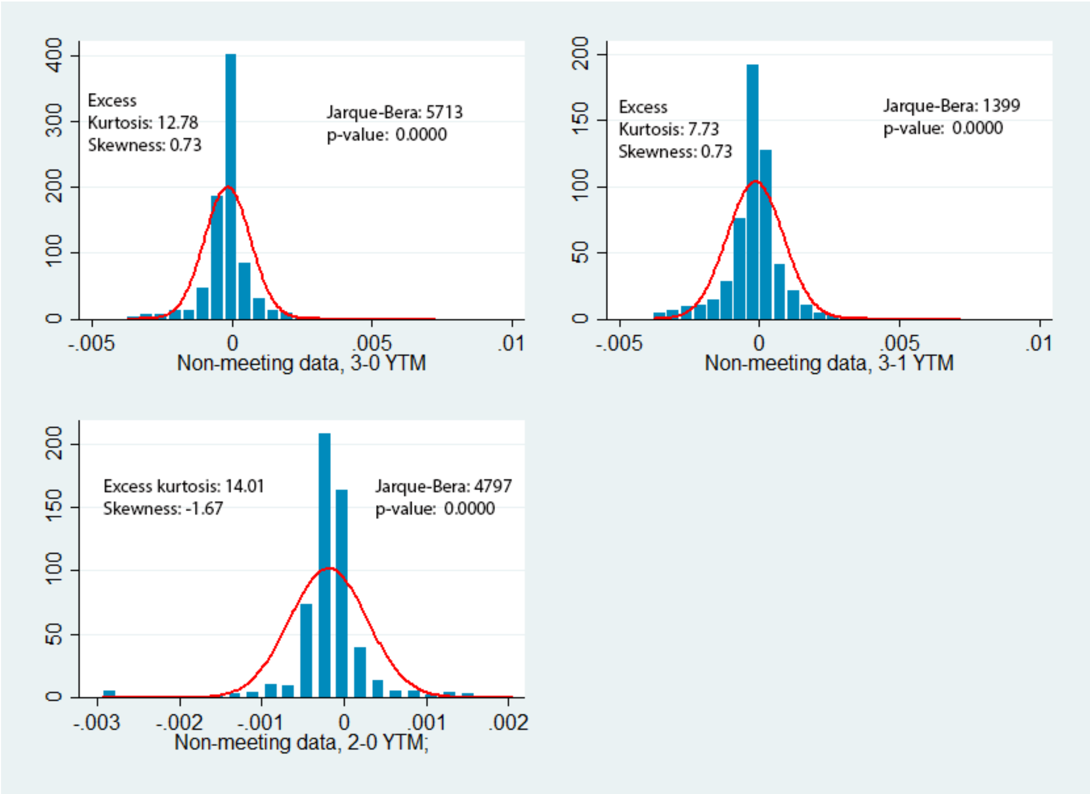

Figure 66: The non-monetary policy meeting (Wednesday and Thursday) price returns and fitted normal distribution for bonds 3-0, 3-1, and 2-0 years-to-maturity periods between 2000 and 2015. The different period's number of observations is respectively 829, 551 and 555.

4. Testing for equal variance – the nonparametric Levene's test

Following are the various jointly and individual tests for equal variance after the methodology described in section 8.4. All equal variance tests are conducted with the nonparametric Levene's test and a 0,01 alpha level, independent of the tested hypothesis.

4.1 The Trading-Time Hypothesis

Following are the various joint and individual significance tests for equal variance between periods with equal trading hours in conjunction with the Trading-Time Hypothesis.

Table 17: Individual and joint significance test for equal variance between price returns including seven trading hours with 0,01 alpha level for bonds 11-9 years-to-maturity period.

	Weekend	**Mon-Tue**	**Tue-Wed**	**Wed-Thu**	**Thu-Fri**	**Jointly**
Variance (upscaled)	12,71	10,35	13,98	14,37	12,55	
Nonparametric Levene's test		1,18	4,40	5,87	1,81	4,57
p-value		0,28	0,04	0,02	0,18	0,00

Table 18: Individual and joint significance test for equal variance between price returns including seven trading hours with 0,01 alpha level for bonds 9-7 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Wed-Thu	Thu-Fri	Jointly
Variance (upscaled)	10,63	8,08	10,85	12,17	10,16	
Nonparametric Levene's test		1,87	1,40	6,14	0,96	3,80
p-value		0,17	0,24	0,01	0,33	0,00

Table 19: Individual and joint significance test for equal variance between price returns including seven trading hours with 0,01 alpha level for bonds 7-5 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Wed-Thu	Thu-Fri	Jointly
Variance (upscaled)	7,05	4,89	6,51	7,63	6,24	
Nonparametric Levene's test		2,86	0,00	3,48	0,18	3,46
p-value		0,09	0,98	0,06	0,67	0,00

Table 20: Individual and joint significance test for equal variance between price returns including seven trading hours with 0,01 alpha level for bonds 5-3 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Wed-Thu	Thu-Fri	Jointly
Variance (upscaled)	3,87	2,94	3,51	4,27	2,98	
Nonparametric Levene's test		0,62	0,05	2,93	0,06	2,09
p-value		0,43	0,83	0,09	0,81	0,08

Table 21: Individual and joint significance test for equal variance between price returns including seven trading hours with 0,01 alpha level for bonds 3-0 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Wed-Thu	Thu-Fri	Jointly
Variance (upscaled)	0,79	0,56	0,88	0,77	0,57	
Nonparametric Levene's test		2,18	0,03	0,40	1,55	1,70
p-value		0,14	0,86	0,53	0,21	0,15

Table 22: Individual and joint significance test for equal variance between price returns including seven trading hours with 0,01 alpha level for bonds 3-1 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Wed-Thu	Thu-Fri	Jointly
Variance (upscaled)	1,17	0,84	1,22	1,14	0,85	
Nonparametric Levene's test		2,23	0,17	0,38	1,46	1,46
p-value		0,14	0,68	0,54	0,23	0,21

Table 23: Individual and joint significance test for equal variance between price returns including seven trading hours with 0,01 alpha level for bonds 2-0 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Wed-Thu	Thu-Fri	Jointly
Variance (upscaled)	0,21	0,23	0,28	0,19	0,13	
Nonparametric Levene's test		0,31	0,70	0,19	3,96	1,91
p-value		0,58	0,40	0,67	0,05	0,11

For the longer-term to maturity bonds, the weekend is not significantly different from the other trading days. However, the weekend variance is found to have significantly equal variance with the other trading days for bonds 5-3 and 3-0 years-to-maturity periods.

4.2 The Calendar-Time Hypothesis

Following are the various joint and individual significance tests for equal variance between periods with equal calendar hours in conjunction with the Calendar-Time Hypothesis.

Table 24:Individual and joint significance test for equal variance between price returns including 72 calendar hours with 0,01 alpha level for bonds entire 1-year maturity.

	Weekend	Mon-Tue	Tue-Wed	Jointly
Variance (upscaled)	7,81	30,34	32,18	
Nonparametric Levene's test		397	477	256
p-value		0,00	0,00	0,00

Table 25: Individual and joint significance test for equal variance between price returns including 72 calendar hours with 0,01 alpha level for bonds 11-9 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Jointly
Variance (upscaled)	12,71	50,47	53,82	
Nonparametric Levene's test		143	193	96
p-value		0,00	0,00	0,00

Table 26: Individual and joint significance test for equal variance between price returns including 72 calendar hours with 0,01 alpha level for bonds 9-7 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Jointly
Variance (upscaled)	10,63	41,02	43,96	
Nonparametric Levene's test		118	148	75
p-value		0,00	0,00	0,00

Table 27: Individual and joint significance test for equal variance between price returns including 72 calendar hours with 0,01 alpha level for bonds 7-5 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Jointly
Variance (upscaled)	7,05	26,75	28,01	
Nonparametric Levene's test		85	104	53
p-value		0,00	0,00	0,00

Table 28: Individual and joint significance test for equal variance between price returns including 72 calendar hours with 0,01 alpha level for bonds 5-3 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Jointly
Variance (upscaled)	3,87	14,76	14,40	
Nonparametric Levene's test		71	82	43
p-value		0,00	0,00	0,00

Table 29: Individual and joint significance test for equal variance between price returns including 72 calendar hours with 0,01 alpha level for bonds 3-0 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Jointly
Variance (upscaled)	0,79	2,76	3,02	
Nonparametric Levene's test		38	44	24
p-value		0,00	0,00	0,00

Table 30: Individual and joint significance test for equal variance between price returns including 72 calendar hours with 0,01 alpha level for bonds 3-1 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Jointly
Variance (upscaled)	1,17	4,08	4,48	
Nonparametric Levene's test		37	43	23
p-value		0,00	0,00	0,00

Table 31: Individual and joint significance test for equal variance between price returns including 72 calendar hours with 0,01 alpha level for bonds 2-0 years-to-maturity period.

	Weekend	Mon-Tue	Tue-Wed	Jointly
Variance (upscaled)	0,21	1,00	0,76	
Nonparametric Levene's test		26	24	14
p-value		0,00	0,00	0,00

The weekend is both individually and jointly significantly different from the other weekday periods for all years to maturity periods.

5. VaR estimates for different years to maturity periods

Following are daily 95% and 99% VaR estimates for the different years-to-maturity periods with added upper tail risk. The control periods are left out from this section as they have been found to compliment the 3-0 years-to-maturity period.

Table 32: Daily 95% and 99% VaR analysis for the weekend and trading days, in percentage and value terms for a 100-mill NOK investment based on price returns from bonds 11-9 years-to-maturity period.

