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MASTER THESIS

Efficiency of the Swedish Option Market and the Effect of Volatility: A test of conversion and reversal strategies

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Abstract

Using Swedish index option spanning the period of 2005 to 2015 the validity of the put-call parity, and thus the efficiency of the option market, has been tested. The impact of volatility on the market efficiency has also been covered in this paper. Theoretical as well as the financial efficiency was tested. I find proof of systematic relative put overpricing and arbitrage possibilities for institutional and private investors alike. These arbitrage possibilities have both statistic and financial significance. No relationship between inefficiencies and volatility were found.

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Chapter 1

Introduction

The derivative market has grown to become one of the most important financial entities. Options play a crucial role for institutional as well as for private investments. Options enable investors to hedge or take positions that otherwise are too expensive or just not possible. The leveraging possibilities are enormous and options are the foundation for many other financial derivatives. Index options were introduced to Sweden in the mid 1980-ties and grew fast top become one of the most popular option types (www.nasdaq.se).

Index options allow investors to get market wide exposure, and speculate on future movements, without having to buy or sell a large number of different securities. The pricing efficiency of the option market is of great importance for everyone from individual investor to institutions and even politicians.
Testing the efficiency of the option market can be done theoretical as well as from an financial viewpoint. One way to test the theoretical efficiency is to compare observed option prices with those implied by theoretical models such as the Black-Scholes option pricing model or put-call parity. In this paper the focus will be on put-call parity as it has fewer restrictive assumptions (Mittnik and Rieken 2000) Violations of put-call parity would imply that inefficiencies exist. To test the efficiency from an financial standpoint hedging strategies can be devised to explore the theoretical inefficiencies. Based on put-call parity hedging strategies can be created that return risk free arbitrage profits if inefficiencies exist (Stoll 1969). Evaluating the magnitude and frequency of these profits will give a clear picture of the financial significance of market inefficiencies.

Volatility is a central part of option pricing. It is reasonable to believe that market inefficiencies might be connected to market uncertainty. Thus, volatility and the impact on market efficiency will be a central part of this paper.
In this thesis I test the efficiency of the Swedish index option market during the

period 2005 to 2015. This is done by investigating put-call parity violations during the sample period. The validity of the put-call parity is tested on statistic basis, by the means of regression and on financial basis, through an ex-ante test. Also the market wide volatility will be taken into account and the effects on put-call parity investigated. Factors such as moneyness, maturity, and transaction cost will in different stages be incorporated in the analysis.

This papers contribution to existing literature regarding option market efficiency is to examine the Swedish option market and the effect of market wide volatility. This paper is the first to my knowledge, that investigate the effect of volatility on the degree of inefficiency of option markets. It is also the first in modern time to test the efficiency of the Swedish option market by the means of put-call parity.

The main findings are that the Swedish index option market suffers from inefficiencies. The validity of put-call parity has been rejected on statistical as well as on financial grounds. The results show that put options to a larger extent are overpriced compared to call options and that arbitrage gains can be made by exploiting these inefficiencies. No proof of a relationship between volatility and inefficiencies were found.

Chapter 2

Previous research and Hypothesis

In this chapter an overview of previous research is presented. Based on this research the hypothesis will be motivated and formulated. How the previous research relates to theory will be discussed in chapter 3.

2.1 Research on the Put-call parity and efficiency of stock indices

First, the research on the fundamentals of the PCP will be discussed. The second part covers Put-Call parity as a measure of informational efficiency. In the third part the applicability of the Put-Call parity will be presented. Finally, literature regarding the relationship between volatility and option returns will conclude this section.

2.1.1 Put-Call parity

A fundamental relationship in option theory is the so called Put-Call parity, which states that a put option can be converted into a call option (with the same strike and maturity) without any additional risk. This relationship between put and call option prices was established by Stoll (1969) and corrected by Merton (1973). Stoll (1969) finds support for the Put-Call parity theory and concludes that the relative put and call prices move together, implying a deterministic relationship. Violations of the PCP would result in arbitrage possibilities which in turn would lead to a correction of the prices and a return to equilibrium. Stoll (1969) states " The existence of Put-Call parity is consistent with the random walk hypothesis", thus, put and call prices lack predictive power.

One problem with the PCP is that it does not take the possibility of early exercise (American options) into account. Stoll (1969) claims that it will never be profitable to exercise the option prematurely, a claim that Merton (1973) rebuffs. While it is not possible to show an exact relationship between American put and call options it is possible to derive upper and lower boundaries within which the difference between the put and call prices (P-C) must lie, (Hull 2012).

2.1.2 Put-Call Parity and Informational Efficiency

Trough out the years there have been many test of the efficiency of financial markets in general, and test of PCP, in particular. Violations against the PCP would imply that inefficiencies exists due to risk free arbitrage possibilities.

Model based test, where observed values are compared to theoretical values from models such as the Black-Scholes option pricing model, suffer from severe drawbacks since it will be a joint test of multiple hypotheses. Not only will the market efficiency be tested but also the validity of the model and the specification of its parameters, (Mittnik and Rieken 2000). By implementing a model free test based on arbitrage possibilities this problem can be avoided. Mittnik and Rieken (2000) calls this a "pure arbitrage" test. This test is based on the condition that there are no systematic arbitrage possibilities in the option market. This removes, to some extent, the problem of joint hypothesis.

2.1.3 Applicability of Put-Call Parity

It is widely excepted that the PCP holds in theory, but applying it in reality has proven difficult. When applying PCP to historic data one must consider factors such as option type (American vs European), dividends, and transaction costs, non of which the original PCP takes into account.

The majority of studies covering efficiency tests based on PCP has been done on U.S. stock options or U.S. index options. A common factor for these studies is that most cover American options and thus suffer from problems related to early exercise. Stoll (1969), Gould and Galai (1973), Klemskosky and Resnick (1979,1980), Evnine and Rudd (1985), all cover American options written on either U.S. stocks or U.S. stock indices. They find moderate to large violations of the Put-Call parity. The mentioned articles differ in, to which extent, they regard dividends and transaction costs.

Gould and Galai (1973) extended the PCP to incorporate transaction costs and taxes. They performed PCP based tests of the efficiency of American style options written on U.S. stocks during the period 1967-1969. They found that without large transaction cost there were substantial violations of the PCP and thus inefficiencies in the option market. Klemkosky and Resnick (1979, 1980) introduced known dividends to the PCP and created upper bounds to address the problem of early exercise. They found that their ex post test of the PCP of American options was consistent with market efficiency, but with some violations. The profitability of the arbitrage opportunities tended to be sensitive to transaction costs and time, the price correction were rapid and thus the economical gain tended to vanish fast.

A subject that the previous papers neglected to discuss is how different types of underlaying asset impacts the understanding of the option market. It is quite straight forward to adjust the PCP for dividends when the underlaying asset is a stock. It is however far more cumbersome to do so for a stock index (but not impossible). Evnine and Rudd (1985) highlights this fact among others. They also discuss the possibility that there are more frequent arbitrage opportunities when the options are written on an index, due to the fact that it is harder to take a position in the asset. Depending on the composition of the index, the distribution of the returns might have some non-desirable attributes. Many option pricing formulas rely on the returns to be lognormal distributed with constant variance. If the underlying asset is a wighted index where previous performance etc. effects the future composition the return process aught to be suffering from nonstationarity (Evnine and Rudd 1985). This will however not be the case for return indices and gross return indices such as the OMXs30 and DAX index.

Earlier research regarded transaction costs as the fixed cost for creating the option conversion. It was calculated by taking an average of brokerage fees, commissions, lending rates, etc. Nisbet (1991) used a more dynamic approach when analyzing the PCP of American style options written on UK equities in the London Traded Options Market (LTOM). Nisebt (1991) evaluated the impact of the bid-ask option price spread and concluded that it is crucial to account for the spread in any empirical study of market efficiency. When using the bid price for the written option and the ask price for the purchased option Nisbet (1991) finds that the number of profitable hedges is reduced by half.

An arbitrageur must act quickly if and when an arbitrage opportunity arises. Option and stock prices change constantly and thus one can argue that the arbitrage possibilities are time sensitive. Kramer and Miller (1995) find that European styled options written on the S&P 500 suffer from less PCP violations compared to earlier work on American styled options and that trading strategies based on PCP are subject to significant liquidity (immediacy) risk. As the trading strategies are exposed to delayed execution many of the once profitable hedges result in losses, (Kramer and Miller 1995).

It is possible to circumnavigate many of the above mentioned complications by choosing specific options. By using European styled options written on gross return (performance) indices the problem of early exercise and dividends can be avoided. One such gross return index is the German stock index called DAX. Choosing to investigate the efficiency of the German option market by using options written on the DAX-index allowed Mittnik and Rieken (2000) to perform in depth ex-post and ex-ante analyses. Since the market for put options is larger compared to the market for call options it is reasonable to assume that there will be differences in PCP violations of conversions and reversals. One can also think that the moneyness of options impact the PCP violations. Mittnik and Rieken (2000) conclude that puts of different moneyness are overpriced compared to calls of the same moneyness, which points to the fact Germany have short selling restriction that does not allow a short position in the index to be taken which is needed for the reversal strategy. Thus making it impossible to take advantage of the arbitrage opportunity.

Finally, one last aspect that needs to be considered when testing PCP is the non synchronousness of the observations. All research, from Gould and Galai (1973) to Mittnik and Rieken (2000), suffer and discuss this aspect to some extent. If the put, call, and underlying asset prices, are not perfectly synchronized, the PCP test will suffer from measurement error bias.The put-call parity formula is dependent on the timing of the observations. If the observations are not registered at exactly the same time the prices might not reflect the true relationship. If any of the prices change between say the option price is registered and the index level is registered the put-call parity formula will no longer be correct.

2.1.4 Volatility and option returns

There are six factors that drive option prices; current price of the underlying asset, strike price, time to maturity, volatility of the underlying asset, the risk free rate, and dividends (Hull 2012). How each of these factors effect the option prices is today well known, but the question is how these factors impact the put-call parity. Previous research has touch upon this subject by investigating some of the factors. The current price of the underlying asset and the strike price are captured in studies which cover the issue of different moneyness. Some papers have also investigate how time to maturity effects the PCP, and as mentioned earlier the effect of dividends. However, how the volatility of the underlying asset effects the PCP has not been investigated.

Volatility is a central concept in asset management. Volatility is widely regarded as a risk measure, since higher volatility results in a more uncertain future. Volatility is also a fundamental part of option pricing. Constantinides, Jackwerth, and Savov (2013) show that factors such as jump, volatility jump, volatility, and liquidity help explain the cross-section of index option returns. It is thus not far fetch that volatility might impact the degree of PCP violations.

2.2 Hypothesis

Based on the previous research put-call parity can be a good tool to investigate the efficiency of an market.There has been a substantial amount of research on the efficiency of the U.S. equity and option market. The number of papers on put-call parity and market efficiency of European markets is quite scarce, and even fewer on the Swedish option market. It can be argued that there should be larger deviations from PCP in smaller markets such as the Swedish, due to lower trading volume. Another reason for choosing the OMXS30 as the underlying asset in this paper, is the fact that it is harder to take a long (short) position in an index compared to a single stock. This ought to result in larger pricing errors (Evnine and Rudd 1984). The lack of research and the possibility of larger deviations due to lack of volume and difficulty of taking a position motivates the us of OMXS30.

