Changes in the creditability of the Black-Scholes option pricing model due to financial turbulences

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Abstract:

This study examines whether the performance of the Black-Scholes model to price stock index options is influenced by the general conditions of the financial markets. For this purpose we calculated the theoretical values of 5814 options (3366 put option price observations and 2448 call option price observations) under the Black-Scholes assumptions. We compared these theoretical values with the real market prices in order to put the degree of deviations in two different time windows built around the bankruptcy of Lehman Brothers (September 15th 2008) to the test. We find clear evidences to state that the Black-Scholes model performed differently in the period after Lehman Brothers than in the period before; therefore we are able to blame this event for our findings.

Keywords:

Investments, Black-Scholes model, financial crisis, option pricing, StockholmOMX30, Lehman Brothers’ bankruptcy
Summary

This present thesis “Changes in creditability of the Black-Scholes option pricing model due to financial turbulences” aims at exploring and explaining if there are significant differences in the reliability and validity of the Black-Scholes model in two periods which are characterized by different returns and volatilities. The purpose is to examine the quality of theoretical prices derived from the model by comparing “normal” and “abnormal” trading days.

The first chapter will introduce the reader to the option background and point out the emergence and discussion of the research problem. In the end of this chapter a disposition of the entire process will be given. Chapter two illustrates the general methodology applied in this work. The methodological design as well as methods of data collection will be discussed.

The theoretical framework is presented in chapter three: there we provide more details about options and option trading, explain the origin of the Black-Scholes model, its input variables, restrictions and how it is applied. Furthermore, a summary covering the main causes and key happenings of the financial crisis which resulted in the bankruptcy of Lehman Brothers on September 15th will be given. We chose this date as a benchmark which divides the time horizon of the research into two windows of the same length. This is in order to ensure that the weight of each window is well balanced among our data sample. The horizon goes from the beginning of June until the end of December 2008. For this period we analyzed 3366 put option contracts and 2248 call option contracts on the StockholmOMX30 index.

After that, the thesis provides an overview about all data selection, preparation and organization issues that were necessary prior to the empirical investigation. The latter was done in three steps. First, we conducted an explorative data analysis by looking at graphs of the options’ time series. Then we continued with a descriptive investigation considering mean, standard deviation, minimum and maximum values of the deviations between market and model prices to finally end up with the final inferential testing of hypotheses which have been stated based on the descriptive investigation.

The results we found are very interesting. From the descriptive and inferential statistics we learn the lesson that there are indeed significant differences between the magnitudes of percentage deviations in the period after compared to the period before Lehman Brothers’ failure. In particular it is possible to argue that the Black-Scholes model does not fit properly during financial turbulences, when sudden changes in the most important input variable, the volatility of the underlying asset, occur\(^1\).

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Table of contents

Definitions ......................................................................................................................... 1

1 Introduction .................................................................................................................. 6
  1.1 Option trading: from history to present day ............................................................ 6
  1.2 A first impression of options .................................................................................. 6
  1.3 Emergence of the problem .................................................................................... 8
  1.4 Discussion of the problem .................................................................................... 8
  1.5 Formulation of the problem and purpose of the research ...................................... 9
  1.6 Limitations of the approach .................................................................................. 10
  1.7 Disposition of the thesis ....................................................................................... 10

2 Research methodology ................................................................................................. 11
  2.1 General motivation and academic background ...................................................... 11
  2.2 Academic design ................................................................................................... 11
  2.3 Interpretational pattern ......................................................................................... 11
  2.4 Research strategy and specific approach ............................................................... 12
  2.5 Data research methodology .................................................................................. 12
  2.6 Reliability, validity and replication of the research ................................................ 13
  2.7 Data sources .......................................................................................................... 14

3 Model world and theoretical frame .............................................................................. 15
  3.1 Introduction into option trading ............................................................................ 15
  3.2 Options .................................................................................................................. 15
  3.3 The Black-Scholes pricing model .......................................................................... 18
    3.3.1 The Geometric Brownian Motion ................................................................... 18
    3.3.2 The Black-Scholes formula ........................................................................... 19
  3.4 Critical discussion .................................................................................................. 20
    3.4.1 The no-arbitrage assumption ......................................................................... 20
    3.4.2 The Geometric Brownian Motion assumption .............................................. 20
    3.4.3 The short-selling assumption ........................................................................ 20
    3.4.4 The no-transaction cost assumption .............................................................. 21
    3.4.5 The riskless instrument assumption and the no-dividend assumption .......... 21
    3.4.6 Justification of the Black-Scholes approach in this thesis .............................. 21
  3.5 Main happenings of the financial crisis .................................................................. 22

4 Data processing ............................................................................................................ 25
  4.1 Basics about quantitative data analysis ................................................................. 25
  4.2 Market differentiation and research horizon ......................................................... 25
  4.3 Data collection process ......................................................................................... 26
Changes in the creditability of the Black-Scholes option pricing model due to financial turbulences

4.3.1 Black-Scholes input variables ................................................................. 26
4.3.2 Data selection methodology ................................................................. 27
4.4 Data preparation and organization ......................................................... 28
  4.4.1 Calculation of theoretical prices ......................................................... 28
  4.4.2 Working with different types of values ............................................. 28
  4.4.3 Trading day averages of differences vs. singly observed differences .... 29
  4.4.4 Calculation of differences and subdivision of the data..................... 29

5 Empirical analysis and inferences ................................................................. 31
  5.1 Purpose and construction of the empirical investigation .................... 31
  5.2 Explorative data analysis ................................................................. 31
  5.3 Descriptive statistics ................................................................. 33
    5.3.1 Measure of sample location and dispersion .............................. 33
    5.3.2 Singly observation based examination of real percentage differences 37
  5.4 Inferential statistics: Hypothesis testing ........................................... 42

6 Concluding discussion .............................................................................. 45
  6.1 Main findings ......................................................................................... 45
  6.2 Reflections of the authors ....................................................................... 46

Reference list .............................................................................................. I
  Academic papers ......................................................................................... I
  Books ........................................................................................................... II
  Organizational reports ........................................................................... II
  Websites .................................................................................................... III

Appendix 1 ................................................................................................. VI
Appendix 2 ................................................................................................. VII
Definitions

American option type
The incorporated right in the option can be exercised at whatever time before or at the expiration date (Bloomberg 2010a).

Arbitrage

Arbitrage means that the investor is able to make returns above the risk free interest rate without taking any risky position. This possibility is often excluded in financial mathematics, as it simplifies model theories. Furthermore, the no-arbitrage assumption is maintainable because if there were possibilities to make arbitrary earnings, they would have been already realized, since many investors are continuously looking for those.

At the money

Call and put options are defined at the money when the stock price equals the strike price (NYSE Euronext 2010d).

Bear spread

This strategy is used when you believe prices are about to decline. A bear spread in call options is designed to make profits by buying call option contracts with a certain strike price and selling call option contracts on the same underlying asset with a lower strike price but with the same expiration date. A bear spread using put options is created by buying put option contracts with a high strike price and selling put option contracts with a lower strike price (The Free Dictionary – Financial Dictionary, 2010a).

Bull spread

This strategy is used when you believe prices are about to rise. A bull spread in call options means buying call options on the underlying asset with a certain strike price and selling call options on the same asset with a higher strike price but with the same expiration date. On the other hand a bull spread in put options is created by buying put options with a low strike and selling put options with a higher strike price but, as said before, the contracts must have the same expiration date (The Free Dictionary – Financial Dictionary, 2010b).

Buyer of an option

The party that buys the option or in general any kind of derivative instrument has the right to buy the underlying asset at expiration date for the pre-specified price (Bodie, Kane & Marcus, 2003, p. 649).
Call option

This type of contract gives the holder the right to buy the underlying asset (Longman Business English Dictionary 2010).

Derivative

A derivative is a security whose value is completely derived from the value of an underlying asset.

Equity option

Options on stocks and option on stock indices are called equity options.

European option type

The investor can exercise the option only at the expiration date of the contract (Bloomberg 2010b).

Exercise price

See definition of strike price.

Expiration date

See definition of maturity.

Holder of an option

See definition of buyer of an option.

In the money

A call option is called in the money when the stock price is above the strike price, while a put option is in the money when the stock price is below the strike price (NYSE Euronext 2010c).

Intrinsic value

At any time the intrinsic value of a call option is given by the difference between the current market price of the underlying asset and the strike price. If the difference is negative, the intrinsic value is equal to zero. For a put option the intrinsic value is given by the difference between the strike price and the current market price of the underlying asset. If this difference is negative the intrinsic value is equal to zero (Business Dictionary 2010a).
Maturity

The *maturity* is the run-time specified in a derivative contract. The contract can only be exercised within or at maturity, depending on the type of the contract (*American* or *European*).

Moneyness

The *moneyness* of an option measures whether the option would have a positive monetary value if it was expired immediately or not. One can distinguish between three types of moneyness: *out of the money*, *at the money* and *in the money*. Look for these definitions separately.

Mortgage

A *mortgage* is a real property (e.g. a building) owned by the borrower and serves as security for the lender to protect him from the case of credit default. It usually includes specified periodical payments and interest rates (Etzel B. J., 2010, *Webster’s New World Finance and Investment Dictionary*, Wiley Publishing Inc., Indianapolis).

Open interest

*Open interest* is the total number of the outstanding option contracts (Chicago Board Options Exchange 2010b).

Option

An *option* is a financial contract that gives the buyer the right, but not the obligation, to buy or sell a specified quantity of an underlying financial or real asset at a given strike price and maturity (Financial Times 2010).

Out of the money

A call option is called *out of the money* if the strike price is above the market price of the underlying asset, while a put option is *out of the money* if the strike price is below the market price of the underlying asset (Chicago Board Options Exchange 2010a).

Premium

Option buyers pay a *premium* to receive the right to exercise the contracts. The premium is therefore the price paid for the option and it cannot be turned back to the investor whether the option is exercised or not (NYSE Euronext 2010b).

Put option

Differently from a *call option*, this contract gives the buyer the right to sell the underlying asset (NYSE Euronext 2010a).
Changes in the creditability of the Black-Scholes option pricing model due to financial turbulences

Put-call parity

This is a parity that always holds for put and call options that are written on the same underlying, have the same strike price and expire at the same expiration date. In equations with call price $C$, put price $P$, strike price $K$, interest rate $r$, time to maturity $T$ and the underlying asset $A$:

\[ C_0 + Ke^{-rT} = P_0 + A_0 \]

Replicating strategy

The idea of a replicating strategy is to shift the money invested in a portfolio between a risky asset and a riskless security. Thereby it is possible to create a position that should have the same payoff as the portfolio if the no-arbitrage principle is accepted (Bodie et al., 2003, p. 712).

Risk free interest rate

A risk free interest rate is simply the rate of return for investments that are totally risk free. In other words it is the price that a borrower has to pay to the lender as compensation for the time factor of the loan (NYSE Euronext 2010f).

Self-financing strategy

A self-financing strategy is a strategy that needs no outside funding. For instance, within a certain portfolio the purchase of an asset is financed by a sale of another asset.

Seller of an option

The seller gives the right to exercise the option to the buyer and has no influence on his decision at expiration date. He must be authorized by the stock market regulations (Bodie et al., p. 650).

Short-selling

Short-selling describes a certain investment strategy wherein the investor borrows an asset and then sells it to someone else. He is, so to speak, “short” in this particular asset but sells it regardless. This strategy includes remarkable risks, as the short-seller has to buy the asset on the market at the end of the borrowing period in order to give it back to the borrower. This strategy is one way to speculate on decreasing asset quotes.

Spot price

The price an underlying currently has is called spot price.

Stock index option

This type of financial instrument allows the investors to buy a call/ put option based on stock indices of several markets or industries without having to buy every individual
Changes in the creditability of the Black-Scholes option pricing model due to financial turbulences

stock (Business Dictionary 2010b). This includes that investors have less transaction costs when they seek to have a rather diversified portfolio. Option valuation by means of option-pricing techniques is exactly the same whether it is done for stock index options or ordinary stock (Chriss, 1996, Black Scholes and Beyond).

**Strike price**

The *strike price* indicates the price at which the investor can exercise the right to buy or to sell the asset (Bloomberg 2010c).

**Time value**

The portion of the option price that is attributable to the amount of time remaining until the expiration of the contract is called *time value*. It is the value the option has beyond its intrinsic value (Chicago Board Options Exchange 2010c).

**Underlying**

The *underlying* is the item based on which a derivative contract is written. Typical underlyings are indices and stocks but every commodity could come into consideration as an underlying asset as well.

**Volatility**

This is the most common measure of the fluctuations of the price of a financial or real asset. From the statistical point of view *volatility* is often calculated as the annualized standard deviation of returns (NYSE Euronext 2010e).

**Writer of an option**

See definition of *seller of an option*. 