	Weekend							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,83 %	-830 624	-0,59 %	-586 428	0,83 %	830 624	0,59 %	586 428
2. Parametric trading-time	-0,83 %	-833 351	-0,59 %	-588 353	0,83 %	833 351	0,59 %	588 353
3. Parametric calendar-time	-1,22 %	-1 219 901	-0,86 %	-861 261	1,22 %	1 219 901	0,86 %	861 261
4. Historical distributional VaR	-1,13 %	-1 125 778	-0,53 %	-528 299	1,04 %	1 044 389	0,48 %	477 668
Historical distributional CVaR	-1,59 %	-1 586 921	-0,89 %	-893 932	1,22 %	1 219 860	0,79 %	790 335
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,00 %	-2 727	0,00 %	-1 925	0,00 %	2 727	0,00 %	1 925
Day-of-the-week and calendar-time (1-3)	-0,39 %	-389 277	-0,27 %	-274 833	0,39 %	389 277	0,27 %	274 833
Day-of-the-week and Historic mehod (1-4)	-0,30 %	-295 153	0,06 %	58 129	0,21 %	213 765	-0,11 %	-108 760
	Mon-Tue							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,75 %	-749 483	-0,53 %	-529 141	0,75 %	749 483	0,53 %	529 141
2. Parametric trading-time	-0,83 %	-833 351	-0,59 %	-588 353	0,83 %	833 351	0,59 %	588 353
3. Parametric calendar-time	-0,70 %	-704 310	-0,50 %	-497 249	0,70 %	704 310	0,50 %	497 249
4. Historical distributional VaR	-0,93 %	-931 611	-0,47 %	-471 988	0,86 %	856 308	0,50 %	504 520
Historical distributional CVaR	-1,09 %	-1 085 187	-0,73 %	-730 224	1,23 %	1 227 729	0,75 %	752 556
Differencing methods:								
Day-of-the-week and trading-time (1-2)	-0,08 %	-83 869	-0,06 %	-59 212	0,08 %	83 869	0,06 %	59 212
Day-of-the-week and calendar-time (1-3)	0,05 %	45 172	0,03 %	31 892	-0,05 %	-45 172	-0,03 %	-31 892
Day-of-the-week and Historic mehod (1-4)	-0,18 %	-182 128	0,06 %	57 153	0,11 %	106 825	-0,02 %	-24 622
	Tue-Wed							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,87 %	-871 201	-0,62 %	-615 075	0,87 %	871 201	0,62 %	615 075
2. Parametric trading-time	-0,83 %	-833 351	-0,59 %	-588 353	0,83 %	833 351	0,59 %	588 353
3. Parametric calendar-time	-0,70 %	-704 310	-0,50 %	-497 249	0,70 %	704 310	0,50 %	497 249
4. Historical distributional VaR	-1,10 %	-1 101 969	-0,55 %	-547 742	1,03 %	1 033 095	0,51 %	505 117
Historical distributional CVaR	-1,27 %	-1 271 439	-0,88 %	-880 806	1,36 %	1 358 723	0,84 %	844 495
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,04 %	37 850	0,03 %	26 722	-0,04 %	-37 850	-0,03 %	-26 722
Day-of-the-week and calendar-time (1-3)	0,17 %	166 890	0,12 %	117 826	-0,17 %	-166 890	-0,12 %	-117 826
Day-of-the-week and Historic mehod (1-4)	-0,23 %	-230 768	0,07 %	67 333	0,16 %	161 895	-0,11 %	-109 959
	Wed-Thu							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,88 %	-883 332	-0,62 %	-623 640	0,88 %	883 332	0,62 %	623 640
2. Parametric trading-time	-0,83 %	-833 351	-0,59 %	-588 353	0,83 %	833 351	0,59 %	588 353
3. Parametric calendar-time	-0,70 %	-704 310	-0,50 %	-497 249	0,70 %	704 310	0,50 %	497 249
4. Historical distributional VaR	-1,12 %	-1 121 642	-0,56 %	-564 796	0,94 %	936 186	0,61 %	609 055
Historical distributional CVaR	-1,27 %	-1 265 426	-0,91 %	-906 126	1,27 %	1 270 664	0,87 %	867 188
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,05 %	49 980	0,04 %	35 287	-0,05 %	-49 980	-0,04 %	-35 287
Day-of-the-week and calendar-time (1-3)	0,18 %	179 021	0,13 %	126 391	-0,18 %	-179 021	-0,13 %	-126 391
Day-of-the-week and Historic mehod (1-4)	-0,24 %	-238 310	0,06 %	58 843	0,05 %	52 854	-0,01 %	-14 585
	Thu-Fri							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,83 %	-825 497	-0,58 %	-582 808	0,83 %	825 497	0,58 %	582 808
2. Parametric trading-time	-0,83 %	-833 351	-0,59 %	-588 353	0,83 %	833 351	0,59 %	588 353
3. Parametric calendar-time	-0,70 %	-704 310	-0,50 %	-497 249	0,70 %	704 310	0,50 %	497 249
4. Historical distributional VaR	-1,07 %	-1 072 999	-0,53 %	-532 270	0,89 %	888 225	0,56 %	558 905
Historical distributional CVaR	-1,29 %	-1 291 479	-0,85 %	-849 590	1,04 %	1 043 277	0,75 %	753 299
Differencing methods:								
Day-of-the-week and trading-time (1-2)	-0,01 %	-7 854	-0,01 %	-5 545	0,01 %	7 854	0,01 %	5 545
Day-of-the-week and calendar-time (1-3)	0,12 %	121 187	0,09 %	85 559	-0,12 %	-121 187	-0,09 %	-85 559
Day-of-the-week and Historic mehod (1-4)	-0,25 %	-247 502	0,05 %	50 538	0,06 %	62 727	-0,02 %	-23 903

Table 33: Daily 95% and 99% VaR analysis for the weekend and trading days, in percentage and value terms for a 100-mill NOK investment based on price returns from bonds 9-7 years-to-maturity period.

	Weekend							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,76 %	-759 500	-0,54 %	-536 214	0,76 %	759 500	0,54 %	536 214
2. Parametric trading-time	-0,75 %	-750 554	-0,53 %	-529 897	0,75 %	750 554	0,53 %	529 897
3. Parametric calendar-time	-1,10 %	-1 098 698	-0,78 %	-775 690	1,10 %	1 098 698	0,78 %	775 690
4. Historical distributional VaR	-1,17 %	-1 171 344	-0,49 %	-494 232	0,94 %	944 664	0,45 %	445 394
Historical distributional CVaR	-1,44 %	-1 443 422	-0,81 %	-813 751	1,11 %	1 106 326	0,73 %	728 488
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,01 %	8 947	0,01 %	6 316	-0,01 %	-8 947	-0,01 %	-6 316
Day-of-the-week and calendar-time (1-3)	-0,34 %	-339 198	-0,24 %	-239 477	0,34 %	339 198	0,24 %	239 477
Day-of-the-week and Historic mehod (1-4)	-0,41 %	-411 843	0,04 %	41 982	0,19 %	185 164	-0,09 %	-90 819
	Mon-Tue							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,66 %	-662 382	-0,47 %	-467 648	0,66 %	662 382	0,47 %	467 648
2. Parametric trading-time	-0,75 %	-750 554	-0,53 %	-529 897	0,75 %	750 554	0,53 %	529 897
3. Parametric calendar-time	-0,63 %	-634 334	-0,45 %	-447 845	0,63 %	634 334	0,45 %	447 845
4. Historical distributional VaR	-0,80 %	-797 935	-0,41 %	-407 498	0,73 %	730 420	0,49 %	485 410
Historical distributional CVaR	-0,98 %	-975 548	-0,65 %	-654 786	0,99 %	989 080	0,65 %	650 686
Differencing methods:								
Day-of-the-week and trading-time (1-2)	-0,09 %	-88 171	-0,06 %	-62 250	0,09 %	88 171	0,06 %	62 250
Day-of-the-week and calendar-time (1-3)	0,03 %	28 049	0,02 %	19 803	-0,03 %	-28 049	-0,02 %	-19 803
Day-of-the-week and Historic mehod (1-4)	-0,14 %	-135 553	0,06 %	60 150	0,07 %	68 038	0,02 %	17 763
	Tue-Wed							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,77 %	-767 314	-0,54 %	-541 730	0,77 %	767 314	0,54 %	541 730
2. Parametric trading-time	-0,75 %	-750 554	-0,53 %	-529 897	0,75 %	750 554	0,53 %	529 897
3. Parametric calendar-time	-0,63 %	-634 334	-0,45 %	-447 845	0,63 %	634 334	0,45 %	447 845
4. Historical distributional VaR	-0,96 %	-955 889	-0,50 %	-503 837	0,91 %	909 324	0,46 %	464 792
Historical distributional CVaR	-1,14 %	-1 140 721	-0,77 %	-766 868	1,20 %	1 203 164	0,76 %	755 619
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,02 %	16 760	0,01 %	11 833	-0,02 %	-16 760	-0,01 %	-11 833
Day-of-the-week and calendar-time (1-3)	0,13 %	132 980	0,09 %	93 885	-0,13 %	-132 980	-0,09 %	-93 885
Day-of-the-week and Historic mehod (1-4)	-0,19 %	-188 575	0,04 %	37 893	0,14 %	142 010	-0,08 %	-76 938
	Wed-Thu							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,81 %	-812 796	-0,57 %	-573 841	0,81 %	812 796	0,57 %	573 841
2. Parametric trading-time	-0,75 %	-750 554	-0,53 %	-529 897	0,75 %	750 554	0,53 %	529 897
3. Parametric calendar-time	-0,63 %	-634 334	-0,45 %	-447 845	0,63 %	634 334	0,45 %	447 845
4. Historical distributional VaR	-1,05 %	-1 049 632	-0,58 %	-579 825	0,84 %	836 971	0,53 %	528 051
Historical distributional CVaR	-1,17 %	-1 166 543	-0,83 %	-832 236	1,15 %	1 149 780	0,78 %	778 947
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,06 %	62 243	0,04 %	43 944	-0,06 %	-62 243	-0,04 %	-43 944
Day-of-the-week and calendar-time (1-3)	0,18 %	178 463	0,13 %	125 996	-0,18 %	-178 463	-0,13 %	-125 996
Day-of-the-week and Historic mehod (1-4)	-0,24 %	-236 835	-0,01 %	-5 984	0,02 %	24 175	-0,05 %	-45 791
	Thu-Fri							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,74 %	-742 734	-0,52 %	-524 377	0,74 %	742 734	0,52 %	524 377
2. Parametric trading-time	-0,75 %	-750 554	-0,53 %	-529 897	0,75 %	750 554	0,53 %	529 897
3. Parametric calendar-time	-0,63 %	-634 334	-0,45 %	-447 845	0,63 %	634 334	0,45 %	447 845
4. Historical distributional VaR	-0,95 %	-946 674	-0,49 %	-489 037	0,86 %	860 455	0,51 %	505 306
Historical distributional CVaR	-1,17 %	-1 167 205	-0,76 %	-755 670	0,96 %	958 031	0,70 %	697 201
Differencing methods:								
Day-of-the-week and trading-time (1-2)	-0,01 %	-7 819	-0,01 %	-5 521	0,01 %	7 819	0,01 %	5 521
Day-of-the-week and calendar-time (1-3)	0,11 %	108 401	0,08 %	76 532	-0,11 %	-108 401	-0,08 %	-76 532
Day-of-the-week and Historic mehod (1-4)	-0,20 %	-203 940	0,04 %	35 339	0,12 %	117 721	-0,02 %	-19 070