To evaluate the efficiency of the Swedish option market both statistic and economic factors must be addressed. If the option market is efficient options should be correctly priced and there should be no risk free arbitrage possibilities. This implies that the put-call parity is not violated. This leads to the first hypothesis.

Hypothesis 1:The put-call parity holds and there are no risk free arbitrage possibilities in the Swedish index option market regardless of moneyness, time to maturity, and transaction costs

If there is proof for an inefficient market the natural follow up questions would be when and where these efficiencies occur. As mentioned earlier volatility is a measure of market uncertainty and it would not be far fetched to assume that this might impact the frequency and magnitude of market inefficiencies. This results in the second hypothesis.

Hypothesis 2: Volatility has no impact on put-call parity violations.

Chapter 3

Theory

In this section the theory needed to fully understand the analysis will be explained. This chapter conist of two main part. The first part addresses the theory behind the Put-Call parity. In the second part, the focus will be diverted to volatility. The main focus of the final section will be aimed at the concept of *"model free implied volatility"*.

3.1 Theory behind the Put-Call parity

The relationship between call and put options was for a long time unknown. Many thought that call options were more expensive compared to put options due to the higher demand of calls. This is however not the case. Today put options are more sought after then calls. Stoll (1969) aimed to find a relationship between calls and puts, this paper resulted in the today well known concept of put-call parity. Stoll (1969) used puts, calls, and the underlying asset to show that when combining these, one can create synthetic positions which had the same payout profile and risk as the nonsynthetic counterpart. If two products have the same payoff profile and risk the price ought to be the same, at least in an efficient market.

Assuming a frictionless market without transaction costs or dividends and using the notations above the Put-Call parity for a European styled option can be

C_t	Market price of call option at time t
P_t	Market price of put option at time t
I_t	Level of underlying asset at time t
K	Strike price
T	Expiration time of the option
r	Annualized risk free rate
τ	$T - t =$ Time to maturity of the option measured in years

TABLE 3.1: List and definition of input variables

expressed as:

$$C_t = P_t + I_t - Ke^{-r\tau} \tag{3.1}$$

Thus a synthetic call can be created by buying a put options (whit the same maturity and strike price), taking a long position in the underlying asset , and borrowing $Ke^{-r\tau}$ at the risk free rate.

The payoff from a long position in a call is max($I_T - K, 0$) at maturity, and the payoff from a long position in a put is max($K - I_T, 0$) at maturity. Assuming $I_T > K$ in (3.1) the cash flow from the call will be $I_T - K$, the put will expire worthless (i.e. cash flow $= 0$), liquidating the debt result in a negative cash flow of $-K$ and selling the underlying asset results in a cash flow equal to I_T.Thus, the payoff from the call is equal to the payoff from the synthetic position, namely $I_T - K$. In the case where $I_T < K$, the call expires worthless (cash flow $= 0$), the value of the put becomes $K - I_T$, selling the underlying asset (cash flow $= I_T$), and liquidating the debt (-K), result in a zero cash flow as well. Equivalently, buying a call, shorting the asset and borrowing K at the risk free rate results in a synthetic position with the same pay off structure as a long put. The positions and their respective pay offs depending on outcome can be seen in table 3.2 below.

Position	Payoff if $I_T > K$	Payoff if $I_T < K$
C_T	$I_T - K$	0
P_T	0	$K - I_T$
$P_T + I_T - Ke^{-r\tau}$	$I_T - K$	0
$C_T - I_T + Ke^{-r\tau}$	0	$K - I_T$

TABLE 3.2: Position and respective payoff

If the PCP is breached, say for instants that the call is overpriced relative to the put, an arbitrage opportunity arises. Writing the overpriced call and buying the underpriced synthetic position results in a zero cashflow at maturity but an immediate cashflow equal to $C_t - P_t - I_t + Ke^{-r\tau} > 0$. This strategy is known as a conversion or the long-hedge. The counterpart, where the call is relative underpriced is called a reversal or short-hedge. A reversal can be achieved by writing a put and buying a synthetic put (this is the same as buying a call and writing a synthetic call). This results in an initial cashflow of $P_t - C_t + I_t - Ke^{-r\tau} > 0$ and zero at maturity (Mittnik, Rieken 2000).

Introducing transaction costs. Reality differs often quite a bit from theory. The original PCP does not take transaction costs into account.Thus, there is a possibility that the PCP violations exist in theory but in reality they only reflect the cost for setting up the conversion or reversal. One could modify the PCP model by subtracting the cost that is related to each element of the hedge. Such as the bid-ask spread for the put and call option, the commissions, clearing fees, and administrative costs, that are related to each position. The Put-Call parity with transaction costs is shown in equation (3.2).

$$C_t = P_t + I_t - Ke^{-r\tau} - T_C \tag{3.2}$$

for

$$T_C = T_S + T_B + T_N \tag{3.3}$$

where

Rather the adding a separate term for each of the different cost, I use T_C which is

T_C	Total transaction cost
T_S	Bid-Ask spread
T_B	Brokerage fees
T_N	Nasdaq fees

TABLE 3.3: Different transaction costs

the combination of the cost that are attributed to where they arise. For instants, Nasdaq charges a fee of 3.50 SEK for each option contract bought or sold.

This quick fix comes however with yet another problem. Some of the cost are hard to correctly estimate and would probably result in measurement errors. Transaction costs will be discussed further in following chapters.

Introducing dividends. As previous research has proven, dividends play an important role for Put-Call parity. Corrections for dividend payments on the underlying asset will however not be made in this paper due to reasons that will be discussed in later chapters.

3.1.1 Volatility and Options

As mentioned in the previous chapter, is volatility one of the factors that effects the price of an option. Volatility is widely known as a risk measure, this is the case since volatility describes the fluctuations of the asset and higher fluctuations means higher uncertainty of future price movements. Options are one-sided, i.e. a call will increase in value as the underlying asset increases in value, but is limited on the downside, and vice-versa the put. As volatility increases so does also the probability that the asset will perform very bad/well. The fact that options are some what one-sided and the nature of the volatility described above results in that higher volatility increases the value of the call and put options (Hull 2012). Risk is a central concept when dealing with asset allocation. This has led to comprehensive studies regarding risk and volatility. The volatility of an asset is often defined as the standard deviation of the asset.

$$\hat{\sigma} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}[r_i - \bar{r}]^2} \tag{3.4}$$

But there are many different approaches to estimate the volatility. Some prefer implied volatility others realized volatility etc. The most famous way to estimate the implied volatility of options is the Black-Scholes implied volatility.

Volatility is the only unknown factor in the Black-Scholes option pricing model and can thus be back out. The implied volatility is forward looking and incorporates the markets expectations of future volatility (Hull 2012).

One problem using the Black-Scholes implied volatility is that it is based on the same strong assumptions as the model itself. One of these being that the volatility is constant. Another assumption, which is based on PCP, is that the implied volatility of identical puts and calls must be the same. Volatility has been shown to exhibit some stylized characteristics such as mean reversion, stationarity, long memory, and non-normality. There are other models that incorporates these factors better. The GARCH model for instants takes the mean reverting nature of volatility into account. More recent, the popularity of so called "model free implied volatility" (MFIV) has risen. The model free implied volatility avoids restrictive assumptions in the same way the put-call parity test does. Jiang and Tian (2005) demonstrated that model free implied volatility is informational more efficient compared to Black-Scholes implied volatility as well as historic variance.

Model free implied volatility The model free implied volatility has enabled investors to trade volatility. The VIX index, also known as the "fear index", is an index that tracks the volatility of options on the Chicago Board Option Exchange (CBOE). This index is based on MFIV and has proven to be a useful tool for investors who's aim it is to get a clean exposure to volatility.

To fully grasp the concept of MFIV one must first understand how volatility and variance swaps are constructed. A volatility (variance) swap is a contract which substitutes the realized volatility (variance) of an asset during a predetermined time period with a fixed volatility (variance) (Hull 2012). The realized volatility can be calculated as:

$$\bar{\sigma} = \sqrt{\frac{252}{n-2}\sum_{i=1}^{n-1}\left[ln\left(\frac{S_{i+1}}{S_i}\right)\right]^2} \tag{3.5}$$

If the fixed volatility is σ_K and the principal is L_{vol}, then the payoff at maturity for the holder of the swap is equal to: $L_{vol}(\bar{\sigma} - \sigma_K)$. The variance swap is much the same, instead of realized volatility ($\bar{\sigma}$) one uses realized variance ($\bar{V} = \bar{\sigma}^2$) (Hull 2012).

Demeterfi et al.(1999) has shown that it is possible to value variance swaps by replicating them with the use of European options. The MFIV and volatility indices such as the VIX, are based on the fair value of future variance which can be extracted directly from the option prices used to value the volatility swaps. An more in depth presentation of how MFIV indices are calculate can be found in the appendix.

Chapter 4

Method

In this chapter the methodology will be explained. The methodology will be based on the paper by Mittnik and Reiken (2000) who investigated the informational efficiency of the German DAX-index option market. First a general description of the market efficiency test will be given. This is followed by a more in depth illustration of how the put-call parity and market efficiency will be tested statistically. This section is concluded by a discussion of the efficiency test of put-call parity.

4.1 General Design of the Market Efficiency Test

Market efficiency in the put-call parity setting implies that any put and call options are efficiently priced regardless of time, thus, the profit from any riskless hedge should be less or equal to zero. In terms of conversion and reversal strategies this can be described as:
for the conversion (long hedge)

$$\epsilon_t^l = C_t - P_t - I_t + Ke^{-rT} - T_C^l \leq 0 \tag{4.1}$$

and for the reversal (short hedge)

$$\epsilon_t^s = P_t - C_t + I_t - Ke^{-rT} - T_C^s \leq 0 \tag{4.2}$$

4.2 Statistical test of Put-Call Parity

The relationships implied by 4.1 and 4.2 will be tested by means of linear regression.

$$C_t - P_t = \alpha_0 + \alpha_1(I_t - Ke^{-rt}) + u_t \tag{4.3}$$

For the PCP to statistically be valid the null hypothesis that $\alpha_0 = 0$ and $\alpha_1 = 1$ must hold. To test the impact of volatility an additional regressor will be added. $V_{SVIX,t}$ is the value of the volatility index SVIX at time t. This results in the following regression:

$$C_t - P_t = \alpha_0 + \alpha_1(I_t - Ke^{-rt}) + \alpha_2 V_{SVIX,t} + u_t \tag{4.4}$$

This regression will not show if volatility causes PCP violation. It will only indicate how the difference between call and put prices are impacted by volatility.

Regressions 4.3 will be run for the entire sample as well as for each year (2005-2015) individually and also for subsamples constructed based on volatility level. Further, a nonparametric sign test of PCP where the option pairs will be divided into subsamples based on moneyness and time to maturity will be conducted. This test is not as sensitive to for instance outliers as the regression and will in addition to pinpointing the effect of moneyness and maturity, work as an backup to the regressions.

