The Weekend Volatility Effect, Value at Risk and Option Pricing in the Market for Gold Futures at the Chicago Mercantile Exchange.

Weekend Volatilitets Effekten, Value at Risk og Opsjonsprising i markedet for Gull Futures ved Chicago Mercantile Exchange.

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Preface

This thesis marks the end of a two-year master's degree in Business Administration with specialization in Finance. My passion for finance reasons its unique combining of the detail and the total, of the micro and the macro. In the world of finance there seem never a detail too small, and never two factors unlinked. The choice of analysing something of such detail as the Weekend Volatility Effect therefore grounds in its grandness as being a determining factor of the relative significance of news and trading on return variability.

I want first of all to thank my main supervisor Espen Gaarder Haug for proposing the topic, close supervision, good advice and many interesting discussions along the way. I also want to thank my co supervisor Ole Gjølberg for being a great motivator and realist. Lastly, for providing me with useful information when required, I would like to thank the Chicago Mercantile Exchange.

Any errors and omissions are the author's sole responsibility.

Abstract

This thesis' objective is to explore the existence of a Weekend Volatility Effect in the market for gold futures at the Chicago Mercantile Exchange during the period 1992-2012, providing the much needed updated conclusions concerning this effect in the market for this particular commodity. The analysis includes open and close prices allowing for the comparison of weekend-, trading day- and overnight returns. A largely negative Weekend Volatility Effect is detected as the weekend's annual return standard deviation on its lowest, for contract maturities ranging from two to three months, is estimated to 5,88% while that of the general trading day is estimated to 20,77%. The 24-hour return variance during the weekend is therefore only 7,6% of that of the general trading day posing a valid argument for the Trading-Time Hypothesis, over the Calendar-Time Hypothesis, due to the significantly greater relevance of trading relative to news on return variability. Further, the Weekend Volatility Effect is largely visible in an analysis of both VaR and option pricing. For the weekend's parametrically estimated VaR at a 99% confidence level, ignoring the present effect results in an estimated loss level of 2,17% points more than the loss-level acknowledging the effect. For a 10% delta call option, priced at the time of Friday's close and maturing at the time of the following Monday's open, assuming the Calendar-Time Hypothesis to hold result in an option overvaluation of 1149%. Equivalently, a call option priced at the time of Monday's open with maturity set to the time of Friday's close is, when priced according to the Calendar-Time Hypothesis undervalued by 63%. The significance of the over- and undervaluation is seen to rapidly reduce as whole weeks are added to the options' maturities. Out-of-the-money options prove much more sensitive, in terms of percentage option over- and undervaluation, to the present Weekend Volatility Effect relative to in-the-money options. Concluding recommendations strongly advice acknowledging the present negative Weekend Volatility Effect in risk estimation and management, with the obvious better fit of trading- than calendar-time as the market's price-generating time-measure.

Sammendrag

Det er denne oppgavens formal å undersøke om det finnes en Weekend Volatilitetseffekt i markedet for gull futures ved Chicago Mercantile Exchange i løpet av perioden 1992-2012, og dermed gi sårt tiltrengte konklusjoner om denne effekten i dette bestemte råvaremarkedet. Analysen inkluderer open og close priser slik at helge-, handledag- og over-natten avkastninger kan sammenlignes. En significant negativ Weekend Volatilitetseffekt påvises ettersom helgens årlige standard avvik, for kontrakter med en maturitet på to til tre måneder, er estimert til 5,88% mens den i løpet av en generell handledag er på 20,77%. Avkastningenes 24-timers varians i løpet av helgen er derfor bare 7,6% av den i løpet av en generell handledag, og resultatene argumenterer derfor for Handletid Hypotesen, over Kalendertid Hypotesen, grunnet den synlige større påvirkningen av handel enn nyheter på variansen i avkastningene. Videre er Weekend Volatilitetseffekten meget synlig i en analyse av VaR og prising av opsjoner. For helgens parametrisk estimerte VaR, med et sikkerhetsnivå på 99%, å ignorere effekten, resulterer i et tapsnivå på 2,17% mer enn det tapsnivået som tar hensyn til effekten. For en 10% delta call opsjon, priset ved fredags close med maturitet satt til tidspunktet for mandags open, å anta Kalendertid Hypotesen til å holde fører til en overestimering av opsjonsverdien med hele 1149%. På same måte fører Kalendertid Hypotesen til en underestimering på 63% av prisen på an call opsjon dersom opsjonen prises ved mandags open med maturitet satt til fredags close. Størrelsen på over- og underprisingen av opsjonene reduseres kraftig når hele uker legges til opsjonenes maturiteter. Out-of-the-money opsjoner viser seg å være mye mer sensitive, i prosent, til den eksisterende Weekend Volatilitetseffekten enn in-the-money opsjoner. Konkluderende anbefalinger råder en anerkjennelse av den eksisterende negative Weekend Volatilitets Effekten ved risiko estimering og håndtering, med en åpenbart bedre passform av handletid i forhold til kalendertid som markedets relevante pris-genererende tidsmål.

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1. Introduction

This thesis' objective is to explore the existence of a Weekend Volatility Effect, namely the differing nature of the weekend's return variance relative to that of the general trading day, in the market for gold futures at the Chicago Mercantile Exchange (hereafter CME). The analysis is based on the 20-year period 1992-2012, providing the much needed updated conclusions concerning the Weekend Volatility Effect in the market for this particular commodity. The study by Ball et al. (1982), being one of few existent current day research papers on the exact topic of the Weekend Volatility Effect in the market for gold, find the effect to be existent and negative when analysing the London Metal Exchange's gold spot market during 1975-1979. The relevance, or the degree of persistence, of these findings in the market for gold futures is therefore determined. A largely negative Weekend Volatility Effect is detected in the market for gold futures at the CME as the weekend's annual return standard deviation, for contracts with maturity ranging from two to three months, is estimated to 5,88% while that of the general trading day is estimated to 20,77%. In other words, for these contract maturities, the 24-hour return variance during the weekend is only 7,6% of that of the general trading day. The significance of the present Weekend Volatility Effect is demonstrated by comparing VaR and option pricing on the basis of ignoring the present effect with those when acknowledging it. The options referred to are options with the gold futures as the underlying, also traded at the CME.

In addition to the lacking updated research on the Weekend Volatility Effect in gold markets, this particular commodity is considered of great interest due to its seemingly changing character. According to the World Gold Council, central banks became collectively net buyers of gold in 2009 after 18 years as net sellers. Also, in 2010 the gold spot price sustained record highs, in particular the London PM fixing spot price achieved 35 separate successive highs in the year to date. As of November 2010, the SPDR Gold Shares that is the largest of the physical gold bullion backed exchange-traded funds, was the second-largest ETF by market capitalization. The recent fall in the gold price, in particular a drop of -9,35% for the close price of the front gold future contract from the 12th to the 15th of April 2013, may call for better risk understanding and more active risk management in this particular market.

Due to the context of the Weekend Volatility Effect, namely the Calendar- and Trading-Time Hypotheses, analysing this effect is equivalent to determining what it is that causes securities' prices to change. According to the Calendar-Time Hypothesis news is what drives prices, and calendar-time is the relevant price-generating time. The Trading-Time Hypothesis, however, argues trading to be the relevant price-generator, and trading-time to be the relevant measure of time. Due to the closing of the exchange during Saturday and Sunday, the two hypotheses argue a differing nature of the returns variance during the weekend relative to that during the general trading day.

By using daily open and close prices of GC gold futures, traded at the CME during the 20-year period 1992-2012, four maturity groups, the “front”, “second”, “third” and “fifth”, are created with their title indicating the time in months until maturity. For each maturity group, a comparison is made of the weekend's return variance with that of the trading days. It is in this way determined whether the return variance of Saturday and Sunday differ from that of the active trading days. A second comparison is conducted of the weekend's return variance with that of the overnight returns between the week's trading days. The CME's gold future weekend returns, as calculated from Friday's close price to Monday's open, inhibit an amount of online trading hours equal to that of the overnight returns enabling a nonparametric statistical testing of the Trading-Time Hypothesis. Due to trading likely being more active during hours of both floor- and online trading, the weekend and overnight returns are relatively more compatible than the weekend and trading day returns as these both contain solely online trading-hours, resulting in more precise conclusions concerning the relative significance of trading on price changes. Resulting conclusions drawn from both comparisons lean toward the greater relevance of trading on the generation of return variance than that of news. Therefore, even if the trading during Monday to Friday overall was of the same volumes as those during the overnights, Saturday and Sunday would still stand out as relatively less volatile. As expected, the significance of the negative Weekend Volatility Effect is much greater according to the first comparison relative to that of the second.

Calculations of Value at Risk, hereafter VaR, and option prices, ignoring the present Weekend Volatility Effect, are based on the total week's estimated return variance. The week's return variance is allocated between the weekend and trading day returns according to their underlying amount of calendar-time. As a result, the Calendar-Time Hypothesis overestimates the return variance during the weekend, and overestimates that during the trading days.

For the weekend's parametrically estimated VaR at a 99% confidence level, ignoring the Weekend Volatility Effect results in an estimated loss level of -3,33%, 2,17% points more than the loss-level of -1,16% acknowledging the present effect. Due to the return distributions being both leptokurtic and skewed, parametric VaR result in some reduction of the overestimation by 0,22% resulting in a total overestimation of 1,95%. For the trading days Monday to Friday, ignoring the weekend volatility effect results in an average day VaR measure at the 95% confidence level of -1,82%, 0,52% less than the loss-level -2,33% acknowledging the present effect.

The difference in implied volatility, depending on whether the present Weekend Volatility Effect is ignored or acknowledged, is seen to be of great significance to the pricing of options on gold futures. For a 10% delta call option, with maturity set to the weekend, assuming the Calendar-Time Hypothesis to hold result in an option overvaluation of 1149%. Equivalently, a call option priced at the time of Monday's open while maturing at the time of Friday's close is, when priced according to the Calendar-Time Hypothesis, undervalued by 63%. The significance of the over- and undervaluation is seen to rapidly reduce as whole weeks are added to the options' maturities. Out-of-the-money options prove much more sensitive, in terms of percentage option over- and undervaluation, to the present Weekend Volatility Effect relative to in-the-money options.

This thesis is structured as follows; Chapter 2 presents the theory of the Weekend Volatility effect, while previous findings of the effect in both gold and non-gold markets are presented in chapter 3. Chapter 4 gives then a general overview of the forces of supply and demand in the world gold market, in addition to a specification of the futures and futures-options gold derivatives traded at the CME. The theories of VaR and the Binomial Option Pricing Model, in the context of a Weekend Volatility Effect, are to be found in chapter 5. Chapter 6 presents the futures price dataset on which the analysis is based, and the chosen options for analysis. Relevant methodology for the testing of the Calendar-and Trading-Time Hypotheses is presented in chapter 7. The methodology enabling the calculation of VaR and option prices, are presented in chapter 8. Then, in chapter 9, the statistical results to the analysis of the Weekend Volatility Effect are presented, while the resulting implications to VaR and option pricing are presented in chapter 10. Concluding thoughts and suggestions for further analysis are to be found in the final chapter 11.

2. The Theory of the Weekend Volatility Effect

An analysis of the Weekend Volatility Effect is, due to its context being that of The Calendar- and Trading-Time Hypotheses, an analysis into what it is that causes security's prices to change. The question is simply; Is it news, trading or both that cause prices to change? The particularity of the days Saturday and Sunday is, as most often is the case, that exchange trading is not conducted during these days. The closing of the exchange does not however imply constraints to the occurrence of news resulting in the weekend's returns being the perfect medium to answer the stated question. The theory of the Calendar- and Trading-Time Hypotheses as well as the Weekend Volatility Effect is to be found in the following three sections.

2.1. The Calendar-Time Hypothesis

According to "The Calendar-Time Hypothesis", first named by French (1980), news is what causes prices to change, and based on the assumption of news occurring randomly, calendar-time is the relevant price-generating time. The hypothesis was first initiated by Fama (1965) arguing; "political and economic news occurs continuously, and if it is assimilated continuously by investors, the variance of the distribution of price changes between two points in time would be proportional to the actual number of days elapsed." Price volatility should, as a result, be independent of whether trading is active or not. The implication of this is constant daily price volatility throughout the week, is the weekend's return variance, the total of that of Saturday and Sunday, to be twice that of the general trading day. The assumed random occurrence of news is crucial for these implications to hold. It is therefore important to note that a statistical rejection of the Calendar-Time Hypothesis does not necessarily disprove the relevance of news. The rejection may well come from a timing bias due to less news occurring during the weekend. This is best described by Clark (1973) in his statement; "The different evolution of price series on different days is due to the fact that information is available to traders at a varying rate. On days when no new information is available trading is slow, and the price process evolves slowly. On days when new information violates old expectations trading is brisk, and the price process evolves much faster”. For a complete analysis, of the significance of news on return variability, occurring news would need to be noted and given weight in terms of relevance. As will be evident from the overview of the world Gold market in chapter 4, relevant news in the market for gold is abnormally vast and variant due to the varied uses of gold. Any further analysis into the questionable random timing of relevant news is therefore beyond the scope of this thesis.

2.2. The Trading-Time Hypothesis

The “Trading-Time Hypothesis”, also named by French (1980), can be seen as the opposing hypothesis concerning what causes securities’ prices to change. This hypothesis argues trading itself to be the significant price-generator, and based on the assumption of the random occurrence of trades within the trading hours, trading-time is argued to be a market’s relevant price-generating time. According to French (1980); “Under the Trading-Time hypothesis, returns are generated only during active trading.” Periods of non-trading, as is normally the case during the weekend, should therefore inhibit zero return variance. In the market for gold futures at the CME, the weekend, when estimated from the time of Friday’s close to Monday’s open, contain 18 hours and 5 minutes of trading-time. This amount of trading-time make up 81% of that contained in the general trading day. The appropriate meaning of trading-time in this particular market should therefore not refer to the traditional number of around 256 days a year as the weekend’s return variance should, according to the Trading-Time Hypothesis, equal 81% of that of the general trading day. If strictly applying theory, the relevant number of days in a year should equal 256 plus 0,81*52, namely 298 days, for the market for gold futures at the CME. As for the Calendar-Time Hypothesis, the assumption concerning the timing of the hypothesized price-generator is crucial for the stated implications to hold. This is best described by Bessembinder (1993) with what he refers to as the “mixture of distributions” hypothesis arguing that the variance per transaction is monotonically related to the volume of that transaction. The trading-hours of golf futures at the CME should be categorized into two groups; those during the open of both the floor- and online trading venues, and those during the open of solely the online trading venue. From an economical perspective there is reason to believe per hour trading volumes to be relative greater during the first category of trading-hours relative to the second. This theory is supported when looking at CME's "time and sales report" of daily online trades of the gold futures contract terminating in April 2013, on the random dates 28th of march, and on the 1st, 5th, 9th, 12th and the 17th of April. During these dates, average online trading volumes within trading-hour category one consist of 59% of total online trades, despite this trading-hour category only making up 22% of a trading day's total trading-time. It is therefore assumed by this thesis that trading is relatively more active during trading-hour category one, namely within the open and close of the OpenOutcry floor-trading venue. A rejection of the Trading-Time Hypothesis does therefore not necessarily imply the irrelevance of solely trading and therefore the relevance of news, but could also reflect volume differences between the comparing trading hours. This issue is dealt with to some extent by performing a separate analysis comparing the weekend's return variance with those of overnight returns. The weekend and overnight returns both include solely online trading-hours as well as the exact same amount of trading-time. The applied procedure will be presented and discussed further in chapter 7.

2.3. The Weekend Volatility Effect

A Weekend Volatility Effect describes a market in which the nature of the returns variability is different during the weekend than during the remaining days of the week. Therefore, only in a market where the Calendar-Time Hypothesis specifies the market's true workings there is no existent Weekend Volatility Effect. In the case of the weekend's return variance being greater than twice that of the general trading day, a positive Weekend Volatility Effect exists. A negative Weekend Volatility Effect exists in the case of the opposite being true. In the case when trading is fully or partly unavailable during the weekend, the Trading-Time Hypothesis correctly specifying the market's workings must indicate an existent negative Weekend Volatility Effect. As is the case in the market for gold futures at the CME, online-trading is partly available during the weekend resulting in the possible rejection of the Trading-Time Hypothesis due to the weekend's returns carrying less variability than according to their amount of trading-time. Put in other words, a negative Weekend Volatility Effect might be of such a size that the Trading-Time Hypothesis, although arguing a reduced return variability during the weekend, is rejected.

3. Previous Findings

Literature exploring the relative significance of news versus trading on return variability is well established in the stock market. As the following stated studies show, the stock market is generally found to be located somewhere in-between the Calendar- and Trading-Time Hypotheses indicating less volatile returns during the weekend relative to those during active trading days. Fama (1965) in his analysis of daily closing prices of thirty stocks of the Dow-Jones Industrial Average from 1957 to 1962 find that the estimated variance of the price return from the time of Friday's close to Monday's close is only 22% greater than that of the general trading day despite containing three times more calendar-time. A similar conclusion is reached by French (1980) when analysing daily close prices of Standard and Poor's composite portfolio from 1953 to 1977. The estimated return variance from the time of Friday's close to Monday's close was found to be only 19% of that of the general trading day. French and Roll (1986) find evidence of an even more significant negative Weekend Volatility Effect when analysing the daily close price of all common stocks listed on the New York and American Stock Exchanges between 1963 and 1982. The estimated return variance from the time of Friday's close to Monday's close was found to be only 10.7% of that of the general trading day. Cutler et al. (1989) analyses the reaction of monthly returns during 1926-1985, and of annual returns during 1871-1886, of the value-weighted New York Stock Exchange portfolio to changes in information concerning macroeconomic performance. Such changes are shown to explain as little as one-third of the return variations. In a separate analysis of day returns to Standard and Poor's composite Stock Index during the period 1941-1987, it proves difficult to explain even as little as half of the variance in aggregate stock prices on the basis of publicly available news bearing on fundamental values. Cutler et al. (1989) states; "many of the largest market movements have occurred on days when there were no major news events."

Findings disproving the Calendar-Time Hypothesis are also present in the commodity markets. In a study of frozen concentrated orange juice futures traded at the New York Cotton Exchange, Roll (1984) proves a clear argument towards the Trading-Time

Hypothesis. This particular commodity has 98% of its U.S. production located around Orlando, causing weather conditions within this region to be the absolute main determining factor of crop conditions of the oranges. Despite this, weather surprises are shown to explain only a small fraction of the observed variability in the futures prices leaving a large amount of inexplicable price volatility.

In the gold spot market, the same argument holds. Ball et al. (1982) investigate the daily AM and PM fixing prices of gold at the London Metal Exchange over the period 1975-1979. Weekend price returns are calculated as the return from Friday's PM fixing to Monday's AM fixing price. Their results show the weekend's return variance to not be much different from that of the general trading day. The per day return variance, of Saturday and Sunday, therefore equals only half that of the general trading day indicating the existence a negative Weekend Volatility Effect.

4. The Gold Market – An overview

A presentation is in this chapter given of gold's main characteristics, supply and demand, as well as a specification of the workings and contract technicalities of the gold derivatives for analysis; namely the GC futures and OG Options traded at the CME. All information given in section 4.1. is to be found on the World Gold Council's website.

4.1. Gold – Supply and Demand

The metallic element Gold has a melting and boiling point of 1064 and 2808 degrees centigrade. Its chemical symbol, Au, is short for the Latin word, "Aurum", which can be directly translated to 'Glowing Dawn'. Gold's properties include ductility, malleability, electrical and thermal conductivity, as well as resistance to corrosion. By the end of 2011, aboveground stocks totals 171.300 tonnes making gold a relatively rare metal. By comparison, the aboveground existence of silver totals around 1.5 million tonnes. 50% of today's existent gold is in the shape of jewellery, 17% in the shape of bars and bullion kept by the official sector, 19% is in the hands of investors, 12% is employed in the technology sector, while 2% is unaccounted for. Gold's historic usage as a medium of exchange dates as far back as 564 BC when King Croesus mints the world's first standardised gold currency. Great Britain is history's first country to adapt a gold standard, in the periods 1717-1919 and 1925-1944, by linking their currency to gold at a fixed rate. Then, in the years 1870-1900 all major countries other than China link their currencies to gold. At the Bretton Woods conference in 1944, following the Second World War, a Gold Exchange Standard is adopted with the US dollar linked to gold and other currencies fixed in terms of the US dollar. The system ends in 1971 when President Nixon "closes the gold window".