Table 34: Daily 95% and 99% VaR analysis for the weekend and trading days, in percentage and value terms for a 100-mill NOK investment based on price returns from bonds 7-5 years-to-maturity period

	Weekend							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,62 %	-618 641	-0,44 %	-436 766	0,62 %	618 641	0,44 %	436 766
2. Parametric trading-time	-0,59 %	-592 480	-0,42 %	-418 296	0,59 %	592 480	0,42 %	418 296
3. Parametric calendar-time	-0,87 %	-867 301	-0,61 %	-612 322	0,87 %	867 301	0,61 %	612 322
4. Historical distributional VaR	-0,86 %	-860 611	-0,42 %	-423 990	0,78 %	783 690	0,37 %	369 245
Historical distributional CVaR	-1,18 %	-1 182 213	-0,69 %	-689 466	0,95 %	948 891	0,59 %	592 091
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,03 %	26 162	0,02 %	18 470	-0,03 %	-26 162	-0,02 %	-18 470
Day-of-the-week and calendar-time (1-3)	-0,25 %	-248 660	-0,18 %	-175 556	0,25 %	248 660	0,18 %	175 556
Day-of-the-week and Historic mehod (1-4)	-0,24 %	-241 969	0,01 %	12 776	0,17 %	165 049	-0,07 %	-67 521
	Mon-Tue							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,52 %	-515 434	-0,36 %	-363 901	0,52 %	515 434	0,36 %	363 901
2. Parametric trading-time	-0,59 %	-592 480	-0,42 %	-418 296	0,59 %	592 480	0,42 %	418 296
3. Parametric calendar-time	-0,50 %	-500 737	-0,35 %	-353 524	0,50 %	500 737	0,35 %	353 524
4. Historical distributional VaR	-0,68 %	-679 446	-0,33 %	-334 506	0,56 %	560 442	0,36 %	362 223
Historical distributional CVaR	-0,84 %	-842 001	-0,52 %	-521 830	0,68 %	680 761	0,48 %	478 787
Differencing methods:								
Day-of-the-week and trading-time (1-2)	-0,08 %	-77 046	-0,05 %	-54 395	0,08 %	77 046	0,05 %	54 395
Day-of-the-week and calendar-time (1-3)	0,01 %	14 697	0,01 %	10 376	-0,01 %	-14 697	-0,01 %	-10 376
Day-of-the-week and Historic mehod (1-4)	-0,16 %	-164 012	0,03 %	29 395	0,05 %	45 009	0,00 %	-1 678
	Tue-Wed							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,59 %	-594 483	-0,42 %	-419 710	0,59 %	594 483	0,42 %	419 710
2. Parametric trading-time	-0,59 %	-592 480	-0,42 %	-418 296	0,59 %	592 480	0,42 %	418 296
3. Parametric calendar-time	-0,50 %	-500 737	-0,35 %	-353 524	0,50 %	500 737	0,35 %	353 524
4. Historical distributional VaR	-0,72 %	-718 382	-0,39 %	-390 239	0,71 %	712 429	0,32 %	315 493
Historical distributional CVaR	-0,95 %	-952 776	-0,61 %	-608 756	0,99 %	985 668	0,57 %	571 829
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,00 %	2 003	0,00 %	1 414	0,00 %	-2 003	0,00 %	-1 414
Day-of-the-week and calendar-time (1-3)	0,09 %	93 746	0,07 %	66 186	-0,09 %	-93 746	-0,07 %	-66 186
Day-of-the-week and Historic mehod (1-4)	-0,12 %	-123 899	0,03 %	29 471	0,12 %	117 946	-0,10 %	-104 218
	Wed-Thu							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,64 %	-643 705	-0,45 %	-454 461	0,64 %	643 705	0,45 %	454 461
2. Parametric trading-time	-0,59 %	-592 480	-0,42 %	-418 296	0,59 %	592 480	0,42 %	418 296
3. Parametric calendar-time	-0,50 %	-500 737	-0,35 %	-353 524	0,50 %	500 737	0,35 %	353 524
4. Historical distributional VaR	-0,74 %	-744 896	-0,43 %	-426 737	0,74 %	742 671	0,47 %	470 269
Historical distributional CVaR	-0,92 %	-920 856	-0,61 %	-613 921	0,95 %	951 325	0,66 %	658 683
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,05 %	51 226	0,04 %	36 166	-0,05 %	-51 226	-0,04 %	-36 166
Day-of-the-week and calendar-time (1-3)	0,14 %	142 969	0,10 %	100 937	-0,14 %	-142 969	-0,10 %	-100 937
Day-of-the-week and Historic mehod (1-4)	-0,10 %	-101 191	0,03 %	27 724	0,10 %	98 966	0,02 %	15 807
	Thu-Fri							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,58 %	-582 241	-0,41 %	-411 067	0,58 %	582 241	0,41 %	411 067
2. Parametric trading-time	-0,59 %	-592 480	-0,42 %	-418 296	0,59 %	592 480	0,42 %	418 296
3. Parametric calendar-time	-0,50 %	-500 737	-0,35 %	-353 524	0,50 %	500 737	0,35 %	353 524
4. Historical distributional VaR	-0,70 %	-696 789	-0,40 %	-403 233	0,69 %	687 472	0,39 %	388 035
Historical distributional CVaR	-0,89 %	-891 816	-0,58 %	-581 682	0,76 %	755 942	0,56 %	561 256
Differencing methods:								
Day-of-the-week and trading-time (1-2)	-0,01 %	-10 238	-0,01 %	-7 228	0,01 %	10 238	0,01 %	7 228
Day-of-the-week and calendar-time (1-3)	0,08 %	81 505	0,06 %	57 543	-0,08 %	-81 505	-0,06 %	-57 543
Day-of-the-week and Historic mehod (1-4)	-0,11 %	-114 547	0,01 %	7 834	0,11 %	105 231	-0,02 %	-23 032

Table 35: Daily 95% and 99% VaR analysis for the weekend and trading days, in percentage and value terms for a 100-mill NOK investment based on price returns from bonds 5-3 years-to-maturity period.