4.3 Efficiency tests of put-call parity

To investigate the economical significance of put-call parity violations previous papers by Mittnik and Reiken (2000) constructed an ex-ante test. This test identified PCP violations and treated them as misspricing signals. When a signal was identified a hedge could be constructed. This enabled the authors to account for immediacy risk, the risk of price movements during the time it takes to create the hedge. Due to data restrictions this is however not possible in this paper. Today it is quite simple to write an algorithm that as soon as the mispricing signal occurs will take a position, which minimizes the immediacy risk. Thus, the immediacy risk will be ignored.

If we look back to equation 4.1 and 4.2 it is easy to understand that violations of these would result in misspricing signals. If $\epsilon_t^s > 0$ this signals that the put is relative overpriced in relation to the call. If $\epsilon_t^l > 0$ the call is relatively overpriced. When these signals are observed a hedge will be created immediately. The mean, standard deviation, t-statistics, p-value, and other inference of ϵ will be calculated and thus the economical significance of the level of efficiency can be understood. This will be done for the entire sample as well as for each year individually and for the volatility based subsamples. Then a comparison can be made between levels of market efficiency during periods of "high", "normal", and "low" volatility. The ex-ante test will be conducted with and without transaction costs.

Chapter 5

Data

In this chapter the data will be discussed. There are five main components of the put-call parity analysis; the index, the options, the risk free rate, the transaction costs, and the volatility. How each of the components are chosen will be commented and motivated. The composition, processing and limitations of the data will also be discussed.

5.1 Index

The underlying asset for this study is the OMXS30 index. The OMXS30 is a price return index consisting of the weighted returns from the 30 most traded assets on the Swedish stock market, Nasdaq.

The data for the index was collected from Bloomberg. The data consists of daily observations, of the last price of each trading day, from 2005 to 2015. From these index-levels the log-returns were calculated. The returns were used to test the distribution and to gather descriptive statistics. As seen in figure 5.1 the returns seem to be well behaved and close to log-normal distributed.

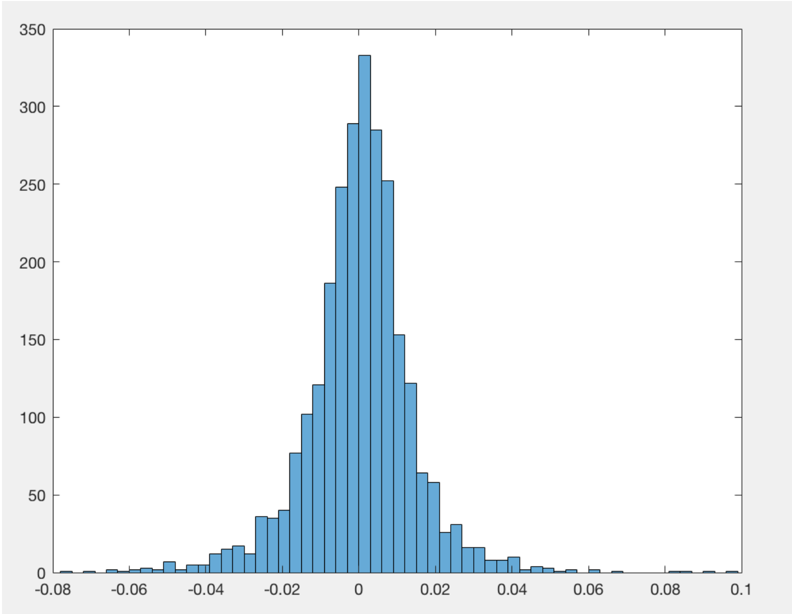

FIGURE 5.1: Histogram of OMXS30 returns 2005 to 2015. Max 9.86%, mean 0.029%
min -7.51%, std 0.2276, skewness 0.0332, kurtosis 7.7960

The past high, lows, and means of the OMXS30 index are presented in table 5.1 below. The lowest value of the index was in 2008 due to the financial crisis. The highest was during the last year of research period.

OMXS30	Max	Min	Mean
2005	966.74	727.56	830.22
2006	1 150.25	878.16	1 012.87
2007	1 311.87	1 053.64	1 201.88
2008	1 058.37	567.61	858.41
2009	975.47	597.76	808.62
2010	1 166.00	923.37	1 040.15
2011	1 179.29	862.17	1 046.00
2012	1 123.35	946.12	1 054.15
2013	1 334.42	1 112.14	1 222.51
2014	1 478.93	1 269.91	1 375.56
2015	1 719.93	1 421.34	1 623.73
Total	**1 719.93**	**567.61**	**1 068.69**

TABLE 5.1: Total and yearly max, mean, and min, of the OMXS30 during the period 2005 to 2015

5.2 Options

The options used in this paper are European styled options written on the OMXS30 index. The data is obtained from SIX and consist of a large number of daily observations of options with different strike and maturity. The data is divided into bid, ask, and closing, prices. There are more bid/ask prices then close prices. The closing price will be used when available, otherwise the mid price will be used. The data ranges from 2005 to 2015. The data was sorted into pairs where call options were matched with the corresponding put option. One problem that will not be regarded in this paper is the fact that all options written on OMXS30 turn Asian at maturity. This means that on the day of expiration the option will be priced based on the average of the index that day, or during a couple of hours that day.

The number of option pairs, the average maturity, moneyness etc is presented in table 5.2 below.

Option distribution				
Total number of options	127 335			
Number of option pairs	57 454			
Maturity				
Pairs with 30 days or less to maturity	20 170	35%		
Pairs with 31-60 days to maturity	19 593	34%		
Pairs with 61-90 days to maturity	15 444	27%		
Pairs with 91 day to maturity or more	2 247	4%		
Moneyness	**Call**		**Put**	
Far out of the money (M<0.9)	393	0.68%	5 369	9.34%
Out of the money (0.9<=M<0.98)	15 681	27.29%	20 088	34.96%
At the money (0.98<=M<=1.02)	15 923	27.71%	15 923	27.71%
In the money (1.02<M<=1.1)	20 088	34.96%	15 681	27.29%
Far in the money (1.1<M)	5 369	9.34%	392	0.68%

TABLE 5.2: Option descriptives. The moneyness is the ratio between the index and strike price. The different moneyness levels are as defined by Mittnik and Reiken (2000)

5.3 Risk Free Rate

As a proxy for the risk free rate, Swedish treasury bills were used. These are, according to Mittnik and Rieken (2000), analogous to the interbank bid and offer rates which they used. 1-,3-, and 6-month t-bills were obtained from riksbanken (www.riksbanken.se). These were linearly interpolated and matched to the maturity of the options.

5.4 SVIX

As a proxy for volatility the MFIV index "SVIX" will be used. The index was obtained from a previous master of science in finance thesis written in 2016 at the University of Gothenburg. The SVIX was calculated using the same option-dataset as is used in this paper. The SVIX index consist of daily observations from 2005 to 2015. The index is plotted in figure 5.2 below.

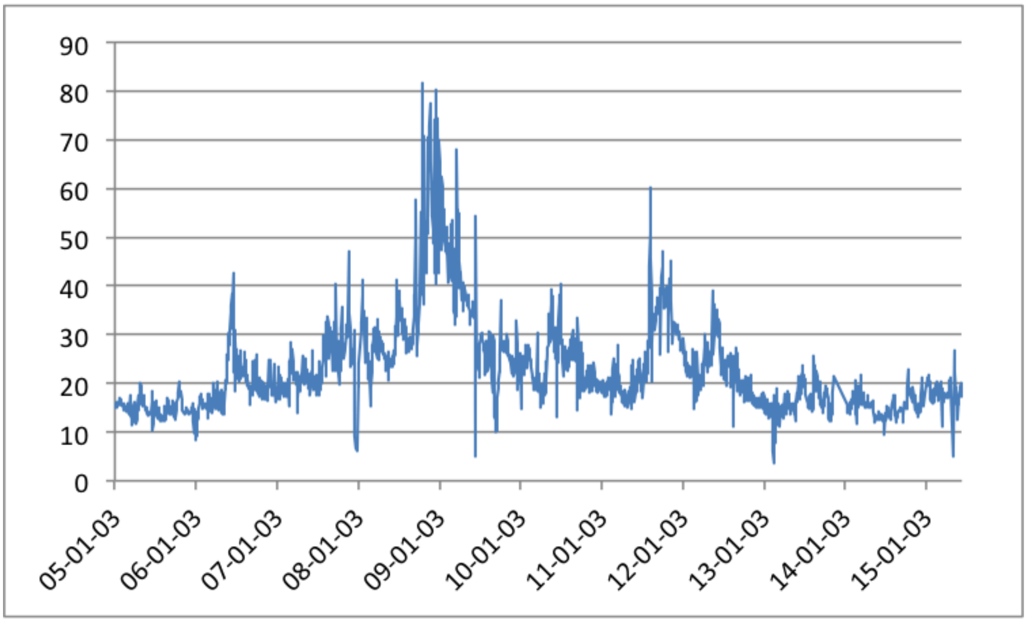

FIGURE 5.2: SVIX index from 2005 to 2015. Max 81.7, mean 22.90, min 3.61, std 9.46

5.5 Transaction Costs

Different levels of transaction costs representing different types of investors will be tested.
T_{c0} = Zero transaction cost
T_{c1} = bid/ask spread and NASDAQ option fee
T_{c2} = bid/ask spread, NASDAQ option fee, and brokerage fee for private investors
The bid-ask spread is used as a transaction cost since the close price not always is

available. Bhattacharya (1983) argues that in general, investors will pay the ask price when buying an asset and receive the bid price when selling. NASDAQ charges a fixed cost of 3.50 SEK for each option contract bought or sold independent of the type of buyer. The costs of taking a short position in the index will not be included in the analysis. The reason for this being that it has not been possible to obtain reliable information regarding these costs. Thus, the risk for measurement error is too high. Instead the results will be discussed in light of the missing costs, and conclusions will be drawn based on economical intuition. The brokerage fees and commissions for private investors have also proven to be difficult to obtain. The reason for this is the fact that there are large deviations in transaction costs based on the level of investor and that the prices have changed drastically the last couple of years as a consequences of new brokers. Mittnik and Rieken (2000) assumed the cost to be 0.1% of the current index value. This is deemed to be a reasonable cost for this paper as well. Toady, brokers charge their costumers between 0.35% to 0.05% depending on size of the trade and level of trader. Other costs are deemed to be negligible for institutional, as well as, for private investors.

5.6 Data Processing

After all the necessary data had been collected, the options were sorted into pairs of matching calls and puts. If there were more then one observation of pairs any given day, the most recent pair was used. The next step was to match the option pairs with the respectively OMXS30 level, SVIX level, transaction cost, and risk free rate. The days were one of the variables were missing were excluded. The next step was to divide the samples into subsamples depending on year, one subsample for each year from 2005 to 2015. Another class of subsamples were also created. This second class of subsamples was divided into high volatility, low volatility, and normal volatility, based on SVIX level.

5.7 Data Limitations

As mentioned earlier there are some limitations. First, the SVIX index does not take dividends into account and thus, the option prices and OMXS30 cannot be corrected for dividends. Since doing so would impact the results of the analyses of the effect of volatility on PCP violations. Another limitation is that transaction costs cannot be completely incorporated. The reason for this is as discussed under subsection 5.5. The largest limitation is the synchronicity of the data. Since the option observations are not timestamped to the second they are sampled, it is impossible to correctly match them with the other variables. This non-synchronicity can however be argued to be constant, or at least randomly distributed across the entire sample and not time dependent. Thus, this will not impact the the effect of volatility on market efficiency. The synchronicity can be assumed to be as large during high volatility periods as during low volatility periods.