Mining production and gold recycling, ordered by significance, are the two main sources of the world's current supply of gold. Average annual supply from mining amounts 2,377 tonnes, or 61,4% of total gold supply, in the years 2007-2011. Several hundred gold mining companies operate on every continent of the globe except Antarctica. Their production is relatively robust due to the dispersion of mines making any single region unlikely to impact total production. New mines are mostly developed to replace currently operating mines, rather than to expand global production levels resulting in a relatively stable production. With new mines taking up to 10 years to come on stream, mining output is relatively inelastic to price changes. Gold recycling accounts for an annual average of 1,449 tonnes, or 37%, of total supply in the years 2007-2011. In contrast to the inelastic mining supply, recycling volumes react to price changes and should according to economical theory therefore add to price stability.

Jewellery-, investment- and industry demand, ordered by significance, make up the world's current gold demand. Average annual gold demand from the jewellery industry, during the years 2007-2011, amounts 2,104 tonnes, or 55,3% of total demand. In 2009 India, East Asia and the Middle East accounts for approximately 70% of the world demand for gold jewellery. During the years 2007-2011 industrial demand for gold accounts for an annual average of 455 tonnes totalling 12% of total gold demand. Due to gold's corrosion resistance, and high thermal and electrical conductivity, the metal is used in various technologies including electronic, industrial, medical and dental. Average annual gold demand for investment purposes, during the years 2007-2011, total 1,296 tonnes, or 32,7% of total gold demand. During this period the price of gold increase by around 534%, possibly being the reason why investment demand is the fastest growing source of demand since 2003. The gold activity of the worlds official sector, meaning that of central banks and other official institutions, has in recent years undergone drastic changes. Historically, the world official sector's gross gold sales outnumber their gross purchases resulting in their net gold activity entering the supply side. The world official sector's gold activity, during the years 2007-2011, amounts an annual net sale of 47 tonnes, or 1,5% of total gold supply. Since 2010, the official sector has become a net buyer after 21 years as a collectively net seller with net purchases of 77 tonnes in 2010 and of 440 tonnes in 2011. Central banks and multinational organisations, such as the International Monetary Fund, currently hold just under one-fifth of global aboveground stocks of gold as reserve assets amounting to around 29,000 tonnes, dispersed across about 110 organisations. On average, central banks hold around 15% of their official reserves as gold, although the proportion varies widely across countries.

4.2. Gold Derivatives; GC Futures and OG Options at the CME

The gold future contract traded at the CME, denoted by GC, is a binding commitment to take, in the case of a long position, or make, in the case of a short position, a physical delivery of 100 troy ounces gold of a minimum of 995 fineness. The contract further specifies for which price and at which date the exchange will occur, ranging from the first till the last business day of the delivery month. The GC future's quoted price is in dollars and cents per troy ounce gold making the specified price of the future contract purchase one hundred times it's quoted price. The gold futures contract is traded both through floor-trading at the Open Outcry in New York and through online-trading at the CME Globex. Trades at both venues are cleared through the CME ClearPort. Clearing fees vary according to the customer's type of membership, the volume traded, and what venue the trade has taken place. The GC futures can also be traded off-exchange, for clearing only through the CME ClearPort. Although an actual futures contract holds no direct cost, margin requirements are demanded by the CME. These requirements, consisting of both initial and maintenance requirements, are set to cover roughly 99 per cent of the possible price moves for a position during a trading day or multiple trading days. Nearly all market agents withdraw from their long position in the GC futures before the time of physical delivery by taking an offsetting short position. Average open interest on a contract's last trading day, during 1992-2012, is 118 contracts. For comparison, average daily open interest at the time when a contract terminates in 60 days is 135.702 contracts. The gold market is typically in "contango" indicating the price of GC futures with shorter maturities to be lower than those with longer maturities, likely reflecting gold's relatively high cost of carry.

An option with the GC futures as the underlying, denoted by OG, give the holder the right to buy, in the case of a call option, or sell, in the case of a put option, one GC futures at any time within a predetermined date at a predetermined strike price. The OG option contract is traded and cleared through the same venues as specified above for the GC futures contract. The OG options are of American style meaning that the time of purchase or sale of the underlying GC future is decided by the option holder, and can occur on any date between the purchase of the option and the option expiration date. Delivery may take place on any business day from the first till the last business day of the option expiration month. Trading expires four business days prior to the end of the month preceding the month of contract expiration. Unlike for futures contracts, options carry a direct cost of purchase determined by the markets current price of the underlying, the current market risk-free interest rate, the market’s anticipated or implied volatility, the contract’s time to maturity and the specified strike price at which the underlying may be bought.

5. Value at Risk and Binomial Option Pricing

It is the purpose of this chapter to provide the necessary theoretical background to the analysis of the implications of a Weekend Volatility Effect. A presentation of Value at Risk is given in section 5.1. including both it's parametric and historical approach of estimation. Section 5.2. presents the Binomial Option Pricing Model as well as the option Greeks of interest for the purpose of understanding the implications of a changing implied volatility on the value of an option.

5.1. Value at Risk

The risk measure VaR, was first introduced by J.P. Morgan's RiskMetrics™ in 1994, and specifies the loss level over a certain period that we at a certain confidence level can expect not to be exceeded. The confidence level specifies the probability of a loss greater then the VaR loss level. VaR can be calculated for both long and short positions, where in the case of a short position the loss level refers to a positive price return. A well-known shortcoming of the risk measure VaR is it's lacking specification of the return distribution beyond the specified confidence levels. Although a VaR loss level at a 95% confidence level specifies a greater loss only to occur with a 5% probability, VaR fails to specify how much greater such a loss might be. Such a specification is made by the compensating risk measure "Expected Shortfall", or Conditional VaR, but is due to work load considerations not included in this thesis' analysis. The Parametric- and Historical methods are the two main approaches to estimating VaR, and are presented as according to Hull (2012).

5.1.1. Parametric Method

The parametric method is based on the assumption that the price returns are normally distributed, and estimates VaR on the basis of the return's estimated standard deviations. For the normal distribution, a certain characteristic percentage of returns, like for example the 5% lowest, may be located by using the returns' standard deviation. For a confidence level of 5%, since N(-1,645)=0,05, one can say with a 95% certainty that a normally distributed variable will not decrease, nor increase, in value by more than 1,645 standard deviations from its mean value. Equivalently, for a confidence level of 1%, N(-2,33)=0,01, one can say with a 99% certainty that a normally distributed variable will not decrease, nor increase, in value by more than 2,33 standard deviations from its mean value. The percentage VaR for the confidence levels of 95% and 99% levels are calculated;

$$95\% VaR = \bar{R}_t \pm (1{,}645 * \sigma_t)$$

$$99\% VaR(t) = \bar{R}_t \pm (2{,}33 * \sigma_t)$$

where $\bar{R}_t$ is the mean return, σ_t is the standard deviation, and t refers to the time period during which the VaR applies. VaR estimates are in this thesis calculated for the weekend and all the trading days including Monday till Friday. The standard deviations, in the above equations, are subtracted from the mean in the case of a long position and added to the mean in the case of a short position. A 95% and 99% VaR in value terms given a certain value of an investment is calculated;

$$95\% VaR = [\bar{R}_t \pm (1{,}645 * \sigma_t)] * investment\ value$$

$$99\% VaR(t) = [\bar{R}_t \pm (2{,}33 * \sigma_t)] * investment\ value$$

5.1.2. The Historical Method

The alternative historical method of estimating VaR, which does not require any underlying assumptions concerning the return's distribution, is calculated directly from the collected sample of historical returns. By counting the total number of historical returns in a sample, then ranging the returns from their largest to their smallest values, one can draw conclusions concerning the maximum loss-level to be expected with a certain confidence level. VaR for a 95% and 99% confidence level is therefore estimated as the 5th and 1st percentile of the return's distribution, located by multiplying 0,05 and 0,01 with the total number of collected returns in the historical dataset. Equivalently, for a short position, the loss-levels one can expect not to be exceeded with a 95% and 99% confidence level is specified by the 95th and 99th percentile of the return's distribution. Again, to get a value estimate of VaR for a certain given investment value the percentage VaR is multiplied by the value of the investment.

5.2. Option pricing

For the pricing of the American type OG options traded at the CME the binomial option pricing model is applied. The model, first developed by Cox et al. (1979), is presented in the altered form in the case of the underlying being a futures contract. To understand the implications of a present Weekend Volatility Effect on option pricing one must fully understand the workings of the option's price. The option Greeks delta and vega are considers the most important for the analysis and are presented in section 5.2.2, although the analysis could include extend far beyond this scope.

5.2.1. The Binomial Option Pricing Model

The binominal tree valuation approach involves dividing the life of the option into a large number of small time intervals of length Δt. The model then assumes that in each time interval the price of the underlying futures moves from its initial value of F_0 to one of two possibilities, F_0u and F_0d, where u>1 and d<1. The movement from F_0 to F_0u is therefore an "up" movement and occurs with probability p, while from F_0 to F_0d is a "down" movement and occurs with probability (1-p). An option gives a payoff f_u in the case of the up movement of the underlying, and a payoff f_d in the case of a down movement.

In particular, for a call and put option;

$C_u = max[0, F_0 u - K] \qquad C_d = max[0, F_0 d - K]$

$P_u = max[0, K - F_0 u] \qquad P_d = max[0, K - F_0 d]$.

The Binomial Option Pricing Model therefore enables the pricing of an American option in that the pricing procedure is to work back through the tree from the end to the beginning, testing at each node to see whether early exercise is optimal. Assuming agents to be risk-neutral[1] lead to two important implications; The first being that a futures price has an expected growth rate of zero, due to the zero direct cost of futures, resulting in the expected futures price at the end of one time step of length Δt years equalling:

$$E(F_{\Delta t}) = pF_0\mathrm{u} + (1 - \mathrm{p})F_0\mathrm{d} = F_0$$

which result in the following by rearranging:

$$p = \frac{1-d}{u-d}$$

The second crucial implication of assuming risk-neutral investors is that the discount rate used for the expected payoff on an option becomes the annual risk-free rate r. The option value is calculated as the present value of the future expected option payoffs:

$$f = e^{-r\Delta t}[pf_u + (1-p)f_d]$$

The significance of the increase and decrease in the price of the underlying future contract is calculated on the basis of its price volatility. The standard deviation of the return on the underlying in a short period of time of length Δt years is $\sigma\sqrt{\Delta t}$ where σ is the annual standard deviation.

[1] A no-arbitrage argument gives the same answer.

u and d are then calculated:

$$u = e^{\sigma\sqrt{\Delta t}}$$

$$d = e^{-\sigma\sqrt{\Delta t}}$$

In the limit as Δt tends to zero and the number of time steps tend to infinity, an exact option value is obtained. According to Hull (2012), the life of an option is in practice typically divided into 30 time steps. With this number of time steps 2^{30}, or about one billion, possible future price paths implicitly considered. Based on recommendations by Espen G. Haug, 50 time steps are more certain to give precise option prices considering 2^{50}, or about 1,1 quadrillion, possible future price paths.

A basing assumption of the Binomial Option Pricing Model is the price of the option's underlying to follows a geometric Brownian motion with a constant drift and volatility. The returns are assumed Gaussian, or normally, distributed which is as will be seen not the case in the market for gold futures at the CME as these returns have in fact both a leptokurtic and skewed distribution. The violation of the normality assumption will, however, not be addressed in this thesis for the purpose of an isolated analysis of the implications of a Weekend Volatility Effect on option pricing.

5.2.2. The Greeks; Delta and Vega

An option's delta is the rate of change of the option price with respect to the price of the underlying asset. Delta is therefore an estimate of the option's sensitivity to movements in the underlying asset price. For a call option an increase in the price of the underlying asset would increase the value of the option, indicating a positive delta. In contrast, an increase in the price of the underlying asset would decrease the value of a put option indicating a negative delta. The absolute value of delta increases as an option becomes in-the-money (Hull, 2012). DdeltaDvolatility is the change in delta for a change in implied volatility (Haug, 2003). In-the-money options, with delta >$|50\%|$, have a delta negatively related to the implied volatility. While out-of-the-money options, with delta<$|50\%|$, have a delta positively related to the implied volatility.

An option's Vega is the rate of change of the option price with respect to it's implied volatility, in other words, the resulting $ price change to a 1% change in implied volatility (Haug, 2003). Vega is therefore an estimate of the option's sensitivity to a change in the implied volatility. The value of vega is equal for put and call options, at it's highest for at-the-money options and decreases as the option becomes more and more out- or in-the-money (Hull, 2012). Vega Leverage is the resulting percentage rate of change in the option's price to a 1% change in implied volatility (Haug, 2003). For an investor, whose value intended for investments is limited; Vega Leverage poses as a more useful measure indicating the percentage change in the investment value, rather the value change in the option price, resulting from a change in the implied volatility. The reason for this is that for a given investment value one can buy many more out-of-the-money options than at-the-money options, resulting in a greater sensitivity of the total investment value to changes in implied volatility when placed in out-of-the-money options than in at-the-money options.

6. The Futures price data and Options chosen for the analysis

It is in this chapter given a presentation of the GC futures price data on which the analysis of the Weekend Volatility Effect is based. The second section contains an overlook of the historic GC futures price development throughout the chosen period 1992-2012. The third and final section specifies the OG options chosen for demonstrating the consequence of ignoring the Weekend Volatility Effect to the pricing of options.

6.1. The Futures Price Data

The analysis is based on daily open and close prices of GC futures traded at the Chicago Mercantile Exchange from the 25th of June 1992 until the end of 2012. The price data is downloaded from the online data bank; www.quandl.com. For the persistent relevance of the statistical testing of the Calendar- and Trading-Time Hypotheses it is crucial for the opening times of the trading venues to stay unchanged throughout the period considered. The choice of time period is therefore naturally limited to the opening of online-trading on the 25th of June 1992, with the opening times of both the CME Globex and the Open Outcry being consistent throughout. Unless stated otherwise, any facts presented in this chapter is to be found on the CME website.

The listed contracts for trading, from the 25th of June 1992 to the 28th of December 1994, have maturities of any February, April, August and October months within the next 23 months, and June and December months within the next 60 months. From the 29th of December 1994 till the 24th of august 2010 the contract selection increase to contracts maturing the current and next two months, in addition to previous listed contracts. Then, from the 25th of august 2010, listed contracts are as today's contract maturities including the current and next two months, any February, April, August, and October months within the next 23 months, and any June and

December months within the next 72 months. The average daily trading volume of the "front" maturity group, during the 20-year period 1992-2012, is in the months January, March, May, July, September and November 26 contracts while that during the months February, April, June, August, October and December is 429 contracts. Since the future contracts maturing in the months of January, March, May, July, September and November are non-existent prior to the 29th of December 1994, and generally less traded than contracts maturing in the remaining six months of the year, the analysis is limited to future contracts maturing in February, April, June, August, October and December.

The analysis is limited to what will be referred to as the "front", "second", "third" and "fifth" contract maturity groups, referring to the number of months until contract maturity. For a contract expiring in December 2012, the "front" maturity group contains December's day returns, the "second" group contains November's day returns, the "third" group contains October's day returns while the "fifth" group contains August's day returns. This grouping of data results in differing maturities within each group. Contained within the "front" group are maturities from 29 days till last day of trading. Maturities are never a full month as trading is conducted until the second or third last business day of the expiration month. The "second" group's maturities range from 25 to 60 days, the "third" group's maturities range from 54 to 90 days, while the "fifth" group's maturities range from 115 to 151 days. Differing maturity contracts are in theory non-comparable making an ideal analysis one of returns generated by a "rolling" contract of a fixed maturity. No such gold future is offered at the CME and synthetically creating one is somewhat constrained by the relatively fewer historical returns it would contain being somewhere below 200. Based on the trade off between more data and less precise maturities grouping, the maturity grouping into "front", "second", "third" and "fifth" is chosen by this thesis calling for some limitation to the validity of the results.

Average daily trading volume of the "front" maturity group is only 421 contracts likely due to investors generally cancelling out their long positions to escape delivery before the contract enters the "front" maturity group. Due to its illiquidity an analysis of this group prove as an interesting comparison to more liquid maturity groups. The “second”-, “third”- and “fifth” maturity groups have average daily trading volumes of 54.636, 47.216 and 11.420 contracts. The “fifth” maturity group is included for the comparable analysis of longer maturity returns. Due to the sharp decrease in trading volumes when moving from the third to the fifth contract longer maturities than 5 months are assumed relatively illiquid. As an example, given the standard contract size of 100 troy ounces, the “second” maturity group’s average daily trading volume of 54.636 contracts implies a trading volume of 5.463.600 troy ounces gold. With a futures price equal to the average price throughout the chosen 20 year period of the four chosen maturity groups, 1670$ per troy ounce, the average daily trading volume of the “second” maturity group implies a dollar value of $9.124.212.000.

Floor-trading of the GC futures, at the Open Outcry, open at 8:20am and closes at 1:30pm, all times in New York time. This implies a 5 hour and 10 minute floor-trading window. In addition, GC futures are available for trading online at the CME Globex from 6:00pm Sunday through 5:15pm Friday, with daily breaks from 5:15pm to 6:00pm. A weekday’s online “session” therefore consists of 23 hours and 15 minutes of trading through the CME Globex. Since our data is limited to open and close prices, those generated by the open and close times of the Open Outcry, online trading time exceed the basis of these prices. The weekend’s estimated return, calculated from Friday’s close price to Monday’s open, consists of 66 hours and 50 minutes. These can be decomposed into 18 hours and 5 minutes of online trading-time and 48 hours and 45-minutes of non-trading. Monday’s estimated return, calculated from Monday’s open to close, only consists of the active 5 hours and 10 minutes of floor trading. The remaining trading day’s estimated return, calculated using only the close prices, are based on 24 hours consisting of 5 hours and 10 minutes of trading through both the Open Outcry and CME Globex, 18 hours and 5 minutes of trading only through CME Globex and 45-minutes of non-trading. The overnight’s estimated returns, calculated from a trading day’s close to the next trading day’s open, are based on 18 hours and 50 minutes consisting of 18 hours and 5 minutes of sole online trading-time and a 45-minute trading break.

The complete set of analysed daily price returns are holiday adjusted, meaning that any return following a holiday have been eliminated.

6.2. The Gold Futures Price during 1992-2012

Figure 1 below draws the historic price path of the daily close price of the GC futures, during the time period 1992-2012, for the four chosen maturity groups.

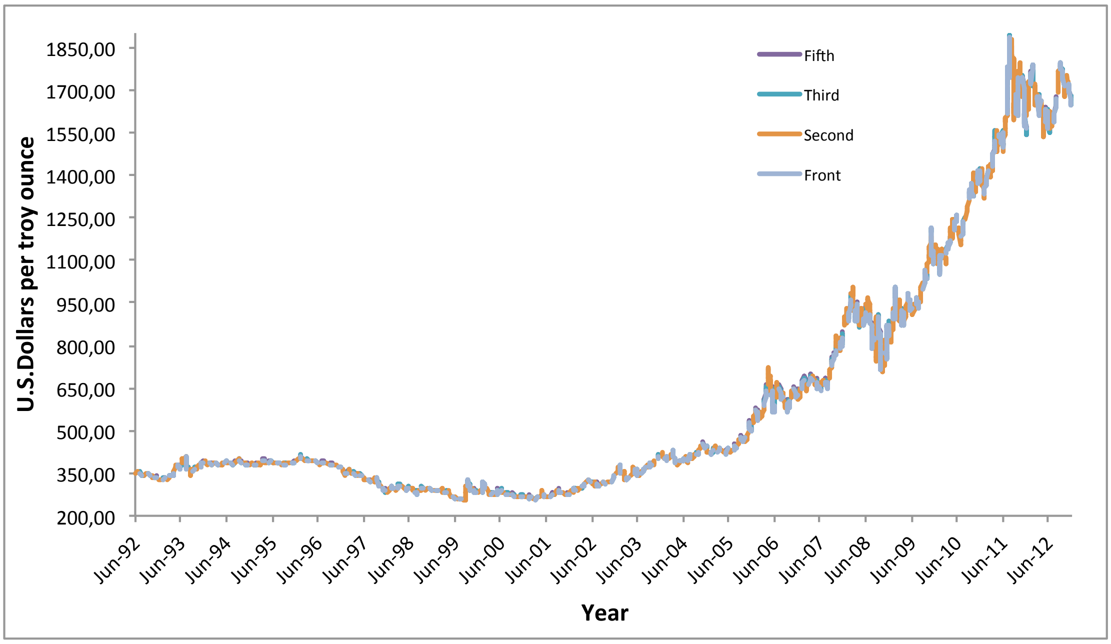

Figure 1: Historical daily close price of GC futures traded at the CME for the "front", "second", "third" and "fifth" maturity groups during 1992-2012.

As seen in figure 1, the historical close price of the four maturity groups are close to perfectly overlapping with a minimum of 253$ and a maximum of 1892$ per troy ounce. As discussed in the previous section, contracts maturing in January, March, May, July, September and November are excluded due to lacking trading volumes. As a result the "front"-, "third"- and "fifth" maturity group contain the price returns during February, April, June, August, October and December while the "second" maturity group contain the price return during the excluded delivery months. The total price return from the start till the end of the analysed time period of the chosen four maturity groups amounts to around 160%. Figure 2 depicts the historic daily close-to-close returns of the four chosen maturity groups.

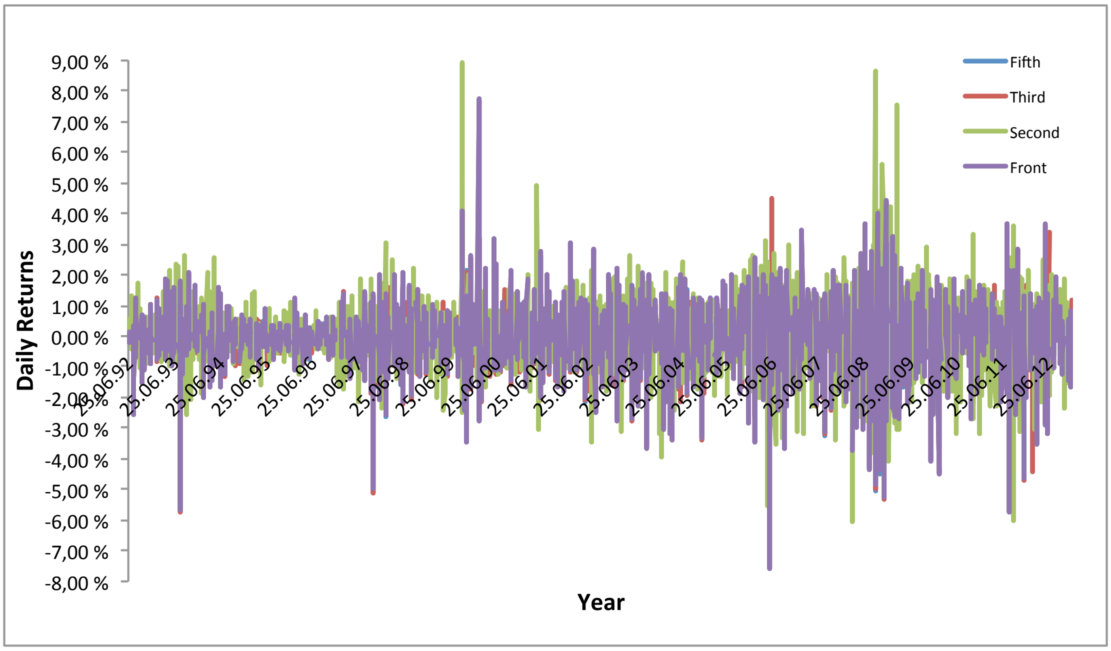

Figure 2: Historical daily close-to-close returns to GC futures traded at the CME for the "front", "second", "third" and "fifth" maturity groups during 1992-2012.

The minimum and maximum returns during the 20-year period are -7,58% and +8,89%. Separate figures for each of the four maturity groups are to be found in the appendix section one. The mean close-to-close returns of the total 20-year period, for the "front", "second", "third" and "fifth" maturity groups are 0,00%, 0,04%, -0,01% and -0,01%. The years 1992-1999 appear from the figure to be a relatively less volatile period, while the remaining years 2000-2012 appears to be a period of greater return variability. There will be no dividing into sub-periods in this thesis, however, such an analytical extension could prove interesting due to the differing trend levels of variance within the 20-year period.

6.3. The Options chosen for analysis

The implications of assuming calendar-time to be the relevant price-generating time in the face of an evident negative Weekend Volatility Effect is analysed for both put and call options of four different strikes set to those of delta equal to +/-75%, 50%, 25% and 10%. The options analysed vary in their time to maturity ranging from a few days to close to two months. Also the option's time of pricing and expiry is taken into account resulting in four chosen groups of options. The first option group are all priced at the time of Friday's close and expires at the time of Monday's open, but has differing maturity lengths.

Option Group 1:

a. Maturity of one weekend, from Friday's close to the next Monday's open, consisting of 2,78 days.
b. Maturity of one week and one weekend, from Friday's close to the 2nd next Monday's open, consisting of 9,78 days.
c. Maturity of three weeks and one weekend, from Friday's close to the 4th next Monday's open, consisting of 23,78 days.
d. Maturity of seven weeks and one weekend, from Friday's close to the 8th next Monday's open, consisting of 51,78 days.

The second group of options analysed are all priced at the time of Monday's open and expires at the time of Friday's close, and has differing maturity lengths.

Option group 2:

a. Maturity of five trading days, from Monday's open to the next Friday's close, consisting of 4,22 days.
b. Maturity of one week and five trading days, from Monday's open to the 2nd next Friday's close, consisting of 11,22 days.
c. Maturity of three weeks and five trading days, from Monday's open to the 4th next Friday's close, consisting of 25,22 days.

d. Maturity of seven weeks and five trading days, from Monday's open to the 8th next Friday's close, consisting of 53,22 days.

Intended to reveal the within week dynamics of the existent Weekend Volatility Effect, the third option group contain five options with differing times of pricing ranging, from the time of Monday's close to the time of Friday's close, but the fixed time of expiry set to the time of Monday's open.

Option group 3:

a. Maturity of 6,78 days, from Monday's close to the next Monday's open.
b. Maturity of 5,78 days, from Tuesday's close to the next Monday's open.
c. Maturity of 4,78 days, from Wednesday's close to the next Monday's open.
d. Maturity of 3,78 days, from Thursday's close to the next Monday's open.
e. Maturity of 2,78 days, from Friday's close to the next Monday's open.

With the same purpose in mind, the fourth group also contains five options with differing times of pricing, ranging from the time of Monday's open to the time of Thursday's close, and with the fixed time of expiry set to the time of Friday's close.

Option group 4:

a. Maturity of 4,22 days, from Monday's open to the next Friday's close.
b. Maturity of four days, from Monday's close to the next Friday's close.
c. Maturity of three days, from Tuesday's close to the next Friday's close.
d. Maturity of two days, from Wednesday's close to the next Friday's close.
e. Maturity of one day, from Thursday's close to the next Friday's close.

The extensive theoretical nature of the chosen options for analysis is due to the necessary isolation of the effect of a changing implied volatility on option pricing. A more realistic nature is seen valuable and the time of the option pricing is therefore set to February 2013. As a result the market price of the option's underlying GC futures at the time of pricing is set to February's average close price, for the future contract terminating in April 2013, of $1.628,20 per troy ounce. Both LIBOR- and

Treasure Bills rates are generally referred to as close to risk-free, while in the market LOBOR rates are more commonly used[2]. Therefore, representing the risk-free rate, the average USD LIBOR of one and two weeks, and of one and two months, during February 2013 represent the risk-free rate. February 2013's average USD LIBOR rates for the four maturities are rounded to 0,17%, 0,19%, 0,20% and 0,25%. For the first and second option groups the annual risk free rates will apply to the option maturity closest to the rates' maturity. In option groups three and four all maturities equal a week or less resulting in the applied risk-free rate of 0,17% throughout.

[2] according to Espen G. Haug.

7. Testing for the Weekend Volatility Effect - Methodology

The specification of the different price returns, the estimation of an annual return standard deviation, the total trading week's return variance, the total overnight's return variance, skewness and kurtosis, and the workings of Jarque and Bera's normality test are all presented in the first three sections of this chapter.
The remaining sections contain the specifications of the two comparing analyses that will be conducted for the detection of the Weekend Volatility Effect. The first, in section 7.4, is a comparison of the weekend's return variance with those of the trading days. The second analysis, in section 7.5, is a comparison of the weekend's variance with those of the overnights between the week's trading days.
While the first comparison will be tested using solely parametric statistics, the nature of the second enables the non-parametric Levene's test for equality of variances. The reason for this is explained further in section 7.3.1. All calculations are conducted using Excel.

7.1. The Price Returns

The price returns are estimated as natural logarithmic price changes. Three types of returns are calculated; those from close-to-open prices for a separation of weekend and overnight returns, those from Monday open to Monday close prices for a separation of Monday returns, and those from close-to-close prices for trading day returns from Tuesday till Friday. Close-to-open returns are calculated in the following manner:

$$R_s = \ln \frac{P(open)_t}{P(close)_{t-1}}$$

where s refers to the weekend and all overnights. In the case of the weekend, t and $t-1$ refers to Monday and Friday. Close-to-open returns between the remaining consecutive trading days are referred to as overnight returns. Open-to-close returns are calculated, for Mondays alone, in the following manner:

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

and will be referred to as Monday returns. Close-to-close returns are calculated:

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

where t refers to the trading days from Tuesday to Friday.

7.2. The Return distribution

Volatility is a term used for market fluctuations, making volatility of returns an indicator of the characteristic riskiness of a market. Commonly used measures of volatility are variance and standard deviation. The return variance determines the distributional spread, namely the average deviation of returns from their mean. The returns standard deviation, a simple transformation of the variance, is a more intuitive measure as it refers to the units of measurements, in this case percentage points of returns. An annual standard deviation measure is a common measure for comparison, and is estimated:

$$\sigma_{annum,t} = \sigma_t * \sqrt{\frac{365}{calendar\ days_t}}$$

where $\sigma_{annum,t}$ is the estimated annual standard deviation based on σ_t; a certain period t's returns standard deviation of. The use of 365 days in a year indicates an underlying assumption of calendar-time to be the relevant price-generating time. In the case of the weekend carrying zero return variance, the more suitable number of around 256 days would give a more accurate annual standard deviation estimate. In the case of the Trading-Time Hypothesis correctly specifying the market's workings, a number of 298 days, as discussed in section 2.2, would be the more appropriate number. The annual standard deviation estimates are computed for the purpose of a common measure for comparison between the different types of returns. The use of 365 days, in the face of an existent Weekend Volatility Effect, therefore poses no threat to reached conclusions.

For the comparison of the weekends return variance to that of the general trading day, the following total variance of the trading week from the time of Monday's open to Friday's close is estimated:

$$\sigma^2_{trading\ week} = \sum \sigma^2_t$$

where t refers to all the trading days. For the purpose of hypothesis testing, this estimated trading week's variance is assumed based on a number of returns equal to the average of those of the trading days. For the comparison of the weekends return variance to that of the general overnight, the following total variance of the four overnights is estimated:

$$\sigma^2_{total\ overnights} = \sum \sigma^2_t$$

where t refers to all four overnights.

7.2.1. The questionable Normality

Both the variance and standard deviation measures are based on the assumption of normally distributed returns. To determine the validity of this assumption the two additional distribution characteristics of skewness and kurtosis is called upon.
The measure of skewness determines whether the returns are distributed symmetrically or asymmetrically around the mean. A skewness of zero implies perfect symmetry and characterizes the normal, or Gaussian, distribution. A positive skew implies asymmetry in that the probability distribution's right tail is longer than the left, indicating that more than 50% of the returns are located to the left of the mean return. With negative skew the probability distributions left tail is longer than

the right tail indicating that more than 50% of returns are larger than the mean return. The measure of skewness is calculated as the following:

$$S = \frac{\frac{1}{n}\sum_{t=1}^{n}(R_t - \bar{R}_t)^3}{(\sigma_t^2)^{1,5}}$$

where R_t is the price return, $\bar{R}_t$ is the mean price return and σ_t^2 is the estimated variance of period t, with t ranging from the weekend, overnights and trading days.

Kurtosis is a measure of both the height and width of a probability distribution. The normal distribution has a kurtosis of 3 making the alternative Fisher kurtosis therefore often a preferred measure as it withdraws the number 3 from the standard measure of kurtosis. Fisher kurtosis is calculated:

$$K = \frac{\frac{1}{n}\sum_{t=1}^{n}(R_t - \bar{R}_t)^4}{(\sigma_t^2)^2} - 3$$

A distribution with broader width and a higher peak than the normal distribution will have a Fisher kurtosis larger than zero, referred to as a Leptokurtic distribution. This would indicate that more observations are located closely around the mean, and in the tails, than those of the normal distribution. In other words, there are more days with near to no activity than the normal distribution would imply. Also, when activity first occurs the probability of these changes being relatively dramatic is higher than what the normal distribution would imply. Fisher kurtosis of less than zero indicates a distribution with a lower peak and a narrower width than that of the normal distribution, and is referred to as a Platykurtic distribution with more observations located in the medium close area around the mean.

Jarque and Bera's test of normality (Jarque and Bera, 1980) detects any deviation from zero skewness and/or zero Fisher's kurtosis, and is calculated as the following:

$$JB = \frac{n}{6}\left(S^2 + \frac{K^2}{4}\right)$$

The Jarque Bera (JB) statistics is chi-squared distributed with two degrees of freedom, resulting in the critical values of 5,99 and 9,21 at the 5% and 1% significance levels. With the null hypothesis being normality, a JB statistic of more than the critical value result in the rejection of the null hypothesis indicating non-normality.

7.3. The Weekend vs. Trading Day Returns

A statistical testing of the Weekend Volatility Effect requires a comparison of the variance of weekend returns with those of the trading days of the week, as well as a total of the trading week. A testing of the Calendar-Time Hypothesis, being that equal calendar-time gives equal return variance, requires a comparison of the return variances of the weekend- and trading days based on the equal amount of calendar-time. A testing of the Trading-Time Hypothesis, being that equal trading time gives equal return variances, requires a comparison of the return variances of the weekend- and trading days based on the equal amount of trading-time. The hypotheses of Calendar- and Trading-Time, although mutually exclusive, rejecting the one does not necessarily imply the other to hold. Null hypotheses are therefore defined for both the Calendar- and Trading-Time Hypothesis.

7.3.1. Test Suitability - Parametric vs. Nonparametric Statistics

The procedures for hypothesis testing based on parametric statistics depend heavily on the assumption of normally distributed testing variables. Nonparametric statistical tests, in contrast, are known to make considerably weaker distributional assumptions, and might therefore be more appropriate in cases of non-normality. Due to the more constrictive distributional assumption of the parametric statistics, these test are usually said to carry relatively more statistical power than their non-parametric counterparts. According to Anderson (1961) this is only the case of median-type nonparametric tests while rank order nonparametric tests carry the same statistical power as parametric statistics. The versatility of the parametric F-test, however, makes it greatly more applicable due to its basis on the testable variable's descriptive statistics. Rank order nonparametric tests, in contrast, work directly with the sample returns causing limitation to the hypotheses that can be tested. As a consequence, the comparison of the weekend and the trading day's return variances can not be conducted using the nonparametric Levene's test as the variances of the returns in question are not comparable when not altered. The nature of the comparison of the weekend and the overnight's returns is, however, such that a comparison of returns variances may be made using a nonparametric Levene's test due to the equal amount of trading-time behind the two return types. According to Anderson (1961), studies of the effect on parametric statistics' precision in the face of non-normality have generally concluded with these being minimal. In addition, according to Fay and Proschan (2010) "one should not necessarily disregard results of a decision rule because it is obviously invalid from one perspective. Perhaps it is valid or approximately valid from a different perspective". The parametric F-test is therefore, in addition to the nonparametric Levene's test, also applied to the comparison of the weekend and overnight return variances.

7.3.2. Parametric Statistics – The F-test

The F-test allows for a comparison of variances. For the testing of the Calendar- and Trading-Time Hypothesis the comparing weekend and trading day return variance must, as previously stated, be based on the equal amount of calendar- and then trading-time. This is achieved by transforming each return variance measure into a standard 24-hour calendar- and trading-time measure. Weekend returns contain 66 hours and 50 minutes of calendar-time, and therefore 2,78 days of calendar-time. Monday's return estimate contains 5 hours and 10 minutes, or 0,22 days, of calendar-time. The remaining trading day returns contain 24-hours, and therefore one day, of calendar-time. The total trading week's return estimate contains 101 hours and 10 minutes, or 4,22 days, of calendar-time. Those returns containing 24-hours are, of course, already in the comparable measure. The weekend, Monday and the total trading week's variances and standard deviations are transformed into 24-hour calendar-time measures in the following manner:

$$\sigma^2_{t,calendar-time} = \frac{\sigma_t^2}{calender-days_t}$$

$$\sigma_{t,calendar-time} = \frac{\sigma_t}{\sqrt{calendar-days_t}}$$

where σ_t^2 and σ_t are the unaltered return variance and standard deviation estimates, $\sigma^2_{t,calendar-time}$ and $\sigma_{t,calendar-time}$ are the altered 24-hour calendar-time variance and standard deviation measures and $calender - days_t$ the number of calendar days within the period t referring to the weekend, Monday and the total trading week. The same logic applies to the differences in trading-time between the three types of returns. Weekend returns contain 18 hours and 5 minutes, or 0,75 days, of trading-time. Monday's day return estimate contain 5 hours and 10 minutes, or 0,22 days, of trading-time. The remaining trading day returns contain 23 hours and 15 minutes, or 0,97 days, of trading-time, while the trading week's total returns estimate is based on 98 hours and 10 minutes, or 4,09 days, of trading-time. Comparable 24-hour variance and standard deviation estimates are again calculated:

$$\sigma^2_{t,trading-time} = \frac{\sigma_t^2}{trading-days_t}$$

$$\sigma_{t,trading-time} = \frac{\sigma_t}{\sqrt{trading-days_t}}$$

where $\sigma^2_{t,trading-time}$ and $\sigma_{t,trading-time}$ are the altered 24-hour trading-time variance and standard deviation measures and $trading - days_t$ the amount of trading-time, in terms of days, within the period t referring to the weekend, Monday and the total trading week.

The null and alternative hypotheses when testing the Calendar-Time Hypothesis are the following:

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

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

where t refers to all trading days and the total trading week. The null hypothesis when testing the Trading-Time Hypothesis is similarly:

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

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

The resulting F-statistic, for a comparison of the weekend's return variance with that of a trading day when the estimated returns variance of the trading day exceed that of the weekend, is defined:

$$F = \frac{\sigma^2_t}{\sigma^2_{weekend}}$$

with σ^2_t and $\sigma^2_{weekend}$ being 24-hour calendar-time measures for a test of the calendar-time hypothesis, and in 24-hour trading-time measures for a test of the trading-time hypothesis. When the opposite is true, the F-statistic is defined:

$$F = \frac{\sigma^2_{weekend}}{\sigma^2_t}$$

Since the F-statistic for a comparison of variances is calculated by dividing the larger variance by the smaller, it will never be less than 1. If the two population's variances equal each other, F is fisher-distributed with n-1 and m-1 degrees of freedom, where n is the number of returns in the numerator return group, while m is the number of returns in the denominator return group. If the F-statistic, at a certain significance level, exceeds the relevant critical value of the F-distribution the null hypothesis is rejected in favour of the alternative hypothesis.

7.4. The Weekend vs. Overnight Returns

A second analysis conducted is a comparison of the weekend's return variance with those of overnights between the week's trading days, and with the total of the overnights. This analysis is seen as helpful for two reasons. Weekend returns, calculated from Friday's close price to Monday's open, contain an amount of solely online trading-time equal to that of overnight returns. By comparing returns based on solely online trading-time, the hours of trading are most likely more comparable in terms of volumes, removing some of the noise of non-random trading volumes on the tested hypotheses. Conclusions enabled by this second analysis are therefore somewhat more robust concerning the relative significance of news and trading on security price changes. A second reason arises due to the comparison's applicability of the non-parametric Levene's test for equality of variances for possibly more robust testing results in the face of the non-normally distributed returns.

7.4.1. Parametric Statistics – The F-test

Again, for the appropriate parametric testing of the Calendar- and Trading-Time Hypotheses, the comparing return variances must be in compatible time measures. The overnight returns contain 18 hours and 50 minutes, or 0,78 days, of calendar-time, and 18 hours and 5 minutes, or 0,75 days, of trading-time. The total of the four overnights contain 75 hours and 20 minutes, or 3,14 days, of calendar-time, and 72 hours and 20 minutes, or 3,01 days, of trading-time. The individual overnights and the total of the overnight's estimated variances are transformed into 24-hour variance and standard deviation measures as before, and the specified testing hypotheses of the Calendar- and Trading-Time are as described in the subsection 7.3.2.

7.4.2. The Nonparametric Levene's test for Equality of Variance

As before, statistical testing of the Calendar- and Trading-Time Hypotheses requires a comparability of calendar- and trading-time in the measures of return variances. This requirement is not as easily solved when dealing with non-parametric inference due to the non-parametric statistics working with the actual returns and not the descriptive statistics. In the comparison of the weekend and overnight returns, the comparing returns contain the equal amount of trading-time enabling a non-parametric test of the Trading-Time Hypothesis. A statistical testing of the Calendar-Time Hypothesis using non-parametric inference, however, requires a different calculation of returns. An example would be price returns calculated from the time of Monday's close to Wednesday's open, and from Wednesday's close to Friday's open. Such an analysis is not included in this thesis, and the tested hypothesis of the nonparametric Levene's test is therefore limited to the Trading-Time Hypothesis.

The original variant of Levene's test, a mean-based test (Levene, 1960), was intended to replace the parametric F-test. Based on findings of non-robustness of the mean-based Levene's test to non-normality, Brown and Forsythe (1974) add to the theory of Levene by developing a median-based Levene's test. A third contribution is made by Nordstokke and Zumbo (2010) with their development of the "Nonparametric Levene's test" being a rank-based Levene's test. In a comparison of the two latest additions they find that in cases with increasing skew, the nonparametric version was superior in statistical power to the median-based version. Since the probability distributions of the daily gold futures prices are generally skewed the Nonparametric Levene's test is chosen.

Each of the overnight's return variance is compared with that of the weekend, and for each test there is therefore two groups. The rank of each return in the total of both groups analysed is first computed:

$$x_{ij} = rank\ (R_{ij})$$

where R_{ij} refers to return j in group i and x_{ij} refers to the rank of return j in the pool of both groups, with i specifying which group the underlying return belongs to. The mean rank within each group is then computed:

$$\bar{x}_i = mean\left(x_{ij}\right)$$

Then, the absolute difference between each return's rank and its group's mean rank is computed:

$$z_{ij} = \left|x_{ij} - \bar{x}_i\right|$$

A classical Analysis of Variance (ANOVA) is then applied to these z_{ij}. A rejection of the null hypothesis requires a test-statistics larger than the critical value of the F-distribution $F_{(\alpha, g-1, n_i-1)}$ where α specifies the level of significance, and $g - 1$ and $n_i - 1$ the degrees of freedom where g is the number of groups being compared and n the number of returns in group i.

8. VaR and Binomial Option Pricing - Methodology

To study the implications of the Weekend Volatility Effect on VaR and option pricing a standard for comparison is naturally assuming no present effect, namely assuming the Calendar-Time Hypothesis to hold. The total week's return variance is the base at which the weekend and trading day return variances are estimated according to the Calendar-Time Hypothesis as specified in section 8.1. Further, for the purpose of option pricing only, variance estimates both according to the day of the week's specific variances and the Calendar-Time Hypothesis, of the different option maturities listed in section 6.3, are specified in sections 8.2 and 8.3. The existent negative Weekend Volatility Effect in the market for GC futures at the CME is at it's most significant for contracts with maturity ranging from two to three months. The VaR and option pricing analysis is based on the statistical findings of this "third" maturity group acting as a somewhat worst-case scenario.

8.1. Weekday variance ignoring the Weekend Volatility Effect

The week's total return variance is estimated based on historic weekday and weekend variances in the following manner:

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

where t refers to the weekend and all trading days. A weekday returns variance measure ϑ_t^2, as according to the Calendar-Time Hypothesis, is then estimated:

$$\vartheta_t^2 = \sigma_{week}^2 * \frac{calendar\ days_t}{7}$$

where t refers to the weekend and all trading days.

8.2. Period variance acknowledging the Weekend Volatility Effect

The implied volatility for each of the options chosen for analysis, acknowledging the Weekend Volatility Effect, is estimated on the basis of the number and nature of the days included in the option's maturity. The return variance, of a certain time period T, is then estimated:

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

where t refers to any weekends and trading days occurring within the period T. In the case of T referring to a time period of one week and five days, from the time of Monday's open to the time of the second next Friday's close, the return variance for Monday to Friday would enter the above equation twice while that of the weekend would enter only once. Again, an annual standard deviation is estimated,

$$\sigma_{annum,T} = \sigma_T * \sqrt{\frac{365}{calendar - days_T}}$$

where $calendar - days_T$ is the number of days within period T.

8.3. Period variance ignoring the Weekend Volatility Effect

The implied volatility for a period T, ignoring the present Weekend Volatility Effect, is estimated on the basis of the total week's return variance:

$$\vartheta_T^2 = \sigma_{week}^2 * \left(\frac{calendar\ days_T}{7}\right)$$

Again, an annual standard deviation estimate is calculated for the purpose of comparison between the option maturities:

$$\vartheta_{annum,T} = \vartheta_T * \sqrt{\frac{365}{calendar\ days_T}}$$

9. The Weekend Volatility Effect - Statistical Findings

Presented in this chapter are the statistical results to the specified two analyses stated in sections 7.3. and 7.4. All posted tables in this chapter have more or less the same outlay. The tables' first row of information, what will be referred to as the return "period", indicates the day or days to which the connected column of information concerns. These consist of the weekend, the different trading days, denoted by the time of the prices on which the returns are based, and the total trading week. The tables' second row reports the amount of calendar- and trading-time behind each return period, both in terms of hours and days. Then, the third row starts with reporting the return variance of each return. The following two variances are transformations of the original return variance into 24-hour calendar- and trading-time variances measures. The same holds for row four where the standard deviation estimates are reported. An annual standard deviation measure is in addition reported, as a common measure of comparison. The fifth row specifies the minimum and maximum return as well as the number of returns in the sample. The sixth row outlines the skewness, kurtosis, and the Jarque Bera test statistic and p-value for the testing of normality. All the returns; the weekend, the trading days and the overnights, for all the future maturity groups are non-normally distributed with varying levels of skewness and leptokurtosis. Statistical tests concerning the existence of a Weekend Volatility Effect is reported in row number seven including test statistics and p-values of the F-test of both the Calendar- and Trading-Time Hypotheses. The additional test statistic and following p-value of the nonparametric Levene's test are outlined in the tables for the comparison of the weekend and overnights in section 9.2. A test statistic followed by one star symbol a rejection of the null hypothesis at the 5% while a test statistic followed by two stars symbol a rejection at the 1% significance level.

9.1. The Comparison of Weekend and Trading Day Returns

Resulting statistical findings to the hypotheses tests specified in section 7.3 are now presented. The following table 1 contain the descriptive statistics and hypotheses testing of the “front” maturity group, while those of the remaining three maturity groups are to be found in the appendix section two.

Table 1: Descriptive statistics and hypotheses testing of the weekend and trading day returns in the “front” maturity group during 1992-2012.

Period	Weekend	MonOpen-MonClose	MonClose-TueClose	TueClose-WedClose	WedClose-ThuClose	ThuClose-FriClose	MonOpen-FriClose
Calendar hours	66,83	5,17	24,00	24,00	24,00	24,00	101,17
Calendar days	2,78	0,22	1,00	1,00	1,00	1,00	4,22
Trading hours	18,08	5,17	23,25	23,25	23,25	23,25	98,17
Trading days	0,75	0,22	0,97	0,97	0,97	0,97	4,09
Variance	0,000043	0,000070	0,000105	0,000101	0,000113	0,000114	0,000504
per 24h. calendar-time	0,000015	0,000326	0,000105	0,000101	0,000113	0,000114	0,000120
per 24h. trading-time	0,000057	0,000326	0,000109	0,000105	0,000117	0,000118	0,000123
Standard Deviation	0,66 %	0,84 %	1,03 %	1,01 %	1,06 %	1,07 %	2,24 %
per annum	7,50 %	34,47 %	19,59 %	19,25 %	20,33 %	20,39 %	20,89 %
per 24h. calendar-time	0,39 %	1,80 %	1,03 %	1,01 %	1,06 %	1,07 %	1,09 %
per 24h. trading-time	0,75 %	1,80 %	1,04 %	1,02 %	1,08 %	1,08 %	1,11 %
Minimum	-2,27 %	-5,51 %	-7,58 %	-5,77 %	-5,67 %	-4,98 %	
Maximum	4,52 %	4,01 %	3,03 %	4,39 %	3,69 %	7,77 %	
No. Of observations	434	434	456	482	454	431	451
Skewness	1,03	-1,57	-1,24	-0,68	-0,85	0,35	
Kurtosis (Fisher's)	6,32	10,41	7,38	5,32	3,71	8,14	
JB normality test	799,02 **	2137,94 **	1151,33 **	605,43 **	315,35 **	1198,64 **	
P value	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	
F-test (calendar-time hypothesis)		21,13 **	6,82 **	6,58 **	7,35 **	7,39 **	7,76 **
P value		< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%
F-test (trading-time hypothesis)		5,72 **	1,91 **	1,84 **	2,05 **	2,07 **	2,16 **
P value		< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%

As can be seen from table 1, by comparing the weekend’s per day variance measure of 0,000015 with that of the average trading day being 0,000120, the general trading day’s returns variance is seen to be eight times higher than that of Saturday or Sunday. In other words, the 24-hour return variance during the weekend is only 12,5% of that of the general trading day. For the “second” maturity group the general trading day’s returns variance is nearly 9,2 times higher than that of Saturday or Sunday. The largest deviation from the Calendar-Time Hypothesis is evident in the “third” maturity group where the general trading day’s returns variance is nearly 13,1 times higher than that of Saturday or Sunday. Then, for the “fifth” maturity group, the general trading day’s returns variance drops to 10,7 times higher than that of Saturday or Sunday. The less liquid short lived “front” maturity group and the longest analysed maturity group “fifth” therefore carry a relatively less significant Weekend Volatility Effect than the “second” and “third” group.

The ratio, of the average trading day's return variance relative to that of Saturday and Sunday, should, according to the Calendar-Time Hypothesis, of course equal one. As expected, the Calendar-Time Hypothesis' F-statistics are rejected at a 99% confidence level for all trading days individually as well as for the trading week in general indicating an existent negative Weekend Volatility Effect. Due to the relative amount of trading-time within the weekend and trading day returns, the ratio, of the average trading day's return variance relative to that of Saturday and Sunday, should, according to the Trading-Time Hypothesis, equal 2,57. The reduced return variance during the weekend, however, is of such significance that also the Trading-Time Hypothesis is rejected at a 99% confidence level. This might sound contradictory, but derives from the fact that the CME is open for online-trading for six hours during Sunday, and is more importantly due to the weekend's estimated return containing 18 hours and 5 minutes of online-trading. As a result the Trading-Time Hypothesis argues the weekend's return variance to 78% of that of the general trading day. A likely reason for the rejection of the Trading-Time Hypothesis is the difference in trading-volumes between hours of solely online-trading, and hours of both floor- and online-trading. The irrelevance of trading on return variability should therefore not be concluded on the basis of the comparison in table 1. This discussion is best continued in the following section when presenting the comparison of the weekend and overnight return variances.

9.2. The comparison of Weekend and Overnight Returns

Resulting statistical findings to the hypotheses tests specified in section 7.4 are now presented. The following table 2 contain the descriptive statistics and hypotheses testing of the "front" maturity group, while those of the remaining three maturity groups are to be found in the appendix section three.

Table 2: Descriptive statistics and hypotheses testing of the weekend and overnight returns in the "front" maturity group during 1992-2012.

Period	Weekend	MonClose-TueOpen	TueClose-WedOpen	WedClose-ThuOpen	ThuClose-FriOpen	Total within-week overnights
Trading hours	18,08	18,08	18,08	18,08	18,08	72,33
Trading days	0,75	0,75	0,75	0,75	0,75	3,01
Calendar hours	66,83	18,83	18,83	18,83	18,83	75,33
Calendar days	2,78	0,78	0,78	0,78	0,78	3,14
Variance	0,000043	0,000027	0,000033	0,000039	0,000033	0,000132
per 24h. calendar-time	0,000015	0,000035	0,000042	0,000049	0,000042	0,000042
per 24h. trading-time	0,000057	0,000036	0,000044	0,000051	0,000044	0,000044
Standard Deviation	0,66 %	0,52 %	0,57 %	0,62 %	0,58 %	1,15 %
per annum	7,50 %	11,29 %	12,40 %	13,41 %	12,40 %	12,40 %
per 24h. calendar-time	0,39 %	0,59 %	0,65 %	0,70 %	0,65 %	0,65 %
per 24h. trading-time	0,75 %	0,60 %	0,66 %	0,72 %	0,66 %	0,66 %
Minimum	-2,27 %	-2,98 %	-2,62 %	-3,94 %	-2,03 %	
Maximum	4,52 %	3,14 %	3,46 %	3,31 %	4,71 %	
No. Of observations	434	456	482	454	431	456
Skewness	1,03	-0,04	0,50	-0,02	1,32	
Kurtosis (Fisher's)	6,32	5,24	4,91	6,48	10,42	
JB normality test	799,02 **	521,69 **	505,10 **	793,99 **	2075,29 **	
P value	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	
F-test (calendar-time hypothesis)		2,27 **	2,73 **	3,19 **	2,74 **	2,73 **
P value		< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%
F-test (trading-time hypothesis)		1,57 **	1,30 **	1,11	1,30 **	1,30 **
P value		< 0,01%	0,25 %	13,60 %	0,33 %	0,29%
Nonparametric Levene's (trading-time hypothesis)		3,71	3,28	1,70	3,16	
P value		5,47 %	7,08 %	19,30 %	7,62 %	

The evident total difference of this second analysis, compared to that between the weekend and trading days, is the seemingly closer market state towards the Trading-Time Hypothesis, and the present Weekend Volatility Effect being of a less significant nature. By comparing the per day return variance of the weekend of 0,000015, with that of the general trading day of 0,000042, the average overnight's returns variance is 2,8 times higher than that of Saturday or Sunday for the "front" maturity group. In other words, the 24-hour return variance during the weekend is 35,7% of that of the general trading day. For the "second" maturity group the general overnight's return variance is 2,5 times higher than that of Saturday or Sunday. For the "third" maturity group the general overnight's return variance is nearly 3,3 times higher than that of Saturday or Sunday. For the "fifth" maturity group the general overnight's return variance is 2,9 times higher than that of Saturday or Sunday.

As expected, the Calendar-Time Hypothesis is rejected at the 99% confidence level for all four maturity groups. As the weekend and overnight returns are based on the equal number of trading-hours, the ratio, of the average overnight's return variance relative to that of Saturday and Sunday, should, according to the Trading-Time Hypothesis, equal two. The weekend's return variance relative to that of the general overnight is therefore less than that according to this hypothesis. Opposing conclusions reached by the F-test and the nonparametric Levene's test concerning the appropriateness of the Trading-Time Hypothesis is naturally worrying as this might indicate the imprecision of the F-test in the face of the leptokurtic returns distributions. The tests are, however, seen as supplements, and conclusions are drawn on the basis of the sum of the two tests. The Trading-Time Hypothesis is failed to be rejected by the F-test for the "third" maturity group, and rejected only at the 95% confidence level for the "fifth" maturity group. The nonparametric Levene's test further suggests the Trading-Time Hypothesis to correctly specify the market's true workings. It's test statistics result in the failure to reject the Trading-Time Hypothesis due to p-value above 5% with the only exception for the comparison of the weekend with the overnight from Monday to Tuesday for the "fifth" maturity group.

10. Resulting implications to VaR and Option-Pricing

The difference in VaR and option pricing according to whether the Weekend Volatility Effect is either ignored or acknowledged are now presented. The following analysis is limited to the findings of the “third” maturity group as this is the group with the most evident Weekend Volatility Effect as well as being one of the most actively traded with an average trading volume of 47.216 contracts. Implications of ignoring the evident Weekend Volatility Effect is therefore expected less significant for the other three maturity groups relative to the results presented in this chapter.

10.1. According to the Calendar-Time Hypothesis

To study the implications of the Weekend Volatility Effect on VaR and option pricing a standard for comparison is naturally assuming no present effect, namely assuming the Calendar-Time Hypothesis to hold. The following table 3 reports the estimated specific day-of-the-week’s returns variances for the “third” maturity group in addition to those according to the Calendar-Time Hypothesis for the weekend and trading days.

Table 3: Estimated weekend and trading day return variances and standard deviations, both acknowledging and ignoring the present Weekend Volatility Effect, for the “third” maturity group during 1992-2012.

Period	**Weekend**	**MonOpen-MonClose**	**MonClose-TueClose**	**TueClose-WedClose**	**WedClose-ThuClose**	**ThuClose-FriClose**	**Week**
Calendar hours	66,83	5,17	24,00	24,00	24,00	24,00	168,00
Calendar days	2,78	0,22	1,00	1,00	1,00	1,00	7,00
Variance acknowledging the effect	0,000026	0,000069	0,000103	0,000103	0,000109	0,000115	0,000525
Variance ignoring the effect	0,000209	0,000016	0,000075	0,000075	0,000075	0,000075	0,000525
Standard Deviation acknowledging the effect	0,51 %	0,83 %	1,01 %	1,01 %	1,04 %	1,07 %	2,29 %
per annum	5,88 %	34,20 %	19,38 %	19,35 %	19,93 %	20,50 %	16,54 %
Standard Deviation Ignoring the effect	1,44 %	0,40 %	0,87 %	0,87 %	0,87 %	0,87 %	2,29 %
per annum	16,54 %	16,54 %	16,54 %	16,54 %	16,54 %	16,54 %	16,54 %

According to the Calendar-Time Hypothesis the total week’s variance is allocated between the weekend and trading day returns of the week according to the amount of calendar-time behind each return. The weekend return is, for example, allocated 2,78 “parts” of the week’s total 7 “parts”, or in other words 40% of the week’s total variance. As expected, the Calendar-Time Hypothesis is overestimating the weekend’s return variance while underestimating those of the trading days. The total week's estimated return variance is of course identical whether one ignores or acknowledges the present Weekend Volatility Effect.

A valuable extension to this analysis is the comparing of specific day-of-the-week's returns variances with those according to the Trading-Time Hypothesis. Such a comparison would somewhat indicate the location, in terms of size, of the Weekend Volatility Effect.

10.2. VaR and the Weekend Volatility Effect

To demonstrate the impact of a present Weekend Volatility Effect, and therefore a deviation from the Calendar-Time Hypothesis, VaR is estimated using the parametric method first according to the Calendar-Time Hypothesis, and then according to the day of the week's specific standard deviations. A comparison of these two VaR estimates isolates the implication of assuming a non-existent Weekend Volatility Effect. As previously stated in the subsection 5.1.1. VaR estimates from the parametric approach assume normally distributed returns. Using the historical method a third VaR estimate is generated for the purpose of demonstrating the impact of assuming normally distributed returns in the face of leptokurtic and skewd returns distributions. This third VaR estimated according to the historical method reflects, in contrast to the parametric method, the true distribution of the historical returns in the dataset incorporating any weekend volatility effect, leptokurtosis and skewness. Therefore, by comparing the second and third VaR estimates one can access the resulting over- or underestimation of risk due to incorrectly assuming the returns' distribution to be normal.

Outlined in the table 4 below are the 99% and 95% VaR for a long position of $10 mill in GC futures. The coloured column is that of the weekend followed to it's right by day VaR estimates for Monday and Tuesday. The table is stacked in two parts for no reason other than presentation, with the second row including day VaR estimates for Wednesday, Thursday and Friday. In the row labelled "method of estimation", the three VaR estimates are reported, both in percentage and value terms, for the weekend and the trading days. Below these estimates are the difference, in both the percentage and value VaR, among the three estimates indicated by the numbers in the brackets. The “total difference” in the bottom row refers to the percentage and value miscalculation of VaR when ignoring the existent Weekend Volatility Effect in addition to the non-normality of the returns. A positive difference indicates an overestimation of VaR, while a negative difference indicates an underestimation.

Table 4: 99% and 95% VaR, in percentage and value terms, for long positions of a $10 mill investment for the weekend and all trading days.

Period	**Weekend**				**MonOpen-MonClose**				**MonClose-TueClose**			
Mean Return	0,04 %				-0,07 %				-0,06 %			
Percentage VaR	99% VaR		95% VaR		99% VaR		95% VaR		99% VaR		95% VaR	
Method of estimation:	Loss in %	Loss in $	Loss in %	Loss in $	Loss in %	Loss in $	Loss in %	Loss in $	Loss in %	Loss in $	Loss in %	Loss in $
1. Parametric method ignoring the effect	-3,33 %	-332 580,55	-2,34 %	-233 598,33	-1,01 %	-100 815,62	-0,73 %	-73 294,51	-2,08 %	-207 908,02	-1,49 %	-148 592,78
2. Parametric method acknowledging the effect	-1,16 %	-115 661,39	-0,80 %	-80 451,54	-2,01 %	-200 755,00	-1,44 %	-143 852,57	-2,42 %	-242 478,33	-1,73 %	-172 999,72
3. Historical method	-1,38 %	-137 537,98	-0,77 %	-77 000,00	-2,85 %	-284 636,34	-1,41 %	-141 453,77	-3,42 %	-341 884,71	-1,77 %	-177 426,81
Total difference (3-1)	1,95 %	195 042,56	1,57 %	156 598,33	-1,84 %	-183 820,72	-0,68 %	-68 159,26	-1,34 %	-133 976,69	-0,29 %	-28 834,03
Difference due to the weekend volatility effect (2-1)	2,17 %	216 919,16	1,53 %	153 146,79	-1,00 %	-99 939,38	-0,71 %	-70 558,06	-0,35 %	-34 570,31	-0,24 %	-24 406,94
Difference due to non-normality (3-2)	-0,22 %	-21 876,60	0,03 %	3 451,54	-0,84 %	-83 881,34	0,02 %	2 398,80	-0,99 %	-99 406,38	-0,04 %	-4 427,10
Period	**TueClose-WedClose**				**WedClose-ThuClose**				**ThuClose-FriClose**			
Mean Return	0,03 %				-0,06 %				0,08 %			
Percentage VaR	99% VaR		95% VaR		99% VaR		95% VaR		99% VaR		95% VaR	
Method of estimation:	Loss in %	Loss in $	Loss in %	Loss in $	Loss in %	Loss in $	Loss in %	Loss in $	Loss in %	Loss in $	Loss in %	Loss in $
1. Parametric method ignoring the effect	-1,98 %	-198 481,72	-1,39 %	-139 166,49	-2,08 %	-207 556,03	-1,48 %	-148 240,80	-1,93 %	-193 392,70	-1,34 %	-134 077,46
2. Parametric method acknowledging the effect	-2,33 %	-232 686,17	-1,63 %	-163 315,12	-2,49 %	-248 909,60	-1,77 %	-177 436,77	-2,42 %	-241 646,83	-1,68 %	-168 145,29
3. Historical method	-3,52 %	-352 429,89	-1,74 %	-173 746,38	-3,20 %	-319 882,43	-2,05 %	-204 733,28	-3,04 %	-304 365,94	-1,60 %	-160 003,41
Total difference (3-1)	-1,54 %	-153 948,17	-0,35 %	-34 579,89	-1,12 %	-112 326,40	-0,56 %	-56 492,48	-1,11 %	-110 973,25	-0,26 %	-25 925,95
Difference due to the weekend volatility effect (2-1)	-0,34 %	-34 204,45	-0,24 %	-24 148,63	-0,41 %	-41 353,57	-0,29 %	-29 195,97	-0,48 %	-48 254,13	-0,34 %	-34 067,83
Difference due to non-normality (3-2)	-1,20 %	-119 743,72	-0,10 %	-10 431,26	-0,71 %	-70 972,83	-0,27 %	-27 296,50	-0,63 %	-62 719,11	0,08 %	8 141,88

As can be seen in table 4, in the row calculated as the difference between the second and first VaR estimate, ignoring the present Weekend Volatility Effect lead to an overestimation of VaR during the weekend, and an underestimation of VaR during the trading days. Also, ignoring the non-normality of the returns distributions, seen as the difference between the third and second VaR estimate, result in an underestimation of the 99% VaR during the weekend and all the trading days of the week. The effect on the 95% VaR varies leading to an overestimation of VaR during the weekend, Monday and Friday, while resulting in an underestimation of VaR during the remaining days of the week. Relative to the effect of ignoring the present Weekend Volatility Effect, the implication of incorrectly assuming returns to be normally distributed is minimal. The partly offsetting effect of the miss-specified returns distribution therefore does not eliminate the overestimation caused by the reduced returns variance during the weekend. The biggest absolute resulting differences to VaR as a result of the faulty assumptions are those of the weekend VaR, although that of Monday is not far behind. In the case of the weekend, assuming returns to be normally distributed and the Weekend Volatility Effect to be non-existent result in a loss level at a 99% confidence level of 3,33%; 1,95% higher than the actual historically occurred loss level of only 1,38%. Such a difference, in the case of an investment of $10 mill would indicate an overestimated loss level by $195 042,56. The same analysis is made for an equivalent short position of $10 mill in GC futures, and is reported in table 5 below.

Table 5: 99% and 95% VaR, in percentage and value terms, for short positions of a $10 mill investment for the weekend and all trading days.

Period	Weekend				MonOpen-MonClose				MonClose-TueClose			
Mean Return	0,04 %				-0,07 %				-0,06 %			
Percentage VaR	99% VaR		95% VaR		99% VaR		95% VaR		99% VaR		95% VaR	
Method of estimation:	Return in %	Return in $	Return in %	Return in $	Return in %	Return in $	Return in %	Return in $	Return in %	Return in $	Return in %	Return in $
1. Parametric method ignoring the effect	3,41 %	340 787,55	2,42 %	241 805,33	0,86 %	86 408,24	0,59 %	58 887,14	1,96 %	195 608,76	1,36 %	136 293,53
2. Parametric method acknowledging the effect	1,24 %	123 868,39	0,89 %	88 658,54	1,86 %	186 347,62	1,29 %	129 445,20	2,30 %	230 179,07	1,61 %	160 700,46
3. Historical method	1,72 %	172 265,39	0,79 %	79 000,00	1,94 %	194 089,21	1,10 %	110 030,73	2,37 %	236 867,74	1,39 %	139 116,69
Total Difference (1-3)	1,69 %	168 522,16	1,63 %	162 805,33	-1,08 %	-107 680,97	-0,51 %	-51 143,59	-0,41 %	-41 258,98	-0,03 %	-2 823,16
Difference due to the weekend volatility effect (1-2)	2,17 %	216 919,16	1,53 %	153 146,79	-1,00 %	-99 939,38	-0,71 %	-70 558,06	-0,35 %	-34 570,31	-0,24 %	-24 406,94
Difference due to non-normality (2-3)	-0,48 %	-48 397,00	0,10 %	9 658,54	-0,08 %	-7 741,59	0,19 %	19 414,46	-0,07 %	-6 688,67	0,22 %	21 583,77
Period	TueClose-WedClose				WedClose-ThuClose				ThuClose-FriClose			
Mean Return	0,03 %				-0,06 %				0,08 %			
Percentage VaR	99% VaR		95% VaR		99% VaR		95% VaR		99% VaR		95% VaR	
Method of estimation:	Return in %	Return in $	Return in %	Return in $	Return in %	Return in $	Return in %	Return in $	Return in %	Return in $	Return in %	Return in $
1. Parametric method ignoring the effect	2,05 %	205 035,06	1,46 %	145 719,82	1,96 %	195 960,75	1,37 %	136 645,51	2,10 %	210 124,08	1,51 %	150 808,85
2. Parametric method acknowledging the effect	2,39 %	239 239,50	1,70 %	169 868,46	2,37 %	237 314,31	1,66 %	165 841,48	2,58 %	258 378,21	1,85 %	184 876,68
3. Historical method	2,83 %	283 250,35	1,56 %	155 666,05	2,18 %	217 692,34	1,51 %	151 354,24	3,15 %	314 536,29	1,63 %	163 237,20
Total Difference (1-3)	-0,78 %	-78 215,29	-0,10 %	-9 946,23	-0,22 %	-21 731,60	-0,15 %	-14 708,73	-1,04 %	-104 412,21	-0,12 %	-12 428,36
Difference due to the weekend volatility effect (1-2)	-0,34 %	-34 204,45	-0,24 %	-24 148,63	-0,41 %	-41 353,57	-0,29 %	-29 195,97	-0,48 %	-48 254,13	-0,34 %	-34 067,83
Difference due to non-normality (2-3)	-0,44 %	-44 010,85	0,14 %	14 202,40	0,20 %	19 621,97	0,14 %	14 487,24	-0,56 %	-56 158,08	0,22 %	21 639,48

Similar results, as those for a long position, apply to a short position in in the GC gold futures. A slight difference, however, is the overall overestimation of the 95% VaR when assuming normally distributed returns in the face of non-normally distributed returns. One possible reason for this could be the generally negative skewness of returns with the exception of the weekend and Friday. In total, relative to the analysis of a long position in GC futures, the overestimation of the weekend's VaR and the underestimation of the trading day's VaR is generally less significant.

10.3. Binomial Option Pricing and The Weekend Volatility Effect

As seen in section 10.1, the implication of ignoring the present Weekend Volatility Effect is an overestimation of the weekend's return variance, and an underestimation of the trading days' return variance. The resulting effect on the price of an option therefore crucially depends on the time of the option pricing, and on the time and length of the option's maturity. It is again worth mentioning that no consideration will be given to the violated normality assumption of the Binomial Option Pricing Model concerning the returns distribution.

10.3.1. Analysis of maturity length - Option group one and two

All the tables in section 10.3. are of the following outlay. The table's first two rows outline the option's time of pricing and maturity, and the length of maturity in terms of days. The third row include the two estimates of option maturity's return variance, the first acknowledging the present Weekend Volatility Effect and the second ignoring it as according to the Calendar-Time Hypothesis. Equivalently, the table's fourth row contains the two return standard deviations both in the maturity time measure and in annual terms. The sixth row states the risk free rate appropriate for the option's length of maturity. In row seven the option prices acknowledging the present Weekend Volatility Effect are outlines in the colour blue for calls and puts with absolute delta values of 10%, 25%, 50% and 75%. Resulting strike prices to these specified deltas are posted to the right of the option prices within the options column. Below the specification of the option's delta is the option price according to the Calendar-Time Hypothesis labelled as "ignoring the effect". The resulting difference between the ignoring and acknowledging of the effect is to be found in the final row both in percentage and $ value terms.

The following table 6 contains the pricing and analysis of option group one as specified in section 6.3. This first group of options is priced at the time of Friday's close and expires at the time of Monday's open with differing maturity lengths. The first coloured column is an option of maturity set to the weekend.

Table 6: Option group one – priced at the time of Friday's close maturing at the time of Monday's open with maturities differing by whole weeks.

Period	Weekend		FriClose-2ndMonOpen		FriClose-4thMonOpen		FriClose-8thMonOpen	
Calendar days	2,78		9,78		23,78		51,78	
Variance acknowledging the effect	0,000026		0,000551		0,001601		0,003700	
Variance ignoring the effect	0,000209		0,000734		0,001783		0,003883	
Standard deviation acknowledging the effect	0,51 %		2,35 %		4,00 %		6,08 %	
per annum	5,88 %		14,34 %		15,67 %		16,15 %	
Sandard deviation ignoring the effect	1,44 %		2,71 %		4,22 %		6,23 %	
per annum	16,54 %		16,54 %		16,54 %		16,54 %	
Risk free rate (annual)	0,17 %		0,19 %		0,20 %		0,25 %	
Option prices acknowledging the effect	Option Price	Strike	Option Price	Strike	Option Price	Strike	Option Price	Strike
Delta= ca. +/-50% (ATM)	3,32	1 628	15,17	1 628	25,86	1 628	39,30	1 628
Ignoring the effect	9,34		17,51		27,29		40,26	
Call								
Delta=75% (ITM)	6,88	1 623	30,95	1 603	52,06	1 586	77,85	1 566
Ignoring the effect	12,45		32,77		53,17		78,59	
Delta=25% (OTM)	1,25	1 634	5,68	1 655	9,60	1 674	14,45	1 700
Ignoring the effect	6,83		7,53		10,74		15,22	
Delta=10% (OTM)	0,40	1 639	1,81	1 678	3,07	1 715	4,63	1 763
Ignoring the effect	5,03		2,90		3,73		5,07	
Put								
Delta=-75% (ITM)	6,93	1 634	32,15	1 655	55,53	1 674	85,89	1 700
Ignoring the effect	12,51		33,99		56,67		86,66	
Delta=-25% (OTM)	1,26	1 623	5,81	1 603	9,97	1 586	15,31	1 566
Ignoring the effect	6,83		7,63		11,09		16,05	
Delta=-10% (OTM)	0,40	1 618	1,85	1 580	3,17	1 548	4,86	1 509
Ignoring the effect	5,01		2,96		3,79		5,27	
Resulting difference	In percentage	In $ value	In percentage	In $ value	In percentage	In $ value	In percentage	In $ value
Delta=50% (ATM)	181,12 %	6,02	15,36 %	2,33	5,54 %	1,43	2,43 %	0,96
Call								
Delta=75% (ITM)	80,99 %	5,57	5,88 %	1,82	2,14 %	1,11	0,95 %	0,74
Delta=25% (OTM)	445,02 %	5,58	32,54 %	1,85	11,90 %	1,14	5,32 %	0,77
Delta=10% (OTM)	1157,88 %	4,63	60,11 %	1,09	21,43 %	0,66	9,62 %	0,45
Put								
Delta=-75% (ITM)	80,48 %	5,58	5,75 %	1,85	2,06 %	1,14	0,89 %	0,77
Delta=-25% (OTM)	441,98 %	5,57	31,31 %	1,82	11,15 %	1,11	4,82 %	0,74
Delta=-10% (OTM)	1148,68 %	4,61	60,06 %	1,11	19,72 %	0,63	8,47 %	0,41

Ignoring the present Weekend Volatility Effect result in the overvaluation of the options in the group one due to the resulting overestimation of the weekend's implied volatility. When comparing option prices horizontally, across the differing option maturities, it is worth noting that an option maturity of a week result in neither an over- nor undervaluation, due to identical implied volatilities both when ignoring and acknowledging the Weekend Volatility Effect as seen in section 10.1. Therefore, adding whole weeks to the options' maturities cause a decreasing sensitivity to, or a fading of, the effect. When adding one week to the options' maturity, moving from the first to the second option in table 6 above, the overestimated implied volatility applies only to 2,78 days out of the total 9,78 days of maturity. For the 10% delta call option, the resulting decreased sensitivity result in an overvaluation of 60,11%. Adding three and seven weeks to the options' maturity, moving to the third and fourth options, result in an overestimation of the 10% delta call option of 21,43% and 9,62%. Some sensitivity to the effect is therefore present also for options of close to 52 days of maturity.

Comparing option prices vertically, within each of the four option maturities, the sensitivity of calls and puts can be seen to be nearly identical. The relative sensitivity of differing option delta values however is greatly varying with relatively greater sensitivity of out-of-the-money options due to the differing effect of the change in implied volatility. As stated in section 5.2.2, vega, the $ value change in the option price for 1% change in implied volatility, is at it's highest for at-the-money options and decreases as an options becomes in- or out-of-the-money. This can be seen in table 6 as the $ value difference for the at-the-money option with maturity set to the weekend is an overestimation of $6,02. With delta equal to 25% and 75%, keeping everything else equal, reduces the $ value overestimation to $5,58 and $5,57 for the call option. With a strike even further away from the market price of the underlying future contract at delta equal to 10%, the $ value overestimation reduces again to $4,63 for the call option, with results concerning the put being close to identical. When looking at the percentage difference in the options' prices, the relative sensitivity of the in-, at- and out-of-the-money options to the Weekend Volatility Effect is of a different nature. This is due to the difference in vega leverage, the percentage change in an option's price resulting from a 1% change in implied volatility, as discussed in section 5.2.2. Due to relatively lower price of out-of-the-money options their vega leverage is higher relative to at- and in-the-money options. An increase in delta from 10% to 75% therefore result in the reducing overvaluation from 1157,88% to 80,99% for the call option with maturity set to the weekend. A second factor causing this reduction arises from the effect of a change in implied volatility on an option's delta. As DdeltaDvol is negative for in-the-money options, an increased implied volatility reduces the option's delta. These two changes have opposing effects on the option's price resulting in a reduced price change. For out-of-the-money options, in contrast, DdeltaDvol is positive meaning that the increase in the implied volatility increases the option's delta. These two changes both positively affect the option value resulting in a greater price change.

Table 7 present the pricing and analysis of option group two as specified in section 6.3. This second group of options is priced at the time of Monday's open and expires at the time of Friday's close with differing maturity lengths. The first option maturity analysed is therefore set to the duration of the trading week.

Table 7: Option group two - priced at the time of Monday's open maturing at the time of Friday's close with maturities differing by whole weeks.

Period	MonOpen-FriClose		MonOpen-2ndFriClose		MonOpen-4thFriClose		MonOpen-8thFriClose	
Calendar days	4,22		11,22		25,22		53,22	
Variance acknowledging the effect	0,000498		0,001023		0,002073		0,004173	
Variance ignoring the effect	0,000316		0,000841		0,001891		0,003990	
Standard deviation acknowledging the effect	2,23 %		3,20 %		4,55 %		6,46 %	
per annum	20,78 %		18,25 %		17,32 %		16,92 %	
Sandard deviation ignoring the effect	1,78 %		2,90 %		4,35 %		6,32 %	
per annum	16,54 %		16,54 %		16,54 %		16,54 %	
Risk free rate (annual)	0,17 %		0,19 %		0,20 %		0,25 %	
Option prices acknowledging the effect	Option Price	Strike	Option Price	Strike	Option Price	Strike	Option Price	Strike
Delta= ca. +/-50% (ATM)	14,43	1 628	20,67	1 628	29,42	1 628	41,73	1 628
Ignoring the effect	11,49		18,74		28,10		40,81	
Call								
Delta=75% (ITM)	29,46	1 604	41,89	1 594	58,97	1 581	82,42	1 562
Ignoring the effect	27,16		40,38		57,94		81,71	
Delta=25% (OTM)	5,40	1 653	7,70	1 665	10,90	1 681	15,32	1 704
Ignoring the effect	3,10		6,17		9,84		14,58	
Delta=10% (OTM)	1,72	1 676	2,46	1 697	3,49	1 728	4,91	1 772
Ignoring the effect	0,65		1,61		2,88		4,48	
Put								
Delta=-75% (ITM)	30,54	1 653	44,10	1 665	63,48	1 681	91,47	1 704
Ignoring the effect	28,24		42,57		62,42		90,73	
Delta=-25% (OTM)	5,52	1 604	7,95	1 594	11,38	1 581	16,29	1 562
Ignoring the effect	3,22		6,44		10,36		15,58	
Delta=-10% (OTM)	1,76	1 583	2,53	1 564	3,62	1 538	5,17	1 502
Ignoring the effect	0,67		1,68		3,04		4,78	
Resulting difference	In percentage	In $ value	In percentage	In $ value	In percentage	In $ value	In percentage	In $ value
Delta=50% (ATM)	-20,37 %	-2,94	-9,35 %	-1,93	-4,50 %	-1,32	-2,21 %	-0,92
Call								
Delta=75% (ITM)	-7,79 %	-2,29	-3,59 %	-1,50	-1,74 %	-1,03	-0,86 %	-0,71
Delta=25% (OTM)	-42,55 %	-2,30	-19,94 %	-1,54	-9,71 %	-1,06	-4,84 %	-0,74
Delta=10% (OTM)	-62,57 %	-1,08	-34,61 %	-0,85	-17,50 %	-0,61	-8,77 %	-0,43
Put								
Delta=-75% (ITM)	-7,52 %	-2,30	-3,48 %	-1,54	-1,67 %	-1,06	-0,81 %	-0,74
Delta=-25% (OTM)	-41,57 %	-2,29	-18,93 %	-1,50	-9,01 %	-1,03	-4,36 %	-0,71
Delta=-10% (OTM)	-61,60 %	-1,08	-33,52 %	-0,85	-15,91 %	-0,58	-7,66 %	-0,40

Ignoring the present Weekend Volatility Effect result in the undervaluation of the options in the group two due to the resulting underestimation of the implied volatility during the trading days. Comparing option prices horizontally, across the differing option maturities, adding whole weeks to the options' maturities cause a decreasing sensitivity to, or a fading of, the effect. When adding one week to the option's maturity, moving from the first to the second option, the percentage undervaluation reduces from -62,57% to -34,61% for a call option with a delta of 10%. Comparing option prices vertically, within each of the four option maturities, the in-, at- and out-of-the-money options have as before varied sensitivity to the present Weekend Volatility Effect. The same relationship, as for the results in table 6, holds also here with the sensitivity of the $ option value being the greatest for at-the-money options, while that of the percentage difference in the option value being the greatest for out-of-the-money options.

10.3.2. Within the calendar- and trading-week – Option group three and four

Option group three and four presents a more detailed analysis enabling an understanding of the Weekend volatility Effect workings within the calendar- and trading-week. For simplicity, the final two option groups is analysed for only call options. As the previous findings are near to identical for both calls and puts, one can expect the following analysis to apply to also put options. The following table 8 presents the analysis of option group three specified in chapter 6.3, with their time of pricing moving from the time of Monday's close to the time of Friday's close while their time of maturity is fixed to the time of Monday's open.

Table 8: Option group three – time of pricing ranging from the time of Monday's to Friday's close, with a constant time of maturity set to the time of Monday's open.

Period	MonClose-MonOpen		TueClose-MonOpen		WedClose-MonOpen		ThuClose-MonOpen		Weekend	
Calendar days	6,78		5,78		4,78		3,78		2,78	
Variance acknowledging the effect	0,000456		0,000353		0,000250		0,000142		0,000026	
Variance ignoring the effect	0,000509		0,000434		0,000359		0,000284		0,000209	
Standard deviation acknowledging the effect	2,14 %		1,88 %		1,58 %		1,19 %		0,51 %	
per annum	15,66 %		14,92 %		13,82 %		11,68 %		5,88 %	
Sandard deviation ignoring the effect	2,26 %		2,08 %		1,89 %		1,68 %		1,44 %	
per annum	16,54 %		16,54 %		16,54 %		16,54 %		16,54 %	
Option prices acknowledging the effect	Option Price	Strike	Option Price	Strike	Option Price	Strike	Option Price	Strike	Option Price	Strike
Delta=75% (ITM)	28,19	1 605	24,86	1 608	20,99	1 611	15,83	1 615	6,88	1 623
Ignoring the effect	28,80		25,89		22,59		18,58		12,45	
Delta= ca. 50% (ATM)	13,80	1 628	12,14	1 628	10,23	1 628	7,69	1 628	3,32	1 628
Ignoring the effect	14,58		13,46		12,24		10,89		9,34	
Delta=25% (OTM)	5,17	1 652	4,55	1 649	3,84	1 646	2,89	1 641	1,25	1 634
Ignoring the effect	5,79		5,60		5,43		5,64		6,83	
Delta=10% (OTM)	1,65	1 674	1,45	1 668	1,23	1 662	0,92	1 653	0,40	1 639
Ignoring the effect	2,00		2,05		2,24		2,73		5,03	
Resulting difference	In percentage	In $ value	In percentage	In $ value	In percentage	In $ value	In percentage	In $ value	In percentage	In $ value
Delta=75% (ITM)	2,15 %	0,61	4,14 %	1,03	7,63 %	1,60	17,37 %	2,75	80,99 %	5,57
Delta= ca. 50% (ATM)	5,64 %	0,78	10,85 %	1,32	19,69 %	2,01	41,59 %	3,20	181,12 %	6,02
Delta=25% (OTM)	11,92 %	0,62	22,90 %	1,04	41,45 %	1,59	95,01 %	2,75	445,02 %	5,58
Delta=10% (OTM)	21,40 %	0,35	41,06 %	0,60	82,65 %	1,01	196,19 %	1,81	1157,88 %	4,63

When moving the time of pricing across the week from the time of Monday's to Friday's close while holding the time of maturity fixed at the time of Monday's open, one removes a larger and larger part of the time period within the week for which the Calendar-Time Hypothesis overestimates implied volatility. The resulting gap, between the implied volatility acknowledging and ignoring the present effect, therefore increases. As a result, the greatest increase in the option overvaluation occurs when moving the time of pricing from Thursday's to Friday's close. For the option with a delta of 10% the resulting percentage overvaluation when pricing according to the Calendar-Time Hypothesis increases from 196,19% to 1157,88%. Comparing option prices horizontally across the differing option maturities, as a consequence, show an increasing overvaluation of the options. Comparing option prices vertically, within each of the five option maturities, the in-, at- and out-of-the-money options have the same relative sensitivity to the present Weekend Volatility Effect as for the previous two option groups. Although being the least sensitive, the In-of-the-money option, with a maturity set to the longest maturity from the time of Monday's close to the time of Monday's open result in an overvaluation of 2,15% when priced according to the Calendar-Time Hypothesis which, for big investors, could prove crucial.

The following table 9 presents the analysis of option group four specified in chapter 6.3, with their time of pricing moving from the time of Monday's open to the time of Thursday's close while their time of maturity is fixed to the time of Friday's close.

Table 9: Option group four - time of pricing ranging from the time of Monday's open to Thursday's close, with a constant time of maturity set to the time of Friday's close.

Period	**MonOpen-FriClose**		**MonClose-FriClose**		**TueClose-FriClose**		**WedClose-FriClose**		**ThuClose-FriClose**	
Calendar days	4,22		4,00		3,00		2,00		1,00	
Variance acknowledging the effect	0,000498		0,000429		0,000327		0,000224		0,000115	
Variance ignoring the effect	0,000316		0,000300		0,000225		0,000150		0,000075	
Standard deviation acknowledging the effect	2,23 %		2,07 %		1,81 %		1,50 %		1,07 %	
per annum	20,78 %		19,80 %		19,93 %		20,22 %		20,50 %	
Sandard deviation ignoring the effect	1,78 %		1,73 %		1,50 %		1,22 %		0,87 %	
per annum	16,54 %		16,54 %		16,54 %		16,54 %		16,54 %	
Option prices acknowledging the effect	Option Price	Strike	Option Price	Strike	Option Price	Strike	Option Price	Strike	Option Price	Strike
Delta=75% (OTM)	29,46	1 604	27,38	1 606	23,93	1 609	19,87	1 612	14,29	1 617
Ignoring the effect	27,16		25,66		22,37		18,49		13,24	
Delta= ca. 50% (ATM)	14,43	1 628	13,39	1 628	11,68	1 628	9,67	1 628	6,94	1 628
Ignoring the effect	11,49		11,19		9,69		7,91		5,60	
Delta=25% (ITM)	5,40	1 653	5,02	1 651	4,38	1 648	3,63	1 645	2,61	1 640
Ignoring the effect	3,10		3,28		2,81		2,24		1,55	
Delta=10% (OTM)	1,72	1 676	1,60	1 672	1,40	1 667	1,16	1 660	0,83	1 651
Ignoring the effect	0,65		0,76		0,64		0,50		0,34	
Resulting difference	In percentage	In $ value	In percentage	In $ value	In percentage	In $ value	In percentage	In $ value	In percentage	In $ value
Delta=75% (ITM)	-7,79 %	-2,29	-6,28 %	-1,72	-6,49 %	-1,55	-6,93 %	-1,38	-7,34 %	-1,05
Delta= ca. 50% (ATM)	-20,37 %	-2,94	-16,43 %	-2,20	-17,00 %	-1,99	-18,18 %	-1,76	-19,30 %	-1,34
Delta=25% (OTM)	-42,55 %	-2,30	-34,72 %	-1,74	-35,86 %	-1,57	-38,25 %	-1,39	-40,46 %	-1,06
Delta=10% (OTM)	-62,57 %	-1,08	-52,58 %	-0,84	-53,99 %	-0,76	-56,91 %	-0,66	-59,63 %	-0,50

This group of options show the relative size of the underestimation of implied volatilities between the trading days, as seen in section 10,1. Monday following by Friday is the two trading days with estimated implied volatilities the furthest away from that according to the Calendar-Time Hypothesis. Thursday, Tuesday and Wednesday then follow with relatively lower estimated implied volatilities. The table's first option, the only one with a maturity including the trading day of Monday, is therefore the most sensitive to the present Weekend Volatility Effect, resulting in an overvaluation of -62,57% for a call option with a delta of 10%, when priced according to the Calendar-Time Hypothesis. Subtracting Monday off the option's maturity, with everything else equal, reduces the undervaluation of the option to -52,58%. Also, a maturity set to the day of Friday, being the day of the second most underestimated implied volatility by the Calendar-Time Hypothesis, proves the second most sensitive to the present Weekend Volatility Effect resulting in an underestimation of -59,63%. Again, comparing the option prices vertically, within each of the five option maturities, the in-, at- and out-of-the-money options have the same relative sensitivity to the present Weekend Volatility Effect as for the previous three option groups.

A graphical presentation of the percentage undervaluation, for the four option groups, when pricing the call option according to the Calendar-Time Hypothesis with deltas of 10%, 25%, 50% and 75% can be found in the appendix section 5.

11. Conclusions and scope for further analysis

Based on the analysis of daily open and close prices of gold futures traded at the Chicago Mercantile Exchange during the years 1992-2012, results show an evident negative Weekend Volatility Effect. The weekend's annual return standard deviation on it's lowest, for contract maturities ranging from two to three months, is estimated to 5,88% while that of the general trading day is estimated to 20,77%. The 24-hour return variance during the weekend is therefore only 7,6% of that of the general trading day posing a valid argument for the Trading-Time Hypothesis, over the Calendar-Time Hypothesis, due to the significantly greater relevance of trading relative to news on return variability.

By looking at the implications to Value at Risk and option pricing, it is evident that the cost, in terms of risk misspecifications and imprecise option valuation, connected to ignoring such an effect can be of significant size. For the weekend's parametrically estimated VaR at a 99% confidence level, ignoring the present effect results in an estimated loss level of 2,17% points more than the loss-level acknowledging the effect. Equivalently, for Monday's parametrically estimated VaR at a 99% confidence level, ignoring the present effect results in an estimated loss level of 1% points less than the loss-level acknowledging the effect. For a 10% delta call option, priced at the time of Friday's close and maturing at the time of the following Monday's open, assuming the Calendar-Time Hypothesis to hold results in an option overvaluation of incredible 1149%. Equivalently, a call option priced at the time of Monday's open with maturity set to the time of Friday's close is, when priced according to the Calendar-Time Hypothesis, undervalued by 63%. The significance of the over- and undervaluation is seen to rapidly reduce as whole weeks are added to the options' maturities. A 10% delta call option with a maturity of 52 days, however, show an overvaluation of 9,62%. Out-of-the-money options prove much more sensitive, in terms of percentage option over- and undervaluation, to the present Weekend Volatility Effect relative to in-the-money options.

Concluding recommendations strongly advice acknowledging the present negative Weekend Volatility Effect in risk estimation and management, with the obvious better fit of trading- than calendar-time as the market's price-generating time-measure.

A valuable extension to this thesis' analysis is the comparing of VaR and option pricing based on the specific day-of-the-week's returns variances with those according to the Trading-Time Hypothesis. Such a comparison would further indicate the location, in terms of size, of the Weekend Volatility Effect. In addition, a further study of this topic should include a division into sub-periods of characteristically low and high return variability. Further would taking into account the possibly differing trading volumes between the trading days give an even deeper understanding of the relevance of trading on return variability. A comparison of the conclusions reached in this thesis concerning the market for gold futures at the CME with an updated study of the gold spot market would also be valuable. No consideration is given to the possible asymmetric occurrence of news relevant for the market for gold futures, and an analysis of the timing pattern of news would therefore add meaning to the statistical results generated in this thesis.

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Appendix

1. The historical Returns

Following are individual figures of the close-to-close returns for each of the four maturity groups analysed during the 20-year period 1992-2012.

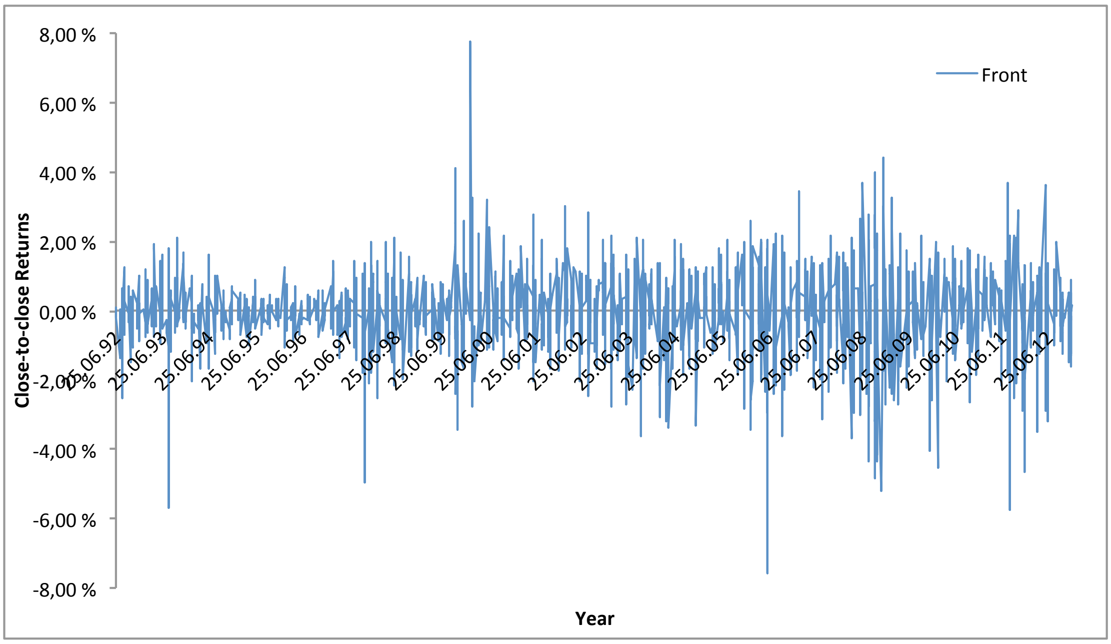

Figure 3: Close-to-close returns for the "front" maturity group during 1992-2012.

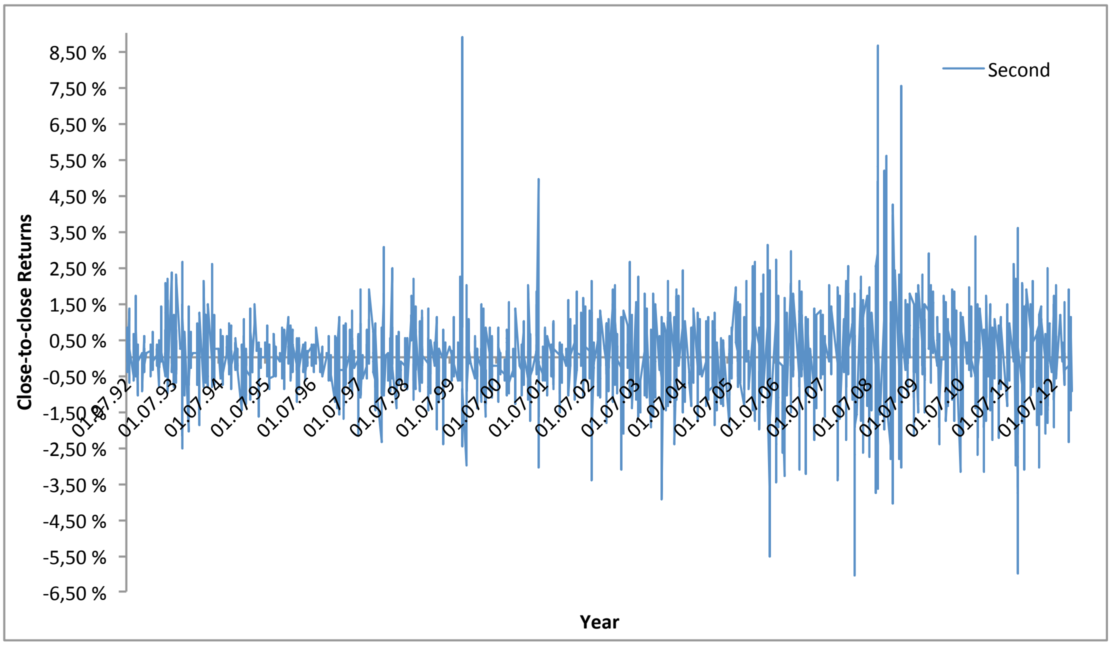

Figure 4: Close-to-close returns for the "second" maturity group during 1992-2012.

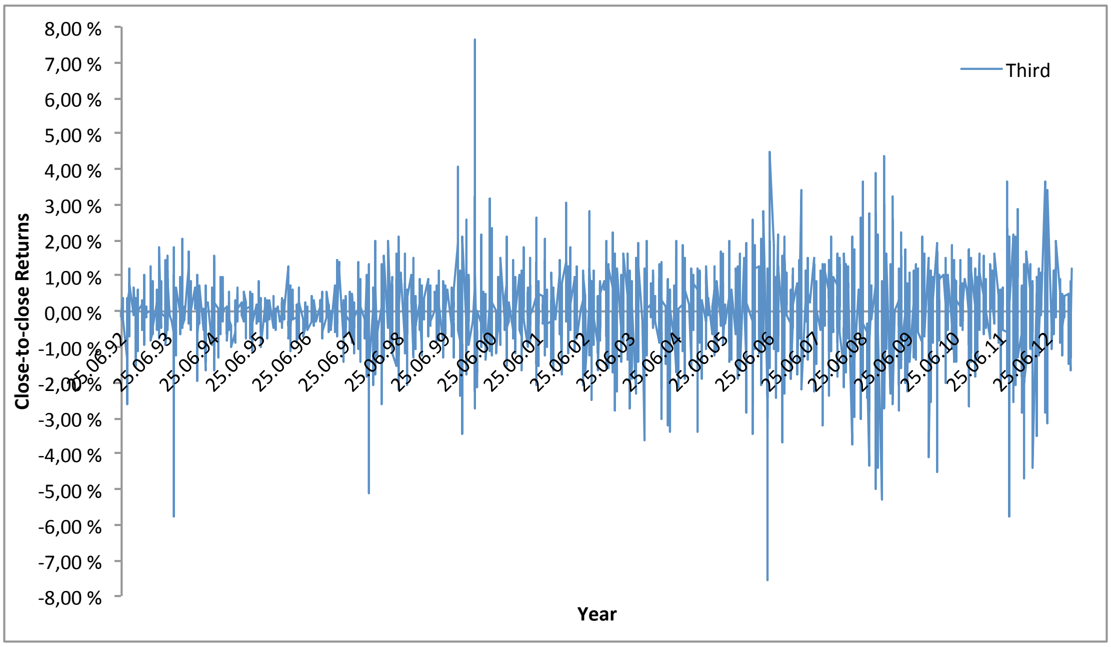

Figure 5: Close-to-close returns for the "third" maturity group during 1992-2012.

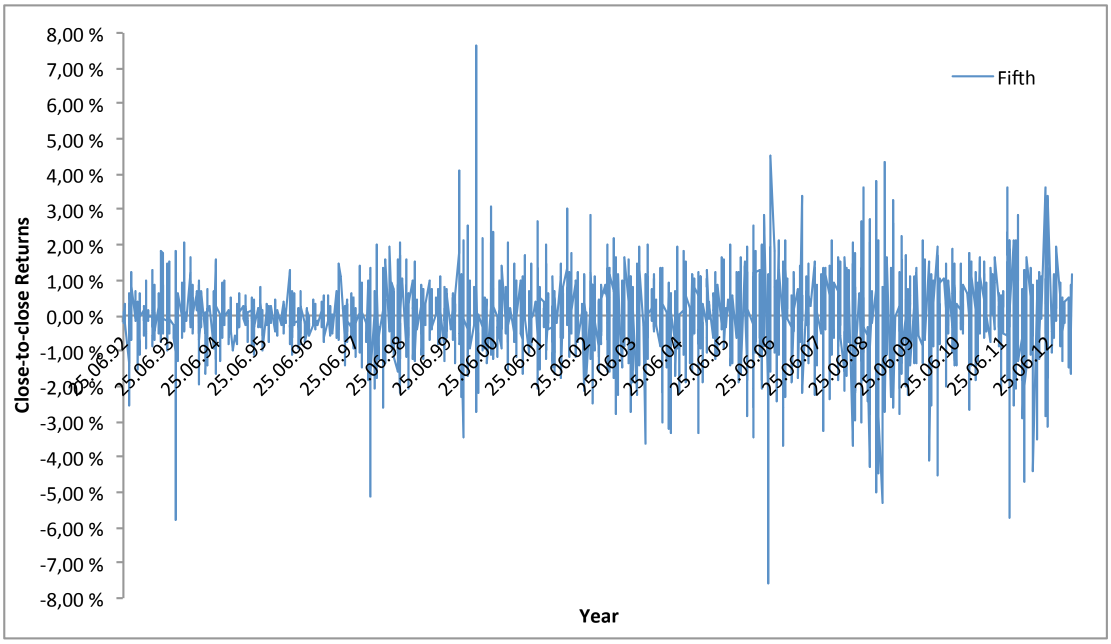

Figure 6: Close-to-close returns for the "fifth" maturity group during 1992-2012.

2. The comparison of the Weekend and trading days

Following are the resulting statistical findings, for the "third", "second" and "third" maturity group, to the hypotheses tests specified in section 7.3.

Table 10: Descriptive statistics and hypotheses testing of the weekend and trading day returns in the "second" maturity group during 1992-2012.

Period	Weekend	MonOpen-MonClose	MonClose-TueClose	TueClose-WedClose	WedClose-ThuClose	ThuClose-FriClose	MonOpen-FriClose
Calendar hours	66,83	5,17	24,00	24,00	24,00	24,00	101,17
Calendar days	2,78	0,22	1,00	1,00	1,00	1,00	4,22
Trading hours	18,08	5,17	23,25	23,25	23,25	23,25	98,17
Trading days	0,75	0,22	0,97	0,97	0,97	0,97	4,09
Variance	0,000035	0,000062	0,000106	0,000111	0,000116	0,000112	0,000507
per 24h. calendar-time	0,000013	0,000287	0,000106	0,000111	0,000116	0,000112	0,000120
per 24h. trading-time	0,000047	0,000287	0,000109	0,000115	0,000120	0,000115	0,000124
Standard Deviation	0,59 %	0,79 %	1,03 %	1,06 %	1,08 %	1,06 %	2,25 %
per annum	6,80 %	32,37 %	19,67 %	20,16 %	20,61 %	20,18 %	20,95 %
per 24h. calendar-time	0,36 %	1,69 %	1,03 %	1,06 %	1,08 %	1,06 %	1,10 %
per 24h. trading-time	0,68 %	1,69 %	1,05 %	1,07 %	1,10 %	1,07 %	1,11 %
Minimum	-2,82 %	-4,19 %	-3,50 %	-6,05 %	-3,96 %	-6,02 %	
Maximum	6,19 %	3,07 %	8,89 %	8,62 %	7,55 %	5,60 %	
No. Of observations	437	437	461	517	502	493	482
Skewness	2,15	-0,97	1,36	0,18	0,53	0,30	
Kurtosis (Fisher's)	28,86	5,10	12,68	11,85	6,26	6,37	
JB normality test	15504,65 **	541,46 **	3232,78 **	3027,87 **	844,17 **	840,94 **	
P value	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	
F-test (calendar-time hypothesis)		22,65 **	8,36 **	8,79 **	9,18 **	8,80 **	9,49 **
P value		< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%
F-test (trading-time hypothesis)		6,13 **	2,34 **	2,45 **	2,57 **	2,46 **	2,65 **
P value		< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%

Table 11: Descriptive statistics and hypotheses testing of the weekend and trading day returns in the "third" maturity group during 1992-2012.

Period	Weekend	MonOpen-MonClose	MonClose-TueClose	TueClose-WedClose	WedClose-ThuClose	ThuClose-FriClose	MonOpen-FriClose
Calendar hours	66,83	5,17	24,00	24,00	24,00	24,00	101,17
Calendar days	2,78	0,22	1,00	1,00	1,00	1,00	4,22
Trading hours	18,08	5,17	23,25	23,25	23,25	23,25	98,17
Trading days	0,75	0,22	0,97	0,97	0,97	0,97	4,09
Variance	0,000026	0,000069	0,000103	0,000103	0,000109	0,000115	0,000498
per 24h. calendar-time	0,000009	0,000320	0,000103	0,000103	0,000109	0,000115	0,000118
per 24h. trading-time	0,000035	0,000320	0,000106	0,000106	0,000112	0,000119	0,000122
Standard Deviation	0,51 %	0,83 %	1,01 %	1,01 %	1,04 %	1,07 %	2,23 %
per annum	5,88 %	34,19 %	19,38 %	19,35 %	19,93 %	20,50 %	20,77 %
per 24h. calendar-time	0,31 %	1,79 %	1,01 %	1,01 %	1,04 %	1,07 %	1,09 %
per 24h. trading-time	0,59 %	1,79 %	1,03 %	1,03 %	1,06 %	1,09 %	1,10 %
Minimum	-1,77 %	-5,74 %	-7,56 %	-5,77 %	-5,75 %	-5,09 %	
Maximum	3,13 %	3,55 %	3,06 %	4,37 %	3,65 %	7,67 %	
No. Of observations	469	469	492	520	520	499	500
Skewness	1,03	-1,52	-1,20	-0,79	-0,85	0,40	
Kurtosis (Fisher's)	6,83	9,84	7,12	5,34	3,72	7,24	
JB normality test	994,27 **	2072,45 **	1157,53 **	672,50 **	362,92 **	1101,53 **	
P value	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	
F-test (calendar-time hypothesis)		33,76 **	10,84 **	10,81 **	11,47 **	12,13 **	12,46 **
P value		< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%
F-test (trading-time hypothesis)		9,14 **	3,03 **	3,02 **	3,20 **	3,39 **	3,48 **
P value		< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%

Table 12: Descriptive statistics and hypotheses testing of the weekend and trading day returns in the "fifth" maturity group during 1992-2012.

Period	Weekend	MonOpen-MonClose	MonClose-TueClose	TueClose-WedClose	WedClose-ThuClose	ThuClose-FriClose	MonOpen-FriClose
Calendar hours	66,83	5,17	24,00	24,00	24,00	24,00	101,17
Calendar days	2,78	0,22	1,00	1,00	1,00	1,00	4,22
Trading hours	18,08	5,17	23,25	23,25	23,25	23,25	98,17
Trading days	0,75	0,22	0,97	0,97	0,97	0,97	4,09
Variance	0,000030	0,000068	0,000103	0,000103	0,000109	0,000115	0,000497
per 24h. calendar time	0,000011	0,000317	0,000103	0,000103	0,000109	0,000115	0,000118
per 24h. trading time	0,000040	0,000317	0,000106	0,000106	0,000112	0,000118	0,000121
Standard Deviation	0,55 %	0,83 %	1,01 %	1,01 %	1,04 %	1,07 %	2,23 %
per annum	6,30 %	34,03 %	19,36 %	19,34 %	19,91 %	20,46 %	20,74 %
per 24h. calendar time	0,33 %	1,78 %	1,01 %	1,01 %	1,04 %	1,07 %	1,09 %
per 24h. trading time	0,63 %	1,78 %	1,03 %	1,03 %	1,06 %	1,09 %	1,10 %
Minimum	-2,52 %	-5,82 %	-7,58 %	-5,75 %	-5,77 %	-5,12 %	
Maximum	3,35 %	3,63 %	3,05 %	4,36 %	3,62 %	7,67 %	
No. Of observations	469	469	492	520	520	500	500
Skewness	0,77	-1,49	-1,21	-0,81	-0,87	0,39	
Kurtosis (Fisher's)	6,72	9,99	7,24	5,37	3,79	7,32	
JB normality test	928,25 **	2124,11 **	1195,11 **	682,40 **	376,34 **	1128,91 **	
P value	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	
F-test (calendar-time hypothesis)		29,19 **	9,45 **	9,43 **	9,99 **	10,55 **	10,84 **
P value		< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%
F-test (trading-time hypothesis)		7,90 **	2,64 **	2,63 **	2,79 **	2,95 **	3,02 **
P value		< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%

3. The comparison of the Weekend and overnights

Following are the resulting statistical findings, for the "third", "second" and "third" maturity group, to the hypotheses tests specified in section 7.4.

Table 13: Descriptive statistics and hypotheses testing of the weekend and overnight returns in the "second" maturity group during 1992-2012.

Period	Weekend	MonClose-TueOpen	TueClose-WedOpen	WedClose-ThuOpen	ThuClose-FriOpen	Total within-week overnights
Calendar hours	66,83	18,83	18,83	18,83	18,83	75,33
Calendar days	2,78	0,78	0,78	0,78	0,78	3,14
Trading hours	18,08	18,08	18,08	18,08	18,08	72,33
Trading days	0,75	0,75	0,75	0,75	0,75	3,01
Variance	0,000035	0,000023	0,000025	0,000026	0,000026	0,000100
per 24h. calendar-time	0,000013	0,000029	0,000032	0,000033	0,000034	0,000032
per 24h. trading-time	0,000047	0,000030	0,000033	0,000035	0,000035	0,000033
Standard Deviation	0,59 %	0,48 %	0,50 %	0,51 %	0,51 %	1,00 %
per annum	6,80 %	10,33 %	10,78 %	11,02 %	11,07 %	10,80 %
per 24h. calendar-time	0,36 %	0,54 %	0,56 %	0,58 %	0,58 %	0,57 %
per 24h. trading-time	0,68 %	0,55 %	0,58 %	0,59 %	0,59 %	0,58 %
Minimum	-2,82 %	-1,50 %	-2,76 %	-1,78 %	-4,61 %	
Maximum	6,19 %	4,20 %	2,44 %	5,74 %	4,03 %	
No. Of observations	437	461	517	502	493	493
Skewness	2,15	1,74	-0,38	2,82	-0,98	
Kurtosis (Fisher's)	28,86	13,96	4,25	31,72	23,89	
JB normality test	15504,65 **	3977,16 **	401,74 **	21715,71 **	11804,09 **	
P value	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	
F-test (calendar-time hypothesis)		2,31 **	2,51 **	2,62 **	2,65 **	2,52 **
P value		< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%
F-test (trading-time hypothesis)		1,54 **	1,41 **	1,35 **	1,34 **	1,41 **
P value		< 0,01%	< 0,01%	0,06 %	0,08 %	< 0,01%
Nonparametric Levene's (trading-time hypothesis)		0,44	0,02	0,24	2,75	
P value		50,75 %	88,76 %	62,45 %	9,80 %	

Table 14: Descriptive statistics and hypotheses testing of the weekend and overnight returns in the "third" maturity group during 1992-2012.

Period	Weekend	MonClose-TueOpen	TueClose-WedOpen	WedClose-ThuOpen	ThuClose-FriOpen	Total within-week overnights
Calendar hours	66,83	18,83	18,83	18,83	18,83	75,33
Calendar days	2,78	0,78	0,78	0,78	0,78	3,14
Trading hours	18,08	18,08	18,08	18,08	18,08	72,33
Trading days	0,75	0,75	0,75	0,75	0,75	3,01
Variance	0,000026	0,000026	0,000026	0,000022	0,000021	0,000096
per 24h. calendar-time	0,000009	0,000033	0,000033	0,000028	0,000027	0,000030
per 24h. trading-time	0,000035	0,000034	0,000035	0,000030	0,000028	0,000032
Standard Deviation	0,51 %	0,51 %	0,51 %	0,47 %	0,46 %	0,98 %
per annum	5,88 %	10,96 %	11,04 %	10,19 %	9,92 %	10,54 %
per 24h. calendar-time	0,31 %	0,57 %	0,58 %	0,53 %	0,52 %	0,55 %
per 24h. trading-time	0,59 %	0,59 %	0,59 %	0,54 %	0,53 %	0,56 %
Minimum	-1,77 %	-3,21 %	-2,96 %	-2,34 %	-1,53 %	
Maximum	3,13 %	5,95 %	2,71 %	1,79 %	3,19 %	
No. Of observations	469	492	520	520	499	508
Skewness	1,03	2,93	-0,35	0,05	1,19	
Kurtosis (Fisher's)	6,83	43,32	5,71	3,35	7,40	
JB normality test	994,27 **	39174,92 **	718,21 **	242,69 **	1255,44 **	
P value	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	
F-test (calendar-time hypothesis)		3,47 **	3,52 **	3,00 **	2,84 **	3,21 **
P value		< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%
F-test (trading-time hypothesis)		1,02	1,01	1,18 *	1,25 *	1,11
P value		41,40 %	45,55 %	3,30 %	0,71 %	12,54%
Nonparametric Levene's (trading-time hypothesis)		1,52	0,14	0,03	0,03	
P value		21,82 %	70,85 %	86,26 %	86,26 %	

Table 15: Descriptive statistics and hypotheses testing of the weekend and overnight returns in the "fifth" maturity group during 1992-2012.

Period	Weekend	MonClose-TueOpen	TueClose-WedOpen	WedClose-ThuOpen	ThuClose-FriOpen	Total within-week overnights
Calendar hours	66,83	18,83	18,83	18,83	18,83	75,33
Calendar days	2,78	0,78	0,78	0,78	0,78	3,14
Trading hours	18,08	18,08	18,08	18,08	18,08	72,33
Trading days	0,75	0,75	0,75	0,75	0,75	3,01
Variance	0,000030	0,000026	0,000026	0,000024	0,000023	0,000100
per 24h. calender time	0,000011	0,000034	0,000034	0,000031	0,000029	0,000032
per 24h. trading time	0,000040	0,000035	0,000035	0,000032	0,000030	0,000033
Standard Deviation	0,55 %	0,51 %	0,51 %	0,49 %	0,48 %	1,00 %
per annum	6,30 %	11,07 %	11,08 %	10,64 %	10,31 %	10,78 %
per 24h. calender time	0,33 %	0,58 %	0,58 %	0,56 %	0,54 %	0,56 %
per 24h. trading time	0,63 %	0,59 %	0,59 %	0,57 %	0,55 %	0,58 %
Minimum	-2,52 %	-3,63 %	-2,70 %	-2,10 %	-1,36 %	
Maximum	3,35 %	5,35 %	2,53 %	1,93 %	3,51 %	
No. Of observations	469	492	520	520	500	508
Skewness	0,77	1,61	-0,24	0,07	1,45	
Kurtosis (Fisher's)	6,72	30,17	4,60	2,95	8,41	
JB normality test	928,25 **	18866,71 **	464,29 **	188,82 **	1649,78 **	
P value	< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%	
F-test (calendar-time hypothesis)		3,09 **	3,09 **	2,86 **	2,68 **	2,93 **
P value		< 0,01%	< 0,01%	< 0,01%	< 0,01%	< 0,01%
F-test (trading-time hypothesis)		1,15	1,15	1,24 **	1,32 **	1,21 *
P value		6,30 %	6,03 %	0,85 %	0,11 %	1,80 %
Nonparametric Levene's (trading-time hypothesis)		4,33 *	0,06	0,12	2,29	
P value		3,80 %	80,66 %	72,92 %	13,09 %	

4. The sample and normal return distributions

Following are the distributions of the weekend and trading day returns for the "third" maturity group during 1992-2012 with the fitted normal distribution.

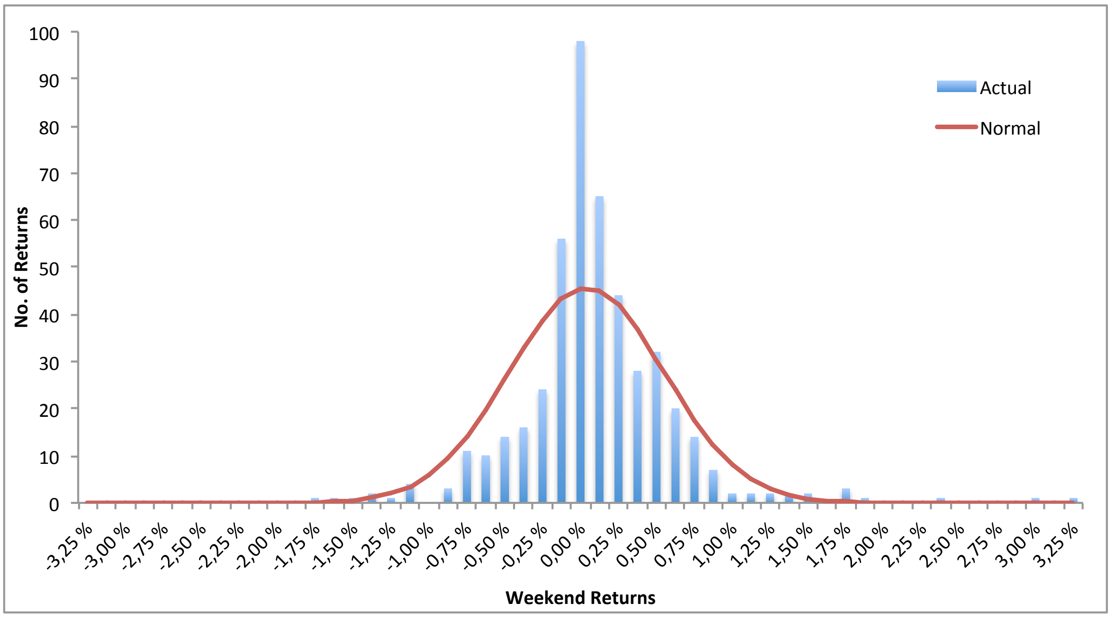

Figure 7: The sample and fitted normal distribution of the weekend returns for the "third" maturity group during 1992-2012.

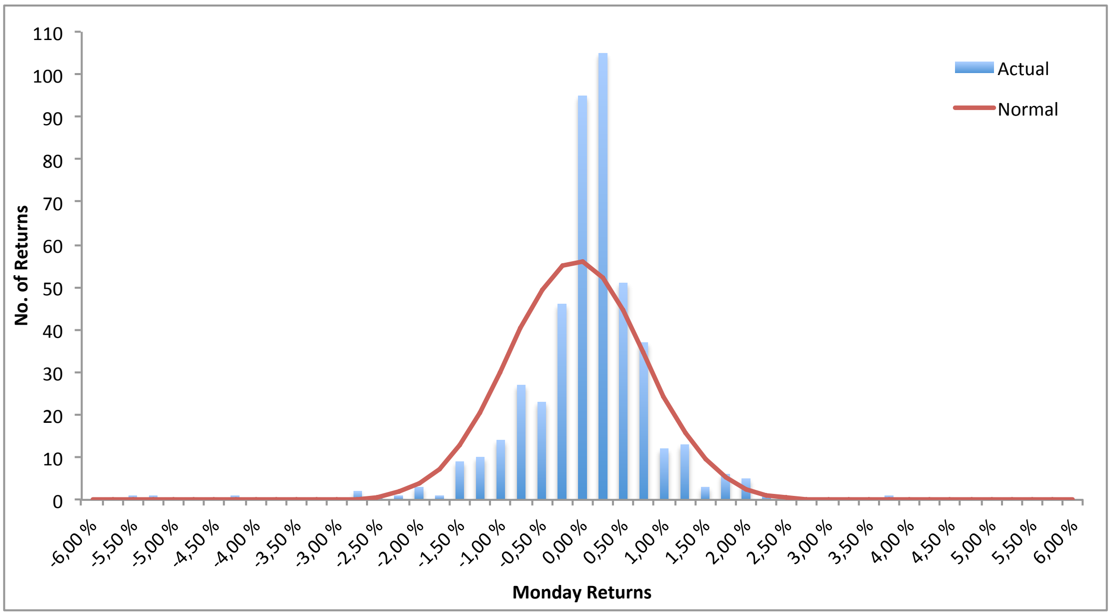

Figure 8: The sample and fitted normal distribution of the Monday returns for the "third" maturity group during 1992-2012.