	Weekend							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,46 %	-458 637	-0,32 %	-323 802	0,46 %	458 637	0,32 %	323 802
2. Parametric trading-time	-0,44 %	-441 313	-0,31 %	-311 571	0,44 %	441 313	0,31 %	311 571
3. Parametric calendar-time	-0,65 %	-646 016	-0,46 %	-456 093	0,65 %	646 016	0,46 %	456 093
4. Historical distributional VaR	-0,56 %	-556 843	-0,29 %	-293 839	0,58 %	575 339	0,30 %	297 284
Historical distributional CVaR	-0,84 %	-836 563	-0,49 %	-485 911	0,78 %	776 565	0,48 %	476 702
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,02 %	17 324	0,01 %	12 231	-0,02 %	-17 324	-0,01 %	-12 231
Day-of-the-week and calendar-time (1-3)	-0,19 %	-187 379	-0,13 %	-132 291	0,19 %	187 379	0,13 %	132 291
Day-of-the-week and Historic mehod (1-4)	-0,10 %	-98 205	0,03 %	29 963	0,12 %	116 702	-0,03 %	-26 518
	Mon-Tue							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,40 %	-400 980	-0,28 %	-283 095	0,40 %	400 980	0,28 %	283 095
2. Parametric trading-time	-0,44 %	-441 313	-0,31 %	-311 571	0,44 %	441 313	0,31 %	311 571
3. Parametric calendar-time	-0,37 %	-372 978	-0,26 %	-263 326	0,37 %	372 978	0,26 %	263 326
4. Historical distributional VaR	-0,51 %	-511 741	-0,28 %	-280 996	0,43 %	425 727	0,27 %	271 873
Historical distributional CVaR	-0,63 %	-629 985	-0,42 %	-421 339	0,53 %	527 301	0,38 %	377 087
Differencing methods:								
Day-of-the-week and trading-time (1-2)	-0,04 %	-40 334	-0,03 %	-28 476	0,04 %	40 334	0,03 %	28 476
Day-of-the-week and calendar-time (1-3)	0,03 %	28 002	0,02 %	19 770	-0,03 %	-28 002	-0,02 %	-19 770
Day-of-the-week and Historic mehod (1-4)	-0,11 %	-110 761	0,00 %	2 099	0,02 %	24 748	-0,01 %	-11 222
	Tue-Wed							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,46 %	-458 408	-0,32 %	-323 640	0,46 %	458 408	0,32 %	323 640
2. Parametric trading-time	-0,44 %	-441 313	-0,31 %	-311 571	0,44 %	441 313	0,31 %	311 571
3. Parametric calendar-time	-0,37 %	-372 978	-0,26 %	-263 326	0,37 %	372 978	0,26 %	263 326
4. Historical distributional VaR	-0,60 %	-597 091	-0,31 %	-308 468	0,52 %	523 139	0,24 %	244 648
Historical distributional CVaR	-0,70 %	-704 553	-0,48 %	-479 741	0,79 %	788 218	0,45 %	445 891
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,02 %	17 095	0,01 %	12 069	-0,02 %	-17 095	-0,01 %	-12 069
Day-of-the-week and calendar-time (1-3)	0,09 %	85 431	0,06 %	60 315	-0,09 %	-85 431	-0,06 %	-60 315
Day-of-the-week and Historic mehod (1-4)	-0,14 %	-138 683	0,02 %	15 172	0,06 %	64 730	-0,08 %	-78 992
	Wed-Thu							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,48 %	-480 670	-0,34 %	-339 357	0,48 %	480 670	0,34 %	339 357
2. Parametric trading-time	-0,44 %	-441 313	-0,31 %	-311 571	0,44 %	441 313	0,31 %	311 571
3. Parametric calendar-time	-0,37 %	-372 978	-0,26 %	-263 326	0,37 %	372 978	0,26 %	263 326
4. Historical distributional VaR	-0,58 %	-576 626	-0,30 %	-304 480	0,57 %	568 065	0,34 %	338 939
Historical distributional CVaR	-0,71 %	-714 432	-0,47 %	-467 862	0,78 %	776 700	0,49 %	493 805
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,04 %	39 356	0,03 %	27 786	-0,04 %	-39 356	-0,03 %	-27 786
Day-of-the-week and calendar-time (1-3)	0,11 %	107 692	0,08 %	76 031	-0,11 %	-107 692	-0,08 %	-76 031
Day-of-the-week and Historic mehod (1-4)	-0,10 %	-95 957	0,03 %	34 877	0,09 %	87 396	0,00 %	-418
	Thu-Fri							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,40 %	-401 836	-0,28 %	-283 700	0,40 %	401 836	0,28 %	283 700
2. Parametric trading-time	-0,44 %	-441 313	-0,31 %	-311 571	0,44 %	441 313	0,31 %	311 571
3. Parametric calendar-time	-0,37 %	-372 978	-0,26 %	-263 326	0,37 %	372 978	0,26 %	263 326
4. Historical distributional VaR	-0,42 %	-418 847	-0,27 %	-274 975	0,42 %	423 150	0,28 %	275 859
Historical distributional CVaR	-0,55 %	-553 661	-0,39 %	-392 830	0,65 %	647 861	0,40 %	398 611
Differencing methods:								
Day-of-the-week and trading-time (1-2)	-0,04 %	-39 477	-0,03 %	-27 871	0,04 %	39 477	0,03 %	27 871
Day-of-the-week and calendar-time (1-3)	0,03 %	28 858	0,02 %	20 374	-0,03 %	-28 858	-0,02 %	-20 374
Day-of-the-week and Historic mehod (1-4)	-0,02 %	-17 011	0,01 %	8 725	0,02 %	21 313	-0,01 %	-7 841

Table 36: Daily 95% and 99% VaR analysis for the weekend and trading days, in percentage and value terms for a 100-mill NOK investment based on price returns from bonds 3-0 years-to-maturity period

	Weekend							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,21 %	-207 565	-0,15 %	-146 542	0,21 %	207 565	0,15 %	146 542
2. Parametric trading-time	-0,20 %	-199 399	-0,14 %	-140 778	0,20 %	199 399	0,14 %	140 778
3. Parametric calendar-time	-0,29 %	-291 891	-0,21 %	-206 077	0,29 %	291 891	0,21 %	206 077
4. Historical distributional VaR	-0,29 %	-293 983	-0,16 %	-158 524	0,25 %	247 920	0,09 %	85 067
Historical distributional CVaR	-0,42 %	-420 421	-0,25 %	-246 741	0,40 %	404 439	0,20 %	201 023
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,01 %	8 165	0,01 %	5 765	-0,01 %	-8 165	-0,01 %	-5 765
Day-of-the-week and calendar-time (1-3)	-0,08 %	-84 326	-0,06 %	-59 535	0,08 %	84 326	0,06 %	59 535
Day-of-the-week and Historic mehod (1-4)	-0,09 %	-86 419	-0,01 %	-11 981	0,04 %	40 355	-0,06 %	-61 476
	Mon-Tue							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,17 %	-174 934	-0,12 %	-123 505	0,17 %	174 934	0,12 %	123 505
2. Parametric trading-time	-0,20 %	-199 399	-0,14 %	-140 778	0,20 %	199 399	0,14 %	140 778
3. Parametric calendar-time	-0,17 %	-168 523	-0,12 %	-118 979	0,17 %	168 523	0,12 %	118 979
4. Historical distributional VaR	-0,28 %	-282 752	-0,14 %	-138 921	0,25 %	254 365	0,10 %	102 517
Historical distributional CVaR	-0,36 %	-363 980	-0,23 %	-226 838	0,42 %	415 458	0,21 %	207 600
Differencing methods:								
Day-of-the-week and trading-time (1-2)	-0,02 %	-24 465	-0,02 %	-17 273	0,02 %	24 465	0,02 %	17 273
Day-of-the-week and calendar-time (1-3)	0,01 %	6 411	0,00 %	4 526	-0,01 %	-6 411	0,00 %	-4 526
Day-of-the-week and Historic mehod (1-4)	-0,11 %	-107 818	-0,02 %	-15 416	0,08 %	79 431	-0,02 %	-20 988
	Tue-Wed							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,23 %	-228 792	-0,16 %	-161 529	0,23 %	228 792	0,16 %	161 529
2. Parametric trading-time	-0,20 %	-199 399	-0,14 %	-140 778	0,20 %	199 399	0,14 %	140 778
3. Parametric calendar-time	-0,17 %	-168 523	-0,12 %	-118 979	0,17 %	168 523	0,12 %	118 979
4. Historical distributional VaR	-0,28 %	-277 452	-0,15 %	-147 599	0,30 %	298 348	0,09 %	87 934
Historical distributional CVaR	-0,30 %	-301 734	-0,23 %	-231 660	0,60 %	604 829	0,24 %	244 630
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,03 %	29 393	0,02 %	20 752	-0,03 %	-29 393	-0,02 %	-20 752
Day-of-the-week and calendar-time (1-3)	0,06 %	60 269	0,04 %	42 551	-0,06 %	-60 269	-0,04 %	-42 551
Day-of-the-week and Historic mehod (1-4)	-0,05 %	-48 659	0,01 %	13 930	0,07 %	69 555	-0,07 %	-73 595
	Wed-Thu							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,20 %	-204 271	-0,14 %	-144 217	0,20 %	204 271	0,14 %	144 217
2. Parametric trading-time	-0,20 %	-199 399	-0,14 %	-140 778	0,20 %	199 399	0,14 %	140 778
3. Parametric calendar-time	-0,17 %	-168 523	-0,12 %	-118 979	0,17 %	168 523	0,12 %	118 979
4. Historical distributional VaR	-0,33 %	-326 186	-0,15 %	-149 531	0,27 %	267 654	0,13 %	126 907
Historical distributional CVaR	-0,35 %	-352 368	-0,24 %	-243 918	0,35 %	352 614	0,22 %	215 734
Differencing methods:								
Day-of-the-week and trading-time (1-2)	0,00 %	4 872	0,00 %	3 439	0,00 %	-4 872	0,00 %	-3 439
Day-of-the-week and calendar-time (1-3)	0,04 %	35 748	0,03 %	25 238	-0,04 %	-35 748	-0,03 %	-25 238
Day-of-the-week and Historic mehod (1-4)	-0,12 %	-121 914	-0,01 %	-5 314	0,06 %	63 383	-0,02 %	-17 310
	Thu-Fri							
	99% VaR		95% VaR		1% VaR		5% VaR	
Method:	Loss in %	Loss in NOK	Loss in %	Loss in NOK	Gain in %	Gain in NOK	Gain in %	Gain in NOK
1. Parametric day-of-the-week	-0,18 %	-176 190	-0,12 %	-124 392	0,18 %	176 190	0,12 %	124 392
2. Parametric trading-time	-0,20 %	-199 399	-0,14 %	-140 778	0,20 %	199 399	0,14 %	140 778
3. Parametric calendar-time	-0,17 %	-168 523	-0,12 %	-118 979	0,17 %	168 523	0,12 %	118 979
4. Historical distributional VaR	-0,24 %	-236 951	-0,13 %	-134 508	0,21 %	210 454	0,09 %	94 181
Historical distributional CVaR	-0,33 %	-329 151	-0,20 %	-204 954	0,31 %	310 400	0,17 %	172 693
Differencing methods:								
Day-of-the-week and trading-time (1-2)	-0,02 %	-23 209	-0,02 %	-16 386	0,02 %	23 209	0,02 %	16 386
Day-of-the-week and calendar-time (1-3)	0,01 %	7 667	0,01 %	5 413	-0,01 %	-7 667	-0,01 %	-5 413
Day-of-the-week and Historic mehod (1-4)	-0,06 %	-60 762	-0,01 %	-10 116	0,03 %	34 264	-0,03 %	-30 210

The different years-to-maturity periods generally shows the same found weekend overestimation and weekday underestimation. As maturity approaches, both volatility and differencing methods declines. This is consistent with the pull-to-par effect from chapter 4.

6. Creating a general trading day variance

Following are the discussion of which price returns should be included for in making a general trading day variance. The most obvious solution is to either include the whole dataset, or to only exclude the weekend return. Table 37 compares these two variances.

Table 37: Comparing variances (upscaled) between non-weekend and the dataset for all different years-to-maturity periods.

Years to maturity	11-9	9-7	7-5	5-3	3-0	3-1	2-0
Non-weekend variance (upscaled)	12,85	10,34	6,34	3,53	0,72	1,07	0,21
Dataset variance (upscaled)	12,82	10,40	6,48	3,60	0,74	1,09	0,21

The differences between the two variances are so small that it is arguably fair to assume them equal without preforming any equal variance testing. Thus, the general trading day variance will be created by the whole dataset.