Chapter 6

Results and Analysis

In this chapter the results and findings will be presented and an analysis of them be given. In the first section the statistical results will be shown and discussed. This is followed by the results of the financial significance test both with and without transaction costs.

6.1 Statistical test of put-call parity

The statistical test of put-call parity is done by ordinary least square regression and is based on the following relationship.

$$C_t - P_t = \alpha_0 + \alpha_1(I_t - Ke^{-r\tau}) + u_t \tag{6.1}$$

If put-call parity were to hold, the constants should be equal to zero and the coefficient should be equal to one. Thus, the null hypothesis is

$\alpha_0 = 0$ and $\alpha_1 = 1$. This regression is run for each year of the samples as well as for the entire sample. The results are shown in table 6.1. As can be seen form the high R^2 the estimated model fits rather well. The R^2 of the total sample is 0.97 and the subsamples range from 0.9214 to 0.9857. All constants (α_0) are negative and statistically different from zero at any significance level. The smallest deviation in absolute terms was in 2005 (-1.3619) and the largest in 2015 (-19.6259). The intercept for the entire sample was -7.4990, this is comparable with Mittnik and Reiken (2000) who estimated an intercept of -1.5697 (assuming the Deutsche Marks was approximately equal to 5 SEk the intercept would be -7.8485) for their similar regression.

Under the assumption that put-call parity holds, at the money puts and calls should trade at the same price. The negative intercepts implies that at the money puts were overpriced compared to calls. Since the contract value of the options are SEK100 per index point the at the money calls in 2005 were on average underpriced by $100x(-1.3619) = -136.19SEK$ compared to the corresponding puts. To see how the moneyness of the options impact the put-call parity the focus is directed to the third column of table 5.1. An α_1 larger than one, suggests that as $I_t - Ke^{-r\tau}$ increases (i.e. the call option becomes deeper in the money and put deeper out of the money), the relative call underpricing decreases. This is only the case for the subsample of 2014 which has a coefficient of 1.0112. This coefficient is statistically different form one at the 1% level. For the subsample 2007, 2008, 2010, and 2011, the null hypothesis that the coefficient is different from one cannot be rejected even at the 10 percent significance level. This means that regardless of moneyness the call options were relatively underpriced due to the negative intercept.

The remaining subsamples as well as the entire samples as a whole have slope coefficients that are statistical significantly lower than one at the one percent significance level. This means that as the call options get deeper in to the money, (and put options deeper out of the money), the relative call underpricing increases.

The validity of the put-call parity is rejected for all periods. The "test of PCP" column represents the F-statistic of the joint hypothesis test with the null that the constant (intercept) is equal to zero and the slope coefficient is equal to one. Given the p-values the null hypothesis can safely be rejected at the 1% significance level for all samples.

The impact of volatility on the spread between call and put prices is estimated by regressing

$$C_t - P_t = \alpha_0 + \alpha_1(I_t - Ke^{-r\tau}) + \alpha_2(svix) + u_t \tag{6.2}$$

The results can be seen in table 6.2. The coefficient of interest is the svix coefficient. It has a value of 0.257 and is statistically significant different from zero at the 1% level. This implies that a one unit increase of the svix volatility index results in a 0.257 increase in the spread between the call and put prices keeping all else equal. It is known that an increase in volatility results in an increase in option prices. The regression results, thus suggest that the call price increases more compared to the put price as volatility increases. To see how this impacts

Sample period (Sample size)	α_0	α_1	R^2	Test of PCP
2005 (2810)	-1.3619 (0.0925) [0.0000]	0.9839 (0.0046) [0.0008]	0.9372 (41917.69) [0.0000]	(131.07) [0.0000]
2006 (2474)	-2.1282 (0.1414) [0.0000]	0.9384 (0.0046) [0.0000]	0.9430 (40927.33) [0.0000]	(20834.83) [0.0000]
2007 (5389)	-3.6611 (0.1255) [0.0000]	0.9978 (0.0016) [0.1785]	0.9857 (370000) [0.0000]	(433.66) [0.0000]
2008 (5283)	-4.4510 (0.1425) [0.0000]	0.9987 (0.0031) [0.6772]	0.9524 (110000) [0.0000]	(496.27) [0.0000]
2009 (4480)	-3.4923 (0.1134) [0.0000]	0.9702 (0.0031) [0.0000]	0.9562 (97717.88) [0.0000]	(587.04) [0.0000]
2010 (5189)	-3.8571 (0.1113) [0.0000]	0.9990 (0.0022) [0.6487]	0.9752 (200000) [0.0000]	(600.94) [0.0000]
2011 (3931)	-5.2294 (0.1619) [0.0000]	0.9998 (0.0029) [0.9469]	0.9685 (120000) [0.0000]	(542.74) [0.0000]
2012 (6171)	-5.9085 (0.1646) [0.0000]	0.9751 (0.0022) [0.0000]	0.9691 (190000) [0.0000]	(1095.96) [0.0000]
2013 (4659)	-7.7745 (0.2052) [0.0000]	0.9941 (0.0029) [0.0387]	0.9626 (120000) [0.0000]	(798.97) [0.0000]
2014 (7012)	-10.6043 (0.1879) [0.0000]	1.0112 (0.0035) [0.0007]	0.9214 (82230.80) [0.0000]	(1666.74) [0.0000]
2015 (10056)	-19.6259 (0.1834) [0.0000]	0.9930 (0.0013) [0.0000]	0.9841 (620000) [0.0000]	(7528.42) [0.0000]
Total (57454)	-7.4990 (0.0572) [0.0000]	0.9728 (0.0071) [0.0000]	0.9700 (1900000) [0.0000]	(11454.73) [0.0000]

TABLE 6.1: Regression results. In the first column the subsample is shown followed by, in parenthesis the number of observations. In the second column are the constants with standard deviations in parenthesis and corresponding p-value in brackets. the third column shows the value of the coefficients followed by standard deviations in parenthesis and the p-value of $H_0 : \alpha_1 = 1$ in brackets. The second to last column shows the R^2, the F-values in parenthesis and corresponding p-values in brackets. The last column represent the test of put-call parity, here the F-values of the joint hypothesis test that $\alpha_0 = 0$ and $\alpha_1 = 1$ are presented followed by the p-values in brackets.

the put-call parity, the data is divided into subsamples depending on level of the SVIX index.

	$C_t - P_t$
$I_t - Ke^{-r\tau}$	0.975
	(1,383.31)**
svix	0.257
	(42.53)**
_cons	-13.305
	(90.09)**
R^2	0.97
N	57,454

* p<0.05; ** p<0.01

TABLE 6.2: Regression results volatility.

The index was sorted into three different classes, low volatility, mid volatility, and high volatility. The mid volatility class corresponds to SVIX levels that are no more or less than one standard deviation from the mean of the SVIX during the period 2005-2015. The option market is deemed to experience low volatility when the SVIX level is below one standard deviation of the mean, and high, when it is more than on standard deviation above the mean.

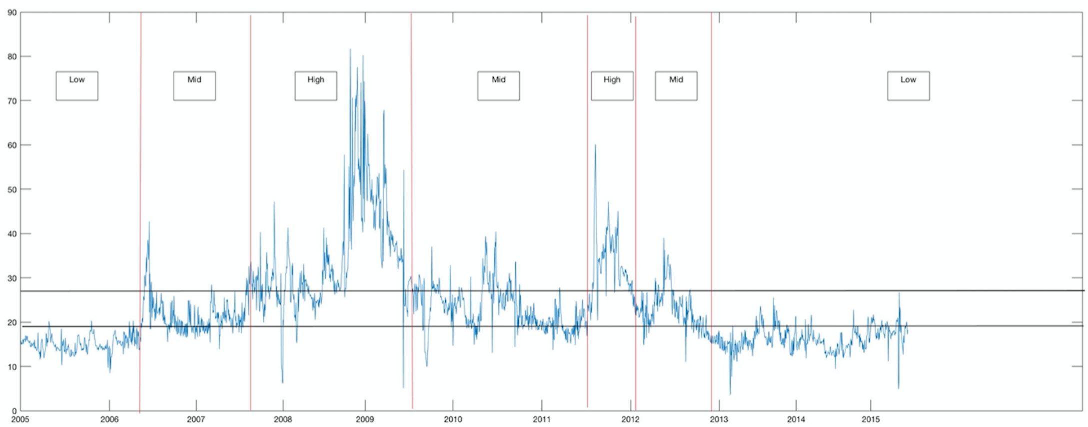

FIGURE 6.1: Svix index divided into high, mid, and low volatility periods. The volatility is high when the svix is more the one standard deviation above mean, and low when it is more than one standard deviation below mean)

Running a new regression based on equation 6.1 but with the new subsample constellations results in table 6.3.

Sample period (Sample size)	α_0	α_1	R^2	Test of PCP
	-2,2892	0.9231	0,9081	(445,09)
P1 (Low)	(0,0048)	(0,1122)	(37141,99)	[0,0000]
(3746)	[0,0000]	[0,0000]	[0,0000]	
P2 (Mid)	-4,3457	0,9954	0,9764	(462,98)
(4569)	(0,1451)	(0,0023)	(1900000)	[0,0000]
	[0,0000]	[0,0463]	[0,0000]	
P3 (High)	-4,0367	0,9955	0,972	(962,62)
(9759)	(0,0937)	(0,0017)	(340000)	[0,0000]
	[0,0000]	[0,0079]	[0,0000]	
P4 (Mid)	-4,1416	0,9942	0,9666	(1092,5)
(9635)	(0,0893)	(0,0019)	(280000)	[0,0000]
	[0,0000]	[0,0021]	[0,0000]	
P5 (High)	-1,1724	0,9928	0,9952	(125,27)
(2176)	(0,0907)	(0,0015)	(450000)	[0,0000]
	[0,0000]	[0,0000]	[0,0000]	
P6 (Mid)	-6,1318	0,974	0,9681	(1032,7)
(5652)	(0,1765)	(0,0024)	(170000)	[0,0000]
	[0,0000]	[0,0000]	[0,0000]	
P7 (Low)	-13,5505	0,9823	0,9741	(8534,8)
(21900)	(0,1176)	(0,0011)	(820000)	[0,0000]
	[0,0000]	[0,0000]	[0,0000]	

TABLE 6.3: Regression results. In the first column the subsample and volatility class is shown and below, in parenthesis, the number of observations. In the second column are the constants with standard deviations in parenthesis and corresponding p-value in brackets. the third column shows the value of the coefficients followed by standard deviations in parenthesis and the p-value of $H_0 : \alpha_1 = 1$ in brackets. The second to last column shows the R^2, the F-values in parenthesis and corresponding p-values in brackets. The last column represent the test of put-call parity, here the F-values of the joint hypothesis test that $\alpha_0 = 0$ and $\alpha_1 = 1$ are presented followed by the p-values in brackets.

The results are similar to those in table 6.1. An interesting observation is that the two low periods have very low (in absolute number) and very high intercepts estimates. The two high volatility periods (period 3 and period 5) have the smallest and third smallest deviation from zero. These results render no clear picture

of how volatility impacts put-call parity violations.
It is evident, both from the yearly regression and volatility-period regressions, that something happens towards the end of the sample period. The intercepts of the regressions for 2014 and 2015 as well as for the last volatility-period (period7) become increasingly negative. In figure 6.2 the OMXs30 index is plotted with the different strike prices corresponding to the options in the sample, imposed. The figure shows how the strike prices initially are quite close to the index level, to later become more dispersed. The reason for this is not clear. Is it due to some underlying market factor which has compelled investors to take positions deeper in- or out-of the money? The more plausible explanation is that the data has been sampled at a higher frequency. The number of observations in 2015 support this argument. With this in mind, should the magnitude of the regression coefficients be viewed with caution.

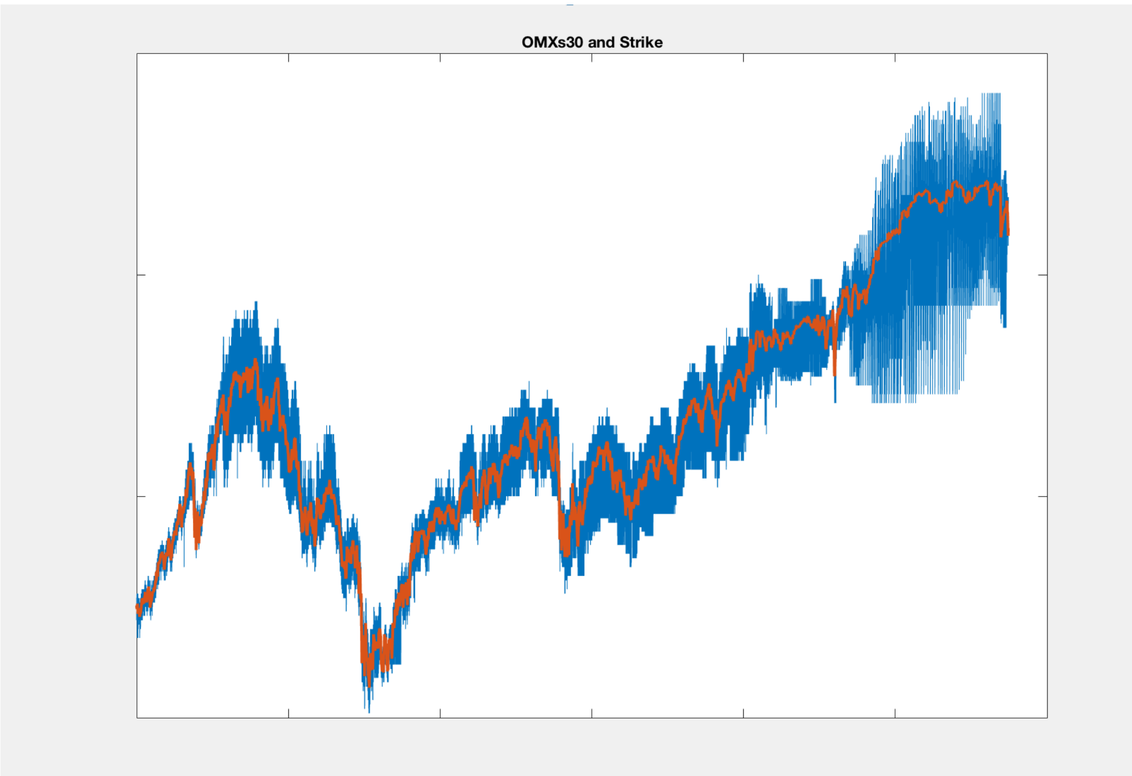

FIGURE 6.2: Plot of OMXs30 index in red and strike prices in blue, from 2005 to 2015.

Since the analysis does not take dividends into account, the regressions might be suffering from heteroskedasticity and large outliers or other violations of OLS assumptions that may induce some form of bias or another. Rubinstein(1985) and Sheikh (1991) used a nonparametric sign test to test for systematic biases in implied volatilities from the Black-Scholes model. The same test was used by Mittnik and Reiken (2000) when evaluating the put-call parity and efficiency of the German DAX-index. The pros of using this test is that it is more robust with respect to outliers among others. The con is that the test does not have the same predictive power as the regression based F-test. The nonparametric sign test compares the market value of the options with the synthetic counterpart. If the put-call parity holds the probability of observing a price of a synthetic option being higher then the market price of the option should be 0.5. Since the regressions made it clear that the puts were overpriced during every subsample, the test will be conducted on the entire sample. First the calls were converted into puts:

$$P_t^{PCP} = C_t - I_t + Ke^{-r\tau} \tag{6.3}$$

If put-call parity were to hold ($P_t^{PCP} = P_t$), the probability of observing a price higher than P_t^{PCP} must be equal to 50%. In table 6.4 the results of the non-parametric test are displayed. Three numbers for each category are presented. For pairs with out of the money calls and in the money puts, with 30 days or less to maturity, the number of observations (call/put pairs) are 4997. The P_t^{PCP} was higher than the market price of the corresponding put in 3423 pairs of the total 4997. The probability of obtaining this result, were PCP to hold is 0%. It is evident from the results that put-call parity can be rejected for all moneyness/maturity classes but one. For far out of the money call far in the money put pairs with more than 91 days to maturity the number of observations was only 8. This is to few observations to produce a reliable probability.

Nonparametric test of put-call parity					
Moneyness	Time-to-maturity				
Call/Put	0-30	31-60	61-90	91-	Total
FOM/FIM	90	152	143	8	393
	52	112	83	0	247
	0	0	0,02	NA	0
OM/IM	4997	5480	4513	691	15681
	3423	3886	3126	476	10911
	0	0	0	0	0
AM	6244	5104	3895	680	15923
	4195	3585	2659	473	10912
	0	0	0	0	0
IM/OM	7158	6665	5462	803	20088
	5047	4733	3846	578	14204
	0	0	0	0	0
FIM/FOM	1681	2192	1431	65	5369
	1347	1869	1176	54	4446
	0	0	0	0	0
Total	20170	19593	15444	2247	57454
	14064	14185	10890	1581	40720
	0	0	0	0	0

TABLE 6.4: Nonparametric test of put-call parity. The first column shows the moneyness, for instance the first row shows matched pairs of far in the money calls and far out of the money puts. The top row indicates how many days the options have to maturity.For each moneyness/maturity group three numbers are displayed. The first is the number of put and call pairs, the second is the number of puts for which the PCP price is higher then the market price, and finally the probability of observing more or equally many $P_t^{PCP} > P_t$ given that PCP holds

It is clear from the regression analysis as well as from the nonparametric test that the validity of put-call parity without transaction costs can be rejected. All the subsamples, both yearly and volatility based show statistically significant put overpricing. The put-call parity can be rejected at any moneyness, maturity, and volatility level. There is no clear connection between level of the SVIX-index and put-call parity violations.

6.2 Efficiency test of put-call parity

To test the economic significance of the put-call parity violations an ex-ante efficiency test is conducted. The violations will be treated as mispricing signals which result in an hedge being created. To correctly evaluate the financial significance of the violations different levels of transaction cost will be tested. First the test will be conducted without transaction costs. When the base line is established two increasing levels of transaction cost will be added. All test will be carried out on the yearly subsamples as well as on the volatility based subsamples.

6.2.1 Test results ignoring transaction costs

When a mispricing signal occurs either a conversion or a reversal strategy will be implemented based on equation 3.11 and 3.12. When $\epsilon_t^L > 0$ the conversion strategy (long hedge) will be initiated and when $\epsilon_t^s > 0$ the reversal strategy (short hedge) will be initiated. Unless $\epsilon_t^L = \epsilon_t^S = 0$ one option will always be overpriced compared to the other. Histograms of the distribution of relative call overpricing (ϵ_t^L) for the yearly subsamples are presented in figure 6.3. The histograms tell the same story as the regression test in the previous section. All histograms are skewed to the left indicating larger put overpricing compared to calls. It also confirms that there are large outliers which might be due to dividends. When the dividends are payed the index drops, not correcting the option prices for this leads to a mispricing signal to initiate a reversal.

The results of the efficiency test ignoring transaction costs with yearly subsamples are presented in table 6.5. All subsamples have negative means for expost profit from long hedges (ϵ_t^L), and positive from the short hedge (ϵ_t^S). The t-statistic used are the results from the modified two-sided t-test created by Johnson (1978). These t-statistics permits asymmetric distributions and are more robust to skewness. The methodology of performing the test can be seen in the appendix.

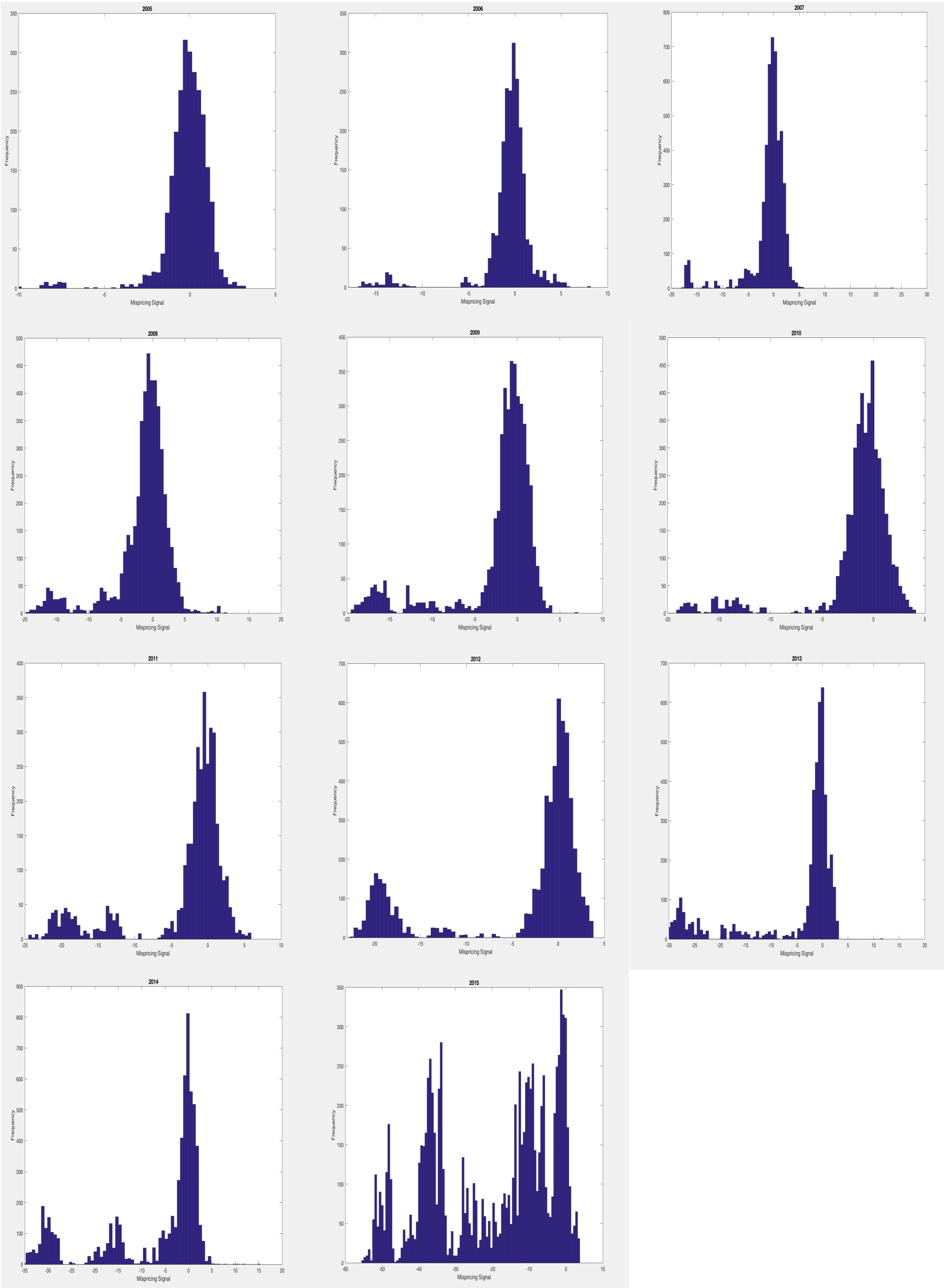

FIGURE 6.3: Histograms of put-call violations

The t-statistics are all negative for the long conversion and highly significant. The reversals have all positive t-statistics and are statistically different from zero. The highest percentage of mispricing signals indicating call overpricing occur in 2005 were 44.63% of the signals indicate that call options were relative overpriced to puts. The lowest percentage of call overpricing signals were in 2015 where only 5,07% of the signals indicated call options to be overpriced. The mean of the profitable long hedges span from 0,69 to 1.63. Since the contract value of the options are SEK100 per index point the average return of the profitable long hedges span from 69SEK to 163SEK. The mean of the profitable short hedges (i.e when $\epsilon_t^S > 0$) span from 3.14 to 21.23 or differently put, from 314SEK to 2123SEK.

Efficiency test of put-call parity ignoring transaction costs

Subsample (Number of pairs)		Mean(ε)	Std(ε)	t-statistic	p-value	# signals	% of pairs	Mean	Std
2005	Long	-1,43	4,79	-20,79	0,00	1254	44,63%	0,69	0,53
(2810)	Short	1,43	4,79	20,79	0,00	1556	55,37%	3,14	5,89
2006	Long	-2,58	7,07	-23,82	0,00	901	36,42%	1,02	1,13
(2474)	Short	2,58	7,07	23,82	0,00	1573	63,58%	4,64	8,13
2007	Long	-3,68	9,18	-38,15	0,00	2197	40,77%	1,26	1,06
(5389)	Short	3,68	9,18	38,15	0,00	3192	59,23%	7,07	10,64
2008	Long	-4,46	10,29	-41,68	0,00	1886	35,70%	1,63	1,53
(5283)	Short	4,46	10,29	41,68	0,00	3397	64,30%	7,84	11,45
2009	Long	-3,68	7,56	-43,29	0,00	1458	32,54%	1,06	0,80
(4480)	Short	3,68	7,56	43,29	0,00	3022	67,46%	5,96	8,26
2010	Long	-3,86	8,02	-45,78	0,00	1508	29,06%	1,08	0,85
(5189)	Short	3,86	8,02	45,78	0,00	3681	70,94%	5,88	8,73
2011	Long	-5,23	9,95	-43,25	0,00	1286	32,71%	1,29	1,10
(3931)	Short	5,23	9,95	43,25	0,00	2645	67,29%	8,40	10,77
2012	Long	-6,72	11,73	-57,52	0,00	2458	39,83%	1,12	0,87
(6171)	Short	6,72	11,73	57,52	0,00	3717	60,23%	11,91	12,68
2013	Long	-7,89	13,49	-51,70	0,00	1301	27,92%	1,00	0,87
(4659)	Short	7,89	13,49	51,70	0,00	3358	72,08%	11,33	14,49
2014	Long	-10,43	15,17	-73,45	0,00	1975	28,17%	1.22	1,06
(7012)	Short	10,43	15,17	73,45	0,00	5037	71,83%	15,00	15,68
2015	Long	-20,09	16,46	-141,17	0,00	510	5,07%	1,29	1,05
(10056)	Short	20,09	16,46	141,17	0,00	9546	94,93%	21,23	16,11

TABLE 6.5: Efficiency test of put-call parity ignoring transaction costs, yearly subsamples. The first column specifies the subsample followed by the number of match put/call pairs in parenthesis below. The second column indicates if it is the long (conversion) or short (reversal) hedge. The third column shows the mean of the ϵ (ex-post profit) followed by the standard deviation. The corresponding t-statistics and p-values for a two-sided test against the mean being equal to zero are shown in column 4 and 5. Column 6 and 7 represent the number of mispricing signals (i.e $\epsilon_t^L > 0$ for the long hedge and $\epsilon_t^S > 0$ for the short hedge) and the percentage of signals in relationship to the number of observations. The last two columns show the mean and standard deviation of the conversion and reversal hedges

The histograms of the relative call overpricing for the volatility based subsamples are shown in figure 6.4. These distributions are also skewed to the left indicating relative put overpricing.

The results of the efficiency test without transaction costs for the volatility based subsamples are presented in table 6.6. The results are coherent with the regression results. There is no clear relationship between the level of the SVIX index and profitable hedges. The two low volatility periods exhibit both highest and second to lowest profitability of the short hedges. The percentage of profitable long or short hedges does not seam to be affected by the volatility.

Efficiency test of put-call parity ignoring transaction costs

Subsample (Number of pairs)		Mean(ε)	Std(ε)	t-statistic	p-value	# signals	% of pairs	Mean	Std
v1 (Low)	Long	-2,73	6,89	-32,06	0,00	1463	38,88%	0,73	0,58
3763	Short	2,73	6,89	32,06	0,00	2300	61,12%	4,94	8,06
v2 (Mid)	Long	-4,38	9,75	-39,40	0,00	1646	36,03%	1,06	1,14
4569	Short	4,38	9,75	39,40	0,00	2923	63,97%	7,44	11,04
v3 (High)	Long	-4,07	9,18	-58,41	0,00	3507	35,94%	1,47	1,31
9759	Short	4,07	9,18	58,41	0,00	6252	64,06%	7,18	10,18
v4 (Mid)	Long	-4,16	8,75	-61,68	0,00	3153	32,72%	1,08	0,84
9635	Short	4,16	8,75	61,68	0,00	6482	67,28%	6,70	9,68
v5 (High)	Long	-1,30	4,06	-20,09	0,00	730	33,55%	1,46	1,23
2176	Short	1,30	4,06	20,09	0,00	1446	66,45%	2,70	4,27
v6 (Mid)	Long	-6,99	12,04	-55,43	0,00	2345	41,49%	1,11	0,86
5652	Short	6,99	12,04	55,43	0,00	3307	58,51%	12,73	12,96
v7 (Low)	Long	-14,24	16,35	-158,80	0,00	3890	17,76%	1,16	1,00
21900	Short	14,24	16,35	158,80	0,00	18010	82,24%	17,56	16,21

TABLE 6.6: Efficiency test of put-call parity ignoring transaction costs, volatility based subsamples. The first column specifies the subsample followed by the number of match put/call pairs in parenthesis below. The second column indicates if it is the long (conversion) or short (reversal) hedge. The third column shows the mean of the ϵ (ex-post profits) followed by the standard deviation. The corresponding t-statistics and p-values for a two-sided test against the mean being equal to zero are shown in column 4 and 5. Column 6 and 7 represent the number of mispricing signals (i.e $\epsilon_t^L > 0$ for the long hedge and $\epsilon_t^S > 0$ for the short hedge) and the percentage of signals in relationship to the number of observations. The last two columns show the mean and standard deviation of the conversion and reversal hedges

The results from the efficiency test without transaction cost for the yearly subsamples as well as for the volatility based subsamples have indicated some large arbitrage possibilities mainly, as the result of relative put overpricing. In 2015 82.24% of the profitable hedges were reversals with a mean profit of 2123SEK. When regarding the relationship in figure 6.2 it is plausible that the profits from 2014, 2015 and volatility period 7 might be exaggerated. Even if this were the case the results from years 2005-2013 show that the arbitrage possibilities which arise

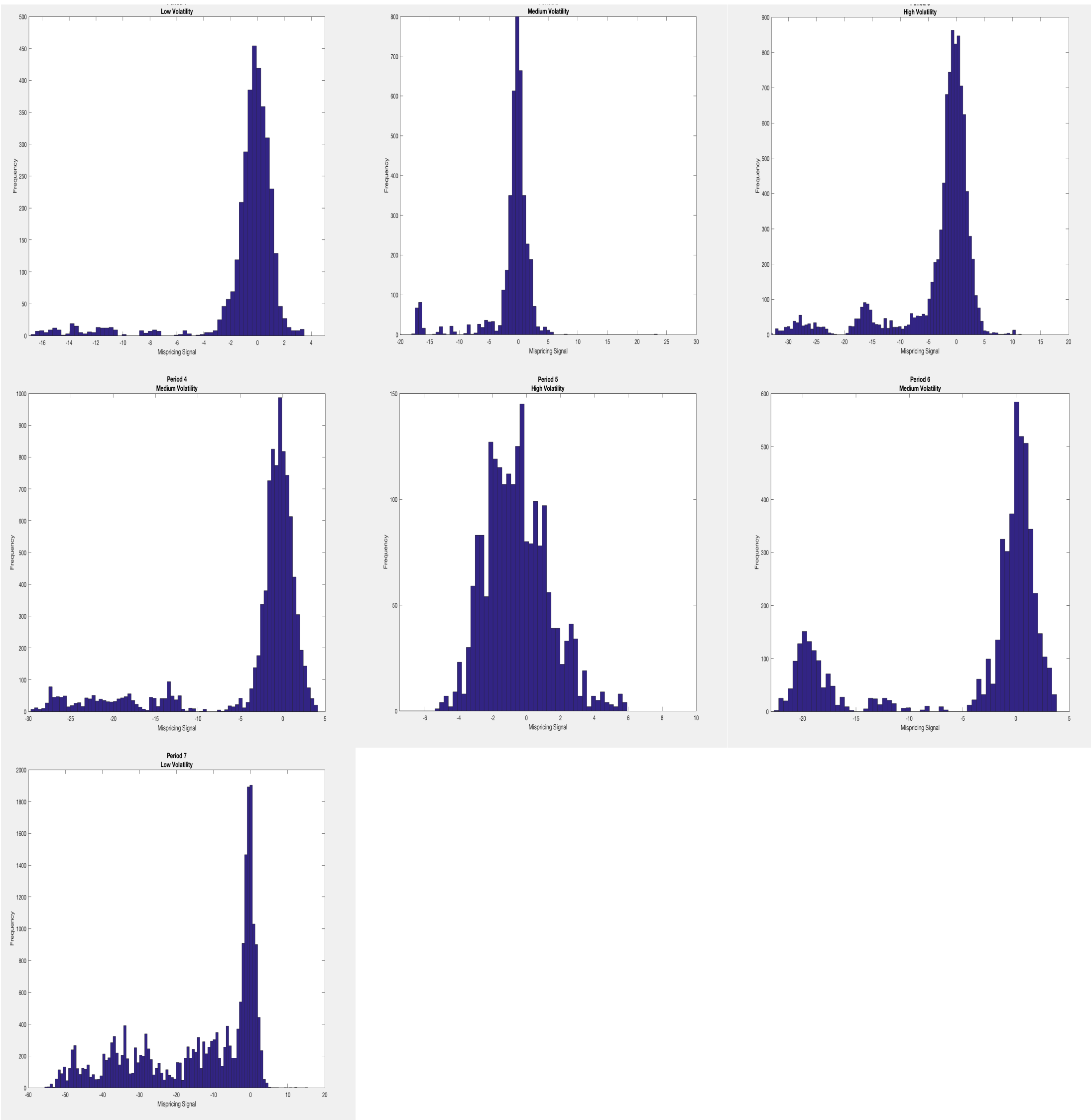

FIGURE 6.4: Histograms of put-call violations, volatility based subsamples

from put-call parity violations have economic significance and can be exploited. The volatility seams however to lack any power to influence the level of put-cal parity violations.

6.2.2 Test results including transaction costs

The first level of transaction cost includes the bid-ask spread and Nasdaq brokerage fee for buying and selling options. This represents institutional investors. When the transaction costs are accounted for the means of ϵ_t^L and ϵ_t^S decreases as well as the number of mispricing signals. The mean of the profitable (ex-ante) long hedges decrease, but the mean of the short hedges increase. Even though there are fewer profitable short hedges the average payoff has increased. This is due to the outliers which became evident from the histograms in figure 6.2. Many of the possible hedges that had profits close to zero became no longer profitable when the transaction costs were included, which results in a higher proportion of highly profitable hedges remaining. The results from the efficiency test with transaction cost level 1 are compiled in table 6.7 Noticeable is that the mean of ϵ_t^S for 2005 is now negative and is no longer statistically different from zero at the 1% significance level.

The result for the volatility based subsamples are presented in the appendix. The results is similar to the yearly subsample. The means of ϵ_t^L and ϵ_t^S have decreased and so has also the number of profitable hedges. Still there is no evidence of volatility having an impact on the number of profitable hedges nor the magnitude. Transaction cost level 2 includes the two previous costs in addition to the commission charged by brokers. This cost level represents the cost of private investors. The results are compiled in table 6.8. The means of ϵ_t^L and ϵ_t^S are negative for the three first years. The number of mispricing signals has decreased further but the remaining profitable short hedges show increased mean return. During the years 2011 to 2015 private investors would find that 31.32% to 78.07% of the short hedges were still profitable with a mean profit of 1399SEK to 2083SEK. As mentioned earlier the magnitude may be exaggerated due to the fact that dividends have not been accounted for and the cost of taking a short position in the index has not fully been incorporated. The result may however not be totally discarded since the long hedge, however few in number, are still profitable as well. The mean profit of the executed long hedges span from 18SEK to 204SEK

The efficiency test for transaction cost level 2 with volatility based subsamples can be seen in the appendix. It shows the same patterns as the yearly test.

Efficiency test of put-call parity with transaction cost level 1

Subsample (Number of pairs)		Mean(e)	Std(e)	t	p-value	# signals	% of pairs	mean	std
2005	Long	-3,14	5,05	-53,58	0,00	185	6,58%	0,47	0,46
(2810)	Short	-0,28	4,78	-2,88	0,03	466	16,58%	7,59	7,46
2006	Long	-4,78	7,51	-48,44	0,00	143	5,78%	1,39	1,01
(2474)	Short	0,37	6,91	2,82	0,00	537	21,71%	9,85	9,65
2007	Long	-6,39	9,26	-76,63	0,00	314	5,83%	0,60	0,53
(5389)	Short	0,97	9,27	8,22	0,00	1193	22,14%	14,88	11,31
2008	Long	-7,99	10,47	-87,05	0,00	195	3,69%	1,38	1,84
(5283)	Short	0,93	10,31	6,96	0,00	1406	26,61%	13,82	12,48
2009	Long	-6,34	8,20	-77,32	0,00	247	5,51%	0,81	0,79
(4480)	Short	1,01	7,06	10,49	0,00	1272	28,39%	9,48	8,37
2010	Long	-5,61	8,05	-73,27	0,00	401	7,73%	0,69	0,51
(5189)	Short	2,11	8,06	22,10	0,00	1810	34,88%	9,49	9,97
2011	Long	-6,94	10,13	-60,72	0,00	383	9,74%	0,95	0,81
(3931)	Short	3,53	9,97	26,56	0,00	1694	43,09%	11,09	11,16
2012	Long	-8,73	11,80	-79,24	0,00	458	7,42%	0,68	0,52
(6171)	Short	4,71	11,72	37,80	0,00	2317	37,55%	16,73	11,45
2013	Long	-9,49	13,61	-64,50	0,00	311	6,68%	0,62	0,41
(4659)	Short	6,29	13,41	39,50	0,00	2036	43,70%	16,70	14,72
2014	Long	-12,65	15,14	-93,35	0,00	370	5,28%	0,89	0,84
(7012)	Short	8,22	15,30	54,22	0,00	3400	48,49%	19,81	14,72
2015	Long	-22,98	16,89	-159,18	0,00	91	0,90%	0,89	0,57
(10056)	Short	17,19	16,14	121,62	0,00	8272	82,26%	21,37	14,76

TABLE 6.7: Efficiency test of put-call parity with transaction costs level 1, yearly subsamples. The first column specifies the subsample followed by the number of match put/call pairs in parenthesis below. The second column indicates if it is the long (conversion) or short (reversal) hedge. The third column shows the mean of the ϵ (payoff) followed by the standard deviation. The corresponding t-statistics and p-values for a two-sided test aginst the mean being equal to zero are shown in column 4 and 5. Column 6 and 7 represent the number of mispricing signals (i.e $\epsilon_t^L > 0$ for the long hedge and $\epsilon_t^S > 0$ for the short hedge) and the percentage of signals in relationship to the number of observations. The last two columns show the mean and standard deviation of the conversion and reversal hedges

The volatility seems to have no clear impact on the profitability or magnitude of option mispricing.

Efficiency test of put-call parity with transaction cost level 2

Subsample (Number of pairs)		Mean(e)	Std(e)	t	p-value	# signals	% of pairs	mean	std
2005	Long	-3,96	5,04	-74,83	0,00	34	1,21%	0,42	0,52
(2810)	Short	-1,10	4,80	-9,50	0,00	316	11,25%	10,28	6,69
2006	Long	-5,80	7,52	-62,94	0,00	74	2,99%	1,28	0,80
(2474)	Short	-0,64	6,90	-4,29	0,00	345	13,95%	14,09	8,17
2007	Long	-7,59	9,27	-96,73	0,00	45	0,84%	0,44	0,40
(5389)	Short	-0,24	9,26	-1,84	0,07	1008	18,70%	16,30	10,30
2008	Long	-8,86	10,50	-99,85	0,00	85	1,61%	2,04	2,16
(5283)	Short	0,06	10,26	0,43	0,67	1216	23,02%	14,98	12,12
2009	Long	-7,17	8,14	-92,27	0,00	76	1,70%	0,75	0,90
(4480)	Short	0,18	7,12	1,75	0,08	981	21,90%	11,47	7,71
2010	Long	-6,64	8,04	-92,09	0,00	93	1,79%	0,41	0,29
(5189)	Short	1,07	8,07	10,42	0,00	1180	22,74%	13,29	9,27
2011	Long	-7,98	10,16	-72,57	0,00	158	4,02%	0,70	0,66
(3931)	Short	2,48	9,93	17,87	0,00	1231	31,32%	13,99	10,60
2012	Long	-9,78	11,81	-91,50	0,00	114	1,85%	0,37	0,29
(6171)	Short	3,66	11,70	28,20	0,00	1952	31,63%	18,69	9,84
2013	Long	-10,70	13,60	-75,31	0,00	30	0,64%	0,18	0,19
(4659)	Short	5,08	13,42	30,69	0,00	1480	31,77%	21,60	12,74
2014	Long	-14,03	15,12	-106,58	0,00	73	1,04%	0,84	0,78
(7012)	Short	6,84	15,32	43,75	0,00	3042	43,38%	20,72	13,92
2015	Long	-24,60	16,91	-171,64	0,00	14	0,14%	0,40	0,25
(10056)	Short	15,56	16,12	109,14	0,00	7851	78,07%	20,83	14,33

TABLE 6.8: *Efficiency test of put-call parity with transaction costs level 2, yearly subsamples. The first column specifies the subsample followed by the number of match put/call pairs in parenthesis below. The second column indicates if it is the long (conversion) or short (reversal) hedge. The third column shows the mean of the ϵ (payoff) followed by the standard deviation. The corresponding t-statistics and p-values for a two-sided test aginst the mean being equal to zero are shown in column 4 and 5. Column 6 and 7 represent the number of mispricing signals (i.e $\epsilon_t^L > 0$ for the long hedge and $\epsilon_t^S > 0$ for the short hedge) and the percentage of signals in relationship to the number of observations. The last two columns show the mean and standard deviation of the conversion and reversal hedges*

Chapter 7

Conclusions

The efficiency of the Swedish option market has been investigated. 57454 pairs of European style options written on the Swedish stock index OMXs30 have been used to evaluate the validity of the put-call parity. How volatility impacts the efficiency has also been tested. The validity of the put-call parity has been rejected on statistical basis. Regression analysis has proven that without transaction cost non of the subsamples ranging from 2005 to 2015 are consistent with put-call parity theory. I have not been able to prove any relationship between the put-call parity violations and volatility.
A nonparametric test was also conducted. This test confirms the findings of the statistical regression test. All subsamples as well as the entire sample shows evidence of relative put overpricing regardless of maturity and moneyness. The magnitude of the violations must be viewed with some caution since dividends have not been accounted for. Tests of the financial significance of the put-call parity violations have shown that conversions as well as reversal strategies can be used to generate abnormal profits. This is true for the case were transaction costs are discarded as well as when they are included.
Institutional investors can find risk free returns ranging from 759SEK to 2137SEK per short hedge and 47SEK to 139SEK from long hedges. Private investors will find that the short hedge will on average, return between 1028SEK to 2083SEK and the long hedge on average 18SEK to 204SEK however not as frequently as for the institutional investor.

The return of especially the short hedges might be somewhat exaggerated due to the fact that dividends was not incorporated. The cost of taking a short position in the assets of the OMXS30 index have not fully been regarded. This might reduce the profitability of the hedges further but not to the extent that would result in market efficiency. The data showed also some strange movements during 2014 and 2015 which puts the validity of the results for these years into question. Even if these two years were disregarded and the magnitude of the short returns were reduced the fact that the long hedges could produce positive returns even when transaction cost were included suggest that the Swedish option market is not fully efficient.

Thus can *hypothesis 1: The put-call parity holds and there are no risk free arbitrage possibilities in the Swedish index option market regardless of moneyness, time to maturity, and transaction costs*, be rejected.

No relationship between volatility and the frequency or magnitude of profitable hedges were found. The null hypothesis that volatility has no impact on the frequency or magnitude of put-call parity violations cannot be rejected. A fact that partially might explain the inefficiencies is that the larger mispricing of put options might simply be the effect of greater demand for puts since the majority of positions in the equity market are long. This does however not address the fact that call options (although at a lower frequency and magnitude) also were overpriced.

Chapter 8

Bibliography

Bhattacharya, D.S. (1983). Transaction data test of efficiency of the Chicago Board Options Exchange, Journal of Financial Economics, Vol.12, pages 161-185

Constantinides, G.M., Jackwert, J.C. and Savov,A. (2013). The puzzle of index option returns, Review of asset pricing studies v3 n2 2013 , pages 229-257

Demeterfi, K., Derman, E., Kamal, M., and Joseph Zou.(1999). More than you ever wanted to know about volatility swaps. Goldman Sachs quantitative strategies research notes, Vol.41

Evnine, J. and Rudd, A. (1984). Index options: The early evidence, The Journal of Finance, Vol.40, No.3, pages 743-756

Gould, J.P. and Galai, D. (1973). Transaction costs and the relationship between put and call prices, Journal of Financial Economics, Vol.1, pages 105-129

Hull, J.C. (2012). Options, futures and other derivatives, Pearson Global Edition

Jiang, J.J. and Tian, Y.S. (2005). Extracting model-free volatility from option prices: An examination of the VIX index, The Journal of Derivatives, Vol.18, No.4, pages 1305-1342

Johnson, N.T (1978). Modified t Test and confidence intervals for asymeteric populations, Journal of the American Statistical Association,Vol.73, No.363, pages 536-544

Kamara, A., Miller, T.W., and Jr. (1995). Daily and intradaily test of European put-call parity, Journal of Financial and Quantitative Analysis, Vol.30, No.4, pages 519-539

Klemkosky, R.C and Resnick, B.G, (1979). Put-call parity and market efficiency, The Journal of Finance, Vol.34, No.5, pages 1141-1155

Klemkosky, R.C and Resnick, B.G,(1980). An ex ante analysis of put-call parity, Journal of Financial Economics, Vol.8 pages 363-378

Merton, R.C. (1973). The relationship between put and call option prices: Comment, The Journal of Finance, Vol.28, No.1, pages 183-184

Mittnik, S. and Rieken, S. (2000). Put-call parity and the informational efficiency of the German DAX-index option market, International Review of Financial Analysis, No.9, pages 259-279

Nasdaq (2017), available online;
https://indexes.nasdaqomx.com/Resource/Index/Methodology

Nisbet, N. (1991). Put-call parity theory and an empirical test of the efficiency of the London traded options market, Journal of Banking and Finance, Vol.16, pages 381-403

Sveriges Riksbank (2017), available online; http://www.riksbank.se/sv/Rantor-och-valutakurser/Sok-rantor-och-valutakurser/

Rubinstein, M. (1985). Nonparametric test of alternative option pricing models using all reported trades and quotes on the 30 most active CBOE option classes from August 23, 1976 trough August 31, 1978, Journal of Finance, Vol.40, pages 455-480

Sheikh, A.M. (1991). Transaction data test of S&P 100 call option pricing, Journal of Finance and Quantitative Analysis, Vol.26, pages 459-475

Stoll, H.R (1969). The relationship between put and call option prices, The Journal of Finance, Vol.25, No.5, pages 801-824

Appendix A

Appendix

A.1 MFIV and VIX calculations

The realized volatility can be calculated as:

$$\bar{\sigma} = \sqrt{\frac{252}{n-2}\sum_{i=1}^{n-1}\left[ln\Big(\frac{S_{i+1}}{S_i}\Big)\right]^2} \tag{A.1}$$

If the fixed volatility is σ_K and the principal is L_{vol}, then is the payoff at maturity for the holder of the swap equal to: $L_{vol}(\bar{\sigma} - \sigma_K)$. The variance swap is much the same, instead of realized volatility ($\bar{\sigma}$) one uses realized variance ($\bar{V} = \bar{\sigma}^2$) (Hull (2012)).

The MFIV and volatility indices such as the VIX, are based on the fair value of future variance which can be extracted directly from option prices. Demeterfi et al.(1999), has shown that it is possible to value variance swaps by replicating them with the us of European options.

The expected average variance between times 0 and T, for any given value of the asset price (S^*) can be expressed as:

$$\hat{E}(\bar{V}) = \frac{2}{T}ln\frac{F_0}{S^*} - \frac{2}{T}\left[\frac{F_0}{S^*} - 1\right] + \frac{2}{T}\left[\int_{K=0}^{S^*}\frac{1}{K^2}e^{rT}p(K)dK + \int_{K=S^*}^{\infty}\frac{1}{K^2}e^{rT}c(K)dK\right] \tag{A.2}$$

where
S^* is the price of the underlying asset
F_0 is the forward price of the asset for a contract maturing at T
$c(K)$ is the price of a European call with strike K and maturity T
$p(K)$ is the price of a European put with strike K and maturity T
Thus, the variance swap can be priced as

$$L_{var}[\hat{E}(\bar{V}) - V_K]e^{-rT} \tag{A.3}$$

Suppose all the prices of European options at all different strikes K_i are known, then, the integrals of A.2 can be approximated by letting S^* be equal to the first strike price below F_0

$$\int_{K=0}^{S^*} \frac{1}{K^2} e^{rT} p(K) dK + \int_{K=S^*}^{\infty} \frac{1}{K^2} e^{rT} c(K) dK = \sum_{i=1}^{n} \frac{\Delta K_i}{K_i^2} e^{rT} Q(K_i) \tag{A.4}$$

The ln function of A.2 can be approximated by:

$$ln\left(\frac{F_0}{S^*}\right) = \left(\frac{F_0}{S^*} - 1\right) - \frac{1}{2}\left(\frac{F_0}{S^*} - 1\right)^2 \tag{A.5}$$

Combining the results from A.4 and A.5 the risk-neutral expected cumulative variance, or the model free implied variance, can be calculated as:

$$\hat{E}(\bar{V})T = -\left(\frac{F_0}{S^*} - 1\right)^2 + 2\sum_{i=1}^{n} \frac{\Delta K_i}{K_i^2} e^{rT} Q(K_i) \tag{A.6}$$

Interpolating the results from A.6 over options that have just above and below 30 days to maturity results in volatility indices such as the VIX.

A.2 Modified t-test

The Johnson (1978) modified t-test:

$$t^J = ((x + \mu_3/6\sigma^2 n) + (\mu_3 x^2/3\sigma^4))(s^2/n)^{-1/2} \tag{A.7}$$

Where x is the sample mean, s^2 is the sample variance, σ^2 is the variance of X, μ_3 is the third central moment of X, and n is the sample size.

A.3 Efficiency test results for volatility based subsamples

Efficiency test of put-call parity with transaction cost level 1									
Subsample (Number of pairs)		Mean(ε)	Std(ε)	t-statistic	p-value	# signals	% of pairs	Mean	Std
v1 (Low)	Long	-4,53	7,33	-56,40	0,00	235	6,25%	0,56	0,54
(3763)	Short	0,94	6,63	9,63	0,00	874	23,23%	9,97	8,80
v2 (Mid)	Long	-6,71	10,00	-65,61	0,00	248	5,43%	0,91	0,99
(4569)	Short	2,05	9,68	16,21	0,00	1169	25,59%	15,09	11,34
v3 (High)	Long	-7,48	9,44	-124,36	0,00	387	3,97%	1,06	1,43
(9759)	Short	0,66	9,11	7,52	0,00	2552	26,15%	12,35	10,87
v4 (Mid)	Long	-5,91	8,81	-95,84	0,00	806	8,37%	0,75	0,60
(9635)	Short	2,41	8,78	31,81	0,00	3296	34,21%	10,83	10,67
v5 (High)	Long	-3,31	4,54	-66,05	0,00	192	8,82%	1,12	0,92
(2176)	Short	-0,70	4,23	-6,89	0,00	695	31,94%	2,83	5,12
v6 (Mid)	Long	-9,01	12,10	-75,69	0,00	428	7,57%	0,66	0,50
(5652)	Short	4,97	12,05	36,82	0,00	2107	37,28%	17,68	11,32
v7 (Low)	Long	-16,23	16,74	-185,86	0,00	802	3,66%	0,79	0,68
(21900)	Short	11,85	16,07	130,33	0,00	13710	62,60%	20,23	14,83

TABLE A.1: Efficiency test of put-call parity with transaction costs level 1, volatility based subsamples. The first column specifies the subsample followed by the number of match put/call pairs in parenthesis below. The second column indicates if it is the long (conversion) or short (reversal) hedge. The third column shows the mean of the ϵ (payoff) followed by the standard deviation. The corresponding t-statistics and p-values for a two-sided test aginst the mean being equal to zero are shown in column 4 and 5. Column 6 and 7 represent the number of mispricing signals (i.e $\epsilon_t^L > 0$ for the long hedge and $\epsilon_t^S > 0$ for the short hedge) and the percentage of signals in relationship to the number of observations. The last two columns show the mean and standard deviation of the conversion and reversal hedges

Efficiency test of put-call parity with tc2

Subsample (Number of pairs)		Mean	std	t	p-value	# signals	% of pairs	mean	std
v1 (Low)	Long	-5,40	7,36	-71,21	0,00	53	1,41%	0,51	0,48
(3763)	Short	0,06	6,60	0,61	0,54	625	16,61%	12,91	7,45
v2 (Mid)	Long	-7,87	10,02	-80,80	0,00	62	1,36%	1,40	0,83
(4569)	Short	0,88	9,66	6,54	0,00	970	21,23%	16,88	10,07
v3 (High)	Long	-8,38	9,41	-146,55	0,00	131	1,34%	1,50	1,96
(9759)	Short	-0,24	9,13	-2,62	0,01	2192	22,46%	13,46	10,49
v4 (Mid)	Long	-6,94	8,82	-118,41	0,00	216	2,24%	0,52	0,46
(9635)	Short	1,38	8,76	17,06	0,00	2300	23,87%	14,26	9,80
v5 (High)	Long	-4,27	4,56	-96,31	0,00	103	4,73%	0,84	0,76
(2176)	Short	-1,66	4,21	-13,82	0,00	314	14,43%	4,68	6,57
v6 (Mid)	Long	-10,06	12,11	-86,95	0,00	104	1,84%	0,35	0,28
(5652)	Short	3,92	12,03	28,11	0,00	1828	32,34%	19,23	9,77
v7 (Low)	Long	-18,09	16,80	-204,61	0,00	127	0,58%	0,62	0,67
(21900)	Short	10,39	16,02	112,53	0,00	12373	56,50%	20,89	14,05

TABLE A.2: Efficiency test of put-call parity with transaction costs level 2, volatility based subsamples. The first column specifies the subsample followed by the number of match put/call pairs in parenthesis below. The second column indicates if it is the long (conversion) or short (reversal) hedge. The third column shows the mean of the ϵ (payoff) followed by the standard deviation. The corresponding t-statistics and p-values for a two-sided test aginst the mean being equal to zero are shown in column 4 and 5. Column 6 and 7 represent the number of mispricing signals (i.e $\epsilon_t^L > 0$ for the long hedge and $\epsilon_t^S > 0$ for the short hedge) and the percentage of signals in relationship to the number of observations. The last two columns show the mean and standard deviation of the conversion and reversal hedges