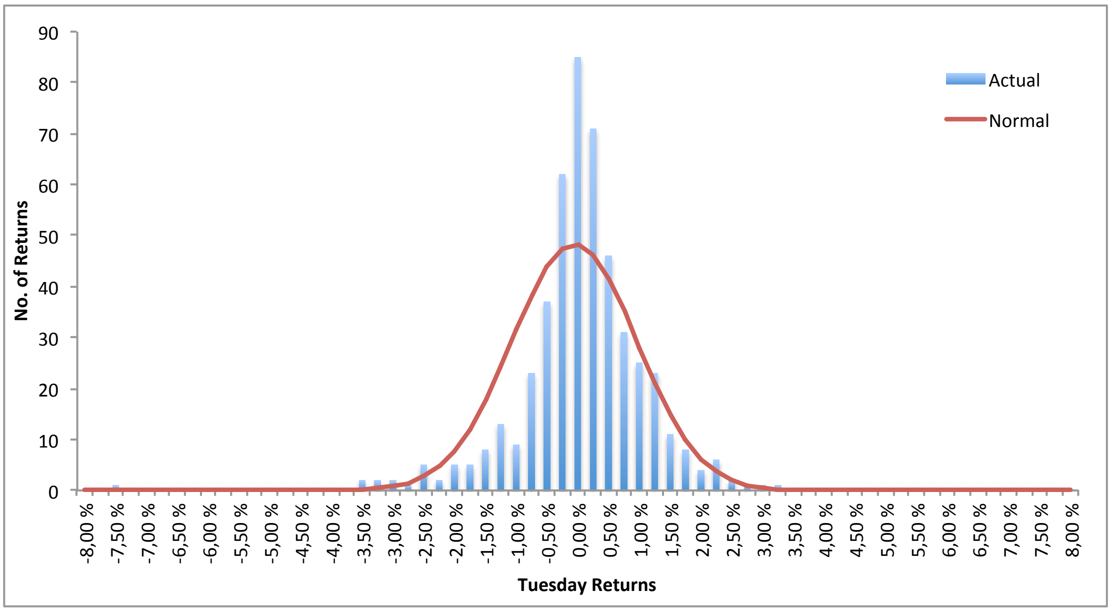

Figure 9: The sample and fitted normal distribution of the Tuesday returns for the "third" maturity group during 1992-2012.

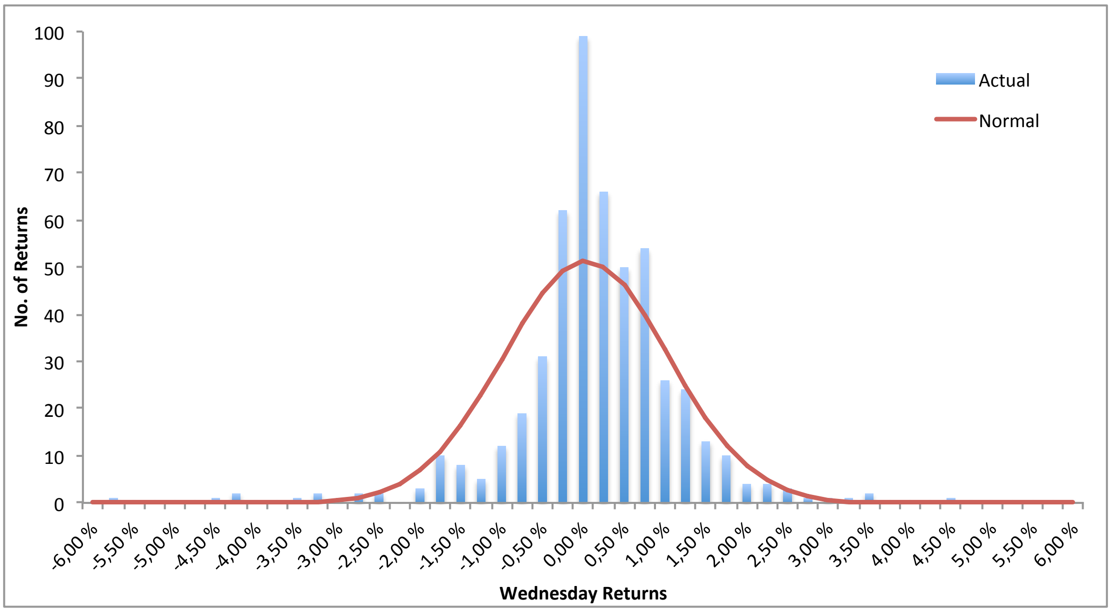

Figure 10: The sample and fitted normal distribution of the Wednesday returns for the "third" maturity group during 1992-2012.

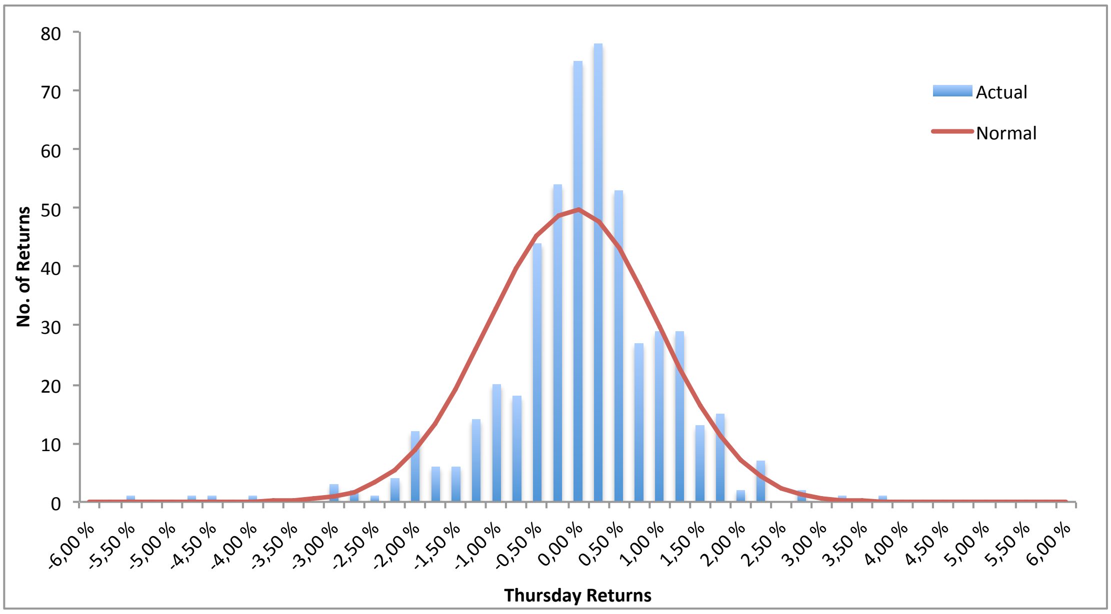

Figure 11: The sample and fitted normal distribution of the Thursday returns for the "third" maturity group during 1992-2012.

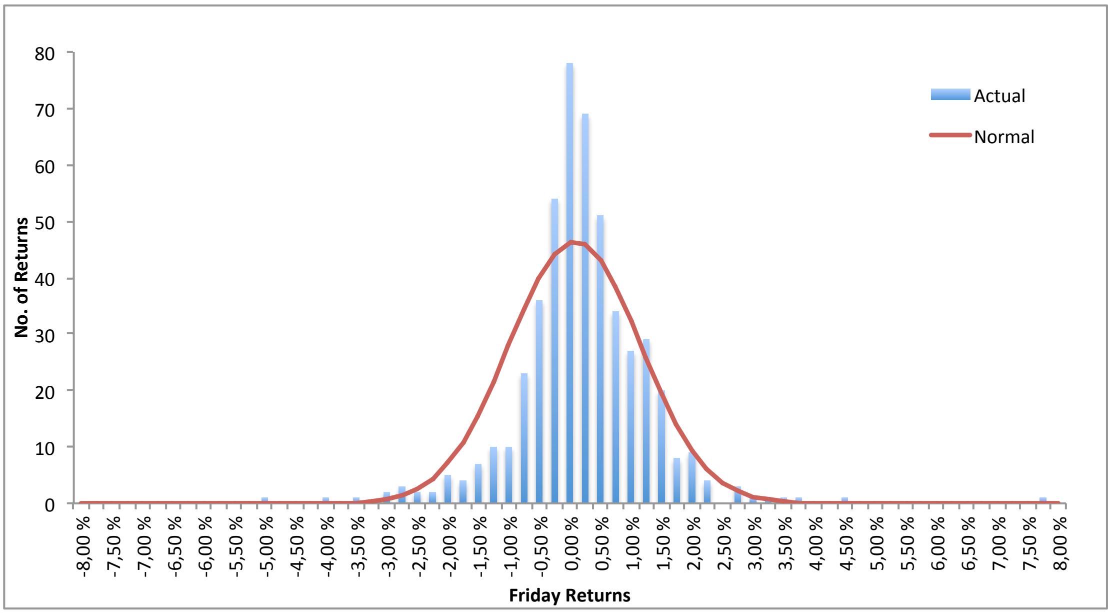

Figure 12: The sample and fitted normal distribution of the Friday returns for the "third" maturity group during 1992-2012.

5. Graphical presentation of the sensitivity of option pricing

Following is a graphical presentation of the percentage undervaluation, for the four option groups, when pricing a call option according to the Calendar-Time Hypothesis with deltas of 10%, 25%, 50% and 75%.

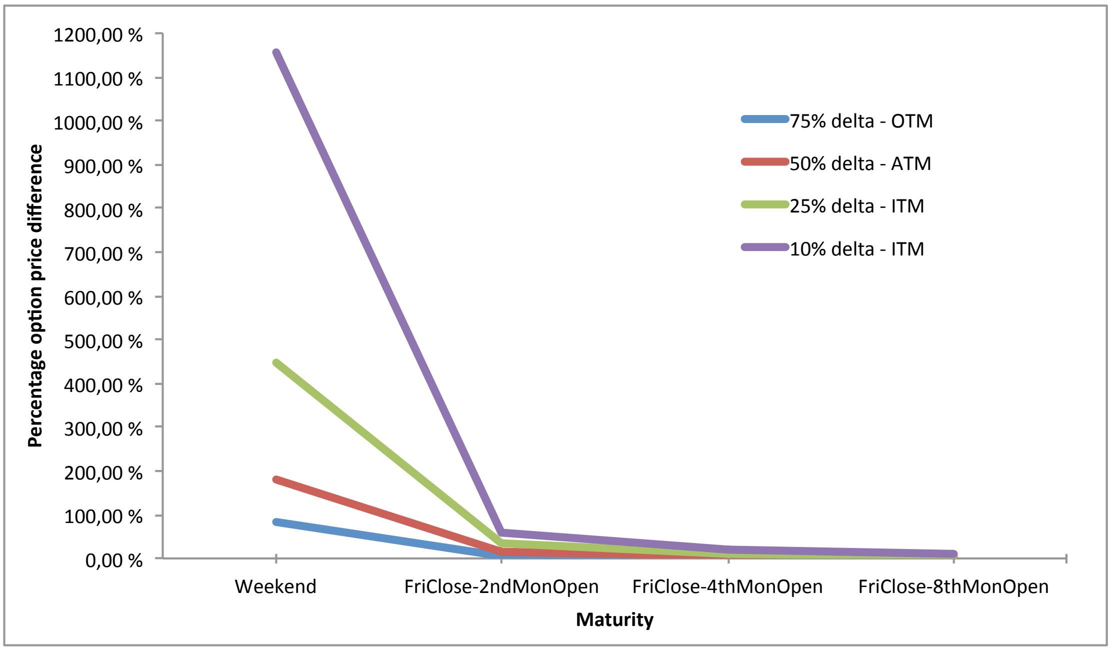

Figure 13: Percentage overvaluation resulting from calendar day volatilities for the first option group – call option with deltas of 10%, 25%, 50% and 75%.

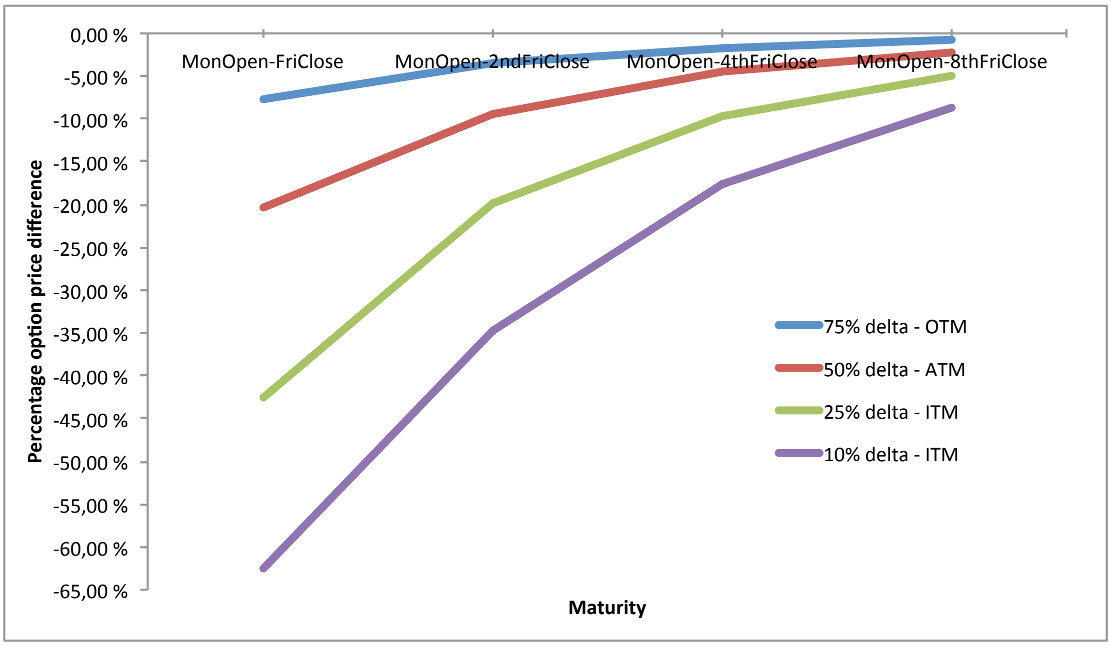

Figure 14: Percentage undervaluation resulting from calendar day volatilities for the second option group – call option with deltas of 10%, 25%, 50% and 75%.

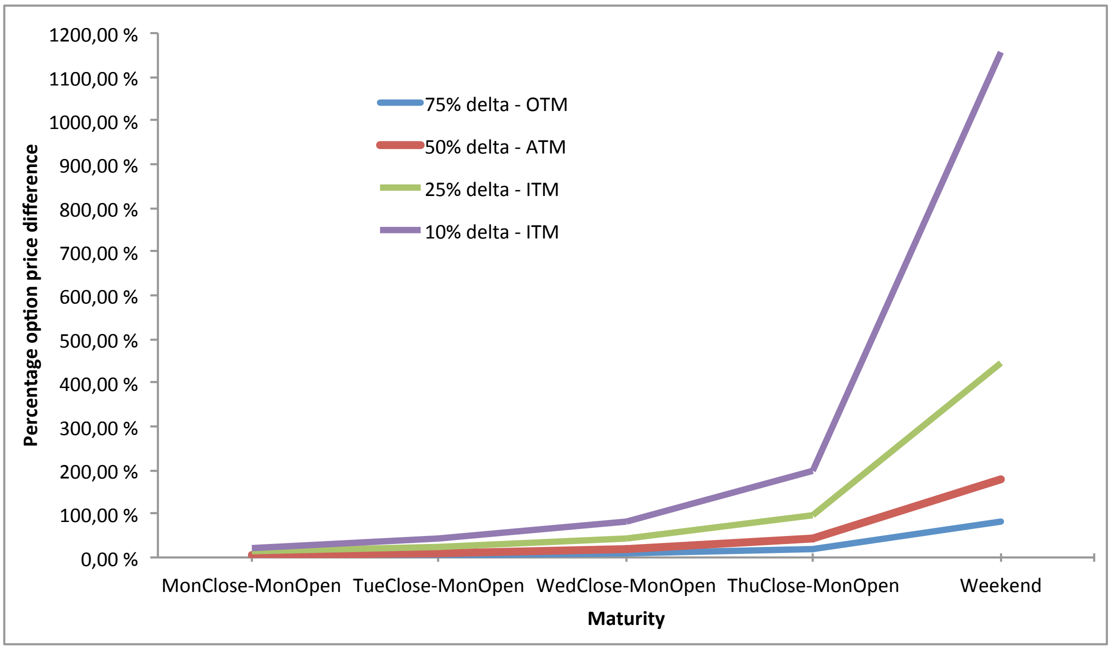

Figure 15: Percentage overvaluation resulting from calendar day volatilities for the third option group – call option with deltas of 10%, 25%, 50% and 75%.

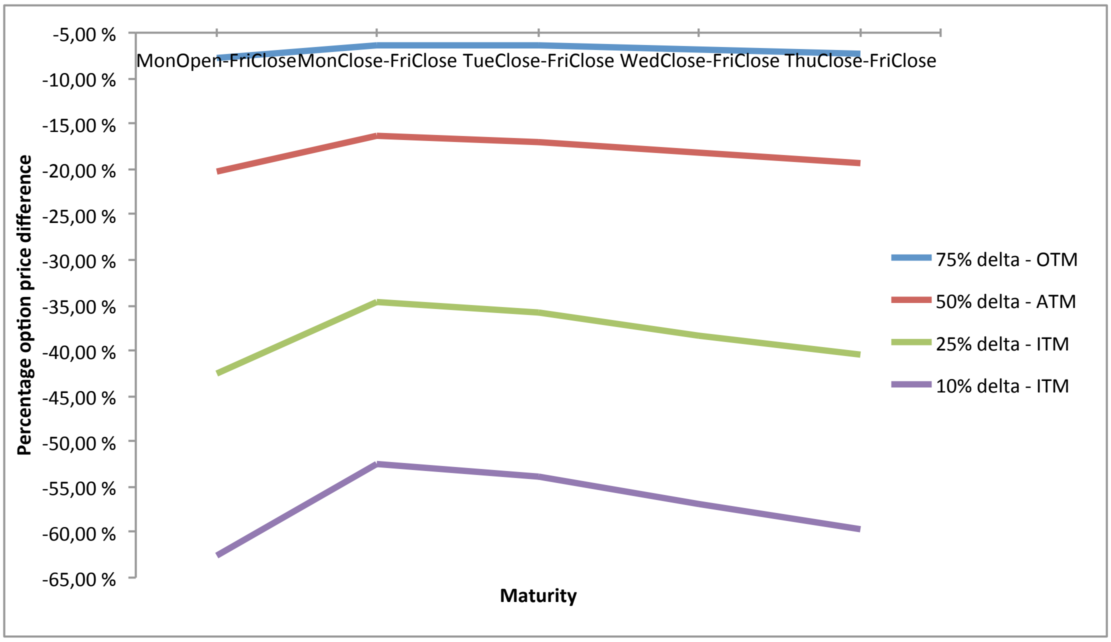

Figure 16: Percentage overvaluation resulting from calendar day volatilities for the fourth option group – call option with deltas of 10%, 25%, 50% and 75%.