7. Option valuation

Following are the comparing option valuation between trading-week method and the naive method for the different years-to-maturity periods. The subsections are divided by maturity and expiration day. The option valuation methodology is found in section 9.2

7.1 *One-week maturity – expiration on Monday's close*

The control periods are left out from this section as they have been found to compliment the 3-0 years-to-maturity period.

Table 38: Option prices from the trading week method and naive method with up to one week's maturity and expiration on Monday's close for bonds 11-9 years-to-maturity period. Option prices from the trading week method is outlined with a dark blue colour, while the option prices from naive method are outlined with a red colour.

	Weekend		**Thu-Mon**		**Wed-Mon**		**Tue-Mon**		**Mon-Mon**	
Call/Put:	Option price	Strike	Option price	Strike	Option price	Strike	Option price	Strike	Option price	Strike
ATM (Δ = 50%)	1,42 2,09	100	2,02 2,41	100	2,47 2,70	100	2,85 2,95	100	3,19 3,19	100
Call:										
ITM (Δ = 90%)	4,72 5,10	99,55	6,68 6,88	99,36	8,16 8,27	99,21	9,42 9,46	99,09	10,53 10,53	98,98
ITM (Δ = 75%)	2,93 3,50	99,76	4,15 4,47	99,66	5,09 5,27	99,58	5,86 5,94	99,52	6,55 6,55	99,46
OTM (Δ = 25%)	0,53 1,10	100,24	0,75 1,08	100,34	0,92 1,10	100,42	1,06 1,14	100,49	1,19 1,19	100,54
OTM (Δ = 10%)	0,17 0,56	100,46	0,24 0,44	100,65	0,30 0,40	100,80	0,34 0,39	100,92	0,38 0,38	101,03
Put:										
ITM (Δ = 90%)	4,75 5,14	100,46	6,74 6,94	100,65	8,25 8,36	100,80	9,54 9,59	100,92	10,69 10,69	101,03
ITM (Δ = 75%)	2,95 3,52	100,24	4,18 4,51	100,34	5,14 5,32	100,42	5,92 6,00	100,49	6,63 6,63	100,54
OTM (Δ = 25%)	0,53 1,10	99,76	0,75 1,08	99,66	0,92 1,11	99,58	1,07 1,15	99,52	1,20 1,20	99,46
OTM (Δ = 10%)	0,17 0,55	99,55	0,24 0,44	99,36	0,29 0,40	99,21	0,34 0,38	99,09	0,38 0,38	98,98
Method difference	Percentage	NOK	Percentage	NOK	Percentage	NOK	Percentage	NOK	Percentage	NOK
ATM (Δ = 50%)	-47 %	0,67	-20 %	0,40	-9 %	0,23	-4 %	0,10	0 %	0,00
Call:										
ITM (Δ = 90%)	-8 %	0,38	-3 %	0,20	-1 %	0,11	0 %	0,05	0 %	0,00
ITM (Δ = 75%)	-19 %	0,57	-8 %	0,33	-4 %	0,18	-1 %	0,08	0 %	0,00
OTM (Δ = 25%)	-108 %	0,57	-44 %	0,33	-20 %	0,18	-8 %	0,08	0 %	0,00
OTM (Δ = 10%)	-227 %	0,39	-84 %	0,20	-36 %	0,11	-13 %	0,05	0 %	0,00
Put:										
ITM (Δ = 90%)	-8 %	0,38	-3 %	0,20	-1 %	0,11	0 %	0,05	0 %	0,00
ITM (Δ = 75%)	-19 %	0,57	-8 %	0,33	-4 %	0,18	-1 %	0,08	0 %	0,00
OTM (Δ = 25%)	-107 %	0,57	-43 %	0,33	-20 %	0,18	-8 %	0,08	0 %	0,00
OTM (Δ = 10%)	-227 %	0,38	-84 %	0,20	-36 %	0,11	-13 %	0,05	0 %	0,00

Table 39: Option prices from the trading week method and naive method with up to one week's maturity and expiration on Monday's close for bonds 9-7 years-to-maturity period. Option prices from the trading week method is outlined with a dark blue colour, while the option prices from naive method are outlined with a red colour.

	Weekend		**Thu-Mon**		**Wed-Mon**		**Tue-Mon**		**Mon-Mon**	
Call/Put:	Option price	Strike	Option price	Strike	Option price	Strike	Option price	Strike	Option price	Strike
ATM (Δ = 50%)	1,30 1,89	100	1,83 2,18	100	2,24 2,44	100	2,58 2,67	100	2,88 2,88	100
Call:										
ITM (Δ = 90%)	4,33 4,67	99,58	6,06 6,24	99,42	7,39 7,48	99,29	8,51 8,55	99,18	9,52 9,52	99,08
ITM (Δ = 75%)	2,68 3,18	99,78	3,77 4,06	99,69	4,60 4,77	99,62	5,30 5,37	99,57	5,94 5,94	99,51
OTM (Δ = 25%)	0,49 0,99	100,22	0,68 0,97	100,31	0,83 0,99	100,38	0,96 1,03	100,44	1,07 1,07	100,49
OTM (Δ = 10%)	0,15 0,49	100,42	0,22 0,39	100,59	0,27 0,36	100,72	0,31 0,35	100,83	0,34 0,34	100,93
Put:										
ITM (Δ = 90%)	4,35 4,69	100,42	8,10 8,33	100,78	8,18 8,29	100,79	7,89 7,93	100,76	7,27 7,27	100,70
ITM (Δ = 75%)	2,69 3,19	100,22	5,02 5,40	100,41	5,09 5,27	100,42	4,90 4,96	100,40	4,52 4,52	100,37
OTM (Δ = 25%)	0,49 0,99	99,78	0,90 1,29	99,59	0,91 1,09	99,59	0,88 0,94	99,60	0,81 0,81	99,63
OTM (Δ = 10%)	0,15 0,49	99,58	0,29 0,52	99,23	0,29 0,40	99,22	0,28 0,32	99,25	0,26 0,26	99,31
Method difference	Percentage	NOK	Percentage	NOK	Percentage	NOK	Percentage	NOK	Percentage	NOK
ATM (Δ = 50%)	-45 %	0,59	-19 %	0,35	-9 %	0,20	-3 %	0,09	0 %	0,00
Call:										
ITM (Δ = 90%)	-8 %	0,33	-3 %	0,18	-1 %	0,09	0 %	0,04	0 %	0,00
ITM (Δ = 75%)	-19 %	0,50	-8 %	0,29	-4 %	0,16	-1 %	0,07	0 %	0,00
OTM (Δ = 25%)	-103 %	0,50	-42 %	0,29	-20 %	0,16	-7 %	0,07	0 %	0,00
OTM (Δ = 10%)	-218 %	0,34	-81 %	0,18	-35 %	0,09	-13 %	0,04	0 %	0,00
Put:										
ITM (Δ = 90%)	-8 %	0,34	-3 %	0,23	-1 %	0,10	0 %	0,04	0 %	0,00
ITM (Δ = 75%)	-19 %	0,50	-8 %	0,38	-3 %	0,18	-1 %	0,07	0 %	0,00
OTM (Δ = 25%)	-103 %	0,50	-42 %	0,38	-19 %	0,18	-7 %	0,07	0 %	0,00
OTM (Δ = 10%)	-217 %	0,33	-81 %	0,23	-35 %	0,10	-13 %	0,04	0 %	0,00

Table 40: Option prices from the trading week method and naive method with up to one week's maturity and expiration on Monday's close for bonds 7-5 years-to-maturity period. Option prices from the trading week method is outlined with a dark blue colour, while the option prices from naive method are outlined with a red colour.

	Weekend		Thu-Mon		Wed-Mon		Tue-Mon		Mon-Mon	
Call/Put:	Option price	Strike	Option price	Strike	Option price	Strike	Option price	Strike	Option price	Strike
ATM (Δ = 50%)	1,06 1,50	100	1,47 1,73	100	1,78 1,94	100	2,05 2,12	100	2,29 2,29	100
Call:										
ITM (Δ = 90%)	3,51 3,76	99,66	4,87 5,00	99,53	5,90 5,98	99,43	6,81 6,84	99,34	7,56 7,56	99,27
ITM (Δ = 75%)	2,18 2,56	99,82	3,02 3,24	99,75	3,67 3,79	99,70	4,23 4,28	99,65	4,72 4,72	99,61
OTM (Δ = 25%)	0,39 0,77	100,18	0,55 0,76	100,25	0,67 0,79	100,30	0,76 0,82	100,35	0,85 0,85	100,39
OTM (Δ = 10%)	0,13 0,38	100,34	0,17 0,31	100,47	0,21 0,28	100,57	0,24 0,27	100,66	0,27 0,27	100,74
Put:										
ITM (Δ = 90%)	3,53 3,78	100,34	6,49 6,67	100,63	6,52 6,60	100,63	6,27 6,30	100,61	5,79 5,79	100,56
ITM (Δ = 75%)	2,21 2,58	100,18	4,03 4,32	100,33	4,05 4,19	100,33	3,88 3,93	100,32	3,59 3,59	100,29
OTM (Δ = 25%)	0,39 0,76	99,82	0,72 1,01	99,67	0,73 0,87	99,67	0,70 0,75	99,68	0,65 0,65	99,71
OTM (Δ = 10%)	0,12 0,36	99,66	0,23 0,40	99,38	0,23 0,31	99,38	0,22 0,25	99,40	0,21 0,21	99,45
Method difference	Percentage	NOK	Percentage	NOK	Percentage	NOK	Percentage	NOK	Percentage	NOK
ATM (Δ = 50%)	-42 %	0,44	-18 %	0,26	-8 %	0,15	-3 %	0,07	0 %	0,00
Call:										
ITM (Δ = 90%)	-7 %	0,25	-3 %	0,13	-1 %	0,07	0 %	0,03	0 %	0,00
ITM (Δ = 75%)	-17 %	0,37	-7 %	0,22	-3 %	0,12	-1 %	0,05	0 %	0,00
OTM (Δ = 25%)	-95 %	0,37	-40 %	0,22	-18 %	0,12	-7 %	0,05	0 %	0,00
OTM (Δ = 10%)	-197 %	0,25	-76 %	0,13	-33 %	0,07	-13 %	0,03	0 %	0,00
Put:										
ITM (Δ = 90%)	-7 %	0,25	-3 %	0,17	-1 %	0,08	0 %	0,03	0 %	0,00
ITM (Δ = 75%)	-17 %	0,37	-7 %	0,29	-3 %	0,13	-1 %	0,05	0 %	0,00
OTM (Δ = 25%)	-96 %	0,37	-40 %	0,29	-18 %	0,13	-7 %	0,05	0 %	0,00
OTM (Δ = 10%)	-202 %	0,24	-76 %	0,17	-33 %	0,08	-12 %	0,03	0 %	0,00

Table 41: Option prices from the trading week method and naive method with up to one week's maturity and expiration on Monday's close for bonds 5-3 years-to-maturity period. Option prices from the trading week method is outlined with a dark blue colour, while the option prices from naive method are outlined with a red colour.