1 Introduction

1.1 Option trading: from history to present day

The very first ‘option’ in financial history dates back to ancient Greece. One of today’s most important derivative instruments was originally devised by Thales, a Greek astrologer and mathematician. It is said that he was able to forecast future olive harvests by observing the position of stars and other celestial bodies and in some years, he predicted an extraordinary good upcoming harvest. Based on this knowledge he negotiated and bought contracts from every olive press owner in the area. These contracts gave him the right to lease the olive presses when the harvest was ready. The press owners saw the chance not to only receive the leasing price but also to have the extra premium of the contract. Thales agreed with them upon leasing prices but did not pay for the lease in advance, thus, if the prediction of the harvest had turned out to be wrong he would not have had to lease the presses and only would have lost the prepayment. Indeed, his forecast appeared to be true, and because Thales had leased all the presses he was able to demand almost every price from the olive farmers (Wilmington Trust, 2010). This idea of paying for the right to buy something is still the basic idea in modern option trading which we are going to introduce in the following paragraph.

Ordinary stock has been traded since the 19th century. During the 20th century, new financial products such as derivatives have been developed and have become more and more important. The most commonly traded derivatives are futures/forwards, swaps and options. In this research we are going to focus on options because they are the most interesting: there are several problems in assessing a more or less correct price for them. The first time options were listed in an official US market was in 1973 at the Chicago Board of Options Exchange. Since that date there has been a remarkable increase in the derivative market, especially in option trading and many countries besides the US established exchange boards for derivatives. The exchange board for both stocks and derivatives in the Swedish market is the Stockholm stock exchange which belongs to the NASDAQ OMX group (“Optionsmäklarna Stock Exchange”). Just to illustrate the importance of derivative markets in numbers, during 2009, the average daily trading volume in NASDAQ OMX derivative contracts amounted to 407,728 compared to only 219,689 in ordinary share products (Nordic Nasdaqomxtrader, 2010).

1.2 A first impression of options

Options are financial contracts between two parties, the buyer and the seller, and they are linked to a certain underlying asset, e.g. stocks, commodities, stock indices, currency rates or interest rates. The buyer or holder of an option has the right but not the obligation to buy or sell a pre-specified quantity of the underlying asset at a pre-specified price (Financial Times, 2010). Two types of options are thinkable; either expiration during the whole contract period is allowed (American style) or expiration is only possible at the final expiration date (European style). The purpose of buying an option can either be speculation or hedging. In the first case the investor takes a risky position based on his anticipation of the future market development. In the other case the hedger simply wants to cover his risky position against undesirable events. As
opposed to the speculator, the hedger only wants to hedge against losses and abandons possible gains in his position. But what is the incentive for the other party within an option contract, the option seller? As opposed to the buyer, who either wants to speculate or hedge, the seller’s incentive to agree to an option contract is the possibility to earn the premium that the buyer has to pay for his right. Remember the pre-payment that Thales had to pay for his contracts. One can compare the motivation of the olive press owners in the aforementioned story to the basic idea that underlies option contracts. The seller earns the premium as final payoff when the option is not exercised by the buyer, while this chance is the incentive for the seller of an option. In short, the seller of the option has opposite expectations with respect to the underlying asset’s price movements than the buyer (Bodie et al., 2003).

One of the most important factors in an option contract is the premium at which the contract is settled. It simply represents the price the buyer has to pay for the right to expire the option. The problem is to compute a fair premium which takes into consideration all the relevant factors. These include the current price of the underlying asset, the underlying asset’s volatility, the strike price of the option, the time to maturity and the risk free interest rate. This problem has been discussed since option trading has been introduced. The first model that included all aforementioned relevant factors was the Black-Scholes model, developed by Fischer Black and Myron Scholes in 1973 (Black & Scholes, 1973). Their approach came up with the famous Black-Scholes-Formula for option pricing. In the same year, Robert Merton published an extension which led in the winning of the Nobel Prize in 1995 along with Myron Scholes. Other models have been developed later on: there has been a lot of research due to high interests of the option industry in good pricing techniques. But all approaches that differed from the one Black and Scholes used, appeared to be much more complex in terms of a practical application than the Black-Scholes-Formula, in which we only have to deal with a formula in an analytical model. This means we can use simple calculus with several observable input variables to estimate the option price. Other models, like for instance the Cox-Ross-Rubinstein model introduced in their paper in 1979 (Cox, Ross & Rubinstein, 1979) need much more effort to estimate a theoretical price than the Black-Scholes model. Without going into detail, in this case the high effort originates from the fact that they use the binomial tree approach and thus get the theoretical option price from an iterative valuation process. Iterative valuation involves an application of high computer power and is therefore not very useful for everyday option pricing. This short digression shall merely serve to better understand why some models can indeed be valuable from a theoretical point of view but present huge disadvantages in their practical application. Since then, even more models have been introduced but the Black-Scholes model is undoubtedly still the one with the highest popularity.

In our research we want to focus on one still very popular model. The fact that the Black-Scholes model is still taught in every finance lesson and often mentioned in actual finance literature seemed enough evidence for us to assume that Black-Scholes still plays an important role in the finance world and still is a common tool to calculate theoretical option prices. This shall serve as a justification to put Black-Scholes theory to the test and not any other option pricing model.
1.3 Emergence of the problem

This section shall serve as an explanation of the main reasons how and why we discovered this particular research problem and why we decided to delve into it. During our studies in the master program of finance at Umeå School of Business and Economics (USBE) we attended the lecture “Investments”, which was about different investment strategies and their correct valuation. During this course we were also confronted with derivatives and corresponding pricing models and it was the first time the Black-Scholes option pricing model was presented to us. At this time the option pricing context was already fascinating for us and therefore it did not take long to decide on the general research field for the master thesis. From the very beginning we knew that we would like to increase our knowledge in this area.

Next, we started with some literature research to get an idea of the current state of research and to possibly find an interesting question that had not been answered so far. Surprisingly, we did not find much literature pursuing an approach which puts the Black-Scholes model during the financial crisis in 2008 to the test. In fact, as this event was quite interesting for many finance experts we expected to find research in this direction as well. This realization encouraged us to combine the Black-Scholes theory with this important event. From now on, we focused our literature research more on this particular direction and advantageously, since we are so to speak an English-Italian-German speaking research team, we were able to look for specialist literature in each of the three languages. One article (Pape & Merk, 2003) that we found on a German database appeared to become an especially important reference concerning our study approach. This article gave us a lot of inspiration for two reasons: first, this research was also about the Black-Scholes model. But secondly – even more essential for us – the way empirical information was included and how the data was investigated in this article seemed to be a fairly persuasive research method. We immediately saw that we could use a similar approach to do some research based on both, the Black-Scholes theory and empirical data somehow related to the financial crisis. In the next paragraph it is discussed how our particular research problem arises due to the financial crisis.

1.4 Discussion of the problem

The following paragraphs are going to shortly present the main happenings that occurred during the financial crisis in 2008 and led to Lehman Brothers’ bankruptcy on September 15th. Furthermore, we will show some aftermaths of the crisis on the derivative market to make clear that the crisis and option pricing models are an interesting combination of topics. Finally, we will come to this section’s main purpose namely, providing a direct connection to section 1.5 the Formulation of the problem.
During 2008, the situation on the financial markets became more and more stressed. One important trigger was the market for CDSs\textsuperscript{2} (more detailed in chapter 3.5) which affected the interbank market and financial markets all over the world. The first disaster occurred on March 14\textsuperscript{th} when Bear Stern collapsed. After that, the month of September 2008 is considered the most representative month to depict this crisis, since a lot of worst-case events took place: it began with Lehman Brothers’ failure on September 15\textsuperscript{th}, continued with the turn of Washington Mutual on the 25\textsuperscript{th} and ended with the Wachovia take over on the 29\textsuperscript{th}. Because of these events the panic started to proliferate in the financial markets and the world stock index level, measured by MSCI World Index\textsuperscript{3}, crashed by 42 percent during 2008. Only after losing another 25 percent in 2009 did the index start to move up again thanks to the active recovering role played by the main Central Banks that flooded liquidity into the financial system in order to re-establish confidence among investors.

Clearly, the crash of the MSCI World Index meant a massive down turn to the financial market. Since stock and stock indices serve as underlying assets for equity options there have been great effects on the option market as well. This is why we are convinced that the crisis in 2008 has all the necessary characteristics for a financially turbulent period that we need for our analysis. The main happenings already taught us that the last financial crisis had effects on prices, especially prices of financial products such as derivatives. This is why we consider a period that starts some months before Lehman Brothers’ bankruptcy and ends some months after it as very informative; it contains 'normal' months in terms of economic turbulences as well as 'abnormal' months. In the end, we are able to compare one period with the other. One of the hypotheses that could be interesting to check is, whether the reliability of the Black-Scholes model varies between two such different periods. The key question or the crucial problem that guides us throughout the entire research is accordingly expressed through the following Formulation of the problem and purpose of the research.

1.5 Formulation of the problem and purpose of the research

Similarly to the hypothesis we stated in the previous paragraph we can sum up the key question of the research as follows: Is there a significant difference between the ability of the Black-Scholes model to assess the real index price whether we consider a 'normal' or an 'abnormal' period?

In other words, the purpose of this study is to find out if there are remarkable differences in the reliability of the Black-Scholes model whether it is applied during ‘normal’ trading days or during ‘financially turbulent’ trading days. This means we want to examine if there is any significant influence of the general market condition on the creditability of results of this model. We conduct this investigation based on StockholmOMX30 index\textsuperscript{4}. If we find significant statistical support for the statement that the market condition has an influence on option pricing quality we could conclude

\textsuperscript{2} Credit Default Swap: an insurance contract in which a lender transfers the risk to another party who is compensated by a series of agreed-upon payments. One party agrees to pay to the other party a fixed periodic payment, while the other party agrees to compensate the first party in the event of certain credit events, such as bankruptcy, default or credit restructuring (Scott, 2010).

\textsuperscript{3} Morgan Stanley Capital International index is one of the most important indices worldwide. It serves as reference index for many other indices and equity funds (Morgan Stanley Capital International, 2010).

\textsuperscript{4} The composition of StockholmOMX30 is given in the Appendix 2.
that the model suffers from greater lack of reliability during periods like the financial crisis in 2008 than it does during ‘normal’ periods.

1.6 Limitations of the approach

When considering the main happenings of the financial crisis one could also state that a natural thesis task would have been to examine these changes in the market after the bankruptcy of Lehman Brothers and compare the two situations before and after this event: however, our approach goes beyond that. In our event study we are interested in finding out how the crisis influenced the Swedish option market and how the Black-Scholes model ‘performed’ during the chosen research horizon. We are not going to analyze whether the Black-Scholes model is good or bad in pricing options but we want to find out if we can draw some conclusions from changes in deviations between real market index prices and theoretical index prices. But there are in fact two main limitations inherent in our research: firstly, we only focus on the Swedish stock and option market and also only on StockholmOMX30 index. This could be problematic in terms of extending our findings to other countries. Secondly, we of course have a restrictive time window and cannot be sure that both, a longer or a shorter choice of research horizon would have led to similar results.

1.7 Disposition of the thesis

The structure of the thesis will be as follows: the next chapter deals with the basic information and definitions about a common frame of a good methodological process. It presents those recommended principles that should be considered with respect to a reliable and valid research project in business administration.

Chapter three discusses details about options and option trading, the Black-Scholes model and its restrictive assumptions as well as its main shortcomings. The model will be introduced from an aplier’s perspective, thus without the entire mathematical derivation of the theory. Moreover, a short overview of the main happenings and the origin of the financial crisis are given as well as how the important benchmark for our work, Lehman Brothers’ bankruptcy, was reached.

Chapter four is meant to give an overview of the whole data collection and processing issues. In particular we will explain all steps that were necessary to obtain a data design which is suitable to run the calculations with the model as well as criteria for the subdivision of findings.

In chapter five, we will finally confront the Black-Scholes model with the “real world”, or the collected data. Moreover, it contains a detailed evaluation of this comparison. Thus, the summary of the main results and the final conclusions is presented in chapter six. The very last paragraph of this thesis relates to a reflection of the learning process and an academic outlook for the research area.
2 Research methodology

2.1 General motivation and academic background

Before starting to work on this research study we differed between two types of knowledge: our general knowledge and the diagnostic knowledge. The general knowledge incorporates knowledge and experience the researcher has acquired during his entire academic life but it does not include special studies for a better understanding of the particular field of the problem. The general understanding that we, as authors of the thesis, have acquired comes from several years of university studies in Italy and Germany respectively and, of course, at Umeå University. Especially the Financial Management course at USBE provided good basics and suggestions for this research. Furthermore, the fact that we have different academic backgrounds – finance and business mathematics respectively – contributed to form an optimal composition for a well-grounded study of the problem. Thus our former education was good preparation to increase our diagnostic knowledge and be able to understand the literature in option theory with its complicated pricing models.