	Weekend		**Thu-Mon**		**Wed-Mon**		**Tue-Mon**		**Mon-Mon**	
Call/Put:	Option price	Strike	Option price	Strike	Option price	Strike	Option price	Strike	Option price	Strike
ATM (Δ = 50%)	0,79 1,12	100	1,09 1,29	100	1,33 1,44	100	1,53 1,58	100	1,70 1,70	100
Call:										
ITM (Δ = 90%)	2,62 2,81	99,75	3,62 3,72	99,65	4,40 4,46	99,58	5,06 5,08	99,51	5,65 5,65	99,46
ITM (Δ = 75%)	1,62 1,90	99,87	2,25 2,41	99,82	2,73 2,83	99,78	3,15 3,19	99,74	3,51 3,51	99,71
OTM (Δ = 25%)	0,29 0,58	100,13	0,41 0,57	100,18	0,50 0,59	100,23	0,57 0,61	100,26	0,63 0,63	100,29
OTM (Δ = 10%)	0,09 0,28	100,25	0,13 0,23	100,35	0,16 0,21	100,43	0,18 0,21	100,49	0,20 0,20	100,55
Put:										
ITM (Δ = 90%)	2,63 2,82	100,25	4,82 4,95	100,46	4,85 4,91	100,47	4,65 4,67	100,45	4,30 4,30	100,41
ITM (Δ = 75%)	1,63 1,91	100,13	2,99 3,20	100,25	3,01 3,11	100,25	2,89 2,92	100,24	2,67 2,67	100,22
OTM (Δ = 25%)	0,29 0,57	99,87	0,54 0,75	99,76	0,54 0,64	99,75	0,52 0,56	99,76	0,48 0,48	99,78
OTM (Δ = 10%)	0,09 0,28	99,75	0,17 0,30	99,54	0,17 0,23	99,53	0,17 0,19	99,55	0,15 0,15	99,59
Method difference	Percentage	NOK	Percentage	NOK	Percentage	NOK	Percentage	NOK	Percentage	NOK
ATM (Δ = 50%)	-42 %	0,33	-18 %	0,20	-9 %	0,11	-3 %	0,05	0 %	0,00
Call:										
ITM (Δ = 90%)	-7 %	0,19	-3 %	0,10	-1 %	0,05	0 %	0,02	0 %	0,00
ITM (Δ = 75%)	-17 %	0,28	-7 %	0,16	-3 %	0,09	-1 %	0,04	0 %	0,00
OTM (Δ = 25%)	-96 %	0,28	-40 %	0,16	-19 %	0,09	-7 %	0,04	0 %	0,00
OTM (Δ = 10%)	-202 %	0,19	-77 %	0,10	-34 %	0,05	-13 %	0,02	0 %	0,00
Put:										
ITM (Δ = 90%)	-7 %	0,19	-3 %	0,13	-1 %	0,06	0 %	0,02	0 %	0,00
ITM (Δ = 75%)	-17 %	0,28	-7 %	0,22	-3 %	0,10	-1 %	0,04	0 %	0,00
OTM (Δ = 25%)	-96 %	0,28	-40 %	0,22	-19 %	0,10	-7 %	0,04	0 %	0,00
OTM (Δ = 10%)	-200 %	0,19	-77 %	0,13	-34 %	0,06	-13 %	0,02	0 %	0,00

Table 42: Option prices from the trading week method and naive method with up to one week's maturity and expiration on Monday's close for bonds 3-0 years-to-maturity period. Option prices from the trading week method is outlined with a dark blue colour, while the option prices from naive method are outlined with a red colour.

	Weekend		**Thu-Mon**		**Wed-Mon**		**Tue-Mon**		**Mon-Mon**	
Call/Put:	Option price	Strike	Option price	Strike	Option price	Strike	Option price	Strike	Option price	Strike
ATM (Δ = 50%)	0,36 0,50	100	0,49 0,58	100	0,60 0,65	100	0,69 0,71	100	0,77 0,77	100
Call:										
ITM (Δ = 90%)	1,18 1,27	99,89	1,64 1,69	99,84	2,00 2,02	99,81	2,30 2,31	99,78	2,57 2,57	99,75
ITM (Δ = 75%)	0,73 0,86	99,94	1,02 1,09	99,92	1,24 1,28	99,90	1,43 1,45	99,88	1,59 1,59	99,87
OTM (Δ = 25%)	0,13 0,26	100,06	0,18 0,26	100,08	0,22 0,27	100,10	0,26 0,28	100,12	0,29 0,29	100,13
OTM (Δ = 10%)	0,04 0,13	100,11	0,06 0,10	100,16	0,07 0,10	100,19	0,08 0,09	100,22	0,09 0,09	100,25
Put:										
ITM (Δ = 90%)	1,19 1,27	100,11	2,17 2,23	100,21	2,20 2,22	100,21	2,10 2,11	100,20	1,94 1,94	100,19
ITM (Δ = 75%)	0,74 0,86	100,06	1,35 1,45	100,11	1,36 1,41	100,11	1,30 1,32	100,11	1,20 1,20	100,10
OTM (Δ = 25%)	0,13 0,26	99,94	0,24 0,34	99,89	0,25 0,29	99,89	0,24 0,25	99,89	0,22 0,22	99,90
OTM (Δ = 10%)	0,04 0,13	99,89	0,08 0,14	99,79	0,08 0,10	99,79	0,07 0,08	99,80	0,07 0,07	99,81
Method difference	Percentage	NOK	Percentage	NOK	Percentage	NOK	Percentage	NOK	Percentage	NOK
ATM (Δ = 50%)	-42 %	0,15	-18 %	0,09	-9 %	0,05	-3 %	0,02	0 %	0,00
Call:										
ITM (Δ = 90%)	-7 %	0,08	-3 %	0,04	-1 %	0,02	0 %	0,01	0 %	0,00
ITM (Δ = 75%)	-17 %	0,13	-7 %	0,07	-3 %	0,04	-1 %	0,02	0 %	0,00
OTM (Δ = 25%)	-96 %	0,13	-40 %	0,07	-19 %	0,04	-7 %	0,02	0 %	0,00
OTM (Δ = 10%)	-201 %	0,08	-79 %	0,04	-34 %	0,02	-13 %	0,01	0 %	0,00
Put:										
ITM (Δ = 90%)	-7 %	0,08	-3 %	0,06	-1 %	0,03	0 %	0,01	0 %	0,00
ITM (Δ = 75%)	-17 %	0,13	-7 %	0,10	-3 %	0,05	-1 %	0,02	0 %	0,00
OTM (Δ = 25%)	-96 %	0,13	-40 %	0,10	-19 %	0,05	-7 %	0,02	0 %	0,00
OTM (Δ = 10%)	-200 %	0,08	-76 %	0,06	-34 %	0,03	-13 %	0,01	0 %	0,00

The different years-to-maturity periods generally shows the same found weekend overvaluation and weekday undervaluation. As maturity approaches, the differencing values in NOK declines but the percentage values stays nearly identical.

7.2 One-year maturity - expiration on Monday's close

This section has only included one short-term period and one long-term period because of the similar result across different years-to-maturity periods.

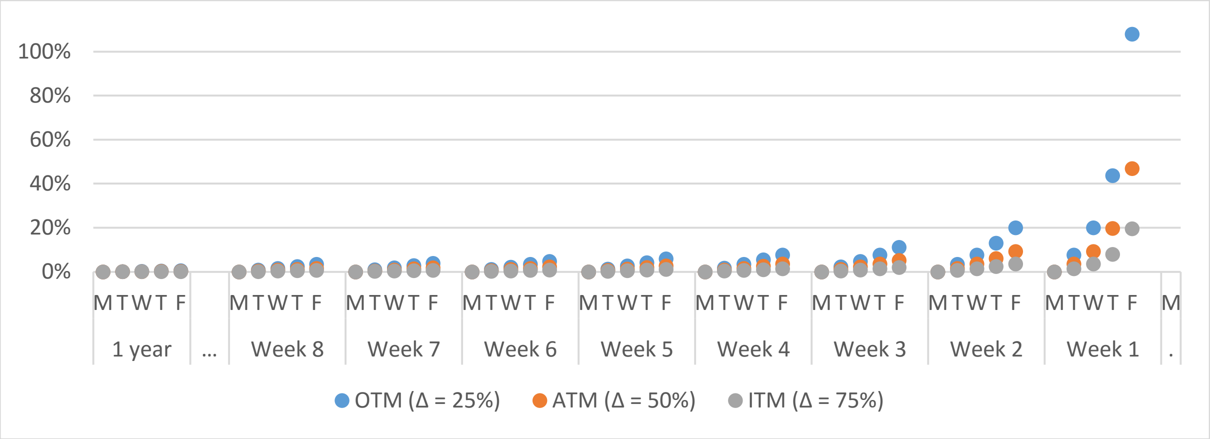

Table 43: Percentage differences between the trading-week method and naive method's option prices for call options with up to one year's maturity and expiration on Monday's close – deltas of 25%, 50% and 75% and based on data from bonds 11-9 years-to-maturity period.

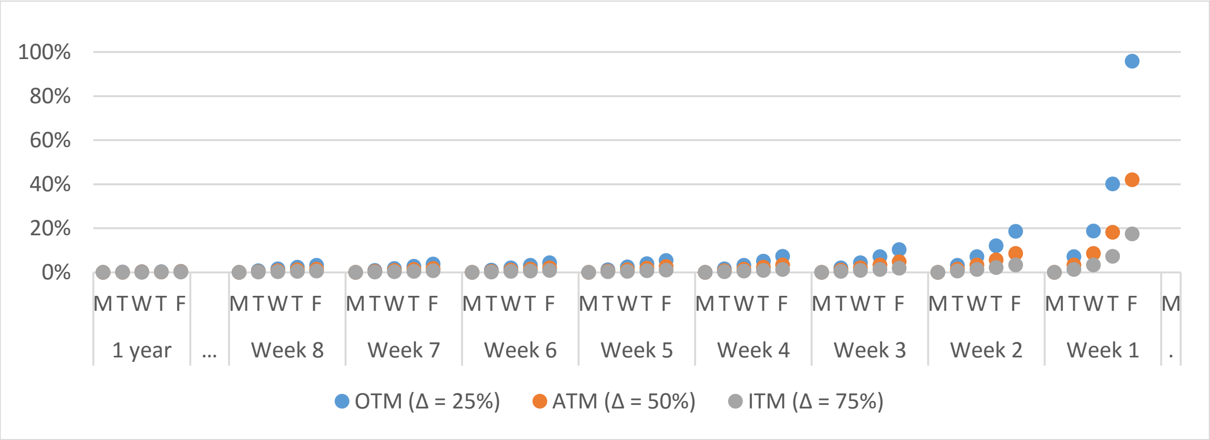

Table 44: Percentage differences between the trading-week method and naive method's option prices for call options with up to one year's maturity and expiration on Monday's close – deltas of 25%, 50% and 75% and based on data from bonds 11-9 years-to-maturity period.

7.3 One-year maturity - expiration on Friday's close

This section has only included one short-term period and one long-term period because of the similar result across different years-to-maturity periods.

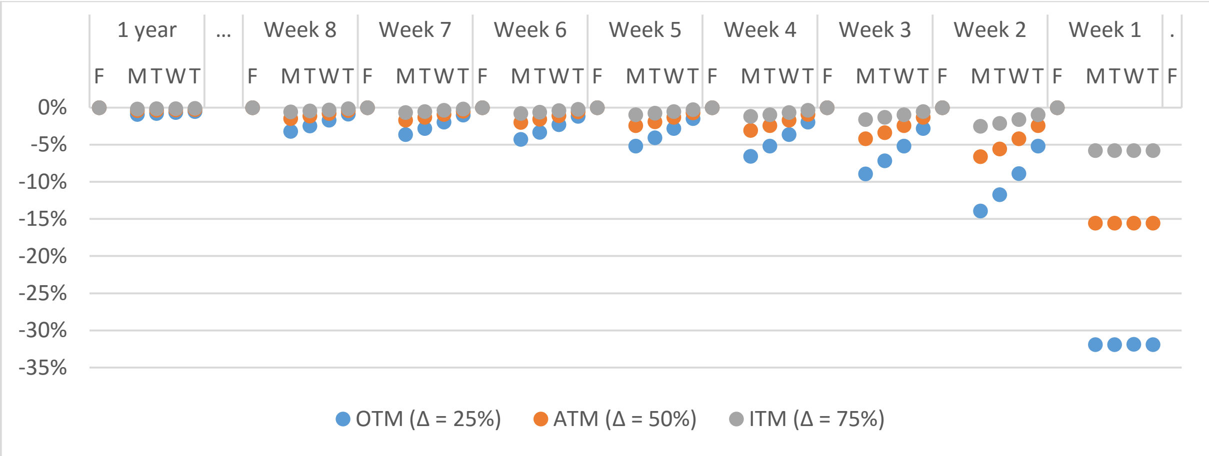

Figure 67: Percentage differences between the trading week method and naive method's option prices for call options with up to one year's maturity and expiration on Friday's close – deltas of 25%, 50% and 75% and based on data from bonds from bonds 11-9 years to maturity period.

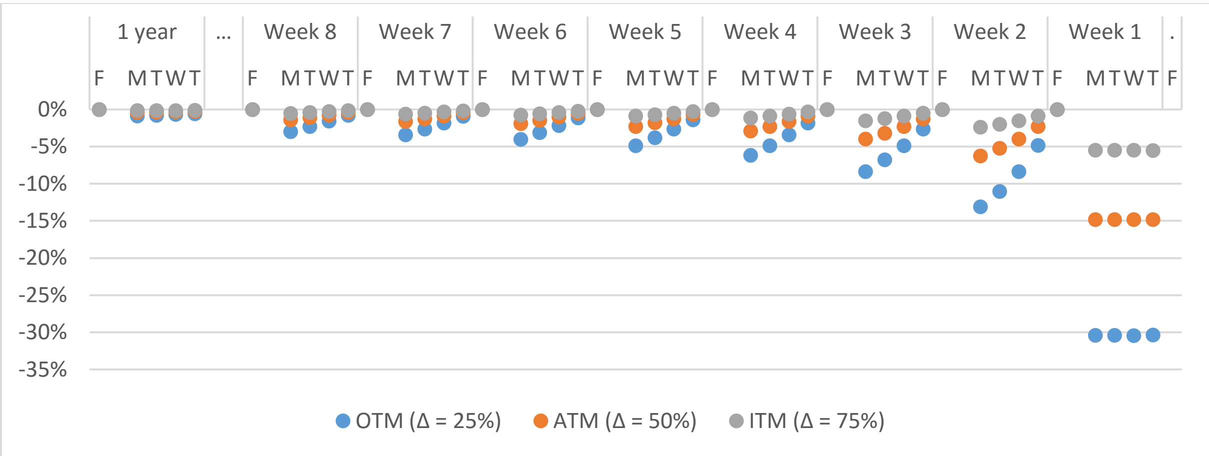

Figure 68: Percentage differences between the trading week method and naive method's option prices for call options with up to one year's maturity and expiration on Friday's close – deltas of 25%, 50% and 75% and based on data from bonds 3-0 years to maturity period.

7.3 One-year maturity - expiration on Wednesday's close

This section has only included one short-term period and one long-term period because of the similar result across different years-to-maturity periods.

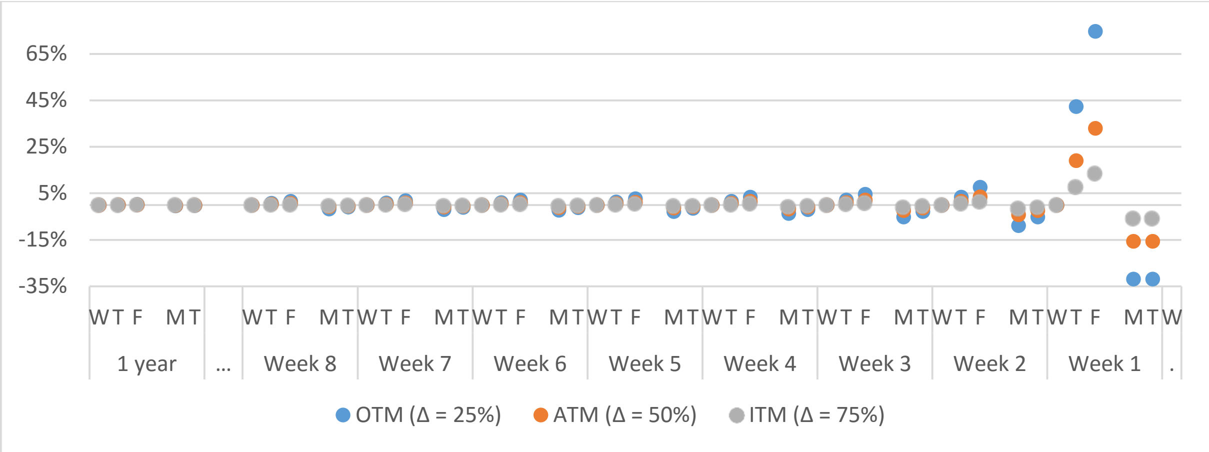

Figure 69: Percentage differences between the trading week method and naive method's option prices for call options with up to one year's maturity and expiration on Wednesday's close – deltas of 25%, 50% and 75% and based on data from bonds 11-9 years to maturity period.

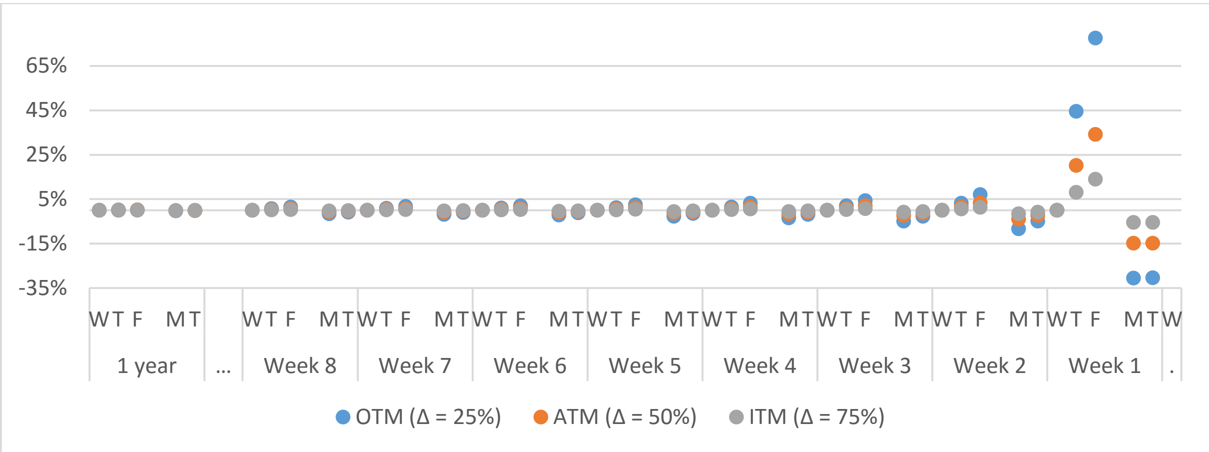

Figure 70: Percentage differences between the trading week method and naive method's option prices for call options with up to one year's maturity and expiration on Wednesday's close – deltas of 25%, 50% and 75% and based on data from bonds 3-0 years to maturity period.