The diagnostic knowledge on the other hand consists mainly of the skills the researcher acquires during his concrete problem analyzing process. It includes pre-studies of details related to the deeper environment of the problem and studies of specialist literature and earlier research results. For us these academic pre-studies have been really useful to get more information about how to organize an optimal process of thesis work and increasing our diagnostic knowledge also helped us in defining and formulating the problem of our thesis. All in all, we feel to have a good academic foundation to conduct the research.

2.2 Academic design

The term ontology serves to describe how the researcher looks at reality and certain observations. We have to make a distinction between objectivism and constructionism: objectivism is defined as an independent view on certain phenomena. It means that the real world is only considered objectively, that is the researcher does not intervene in his study environment with personal interpretations. On the other side, the term constructionism refers to the opposite philosophical theory stating that social and economic phenomena are emerging in a changing context and thus are influenced by social actors. The constructivist approach would be, for instance, research that is done based on interviews where the researcher also has to build a kind of particular “reality” (Bryman & Bell, 2007, p. 22-23). However, the approach in economics and finance often tends to be objectivistic since the researcher has to deal with a given reality. This is of course also the case within our research.

2.3 Interpretational pattern

The term epistemology mainly refers to the nature or the scope of knowledge. An epistemological consideration regards the problem of what should be judged by the researcher as “acceptable knowledge” while conducting a study. Epistemology distinguishes between two different types of knowledge: positivistic and interpretivistic
knowledge. In approaches based on positivism, methods known from the natural sciences are applied to explain general phenomena. Only what can be verified empirically is considered knowledge which means that the main purpose is to generate statements and test them. On the other hand interpretivism is not anchored in the natural sciences context and it is substantially built on the assumption that subjective knowledge describes the world (Ibid, p. 16).

Therefore, this thesis acquires to follow a positivistic approach as the judgment of models should be derived from a clear objectivistic perspective. Our conclusions will be based on descriptive statistics (see next paragraph) rather than interpretivistic methods.

2.4 Research strategy and specific approach

In combining theory and praxis in an academic paper there are also two different types of research strategy: deductive and inductive. The inductive knowledge moves from specific observations to broader generalizations and theories. Informally, this approach is called bottom-up. It starts with specific observations and measures and it continues with the detection of pattern and regularities. The third step regards the formulation of some tentative hypotheses that can be explored. Finally, the process ends up with the development of general conclusions or theories. An inductive approach always includes an implication of new findings (Web Center for Social Research Methods, 2010a). On the other hand, the deductive knowledge is used to work from a general perspective to a more specific one. Sometimes this is informally called top-down approach and it starts with the explanation of the theory about the topic of interest. The second step provides the formulation of specific hypotheses that have to be tested and continues with the collection of observations to assess the hypotheses. Then, it confirms or rejects the theory. Inductive reasoning is more open-ended and explanatory, while deductive reasoning is narrower and more related to the testing of the hypothesis. In our thesis we have decided to start from theory and apply it to a specific problem. In the end, we will conduct hypotheses testing and receive statistical support in favor or against the theory. So, we are going to adopt a deductive (sometimes also referred as descriptive) approach rather than an inductive one.

2.5 Data research methodology

There are two types of research methodologies that have to be distinguished: a quantitative or qualitative method. This distinction goes side-by-side with the one from section 2.4. The quantitative strategy is an empirical investigation of questions the researcher formulates on the collected data. It usually uses hypothesis-testing with the aim of coming up with a result that rejects and excludes a certain preliminary guess. More detailed, this approach consists of deductive statements focusing on a verification of already existing theories. This verification is done by means of statistical examinations and analyses. In our work we decided to use this methodology because we do not want to extend or improve the Black-Scholes model. Instead, we adopt it as a measure to verify its creditability during different market conditions. Thus the idea of increasing our knowledge is the main motivation for the research. In other words, our study is driven by a student’s perspective and not for instance by a shareholder’s, broker’s or rating agency’s perspective.
Changes in the creditability of the Black-Scholes option pricing model due to financial turbulences

The different qualitative approach either consists of the analysis of human/social behavior in order to explain observations or behavioral phenomena in the social sciences, or consists of the implementation of new findings in a model or theoretical environment. This is not properly the approach we decided to choose because it would go beyond the scope of this thesis. We concentrate on a substantiated quantitative investigation.

2.6 Reliability, validity and replication of the research

In a business research, reliability is a general concept that relates to the extent to which the data collection techniques or analytical procedures yield to consistent findings. The concept of reliability is highly related to whether our results are repeatable. That is, we refer to this concept when we ask if the measures would yield the same results and similar observations if they were applied by other researchers, to other markets and different financial instruments. Shortly, reliability is a criterion to determine the transparency of the usage of the raw data. We are convinced that our thesis is highly reliable, because we have been inspired by two academic papers, Pape and Merk (2003) and Bodurtha and Courtadon (1987). Thus we can be sure that our methods did not only work in our case but already succeeded in former studies. Beyond this, the quantitative approach to test certain theories by the usage of empirical information is very common to produce realistic results in business administration and especially in finance (Yin, 2009, p. 40-45).

The second basic concept which is directly linked to reliability has also been taken into consideration: validity. Primarily, it concerns the problem whether the findings truly are what they seem to be. Particularly, the researcher should ask himself if the relationship between research result and research input is causal or not. In social science works a valid research should consist of measures which lead to valid conclusions or which enable to derive valid inferences. It must be underlined that measures, samples or designs are not valid on their own; the approach itself has to be valid thanks to valid propositions. In a business research, like the present one, we have to pay attention on some judgment criteria such as the way how the analyses and evaluations are done and evidence is derived. There are two possible approaches: either you want to test the market by comparing it with a model or you want to test a model by measuring its creditability by means of the market. The aim of this thesis is to test a model, thus it is based on real market data, in particular a stock index which grants to reflect a broad picture of the whole market. Accordingly, the final results are easier generalizable than results derived from a more specialized financial instrument. The second criterion in relation with validity is that there should be a high causality between observations and their origins. This can also be understood as having a clean research window without other things that may have caused the observations. In section 4.2 we are going to argue that we have such a clean research window and thereby a true causal relationship between our findings and the event of Lehman Brothers’ bankruptcy. (Saunders, Lewis & Thornhill, 2009, p. 156-157; Jankowicz, 2005, p. 5; Web Center for Social Research Methods, 2010b).

The third central element in evaluating academic business research projects is replication which is directly linked to the possibility for other researchers to replicate the findings. As soon as other researchers have access to the corresponding data it is
absolutely possible to do exactly the same event study on a different market or a different instrument. That is why we are going to give detailed information about all the procedures and analyses we have adopted throughout the work to the reader. Furthermore, we will provide our Excel tools we used for the preparation and organization of the data in the Appendix 1 to clarify these tasks (Yin, 2009, p. 40-45).

2.7 Data sources

In this research study we have used three electronic databases in order to collect all the financial data we needed for our analyses. The first and most important one is Thomson Reuters DataStream available at the library of Umeå University. According to the information published on the official webpage it is the world’s largest financial and statistical database that covers a wide range of asset classes, estimates, fundamentals, indices and economic data (Thomson Reuters, 2010). There we found all the historical prices and related information of Stockholm OMX30 call and put options as well as the continuously compounded measure of volatility. We also used data published by Sweden’s “Riksbank”. This is Sweden’s Central Bank that provides data for historical interest rates of Treasury Bills. For some general benchmarks and information on stock and derivative volumes we sometimes resorted to Nasdaq-OMX, the world’s largest exchange company delivering trading information, exchange technology and public services across six continents with more than 3700 listed companies (Nasdaq OMX, 2010a).
3 Model world and theoretical frame

3.1 Introduction into option trading

Option contracts are very useful because they satisfy the needs of the risk averse investor as well as the speculator. These types of financial instruments permit the adoption of long or short positions. It depends on the position whether the agent has a limited or unlimited downside risk and a limited or unlimited upside chance (more details in section 3.2). Besides this they allow trading with respect to an interesting factor: volatility. In this section we give a detailed picture of the background of option trading, reasons for and strategies beyond it.

The most attractive characteristic of options is represented by the insurance (hedging) they provide. It is possible, for example, to imagine an investor who holds a diversified portfolio of stocks and he decides to face the risk of a market downturn by buying market index put options. If the market goes up, the investor will benefit if we neglect the pre-payment of the premium because he holds stocks. If the market goes down he will only lose a maximum amount equal to the premium he paid for the option because he covered his risky stock position through the long position in the option (Bodie et al., 2003). Thus, the investor is able to earn a potential gain – if the market rises – and if the forecasts are wrong he is protected against it. Beyond this, options can also be used to take advantage of price movements with a limited risk exposure (speculation). In this case the same investor will take a long position in a call contract, which is characterized by an outlay for the premium and a potential gain if the market rises. Note that the obtained exposure is different from the one that would be generated by the purchase of the underlying asset. A direct investment in the underlying asset means that the investor will face the same gains as long as the market goes up but, his position is completely unprotected as soon as the market suffers from downturns. Contrarily, an investment in a long option position prevents the investor from unlimited downturn but also allows benefiting from upturns. With the purpose of reducing the initial outlay, but guaranteeing at the same time a hedging on the possible losses, an investor or hedger can also choose to build up some strategies given by a particular combination of different options. These strategies are for example, a bull spread when the expectations are for a light bull market, and alternatively a bear spread when the expectations are for a light bear market. The bull spread (bear spread) is built by the purchase (sell) of one call option with a lower strike price and by the sell (purchase) of a call option with a higher strike price but with the same time to maturity. Both strategies are also possible in put contracts with analogue structure.

3.2 Options

To begin, we will give the necessary definitions that are important to introduce option theory. Thus, the following can be to some extent overlapping with the definitions we gave at the very beginning of this thesis. Please check this alphabetical listing for more detailed explanations. In the following sections we will often refer to the book Black Scholes and Beyond: Option Pricing Models by Chriss Neil, 1996. There are plenty of specialist books dealing with the Black-Scholes model and we could have taken any as
Changes in the creditability of the Black-Scholes option pricing model due to financial turbulences

reference in this thesis but we decided to only refer to one source to have a harmonic presentation with consistent model notations and a reasonable theory construction.

Options are contracts which give the buyer (sometimes also denoted as the holder) the right to expire the contract whereas the seller (sometimes also denoted as the writer) has no option and must comply with the decision of the buyer. This decision depends on whether it is advantageous to expire the option. Expiration is advantageous if the option lays “in-the-money”, whereas an “out-of-the-money” option would not be exercised. The value of an option neglecting the option premium is specified as follows:

![Graphs of Call and Put options]

**Call-option:** buyer (long position)
\[
\text{Call - Payoff} = \max(A_T - F, 0)
\]

**Put-option:** buyer (long position)
\[
\text{Put - Payoff} = \max(F - A_T, 0)
\]

Source: Bluhm, Overbeck & Wagner, 2003

Herein, \(F\) denotes the strike price of the option that is the stipulated price for exercising the option at maturity, \(A_t\) denotes the spot price of the underlying asset at time \(t\) and \(T\) is assumed to be the time to maturity running from \(t = 0, \ldots, T\). A very important issue and
Changes in the creditability of the Black-Scholes option pricing model due to financial turbulences

to some extent also the motivation for this research is the difference between the value and the price of an option. If we talk about value we mean the intrinsic worth of the contract. In contrast to this, the price is what is actually paid for the contract when it is traded. Obviously, at expiration the valuation of an option is trivial and the price will be equal to the value, \( \text{price} = A_T \). But valuation some moments before expiration, i.e. for \( t < T \) can be a quite challenging task since no one is able to exactly assess what the option will be worth at expiration. Market prices before expiration only reflect future expectations but do not necessarily match with the true worth. This research does to some extent examine this contrast, but mainly focuses on differences within this contrast between different periods.

Besides the sheer size of the contract, every set of data to which a contract can be reduced in theoretical option pricing has now been introduced. During this thesis, it is the premium or the settlement price of the contract which lies at the center of attention. But to run theoretical analyses, even more input data is required and that is the interest rate for risk free securities and an estimate of the future volatility of the underlying instrument (Chriss, 1996, p. 25). To obtain an interest rate we accessed treasury bills issued by the Swedish “Riksbank”. This institution offers bills with maturity of 30 days, 60 days, 90 days, 6 months or 12 months. For our calculations of the theoretical option prices we always used the corresponding treasury bill that best fits the actual maturity of the option. We only considered options with expiration on January 23rd 2009 and compared their actual market prices with theoretical Black-Scholes prices between June 02nd 2008 and December 31st 2008. We decided to focus on January 23rd options because we needed data which cover the entire second half of 2008, which is of course true for January 23rd options. Moreover, we did not want to mix options with different expiration dates as we wanted our data to be as homogenous as possible. Different expiration dates would possibly have diluted our findings and complicated the final reasoning. For reasons of the scope of the available data, we decided to choose the next possible expiration date after the ending of our specified research horizon. The further you move away from this point, the less data covering the entire research window you will find.

The need for a realistic volatility of StockholmOMX30 was harder to satisfy. We learned from former research that it is often the volatility that evokes substantial deviations between actually observed and theoretical prices and thus finally led to great restrictions of many models. This problem will be discussed in more details in section 3.4. Concisely, we eventually had to decide between two alternatives, either to calculate implied volatilities during the months prior to our research period or to simply take the volatility data provided through Thomson Reuters DataStream. We decided to follow the latter alternative for two reasons: first using historical volatilities to calculate upcoming option prices would have led to huge distortions in calculations, since volatility also suffered from dramatic change due to the financial turbulences in 2008, and above all the bankruptcy of Lehman Brothers; secondly we realized that the time and scope to finish this thesis would not be sufficient to include advanced volatility forecasting models. So we decided to depend on the Thomson data for the volatility of StockholmOMX30.

Let us finally talk a little bit about the premium of an option. The difference between value and price has been explained above, but what is the premium’s relationship to these definitions? The premium of an option is simply the price the two parties within
an option contract have to agree upon. It is either a direct agreement ("over-the-counter contract") or a standardized format. The data we fell back on is of course of standardized format, traded on the Stockholm stock exchange. However, in option pricing theory, it is not the market premium that is in the center of attention but rather the fair value or theoretical value of the premium (Ibid, p. 26). This is exactly what the Black-Scholes option pricing model has been developed for. But before we jump into the calculation of theoretical values we will try to impart a better understanding of the formula.

3.3 The Black-Scholes pricing model

The Black-Scholes formula for call options has been developed by Fischer Black and Myron Scholes in 1973. It is based on some assumptions; primarily the no-arbitrage assumption. During the whole option pricing theory we assume that there are no possibilities to make arbitrary profits. As already mentioned in the definitions section this assumption is not very restrictive.

Further assumptions in the Black-Scholes world:

- The stock prices/ stock index prices follow a Geometric Brownian Motion.
- Short-selling is allowed.
- There are no transaction costs.
- There are always risk-free instruments such as treasury bills available.
- There are no dividend payments.

The very last assumption can be easily given up in a more general context. This was the main contribution of Robert Merton to this topic (Merton, 1973).

When we talk about pricing models we always have to accept that they are not predictive in the literal sense but probabilistic. That is, statements about the future are not precise, but rather these models assume that future prices follow a certain distribution derived from historical data and other relevant input data. The distribution assumption provides information which allows statements about the probability of future stock or stock index prices (Ibid, p. 94).

3.3.1 The Geometric Brownian Motion

The distribution assumption underlying the Black-Scholes formula is the Geometric Brownian Motion. This assumption is motivated through the following thinking according to “Black Scholes and Beyond” (Ibid, p. 98): “The return on a stock price between now and some very short time in the future is normally distributed.”

This means in equations:

\[
\frac{\Delta A_t}{A_t} \sim N(\mu \Delta t, \sigma^2 \Delta B_t) \quad \Leftrightarrow \quad \frac{A_t + \Delta t - A_t}{A_t} = \mu_A \Delta t + \sigma_A \Delta B_t
\]

Herein, \( A_t \) describes the price of the underlying asset at time \( t \), \( \mu_A \) and \( \sigma_A \) are fixed coefficients and \( B_A \) is the Standard Brownian Motion (Bluhm et al., 2003). According to
the Geometric Brownian Motion, the price of the underlying asset can now be derived and is defined as:

\[ A_t = A_0 \exp \left( \left( \mu_A - \frac{1}{2} \sigma_A^2 \right) t + \sigma_A B_t \right) \]

The derivation of this expression or the proof that this expression is indeed equivalent to the aforementioned thinking of stock prices’ behavior needs a deep understanding of calculations and techniques from stochastic mathematics, such as the solution of stochastic differential equations and stochastic integration. We will not deepen the theoretical derivation here and would like to recommend the specialized literature on this area. Interested readers may refer directly to Black & Scholes (1974), to Hull (2009), or to Bluhm et al. (2003).

### 3.3.2 The Black-Scholes formula

The Black-Scholes formula is ultimately derived from the no-arbitrage principle. The idea is to construct a riskless portfolio that is supposed to represent a self-financing replicating hedging strategy for the writer of the option. Self-financing means that the writer of the option does not have to finance this hedging position by himself but he can instead use the premium of the option to enter this position. Replicating means that the risky position in the option is covered in every case no matter in which direction the price of the underlying asset moves.

Let us now advance to the formula itself. It needs five input parameters:

- The price of the underlying \((A_t)\) stock or stock index at time \(t = 0\).
- The risk-free interest rate \((r)\) that is the rate of Swedish treasury bills in our case.
- The strike price \((K)\) of the option.
- The time to maturity \((T)\).
- The volatility \((\sigma)\) of the underlying stock or stock index.

After more detailed considerations using the idea of a self-financing replicating strategy for the option and the fact that this strategy can be built on a normal distribution assumption, the Black-Scholes formula for European call options can be finally presented (Chriss, 1996, p. 120-123):

\[ C_t = N(d_1)A_t - e^{-r(T-t)}KN(d_2) \]

With \(N(\cdot)\) = cumulative normal distribution function and \(d_1, d_2\) as follows:

\[ d_1 = \frac{\log \frac{S_t}{K} + (r + \frac{\sigma^2}{2})(T-t)}{\sigma \sqrt{T-t}} \quad d_2 = d_1 - \sigma \sqrt{T-t} \]

The formula for a European put option can easily be derived by an application of the put-call-parity.
$P_t = -N(-d_1)A_t - e^{-r(t-t)}KN(-d_2)$

We see that these formulas can directly be applied if equity options are to be priced. Now it is obvious why Black-Scholes pricing has become so popular.

3.4 Critical discussion

In this section the economic assumptions presented at the very beginning of section 3.3 shall be discussed.

3.4.1 The no-arbitrage assumption

When this assumption no longer holds, there are easy opportunities for arbitrage, because then the price of the hedge of the option will differ from the option price itself. Remember that both positions are essentially equivalent. So the question is, whether this assumption is realistic. We already mentioned above that the assumption is not very restrictive and this is especially true for markets with many trades, where the mechanisms of demand and supply guarantee fast price adjustments. At least for our research that is based on Stockholm OMX30 which clearly is a rather continuously traded asset we will probably do well accepting the no-arbitrage principle. (Ibid, p. 203).

3.4.2 The Geometric Brownian Motion assumption

This is the most restrictive assumption because reality provides many examples which contradict the idea that stock price or stock index movements have the same statistical properties like a Geometric Brownian Motion. First, it assumes that stock returns are normally distributed, but studies reveal that “large movements in stock prices are more likely than a normally distributed stock price model would predict” (Ibid, p. 115). This means in practice that the likelihood of large downward movements of equity prices is strongly underestimated. Secondly, the Geometric Brownian Motion assumes the underlying’s volatility to be constant. This assumption is also inherent in our calculations, although we work with volatilities that are varying from day to day. But the volatility is of course kept constant within one particular theoretical price calculation. In reality, it is in fact not only the changes in the underlying asset that affects the value of an option but also the changes in volatility that are highly correlated with changes in the option value (Ibid, p. 203). This fact must not be ignored in examining theoretical option prices. Some studies, e.g. Pape and Merk (2003), even came up with the conjecture that volatility is negatively correlated with the equity price. Alternative models to deal with these phenomena have been developed by Cox & Ross (1976), Geske (1979) and Rubinstein (1983) (cited in Pape & Merk, 2003).

3.4.3 The short-selling assumption

The hedging portfolio that is constructed to cover the risk of the option consists of a long position and a short position. More precisely, the proceeds from the short position are necessary to finance the long position. If there are problems in short-selling certain
assets all conclusions drawn from this assumption are wrong and the Black-Scholes hedging strategy will not be self-financing (Chriss, 1996, p. 201).

3.4.4 The no-transaction cost assumption

In reality, there are naturally transactions costs. To just name a few: bid-ask spreads, broker fees, commissions, exchange costs, etc. Comparable to the short-selling assumption this also influences the real total cost of hedging and thus deforms the relationship between the value of the hedging position and the value of the option. However, to diminish this point of criticism we can suggest that transaction costs only play a subordinate role within stock indices. (*Ibid*, p. 203).

3.4.5 The riskless instrument assumption and the no-dividend assumption

There are indeed always risk-free instruments available. Almost every state is likely to offer securities like treasury bills, not to forget the huge amount of banks and other financial institutions all over the world, which also offer risk-free money investments.

The no-dividend assumption can be abandoned through easy extensions of the original Black-Scholes model. Just to reiterate: this was Merton’s contribution to this research area (Merton, 1973).

3.4.6 Justification of the Black-Scholes approach in this thesis

In the previous sections and also in section 1.2 we explained the application of the Black-Scholes formula to some extent. During this short paragraph we want to refresh these arguments and add some more reasons for the adequacy of the original Black-Scholes model for our research target.

There are many reasons to guess that Black-Scholes still plays a significant role in actual option pricing. It is an analytical approach, which means it is easily comprehensible from the practitioner’s point of view and manageable without a huge application of software. Furthermore, even models with a much higher degree of complexity also suffer from similar or alternate weaknesses, which is why there is no paradigm in option pricing that is better than Black-Scholes (Chriss, 1996, p. 204). We want to finish this section with the most important justification for the usage of Black-Scholes in this thesis. In order to do so, the key question that is going to be analyzed has to be emphasized again. It is not our purpose to show weaknesses of Black-Scholes due to remarkable price deviations in the model. This has been done sufficiently in former research. Instead, we want to give a response to the issue of whether differences in performance and reliability of this model can be evoked by the consideration of different periods. In fact we expect this hypothesis to be true because studies showed that volatility has a great impact on pricing. In the end, we plan to go beyond this statement and try to find more details to improve the picture of the influence that a financial crisis has on option pricing with the Black-Scholes formula.
3.5 Main happenings of the financial crisis

According to the OECD paper (Blundell-Wignall, Atkinson & Hoon Lee, 2008) the last financial crisis has been caused by two components. On one hand, global macroeconomic policies affected liquidity of banking and credit systems. On the other hand, a very low effective system of rules, which claimed acting as a second line defense, has been a key factor for the crisis. According to another economic research institution, the International Monetary Fund (International Monetary Fund, October 2008, p. 131-145) it is reasonable to argue that the financial crisis of 2008 has been caused by the distortions and incentives begun by the previous monetary policies: in fact, the financial sector created a new business model in order to take advantage of the incentives created during the last 20 years (World Economic Outlook, October 2008).

In this section we want to give a short but exhaustive description of the main events preceding Lehman Brothers Holding Inc. bankruptcy announced on September 15th 2008. According to the opinion of Cyril Monnet (2010), Lehman Brothers’ bankruptcy, the bank-giant which had recourse to Chapter 115, can be considered one of the greatest financial failures in the whole history of bankruptcies. September and October 2008 can probably be featured as the most significant months to represent the crisis but it is also important to describe what happened before to understand how we reached that point. Several elements that have to be taken into consideration are listed as follows:

- **Securitization**6: This allows banks to maintain a liquid portfolio of assets and makes available the opportunity to obtain credit for persons who could not get it previously. The problem is that the true default probabilities are diluted through securitization.

- **The failure of the so-called subprime mortgages**: The quality and the creditability of existing mortgages have been deteriorating if we consider its customers’ true profiles. The credit reliability of many clients has been overestimated; furthermore the securitization process allowed many lenders to sell these ‘bad’ loans on derivative markets. The true “quality and creditability” of the debtors has become more and more blurred (Troshkin, 2008; Cohen &Villemot, 2008).

- **The Basel regulations**: This recommends commercial banks and other financial institutions to keep adequate reserves in case of defaults of large creditors; however, it must be underlined that reserves are costly and they do not solve bank problems as the need to match large maturity assets with short maturity liabilities. A lot of banks had created new off-balance instruments such as SIVs7, CDS and securitization in order to take advantage of the new opportunities that arose due to new laws in the bank loans system. SIVs are bundles of bundles and

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5 Chapter 11, Reorganization under the Bankruptcy Code – US Courts: the chapter of the Bankruptcy Code providing (generally) for reorganization, usually involving a corporation or partnership. A chapter 11 debtor usually proposes a plan of reorganization to keep its business alive and pay creditors over time. People in business or individuals can also seek relief in chapter 11 (United States Courts, 2010).

6 Securitization is a process created to package debt instruments into one group and then to issue new debt securities backed on the pool of assets that the debt is issued on. In this kind of operation the investor receives the cash flow from the underlying debt. This process primarily re-distributes risk among a wider group of investors (Etzel, 2010).

7 Structured Investment Vehicle: it is a special type of contract that utilizes third-part borrowing in addition to short-term debt to finance the purchase of long-term assets (Scott, 2010).
are extremely flexible but at the same time quite hard to value, something like the *Russian doll Matryoshka*\(^8\). SIVs have also been promoted by the monetary authorities in order to promote house purchasing for many poor families, maintain liquid bank portfolios, increase the growth of the financial sector and reduce the costs of public debt financing (Borgman, 2009). The increasing demand for real estate, favored also by SIVs, led the rise in prices, and this again brought up the risk of cutting off poor families. Therefore, monetary authorities arranged secured mortgages with more and more flexible criteria and banks “covered” them by means of CDSs (*ibid.*). All this was possible due to the new regulations which allowed banks to get out of the prudential laws stated by Basel I and Basel II by putting new assets in these off-balance vehicles. Beyond this they could take advantage of the financial leverage to finance highly profitable credit operations without the need to return to their own capital (Cline, 2009; Reinhart & Rogoff, 2008).

- The easy money of the twenties caused a rapid increase of asset prices, particularly real estate prices. This allowed American households to enjoy high living standards through the usage of loans and credit cards. A system of laws made household debts increase as home prices were raising. Unfortunately, when real estate prices started to decrease at a rate of ten percent per year it created a vicious circle: the reduction in home prices obliged several households to declare bankruptcy and this led banks to offer houses which were not yet completely paid off for auctions. This naturally caused further reductions in real estate prices. It must also be mentioned that many of these families had borrowed money to buy cars, furniture and other household appliances and so, this deleveraging has also contributed to the extension of the crisis far beyond the mortgage market (Herring & Wachter, 2008; Walterskirchen, 2009).

Many economists may have expected a slowing down of the demand for real estate and a *soft-landing* for the general economy through a reduction of house prices and a short recession. But instead, after the terrorist attacks on 9/11 all the main central banks began to increase the monetary base in order to avoid panic among investors. An optimal result was reached, but the consequence was a continuous expansion of credit and real estate prices. Official interest rates at one percent in USA and zero percent in Japan, fixed currency rates in China and the accumulation of enormous monetary reserves by sovereign investment funds have given an input to overfill the “liquidity tank forcing it to flood”. This flow yielded the creation of a speculative bubble on financial assets and excessive leverage. This notwithstanding, the leaks in the legislative system had started already in very precise sectors in 2004: mortgage securitization and off-balance activities. The easy credit practice had caused troubles previously: some commercial banks and financial institutions such as Northern Rock, Fannie Mae and Freddie Mac seriously faced the risk of bankruptcy, which could only be avoided by state intervention (Sieczka, Sornette & Holyst, 2010). The problem appeared by the fact that securitization practice relied on the demand of financial markets and the possibility to sell back bundles when liquidity was required. As soon as the flow of payments on a certain number of bundles slows down it is also possible that several potential buyers back out and those who already own the bundle will try to get rid of it through a *CDS* (Aglietta, 2008). Suddenly the insurers were exposed to large refund claims: the flow of

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\(^8\) *Matryoshka*: it is sometimes known as Russian nesting doll or Babushka doll and it is composed by a set of dolls of decreasing sizes placed one inside the other (Wikipedia, 2010).
payments was not slowing down although the economy was entering into a recession. The relaxing credit criteria made available the rise of further debt even to parts of the population with uncertain income and the increase of other financial prices compensated the household balances. In the end, demographical changes were reducing the number of new buyers and the easy credit permitted the costumers to get bogged down in debt (Buiter, 2007). As a consequence the market became paralyzed and finally the pressure became so strong that the dam did not hold.
4 Data processing

4.1 Basics about quantitative data analysis

As discussed earlier, the general aim of quantitative research again, it is about discovering, describing and testing phenomena of data. This approach is very common if empirical questions are to be examined, such as questions about behavioral issues, results of measurements in natural sciences or examinations about the performance of economic factors. In most cases the researcher has some speculative guesses about the phenomena that could be determined through the studies even before the research work begins; that is so to speak the reason and the motivation for an analysis in the chosen research area. The researcher’s aim is now to find empirical evidence in favor of the supposition or empirical protest against it. Once the researcher decided in which area and in particular which problem he would like to investigate, he can start to think about which data is required to carry out the work. At this point we would like to refer to section 4.3 Data collection process. There you will find a detailed report about the tasks we had to undertake to get suitable data for our quantitative approach.

Our mean of comparison is just the difference between these two prices, respectively the percentage difference. The different techniques that could be considered in such an investigation concerning differences are presented in section 4.4 Data preparation and organization. In short, the aim of this chapter is to introduce the techniques we finally adopted in chapter 5.

4.2 Market differentiation and research horizon

We decided to work with StockholmOMX30 as empirical data. Stockholm, because we want to learn more about the Swedish option market and an index option because it does not only reflect one company but gives a well-rounded picture of the most important listed firms in the considered market. Moreover, index options are more frequently traded than options on single stocks, so the data is more reliable and the bid-ask-spread tends to be lower. Another advantage of indices is that they are more powerful to support the impression of a “clean” research window than ordinary stock since they are not as vulnerable to events which only concern one firm instead of the entire market (e.g. management announcements may have influence on single stock behavior). Thereby we can be sure that any conspicuousness we may observe in the second window of our research horizon is truly related to the bankruptcy event of Lehman Brothers.

The research horizon is fixed around an important benchmark: the most significant picture during the whole financial crisis, Lehman Brothers’ bankruptcy announcement declared on September 15th in 2008. That day will be point zero for the task of data collection. Starting from $t_0$, we consider data from the same number of months before and after that date. This guarantees that the importance of ‘normal’ trading days and ‘abnormal’ trading days is equally distributed in our investigation. Investors do not need much time to react on modified market conditions (Hirshleifer, 2001), which is why good results can also be achieved by analyzing only six or seven months. This is
advantageous in terms of data collection, the whole empirical studies and the time to produce good research results. Last but not least a rather short time window allows us to state that the observed phenomena are highly related to the above mentioned event. Our definite horizon will last from 2008/06/02 to 2008/12/31 that is exactly three and a half months before and three and a half months after Lehman Brothers’ bankruptcy announcement.

4.3 Data collection process

After collecting the data it had to be prepared for our research. Some Black-Scholes input variables had to be modified such that they have the right design for an application in the Black-Scholes model.

4.3.1 Black-Scholes input variables

Recall from chapter 3.2 Options, that there are five input variables required to work with the Black-Scholes option pricing formula. These are the underlying asset price, its volatility, the strike price of the option, the option’s time to maturity and the risk free interest rate as the whole model is based on the no-arbitrage principle. This information had to be downloaded from two different download sources. The primary data base for this study is Thomson Reuters DataStream, available at the library of Umeå University, from which we got all the input variables for our calculations. The second one is the Swedish “Riksbank” that provides data for daily measures of the yield of Treasury Bills. All these data have been collected for the period from June 2nd 2008 until December 31st 2008. According to our point zero, which is the bankruptcy announcement of Lehman Brothers on September 15th 2008, we compare the results from our calculations between two time windows of almost the same length: the period before (75 trading days) and after this event (78 trading days). In the following we are going to shortly present which of the downloaded input variable data had to be modified and how the modified design differs from the original one.

The first input variable we want to describe here is the underlying asset, which is, in our research, a stock index, StockholmOMX30 (OMXS30), the leading share index of Stockholm Stock Exchange. It is composed by the thirty most actively traded stocks on the Stockholm Stock Exchange and the fact that only a limited number of firms compose this index, guarantees that all the underlying shares of the index have excellent liquidity, which results in an index that is highly suitable as underlying for derivative products such as options. Moreover, according to the information available from the official webpage, OMXS30 is also used for structured products, such as warrants, index bonds, exchange traded funds (e.g. XACT OMX) and other non-standardized derivatives products (Nasdaq OMX, 2010b).

In financial mathematics, the time to maturity is commonly pictured similarly to the way percentages are pictured. A maturity of one year would be expressed with the number one, a two years maturity with the number two and so on. This includes that fractional maturities are used for periods shorter than one year. The prevailing assumption in financial mathematics is that a year effectively consists of 252 trading days (Chriss, 1996, p. 15). Therefore, we obtain for instance a maturity of \( \frac{30}{252} = 0.119 \) for a 30 days option. In our case we had to figure out the number of remaining trading
days for each of our $75 + 78 = 153$ trading days (June 2\textsuperscript{nd} until December 31\textsuperscript{st}) and then divide this number by 252 to get the correct design for the maturity.

For \textit{risk free interest rate} we simply used the yield of the Swedish Treasury Bills. Its adjustment for our requirements was to some extent similar to the adjustments of the time to maturity, but less complicated. Since we had no trading day based but only 30, 60, 90 and 180 days of maturity information about interest rates of the treasury bills issued by the Swedish “Riksbank”, we were forced to match each option with the corresponding interest rate. This match was done following the principle that each option should be matched with the particular interest rate which - in terms of maturity - fits best the actual maturity of the option. That is, we use the same interest rate for all trading days in the first interval, another interest rate for all trading days in the second interval and so on up to four intervals. It is clear that the interval limits are 45 [=(60+30)/2], 75 [=(60+90)/2] and 135 [=(90+180)/2]. Since we have 166 trading days total (from June 02\textsuperscript{nd} until January 23\textsuperscript{rd}), we applied the 180 days interest rate for all price calculations in the interval [June2\textsuperscript{nd};September10\textsuperscript{th}], the 90 days interest rate for the interval [September1\textsuperscript{st};November9\textsuperscript{th}], the 60 days interest rate for the interval [November10\textsuperscript{th};December8\textsuperscript{th}] and the 30 days interest rate for the interval [December9\textsuperscript{th};December 31\textsuperscript{st}]. This strategy goes back to a paper (Bodurtha & Courtadon, 1987) in which they also used yields of treasury bills as risk free interest rate and matched options and T-bills with corresponding maturities.

Concerning the volatility we chose to adopt a simplified approach: we used an implied volatility approach to run our estimations following the method proposed by Whaley (1982, cited in Bodurtha & Courtadon 1987, p. 158). This can be considered as a valid procedure mainly due to two reasons: first, it gives some indications about daily volatility changes and secondly it gives the model more credibility as a pricing tool \textit{(Ibid.)}. Fortunately, Thomson Reuters Datasync provides expedient volatility data, so we could directly use the downloaded volatility data in the Black-Scholes model.

The same is the case for the two remaining input variables, the index price for the 38 put and call options and the strike price. These data could be used for the calculations without further modifications.

\textbf{4.3.2 Data selection methodology}

In the previous section we described the method we used to select and collect all the input variables in order to apply the Black-Scholes formula and thus derive a theoretical price for each option contract. In this section we will explain the criteria we adopted for the comparison of option market prices with the theoretical prices.

First we want to point again to the fact that only market prices of option contracts with expiration at January 23\textsuperscript{rd} 2009 have been chosen and downloaded. Refer to section 3.2 for a detailed explanation of this decision. Among all the possible strike prices we selected only the contracts that show a complete historical price series for the time window we take into account. This procedure has been applied both for call and put options. Since they only differ in the strike prices and use the same underlying assumptions it is not hard to run all the investigational tasks twice. But in the end, we have twice as much information for final summaries and conclusions, which makes the
result picture more strongly funded. It is also important to emphasize that the size of our sample results in a compromise between two conflicting requirements: certainty and accuracy of the results on the one hand and the need not to avoid immense costs and time commitment for the investigation on the other hand. The correct procedure in order to determine how big the sample must be considers both, the detection of the size of the universe of our interest and the choice of the confidence level and maximum error we are willing to accept. We are convinced that our sample is big enough to make a correct analysis since we have collected a total amount of 5814 call and put option contract prices.

Regarding the database veracity we can argue that there should be no remarkable errors in our sample since Thomson Reuters Datastream provides tools and historical data that are also applied by investment professionals.

4.4 Data preparation and organization

As soon as the data had the correct design we were able to use it for the calculation of the Black-Scholes option prices, which are exactly the theoretical prices needed for comparison with the observed market prices.

4.4.1 Calculation of theoretical prices

In order to calculate the theoretical prices we applied the Black-Scholes model using simple software running on Excel worksheets. Please remember the thorough explanations of all formulas from section 3.3.2. The interpretations of the two factors $N(d_1)$ and $N(d_2)$ are presented below:

- $N(d_1)$ denotes the factor by which the present value of contingent receipt of the stock index exceeds the current stock price.
- $N(d_2)$ denotes the risk-adjusted probability that the option will be exercised (Nielsen 1992, p. 1-2).

4.4.2 Working with different types of values

There are four kinds of differences that we could work within our analyses. The first and second relate to the percentage differences wherein one can distinguish between real and absolute values of percentages. The third and fourth relate to real price differences which also can be presented in real or absolute numbers. In the following passage we are going to explain when we decided to use which design of the price deviations.

Due to two reasons we decided not to rely on the variants three and four, i.e. working with real price differences. First, working with percentages instead of real numbers allows an easier interpretation of the results since percentages contain more information than just numbers. The second advantage in using percentages refers to a problem that arises through the aggregation of data: in our aggregation we needed weighted averages that include the size of the total sample in order to find conclusions; therefore, we required percentages as measurement for price differences. But, when did we use variant one and when did we rely on variant two?
For variant one, real percentage differences were applied whenever we needed a general overview of phenomena in the data. In particular variant one allows differing between positive and negative price deviations. This design will appear in section 5.3.2. For variant two, the design with absolute value differences has been used every time we wanted to avoid positive and negative values neutralizing each other. This argument was particularly important to produce a picture of the pure magnitude of deviations from zero in section 5.3.1. The other important application of this data design was the hypothesis testing process - see section 5.4.

4.4.3 Trading day averages of differences vs. singly observed differences

Besides the differentiation between percentages and real values we also varied between using an aggregation of all contracts on a trading day basis and using the singly observed differences. In practical terms, the aggregation was done through an average calculation of all 16 (for the call options), respectively 22 (for the put options) observed differences at each trading day. The result is a sample with 153 aggregated averages. The same thing was also done for the kind of moneyness, which yielded a sample with 153 aggregated averages for the ‘out of the money’ case, the ‘at the money’ case and the ‘in the money’ case. The main advantage of aggregation of data is that it is possible to obtain a whole picture of all observations. On the other side, there is always the risk of losing outliers and therefore getting wrong information about position and dispersion measures. That is why, we only used aggregated data when we wanted to describe and analyze our sample as a whole time series, while we considered singly observed trades every time we wanted to examine their degree of deviation and discover certain characteristics about their behavior.

4.4.4 Calculation of differences and subdivision of the data

Once we got our sample of theoretical prices we calculated percentage differences between market and theoretical prices. We derived the percentage differences for each option contract on a daily basis by calculating the real difference between the market and the theoretical price and then dividing this difference by the market price. As a result, we obtained a measure of how much market prices differ relative to the theoretical values derived from the Black-Scholes formula. After that, we were able to aggregate all put respectively call contracts in order to obtain a daily average of percentage differences.

To obtain a more detailed picture within our data investigation, we subdivided the data in three categories consisting of different types of moneyness. Practically, we pooled all in the money, at the money, and out of the money options in separate groups to provide an analysis not only of the total sample but also in a more differentiated context. The separation was done according to the work of Pape and Merk (2003). A single trading day differences observation from call options is defined as in the money, when its corresponding market price is 1.05 times the strike price or higher. An observation is considered out of the money when the market price is 0.95 times the strike price or lower. Last but not least, an observation is at the money when the market price is in between these two bounds. Analogues to put options, an observation is considered in the money when the market price is 0.95 times the strike price or lower, out of the money
when the market price is 1.05 times the strike price or higher and at the money when the market price is in between these two bounds.

The second element on which we decided to subdivide our sample is whether a contract is overpriced or underpriced in the model. To do that, we simply defined a result as overpriced when the percentage difference between market and theoretical prices is positive and underpriced when it is negative. We are strongly convinced that this type of analysis will be very useful for our research in order to, first make deeper classifications and analyses, and secondly, find some interesting characteristics among option contracts.
5 Empirical analysis and inferences

5.1 Purpose and construction of the empirical investigation

We remind the reader that the purpose of this research is the empirical investigation of price deviations within two different periods of time. The general set up of this empirical analysis and statistical examination will consist of three steps. The start of any quantitative statistical investigation should always be an explorative study of the data (section 5.2). Here, the statistician ‘explores’ some basic characteristics of the data. Distribution assumptions are checked and based on this knowledge it can be decided which technique has to be used in the inferential part of the statistical analysis. After that the statistician starts with some first analyses of the data. This serves as a ‘description’ of the data and brings up information such as mean, range, median, standard deviation and variance. Appropriately, this is referred to descriptive statistics (section 5.3). Through the study of the descriptive results, the researcher often derives possible statements and is probably even able to formulate concrete ‘hypotheses’. This keyword brings us to the last step of empirical analysis: the inferential statistics. Here, the researcher examines if there are final ‘inferences’ that can be drawn from the data, specifically from the before stated hypotheses (section 5.4). To sum up this introduction, chapter 5 will provide a three-step analysis of the price differences and the deviations in price differences between the two periods.

5.2 Explorative data analysis

Explorative data analysis is important with respect to the decision of which particular test is required to verify a given hypothesis. The question is always whether the data can be considered normally distributed. In the case of a normal distribution, parametric tests such as the t-test are most suitable whereas we need non-parametric tests as soon as there is no indication for a normal distribution. The most common non-parametric test in this context is the “Mann-Whitney-U test” (sometimes also referred to “Mann-Whitney-Wilcoxon test” or “Wilcoxon rank test”). So, the first step in empirical analysis is to find out whether the normal distribution assumption is acceptable or not. For this purpose the statistician usually takes a look at the Quantile-Quantile plot (“qq-Plot”). If the data points from the sample are distributed along the straight line, the normal distribution assumption is retained and parametric tests can be applied during the inferential statistics. However, if the data points do not follow this line we have to assume that the sample is not normally distributed which requires the non-parametric Mann-Whitney-U test for the inferential part. Clearly, as we need to interpret our sample as a time series we do the explorative statistics based on the aggregation variant from section 4.4.4. Moreover, since we are interested in absolute deviations from zero and thus need to avoid neutralization due to positive and negative values we refer to absolute value percentages here.
Changes in the creditability of the Black-Scholes option pricing model due to financial turbulences

**Figure 1A** QQ-Plot for the 16 call options

![Normal Q-Q Plot of Total Sample](image1)

**Figure 1B** QQ-Plot for the 22 put options

![Normal Q-Q Plot of Total Sample](image2)

Figure 1A clearly shows that the normal distribution assumption has to be rejected. The decision for the other qq-plot is a little bit harder and guided by our experience in analyzing financial data. Even if the points in the qq-plot seem to nearly lie on the straight line it is problematic to assume a normal distribution. This is confirmed when we look at the fat tails and the centre of the plot. This means for both cases that we have to refer to the Mann-Whitney-U test in chapter 5.4, Hypothesis testing.
5.3 Descriptive statistics

The descriptive statistics part is divided into two subsections, 5.3.1 “Measure of sample location and dispersion” and 5.3.2 “Singly observation based examination”. Subsection 5.3.1 shall present some general characteristics about the sample as a time series and figure out the most important features needed to provide a satisfactory picture of the data. It serves as a preparation for 5.4 since testing also refers to the sample from the time series perspective. 5.3.2 is a special investigation based on the singly observed differences. The purpose is to discover and classify different kinds of deviation degrees and subdivide observations into two groups, overpriced and underpriced theoretical prices.

5.3.1 Measure of sample location and dispersion

Trading day based examination of percentage differences (absolute values)

Table 1A Descriptive Statistics CALL OPTION TOTAL SAMPLE

<table>
<thead>
<tr>
<th>Period</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>75</td>
<td>.1900</td>
<td>4.2400</td>
<td>.756933</td>
<td>.8188175</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After</td>
<td>78</td>
<td>.6000</td>
<td>139.0000</td>
<td>11.384615</td>
<td>18.7497714</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>78</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1B Descriptive Statistics CALL OPTION OUT OF THE MONEY

<table>
<thead>
<tr>
<th>Period</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>75</td>
<td>.1600</td>
<td>4.2800</td>
<td>.741467</td>
<td>.8267254</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After</td>
<td>78</td>
<td>.4800</td>
<td>96.6900</td>
<td>8.104744</td>
<td>13.1566017</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>78</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1C Descriptive Statistics CALL OPTION AT THE MONEY

<table>
<thead>
<tr>
<th>Period</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>75</td>
<td>.0200</td>
<td>.7000</td>
<td>.085333</td>
<td>.0925514</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After</td>
<td>15</td>
<td>.0500</td>
<td>.7700</td>
<td>.276000</td>
<td>.2005279</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1D Descriptive Statistics CALL OPTION IN THE MONEY

<table>
<thead>
<tr>
<th>Period</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>75</td>
<td>.0000</td>
<td>.4500</td>
<td>.072297</td>
<td>.0586970</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After</td>
<td>6</td>
<td>.0200</td>
<td>.2700</td>
<td>.110000</td>
<td>.0931665</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
At first we immediately recognize that both in the total sample and the three subsamples all descriptive sample measures present an increase in the second period compared to the first. The time series’ location, illustrated by mean and range increases and also the time series’ dispersion, and expressed by the standard deviation, goes up. This suggests the hypothesis that a financial crisis makes price deviations change in their degree of deviation. We are trying to find statistical support for this statement in section 5.4.

If we take a more detailed look at the evaluation, we also see that the number of valid observations for in the money options is only six in the period after Lehman Brothers. This is due to the massive downturn of the market price which ‘kicked’ many call options out of the money. Even within the at the money category, there are only 15 price observations left. The result for put options will be the opposite one. This can be verified in the next paragraphs. However, we can point out that it is the out of the money category which is largely responsible for the picture in table 1A. We will see this again in section 5.3.2, where the degrees of price deviations are measured more explicitly, but even now we can guess that the change in the degree of deviations in the total sample will go side-by-side with the change in the degree of out of the money options, since they are the main drivers of the total picture.

Figure 2A Call deviations in percentage differences from the market over time
theoretical prices and the market prices were this extreme because of the overreaction of investors that is commonly observed in relation with stock market announcements (De Bondt, 1984). But regardless this special case, the development can only serve to strengthen what we already assumed in the very beginning of this thesis and also suggested in the previous paragraph. Furthermore, we can consider this graph as a confirmation that our choice of the research horizon was absolutely correct. It seems that it took almost exactly three months to finally reach a normal deviation level again.

In the following, the same evaluations and suggestions will be done with the put option sample:

Table 2A Descriptive Statistics PUT OPTION TOTAL SAMPLE

<table>
<thead>
<tr>
<th>Period</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Total Sample</td>
<td>75</td>
<td>.00</td>
<td>.51</td>
<td>1.586</td>
<td>.12475</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After Total Sample</td>
<td>78</td>
<td>.00</td>
<td>.84</td>
<td>2.081</td>
<td>.19395</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>78</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2B Descriptive Statistics PUT OPTION OUT OF THE MONEY

<table>
<thead>
<tr>
<th>Period</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Out of the Money</td>
<td>75</td>
<td>.01</td>
<td>.85</td>
<td>3.100</td>
<td>.20177</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After Out of the Money</td>
<td>16</td>
<td>.02</td>
<td>2.17</td>
<td>7.355</td>
<td>.61877</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2C Descriptive Statistics PUT OPTIONS AT THE MONEY

<table>
<thead>
<tr>
<th>Period</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before At the Money</td>
<td>75</td>
<td>.00</td>
<td>.56</td>
<td>1.099</td>
<td>.10570</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After At the Money</td>
<td>50</td>
<td>.00</td>
<td>.78</td>
<td>2.132</td>
<td>.18462</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2D Descriptive Statistics PUT OPTION IN THE MONEY

<table>
<thead>
<tr>
<th>Period</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before In the Money</td>
<td>75</td>
<td>.01</td>
<td>.28</td>
<td>1.172</td>
<td>.07768</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After In the Money</td>
<td>78</td>
<td>.00</td>
<td>.69</td>
<td>1.966</td>
<td>.16505</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>78</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From the tables above it is possible to find some common trends among the four categories: in the period that follows the Lehman Brothers’ bankruptcy, all the location and dispersion measures such as maximum value, mean, and standard deviation are characterized by higher values compared to the period before Lehman Brothers. This clearly shows us that this particular event changed conditions on financial markets and
had a deep impact on the way investors priced financial instruments, such as the option contracts in our research. In section 5.4 we will conduct specific inferential tests to judge whether these differences are statistically significant or not.

Beyond this, it is interesting to notice that out of the money options seem to have been affected much more by the event than at the money or in the money options since the standard deviation jumped from 20 percent to 62 percent, while in the other type of contracts it only leaped from 11 to 18 percent or from 8 to 17 percent respectively. But we should not trust this result too heavily because of the low number of valid out of the money observations in the period after the event. This phenomenon could, for example, be caused by an extreme outlier, who could have had a very strong influence on the statistic due to the low sample size of only 16 observations. Indeed, this explanation is very likely when we consider the maximum percentage difference that has been measured for out of the money options: 217 percent!

**Figure 2B** Put deviations in percentage differences from the market over time

The chart in the figure above shows the development of the percentage differences over time: differently from the call option graph that shows a regular flat trend before Lehman’s failure, the put option graph exhibits two periods of high dispersion around the mean. The first period starts at the beginning and ends around August 4th, while the second period starts exactly after Lehman Brothers’ failure. There has been a considerable increase in the absolute deviations from the mean from September 15th, 2008 until November 3rd, 2008, when the situation was slowly getting back to “normality”. To sum up, this graph is a further signal to analyze whether there are significant differences between the two periods.
5.3.2 Singly observation based examination of real percentage differences

Focus on the type of the pricing error

In this paragraph we take a look at the percentage price differences for both, put and call options. The following tables contain in each case a comparison between the proportions of contracts whose theoretical price was smaller than the market price ("underpricing") and contracts whose theoretical price was greater than the market price ("overpricing"). These proportions are both presented in absolute numbers and percentages and are differentiated between the periods and whether the options were out of the money, in the money or at the money.

Table 3A Mispricing error for Call options

<table>
<thead>
<tr>
<th>Total period</th>
<th>Out of the Money</th>
<th>At the Money</th>
<th>In the money</th>
<th>Total sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of observations</td>
<td>1811</td>
<td>376</td>
<td>261</td>
<td>2448</td>
</tr>
<tr>
<td>Underpricing</td>
<td>421</td>
<td>180</td>
<td>182</td>
<td>783</td>
</tr>
<tr>
<td>Overpricing</td>
<td>1390</td>
<td>196</td>
<td>79</td>
<td>1665</td>
</tr>
<tr>
<td>Percentage Underpricing</td>
<td>23,25%</td>
<td>47,87%</td>
<td>69,73%</td>
<td>31,99%</td>
</tr>
<tr>
<td>Percentage Overpricing</td>
<td>76,75%</td>
<td>52,13%</td>
<td>30,27%</td>
<td>68,01%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Before Lehman Brothers</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of observations</td>
<td>621</td>
<td>325</td>
<td>254</td>
<td>1200</td>
</tr>
<tr>
<td>Underpricing</td>
<td>154</td>
<td>178</td>
<td>180</td>
<td>512</td>
</tr>
<tr>
<td>Overpricing</td>
<td>467</td>
<td>147</td>
<td>74</td>
<td>688</td>
</tr>
<tr>
<td>Percentage Underpricing</td>
<td>24,80%</td>
<td>54,77%</td>
<td>70,87%</td>
<td>42,67%</td>
</tr>
<tr>
<td>Percentage Overpricing</td>
<td>75,20%</td>
<td>45,23%</td>
<td>29,13%</td>
<td>53,33%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>After Lehman Brothers</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of observations</td>
<td>1190</td>
<td>51</td>
<td>7</td>
<td>1248</td>
</tr>
<tr>
<td>Underpricing</td>
<td>267</td>
<td>2</td>
<td>2</td>
<td>271</td>
</tr>
<tr>
<td>Overpricing</td>
<td>923</td>
<td>49</td>
<td>5</td>
<td>977</td>
</tr>
<tr>
<td>Percentage Underpricing</td>
<td>22,44%</td>
<td>3,92%</td>
<td>28,57%</td>
<td>21,71%</td>
</tr>
<tr>
<td>Percentage Overpricing</td>
<td>77,56%</td>
<td>96,08%</td>
<td>71,43%</td>
<td>78,29%</td>
</tr>
</tbody>
</table>

If we consider the total sample, we can assert that the Black-Scholes model tends to overprice the options. This is the case for all three different period designs. Furthermore, we can note that in the period after the Lehman Brothers’ bankruptcy, the overstatement of the real market prices was even more distinct than before this event or within the total period. This observation also holds for all three types of ‘moneyness’. At the money options after Lehman Brothers have an especially high tendency to be overpriced, but one has to take into consideration that there are only 51 price comparisons that enter in this figure. We obtain an even more extreme picture for the in the money options: in this category there are only 7 single price observations left after
Lehman Brothers. But on the other hand, we see that *out of the money* options present the highest proportion of overpricing in the period after Lehman Brothers, which we can take as indicators that this is likely to be true for *in the money* and *at the money* options, as well.

**Table 3B** Mispricing error for Put options

<table>
<thead>
<tr>
<th>Total period</th>
<th>Out of the Money</th>
<th>At the Money</th>
<th>In the Money</th>
<th>Total Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of observations</td>
<td>701</td>
<td>449</td>
<td>2216</td>
<td>3366</td>
</tr>
<tr>
<td>Underpricing</td>
<td>491</td>
<td>116</td>
<td>647</td>
<td>1254</td>
</tr>
<tr>
<td>Overpricing</td>
<td>210</td>
<td>333</td>
<td>1569</td>
<td>2112</td>
</tr>
<tr>
<td>Percentage Underpricing</td>
<td>70,04%</td>
<td>25,84%</td>
<td>29,20%</td>
<td>37,25%</td>
</tr>
<tr>
<td>Percentage Overpricing</td>
<td>29,96%</td>
<td>74,16%</td>
<td>70,80%</td>
<td>62,75%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Before Lehman Brothers</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of observations</td>
<td>629</td>
<td>325</td>
<td>696</td>
</tr>
<tr>
<td>Underpricing</td>
<td>481</td>
<td>107</td>
<td>115</td>
</tr>
<tr>
<td>Overpricing</td>
<td>148</td>
<td>218</td>
<td>581</td>
</tr>
<tr>
<td>Percentage Underpricing</td>
<td>76,47%</td>
<td>32,92%</td>
<td>16,52%</td>
</tr>
<tr>
<td>Percentage Overpricing</td>
<td>23,53%</td>
<td>67,08%</td>
<td>83,48%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>After Lehman Brothers</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of observations</td>
<td>72</td>
<td>124</td>
<td>1520</td>
</tr>
<tr>
<td>Underpricing</td>
<td>10</td>
<td>9</td>
<td>532</td>
</tr>
<tr>
<td>Overpricing</td>
<td>62</td>
<td>115</td>
<td>988</td>
</tr>
<tr>
<td>Percentage Underpricing</td>
<td>13,89%</td>
<td>7,26%</td>
<td>35,00%</td>
</tr>
<tr>
<td>Percentage Overpricing</td>
<td>86,11%</td>
<td>92,74%</td>
<td>65,00%</td>
</tr>
</tbody>
</table>

From table 3B we can draw some useful conclusions: *out of the money* contracts seem to be overvalued in the period before our event study and undervalued in the period after. If we look at the total sample we also get support for the statement that Black-Scholes tends to produce a greater overpriced proportion in the ‘turbulent’ period than usual. With a symmetric argumentation to the previous interpretation of table 3A we find a significant decrease (from 629 to 72) in *out of the money* options in table 3B. Of course, this is due to the financial crisis and the crash of the worlds’ stock markets which meant in a huge slip into *in the money* for StockholmOMX30 put options. Moreover, if we observe the statistics regarding *in the money* options it is possible to see that for the total period – with 2216 valid prices – 70 percent are overpriced, but to the contrary of call options, the proportion of overpriced values declined in the crisis. Table 3B shows a general overpricing in both periods for *at the money* options but an even more distinct overpriced proportion in the after period. Finally, if we take the total sample into consideration, we can say that the Black-Scholes model tends to overprice options, but we must not forget that the results in the *in the money* category contradicts this observation.
Focus on the range of the deviations
This investigation has a different aim than the previous one. Here we do not pay attention to the fact that the price deviation can be positive or negative – yielding underpricing or overpricing. Instead, we count price differences in three different intervals and therefore work with the absolute value adjusted differences. This approach has already been announced in section 4.4.4. The intervals have different characteristics in terms of the severity of the deviation between the model price and the market price. Practically, we gather all prices that only range five percent from the market price in each first category. The second category presents deviations up to ten percent from the market price and the third category contains deviations up to twenty percent from the market price. Like in the previous paragraph we also give a detailed picture based on the moneyness and the particular period.

Table 4A Degree of deviation from the market price for calls

<table>
<thead>
<tr>
<th>Total period</th>
<th>Out of the Money</th>
<th>At the Money</th>
<th>In the money</th>
<th>Total sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of observations</td>
<td>1811 (74%)</td>
<td>376 (15%)</td>
<td>261 (11%)</td>
<td>2448</td>
</tr>
<tr>
<td>(+/-5%)</td>
<td>56</td>
<td>153</td>
<td>86</td>
<td>295</td>
</tr>
<tr>
<td>(+/-10%)</td>
<td>104</td>
<td>237</td>
<td>201</td>
<td>542</td>
</tr>
<tr>
<td>(+/-20%)</td>
<td>213</td>
<td>325</td>
<td>248</td>
<td>786</td>
</tr>
<tr>
<td>Percentage (+/-5%)</td>
<td>3,09%</td>
<td>40,69%</td>
<td>32,95%</td>
<td>12,05%</td>
</tr>
<tr>
<td>Percentage (+/-10%)</td>
<td>5,74%</td>
<td>63,03%</td>
<td>77,01%</td>
<td>22,14%</td>
</tr>
<tr>
<td>Percentage (+/-20%)</td>
<td>11,76%</td>
<td>86,44%</td>
<td>95,02%</td>
<td>32,11%</td>
</tr>
</tbody>
</table>

| Before Lehman Brothers | |
|------------------------|----------------|-------------|-------------|--------------|
| no. of observations | 621 (52%) | 325 (27%) | 254 (21%) | 1200 |
| (+/-5%) | 38 | 147 | 84 | 269 |
| (+/-10%) | 69 | 225 | 196 | 490 |
| (+/-20%) | 146 | 297 | 242 | 685 |
| Percentage (+/-5%) | 6,12% | 45,23% | 33,07% | 22,42% |
| Percentage (+/-10%) | 11,11% | 69,23% | 77,17% | 40,83% |
| Percentage (+/-20%) | 23,51% | 91,38% | 95,28% | 57,08% |

| After Lehman Brothers | |
|-----------------------|----------------|-------------|-------------|--------------|
| no. of observations | 1190 (95%) | 51 (4%) | 7 (1%) | 1248 |
| (+/-5%) | 18 | 6 | 2 | 26 |
| (+/-10%) | 35 | 12 | 5 | 52 |
| (+/-20%) | 67 | 28 | 6 | 101 |
| Percentage (+/-5%) | 1,51% | 11,76% | 28,57% | 2,08% |
| Percentage (+/-10%) | 2,94% | 23,53% | 71,43% | 4,17% |
| Percentage (+/-20%) | 5,63% | 54,90% | 85,71% | 8,09% |

Let us again start with the results in the total sample. What we see is rather remarkable and also gives us evidence for the hypothesis we already stated as a guess back in
Changes in the creditability of the Black-Scholes option pricing model due to financial turbulences

Chapter 1. At first glance, the information is quite frustrating, since only 32 percent of all prices (total period and total sample) are situated in the 20-percent interval (compare approach by Pape & Merk). But as often emphasized earlier in this paper, this is not what we want to show in this research. What we consider very interesting in this table 4A is the comparison of the period before Lehman Brothers with the one after. Here we find that before Lehman Brothers, as many as 57 percent of all options were priced within a twenty percent deviation range, whereas after Lehman Brothers we only find 8 percent, with an equal or less than twenty percent deviation from the market price. This means that, we indeed found empirical support for the statement that price deviations differ whether they originate from the first or the second period.

Another interesting conclusion from table 4A above is that in the money options and to some extent at the money options present a rather high proportion within the twenty percent deviation range. Thus, for options underlying one of those types of moneyness the Black-Scholes pricing model did an “acceptable”9 job. This holds for the total period, the period before Lehman Brothers, and, with some restrictions, also for the very last period. But unfortunately, the problem is again the small number of data. Exactly the opposite result appears for out of the money options. Even during the period before Lehman Brothers, only almost 24 percent of the model prices did not differ more than twenty percent from the market prices. In the period after the bankruptcy, this number decreased to only six percent. This seems to be one thing that surely can be learned from this table 4A: the ability of the Black-Scholes model to assess the market price is in general weak for in the money options, but is especially so during a turbulent period like after Lehman Brothers. It is hard to find an explanation for the general weakness in pricing out of the money options. Furthermore, it is not clear why the ability to price out of the money options differs from the ability to price in the money options, because both types are “farther away” from the strike price than at the money options. But again, the small number of in the money observations makes our analysis hard and restricts our ability to generalize this observation.

To sum up, the most important result from this investigation is that there are massive differences between price deviations in the period before Lehman Brothers and the period after Lehman Brothers. We can pick more figures out of table 4A to strengthen that point: the total sample presents a 22 percentage (before) against a two percentage (after) in the five percent deviation range. That is undeniably an obvious result. In section 5.4, we are going to continue with examining this phenomenon and carry out an inferential analysis on this very hypothesis: “Is there any statistical support that price differences between theoretical prices and market prices differ whether they originate from a ‘normal’ or a ‘turbulent’ period’”?

9In this context, the characteristic “acceptable” appears without theoretical justification. It just refers to the huge difference between the results in the different moneyness categories. Considering the weak results of the out of the money category, one might approve that the numbers 54.90%, respectively 85.71% within the twenty percent range is “acceptable” for in the money respectively at the money options.
Again, we would like to start the description and presentation of the results in table 4B by looking at the total sample: we can see that almost 60 percent of all price deviations are located in the 20-percent interval, 36 percent are in the ten-percent interval and 19 percent of the data is located in the five-percent interval. With respect to the period before our event it is possible to find that almost 61 percent of all option contracts were priced within the twenty percent deviation range, and for the period after Lehman Brothers the percentage is quite the same, presenting 57 percent with an equal to or less than twenty percent deviation from the market price. This means that to the contrary of the findings with call options we do not find such strong empirical support for the statement that price deviations differ whether they originate from the first or the second period. Regarding out of the money options it is possible to argue that for the total period only 32 percent of the data lies within the 20 percent bounds, 19 percent are situated in the ten percent interval and only eight percent in the five percent interval. Almost the same percentages with small differences can be seen when looking at the period before Lehman Brothers’ failure, while the period after this event tells us that the
percentages are much smaller: 29 percent, eight percent, and three percent in the 20, ten, and five percent intervals respectively. But this phenomenon is probably due to the relatively scarcity of available data. Another interesting conclusion we can draw from table 4B is that the percentages of in the money option contracts within the three bounds are 22 percent, 40 percent, and 65 percent. If we look at the differences between the two observed periods we can also argue that the percentages decrease meaning that more trades exhibit greater differences than 20 percent in the second interval. This picture is especially obvious for at the money options: it is evident that in the period after the Lehman Brothers’ bankruptcy more trades exhibit percentage differences standing outside the 20 percent bounds. This goes side-by-side with the final hypothesis stated at the end of the call option deviation range investigation. Now, we are sufficiently prepared for the inferential analysis.

5.4 Inferential statistics: Hypothesis testing

Inferential statistics is used whenever a statistician wants to find empirical support for a certain hypothesis. There are methods to test hypotheses with statistical software, like SPSS, which we used for this thesis. As already mentioned in paragraph 5.2, we have to use the non-parametric Mann-Whitney-U test (compare with approach by Pape & Merk). The basic idea of hypothesis testing is that you formulate the opposite statement (always referred to as the “null hypothesis”) from the one you want to prove. Next, you try to find indicators that recommend a rejection of the null hypothesis. These indicators are provided by inferential statistics. The only thing software like SPSS does when you click on the button “hypothesis test” is an assessment of whether the sample contradicts the hypothesis. One additional factor that the statistician has to decide is the confidence level he wants to reach in his test. Common confidence levels are 95 and 99 percent, i.e. in five or one percent of all cases a false rejection is accepted. We decided to use the 95 percent confidence interval since our sample is sufficiently big. A common rule of thumb is to use a wide confidence interval (e.g. 99 percent) when you are less confident in the sample and to use a narrow confidence interval (e.g. 95 percent) when the sample size is big enough. Finally, we want to put this section in the context of the classifications and subdivisions from section 4.4. We refer to the time series perspective as we investigate whether the degree of deviations in the period before Lehman Brothers is different from the degree of deviations in the period after Lehman Brothers. Thus we use trading day based and absolute value data.

Null hypothesis: “There is no statistical support that price differences between theoretical prices and market prices differ whether they originate from a ‘normal’ or a ‘turbulent’ period”.

Or more precisely: “Price differences between theoretical prices and market prices do not differ whether they originate from a ‘normal’ or a ‘turbulent’ period”.

42
Changes in the creditability of the Black-Scholes option pricing model due to financial turbulences

Table 5A Result for call options:

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Test</th>
<th>Sig.</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>The distribution of Total Sample is the same across categories of Period.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>.000</td>
<td>Reject the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of Out of the Money is the same across categories of Period.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>.344</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of At the Money is the same across categories of Period.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>.000</td>
<td>Reject the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of In the Money is the same across categories of Period.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>.000</td>
<td>Reject the null hypothesis.</td>
</tr>
</tbody>
</table>

Asymptotic significances are displayed. The significance level is .05.

Table 5B Result for put options:

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Test</th>
<th>Sig.</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>The distribution of Total Sample is the same across categories of Period.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>.000</td>
<td>Reject the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of Out of the Money is the same across categories of Period.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>.000</td>
<td>Reject the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of At the Money is the same across categories of Period.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>.000</td>
<td>Reject the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of In the Money is the same across categories of Period.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>.366</td>
<td>Retain the null hypothesis.</td>
</tr>
</tbody>
</table>

Asymptotic significances are displayed. The significance level is .05.
From the tables above we can draw some important conclusions about the way investors price options during the two time windows in our horizon. As we can see, the null hypothesis is rejected at a 95 percent confidence level for both call and put option contracts in the categories total sample and at the money. This means that there is no statistical support for the assumption that the deviations from real market prices are similarly distributed across the two time windows. This result is in accordance with what we saw in 5.3.2.

The difference between both test summaries relates to the different but symmetric definition of moneyness which is inherent in its classification: of course, whenever a put option is in the money the corresponding call option will be out of the money and vice versa. There is no difference in the at the money case, since this category reflects contracts whose strike price is ‘close’ to the index price and this approves to both put and call options. We will see that the explanations for the non-rejection of hypothesis 2 in table 5A are directly related to the explanations for the non-rejection of hypothesis 4 in table 5B. There are two possible reasons for these phenomena. Either it is indeed true that the Black-Scholes creditability is the same across the two periods or there is not sufficient confidence in the data. We tend to vote in favor of the second argument since in the period after the Lehman Brothers’ bankruptcy we can only work with 6 trades out of 78 or 7 singly observed price deviations out of 1248 in the call case. In the put case it is 16 trades out of 78 or 72 singly observed price deviations out of 1716.
6 Concluding discussion

6.1 Main findings

The main purpose of our work was to verify if the original Black-Scholes option pricing formula fits in a financially turbulent period or not. To answer this question we decided to compare a normal period to an abnormal one in order to look out for anomalies or biases in the price deviations.

Through the empirical investigation we found significant differences in the way how investors price put and call options on the StockholmOMX30 index in the period before and after Lehman Brothers’ failure. In particular our results show that, during financial turbulences, the Black-Scholes model does not tend to react quickly to changes in market volatility. This is the main weakness of the model since in modern financial times economic agents should be able to price structured financial instruments within only a few seconds and thus the rapidity a model has to deal with changed input variables is crucial for a “good or bad” pricing. Our work has investigated the performance of the Black-Scholes model to price index options in two different time windows. The results mainly consist of analyses of percentage differences between market prices and theoretical prices. These differences are significantly higher during the post-event study independently from the type of moneyness of the options. This impression is confirmed by the statistics on the magnitude of percentage deviations from market prices. The moneyness does not affect our findings in this case, since all kinds of option contracts are characterized by the fact that there is a higher percentage with a deviation outside the limits of 20 percent deviation in the second period than in the first one.

Both call and put options generally tend to be overpriced but they are more likely to be overpriced in the period after Lehman Brothers than before. Out of the money call options do not present a significant change in their proportion of overpricing between the periods. In the money put options seem to show a decreasing proportion of overpriced observations in the period after Lehman´s scandal which is the opposite result to the total sample.

The degree of mispricing for call options drops from 57 percent (in the ‘before period’) to 8 (in the ‘after period’) percent within the 20 percent deviation range. The main driver of this figure, the out of the money type does not present such a huge decline but still loses almost 20 percent (from 23 ‘before’ to 5 ‘after’) in the 20 percent deviation range. For put options, the degree of mispricing does not change significantly between both periods, but its main driver, the in the money type presents a drop from 76 percent (in the ‘before period’) to 60 percent (in the ‘after period’). At the money put options show a much more distinct decrease in the degree of mispricing. To sum up, it appears that the Black-Scholes model presents even greater inaccuracies when pricing call options than put options but the results from both types supported our intention to conduct hypothesis testing.

Through the inferential analysis, the conclusion we drew from the mispricing investigation is clearly strengthened. The hypothesis that the distribution of the
percentage differences is the same across both periods is rejected apart from the *in the money* type in call options and the *out of the money* type in put options.

### 6.2 Reflections of the authors

The terms validity and reliability are highly related to our personal reflection of the work. In section 2.6 we already discussed those important principles in order to judge our individual study approach. In the end, we are still convinced in the study approach inspired by the works of Pape and Merk or Bodurtha and Courtadon. Furthermore, we still guess that the same approach applied to another stock market and another financial instrument would lead to similar results and conclusions.

One important element in our reflection was also if there could be other explanations for the final findings if we go beyond the pure option pricing theory. Actually, there are two possible approaches to explain the fact that Black-Scholes ability to approximate the market price suffers from anomalies on financial markets. Firstly, we can directly doubt the model itself and claim that the assumptions that have been discussed critically in section 3.4 are too restrictive. Like mentioned in the previous section, the assumption regarding the volatility is likely to be the main weakness of the model. But also the application of the underlying asset and risk-free interest rate is more problematic during financially turbulent periods. Thus, we claim these three input variables to be responsible for the increasing price deviations after Lehman Brothers. But secondly, now at the end of the research we nevertheless should ask this fundamental question again, as it is possible that due to the findings, other explanations may increase in importance. For instance, one should also consider the possibility that it is not a fault of the Black-Scholes model that price deviations increased after September 15th. Instead one could also blame the investors’ behavior, which led to massive changes in demand and supply and consequently to price downturns. This examination can be considered as open question or academic outlook for further research, as we totally ignored the investors’ perspective in our research.

All in all, there is one true thing we can state and that is precisely what we wanted to achieve. There is no difference whether the model was wrong or the investors, because in fact, the price deviations of options on StockholmOMX30 have been influenced by Lehman Brothers’ bankruptcy. The lesson that can be learnt from this research is that one has to be much more careful in applying a pricing model for derivatives when there are indicators for abnormal happenings in the corresponding market.
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Chicago Board Options Exchange [online] (cited 27 February 2010b). Available at: http://www.cboe.com/LearnCenter/glossary_m-r.aspx#O

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Changes in the creditability of the Black-Scholes option pricing model due to financial turbulences

Appendix 1

In this section we want to give advice about all Excel formulas we used for our data preparation and organization.

Calculation of theoretical prices: (notations according to 3.3.2)

\[ d_1 = \frac{\ln(A/(K*\exp(-r*T)))+(r+0.5*(\sigma)^2)*(T))/((\sigma*(T)^{1/2})}{\sigma*(T)^{1/2}} \]

\[ d_2 = d_1 - \sigma*\sqrt{T} \]

\[ N(d_1) = \text{NORMSDIST}(d_1) \]

\[ N(d_2) = \text{NORMSDIST}(d_2) \]

\[ \text{Price}_{\text{Call}} = (A*N(d_1))-K*N(d_2)*\exp(-r*T)) \]

By applying put-call-parity: \[ \text{Price}_{\text{Put}} = \text{Call}+K*\exp(-r*T)-A \]

Calculation of moneyness:

Call:

\[ =\text{IF}(\frac{\text{Index}}{\text{Strike}})\geq1.05;"ITM";\text{IF}(\frac{\text{Index}}{\text{Strike}})\leq0.95;"OTM";"ATM") \]

Put:

\[ =\text{IF}(\frac{\text{Index}}{\text{Strike}})\geq1.05;"OTM";\text{IF}(\frac{\text{Index}}{\text{Strike}})\leq0.95;"ITM";"ATM") \]

Calculation percentage differences:

\[ \text{difference} = (\text{market}_{\text{price}} - \text{model}_{\text{price}}) / \text{market}_{\text{price}} \]
Appendix 2


ABB Ltd
Alfa Laval AB
ASSA ABLOY AB ser. B
Atlas Copco AB ser. A
Atlas Copco AB ser. B
AstraZeneca PLC
Boliden AB
Electrolux, AB ser. B
Ericsson, Telefonab. L M ser. B
Getinge AB ser. B
Hennes & Mauritz AB, H & M ser. B
Investor AB ser. B
Lundin Petroleum AB
Modern Times Group MTG AB ser. B
Nordea Bank AB
Nokia Corporation
Sandvik AB
Svenska Cellulosa AB SCA ser. B
SCANIA AB ser. B
Skandinaviska Enskilda Banken ser. A
Securitas AB ser. B
Svenska Handelsbanken ser. A
Skanska AB ser. B
SKF, AB ser. B
SSAB AB ser. A
Swedbank AB ser A
Swedish Match AB
Tele2 AB ser. B
TeliaSonera AB
Volvo, AB ser. B