8. Theta and vega

Following are the comparing theta and vega estimates between trading-week method and the naive method for one short-term period and one long-term period. Other periods is ommited because of the similar result across different years-to-maturity periods. The option valuation methodology also applies for theta and vega, and is found in section 9.2

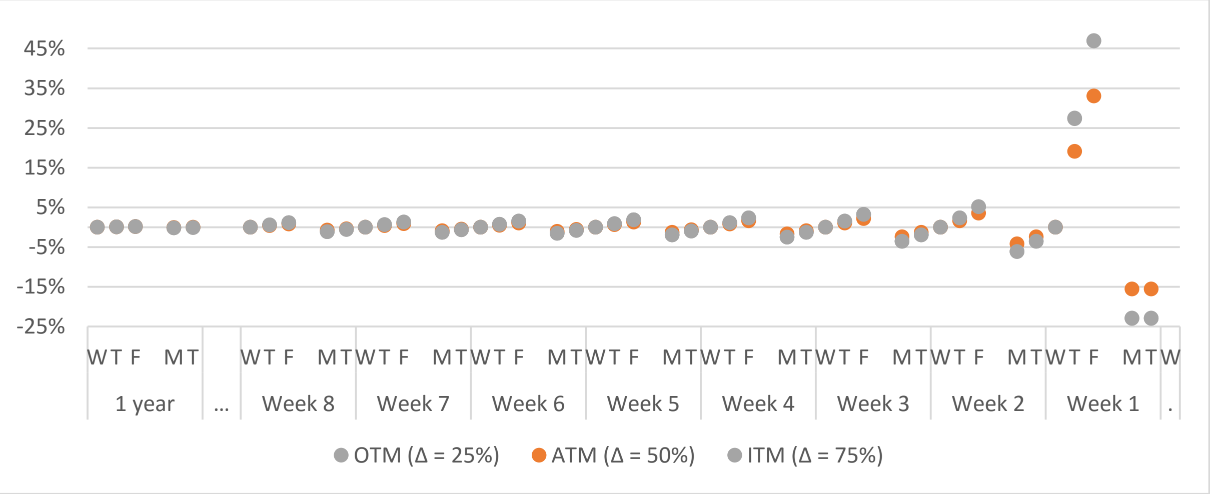

Figure 71: Percentage differences between the trading week method and naive method's theta for call options with up to one year's maturity and expiration on Wednesday's close – deltas of 25%, 50% and 75% and based on data from bonds 11-9 years to maturity period.

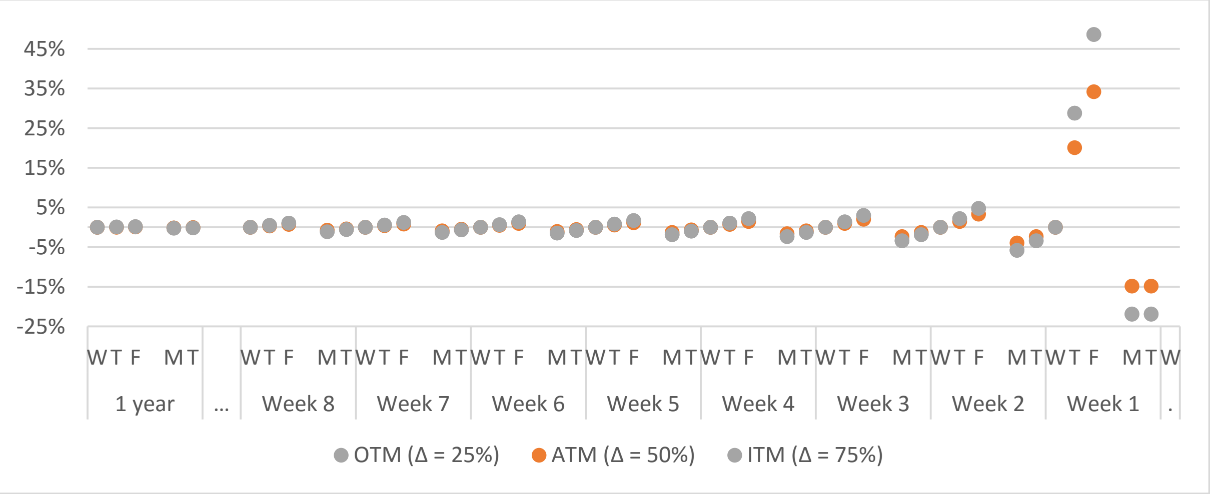

Figure 72: Percentage differences between the trading week method and naive method's theta for call options with up to one year's maturity and expiration on Wednesday's close – deltas of 25%, 50% and 75% and based on data from bonds 3-0 years to maturity period.

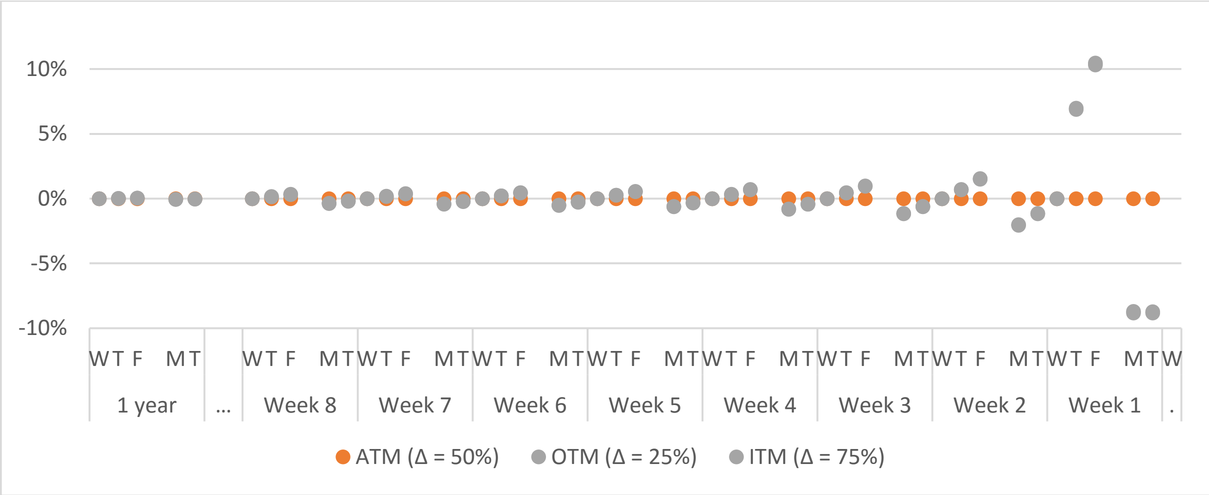

Figure 73: Percentage differences between the trading week method and naive method's vega for call options with up to one year's maturity and expiration on Wednesday's close – deltas of 25%, 50% and 75% and based on data from bonds 11-9 years to maturity period.

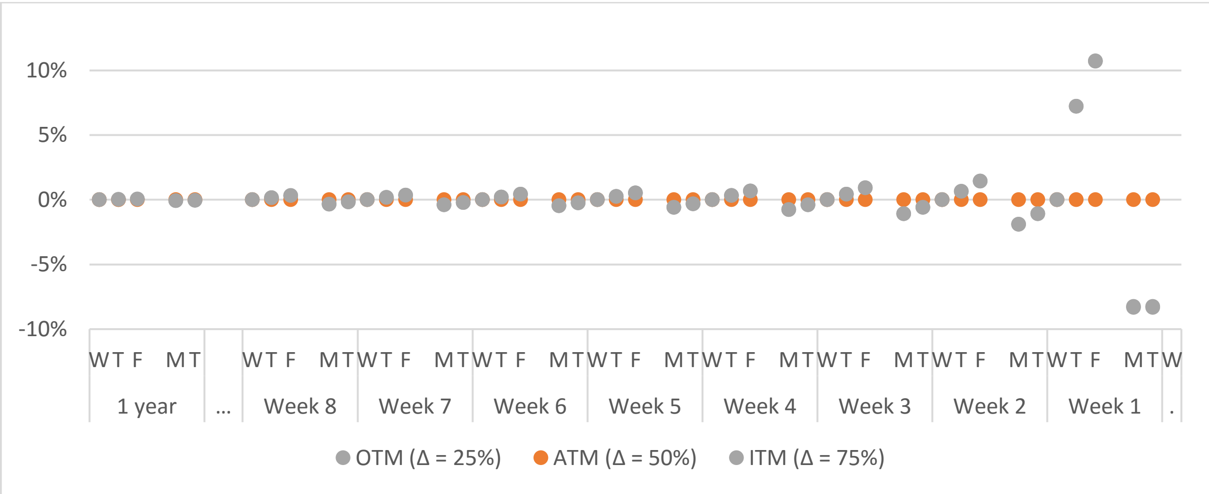

Figure 74: Percentage differences between the trading week method and naive method's vega for call options with up to one year's maturity and expiration on Wednesday's close – deltas of 25%, 50% and 75% and based on data from bonds 3-0 years to maturity period.

Norges miljø- og biovitenskapelig universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway