ARBITRAGE POTENTIAL IN THE EUREX ORDER BOOK – EVIDENCE FROM THE FINANCIAL CRISIS IN 2008

Peter Schober*, Martin Wagener**

Abstract

In this paper we investigate the valuation efficiency of the Eurex market for DAX single stock options. As a measure of arbitrage potential we use an adapted version of Stoll's put-call parity model. By calculating deviations from the theoretical fair put and call prices before and during the financial crisis in 2008, we find evidence for a decrease in market's valuation efficiency. Valuation efficiency is even worse for German financial stocks for which short selling was restricted. Although considerable profit opportunities are found, only a small number turn out to be profitable after transaction costs are considered. Our research complements the existing research by investigating American type stock options on a fully electronic exchange in both, volatile and stable markets***.

Keywords: Arbitrage Potential, Valuation Efficiency, Financial Crisis, Volatility, Short-selling

*Department of Finance, Goethe University Frankfurt, Germany
**Stuttgart Stock Exchange, Germany
***We thank Eurex Frankfurt AG for supporting our research – especially Uwe Schweickert for helpful comments and suggestions. In addition, we thank the Securities Industry Research Centre of Asia-Pacific (SIRCA) for providing the data.

1 Introduction

In this study we investigate the valuation efficiency of the Eurex market for stock options of DAX constituents. By comparing arbitrage potential before and during the financial crisis in 2008, we find evidence of the impact of volatile markets on valuation efficiency. As a measure of arbitrage potential we use the put-call parity model developed by [Stoll(1969)]. The model is empirically tested with a data set for its validity. We use a linear regression model to identify the crucial factors for relative mispricings of puts and calls. In a second step, the extent to which these mispricings are exploitable is delimited by considering transaction costs.

Prices on an efficient market adjust rapidly to new information as it occurs [Fama(1970)]. There are several factors influencing the operation, information and valuation efficiency of a market. While researchers often use liquidity measures to compare the performance of security or derivative markets [Bessembinder and Kaufman(1997)], it is more difficult to test if all information is fully reflected in prices. In valuation efficient markets the information must be processed not just completely but also correctly. In particular, the rule of no-arbitrage says that there are no arbitrage possibilities [Björk (2005)]. Arbitrage potential is the possibility of gaining a trading profit as a result of pricing irregularities between two linked instruments. In option markets, pricing irregularities can appear market-inherently: The derivative might not have the theoretical value it should have, given the price of its underlying. These mis-valuations enable arbitrageurs to make risk-free profits. They take a mis-valued position and hedge it completely by trading the underlying. As the derivative market price converges to the theoretical valuation, the arbitrageur closes the hedge and realizes the profit. Arbitrage is self-correcting: The demand on a "cheap" derivative raises its price while the supply on the overpriced derivative pushes the price until fair valuation is reached.

In general, a derivative is a contract which gives its holder the right to buy or sell the underlying asset of the contract at a pre-determined price at a specific future point in time. A call option contract gives its holder the right to buy the underlying stock from the writer of the contract at a certain price at a given time. A put option contract gives its holder the right to sell the underlying stock to the writer at a certain price at a given time. The premium paid to the writer of an option contract (i.e. the price of the option) is determined by two factors [Natenberg(1994)]: the *intrinsic value* of the option and the *time value* of the option. The intrinsic value is the difference between the current stock price and the strike price. An option with a positive intrinsic value is said to be *in-the-money*. When the intrinsic value is zero, the option is *at-the-money* and when the intrinsic value is negative, the option is *out-of-the-money*. The time value is the additional amount of money the writer is charging for the option contract. It is influenced by several factors: the maturity of the option, the riskless interest rate and the volatility of the underlying. Options can be exercised by the holder either only at the expiration date, *European type* options, or at any time before (early exercise) and on expiration, *American type* options. We analyze American type DAX stock options traded at Eurex. Exchange traded stock options are highly standardized regarding the underlying, contract size, maturity and other features such as breaking clauses. For exchange traded options, expiration dates are every third Friday in March, June, September and December. The contract size of the Eurex options investigated in this paper is 100 stocks per contract[1]. Eurex issues the options traded on their platform and defines the contract specifications. Trading at Eurex' option market is a hybrid form of continous double auction and market making. Any trading member can act as a market maker as long as the member fulfills certain market maker obligations. Market makers profit from significantly reduced fees.

Eurex exchange was formed through the merger of Deutsche Terminbörse (DTB) and the Swiss Options and Financial Futures Exchange (SOFFEX) in 1998[2]. Today, Eurex is one of the largest international derivatives exchanges. It has a diversified product portfolio consisting of standardized derivatives on financial products such as options and futures on equity and equity indices, interest rate and credit. With a turnover of 3,172 million traded contracts in 2008, Eurex is the second largest security derivatives exchange worldwide (CME Group: 3,287; NYSE Liffe: 1,510 traded contracts). About two third of Eurex' total turnover is in equity index products and equity products. This is followed by the Euro-Bund, Euro-Schatz and Euro-Bobl futures.

By analyzing arbitrage potential on the Eurex market for American type DAX stock options we investigate the influence of volatility on option market efficiency. We test the following two hypotheses empirically in our study:

H1: Theoretical arbitrage potential increases in volatile markets;

H2: The Eurex option market is valuation efficient given the boundaries set by transaction costs

We find that the put-call parity model is more often violated in the data sample which is taken from a time frame of highly volatile market environment. However, these pricing irregularities do not seem to be exploitable after considering transaction costs.

The remainder of this paper is organized as follows. Section 2 discusses prior research on put-call parity models. The characteristics of our data samples are depicted in section 3. The parity model and the two-step approach of our analysis are presented in section 4. In section 5, we test put-call parity theory on the data samples (step one). Afterwards the data set is analyzed to determine to which extent these possible inefficiencies are exploitable (step two). A summary concludes the paper in section 6.

2 Related work

In this subsection we provide an overview on academic work on option valuation and related studies using put-call parity models. It is important to distinguish the settings of put-call parity models for European type (index) options from the model specifications for American type (stock) options. As we analyse the latter, the literature review focuses on this type[3].

In previous studies data quality has always been a challenge. Before 1990 option trading, especially in the US, was mostly organized off-exchange and neither data dissemination nor trading was electronically supported. Hence, data sets suffer from only few observations on weekly basis and consist mainly of closing prices. However, the empirical results of [Stoll(1969)], [Gould and Galai(1974)] and [Klemkosky and Resnick(1979)] allow interesting insights. [Nisbet(1992)] provides the first analysis of options traded on an electronically organized market. In general, the academic research on put-call parity develops along the following lines:

The basic model for European type, dividend payout protected options is developed by [Stoll(1969)]. The general idea of put-call parity is that the conversion of puts into calls and vice versa is possible without risk and capital investment. If calls are overpriced compared to puts, a call C can be written and a combination of a long position S in the stock and the corresponding[4] put P can be bought – a so-called *synthetic call*

$$M = C - S{*}i/(1 + i) - P$$

The profit from this conversion is M. A long strategy in the underlying stock costs $S{*}i/(1{+}i)$, whereas $S{*}i$ is the interest cost of the interest i the trader would gain for the amount S and the term $1/(1{+}i)=1/(1{+}i)^1$ reflects the discount of the interest costs for one period. If puts are overpriced compared to calls, a synthetic put can be bought by writing a put, selling the stock short and buying a call

$$N = P + S{*}i/(1 + i) - C$$

The profit from this conversion is N. If neither calls nor puts are overpriced, arbitrage is not possible and the market is efficient. This means, $M = N = 0$ and so it follows from

$$M = C - S{*}i/(1 + i) - P \text{ or } N = P + S{*}i/(1 + i) - C$$

$$\Leftrightarrow C - P = S{*}i/(1 + i) \qquad (1)$$

[1] An exception are Allianz and Münchener Rück stock options. They have a contract size of ten.

[2] While DTB started trading in 1990 and was integrated in the newly founded Deutsche Börse AG in 1993, SOFFEX took up business in 1988.

[3] For European options, put-call parity systematically leads to prices which would not hold, if early exercise were possible [Natenberg(1994)].

[4] I.e. the call and the put have the same strike price and maturity.

Equation (1) states Stoll's European put-call parity model [Stoll(1969)]: the difference of call and put prices should be equal to the discounted costs of carrying of the stock price[5]. Thus, arbitrage between the option market and the stock market is possible if prices vary. The potential gain from a conversion strategy is the difference of the option's market price to the synthetic's price. [Stoll(1969)] also adapts his model for two periods in which the stock price S in period one changes by ΔS in period two[6].

$$C - P = S - E / (1 + i).$$

Obviously, this formulation also includes equation (1) as the special case were $E = S$.[7] [Merton(1973b)] proves that it is never optimal to early exercise a call option if it is dividend payout protected. In a comment on [Stoll(1969)], he points out that premature exercise might be rational for American put options [Merton(1973a)]. Hence, [Merton(1973a)] reveals that Stoll's [Stoll(1969)] put-call parity is only valid for European type options. He argues that early exercise is favorable in the cases where the time value of the put is less than the interest rate gains from reinvesting the money obtained from early exercise. If the writer of a put finds the put exercised against him before maturity, he loses the interest on the short sale for the time remaining to maturity. [Gould and Galai(1974)] are the first who incorporate transaction costs in the parity model for American options. They subtract the transaction costs for the call, put and stock purchase from Stoll's [Stoll(1969)] relative parity equation and incorporate a factor for margin requirements on stock purchases/sales for covering the strike price. The papers of [Stoll(1969)], [Merton(1973a)] and [Gould and Galai(1974)] analyze off-exchange traded, dividend payout protected options only.

[Klemkosky and Resnick(1979)] adapt the parity model for dividend payments for *on-exchange* traded, *non-dividend payout protected* options. Important about dividends is that it is optimal to exercise a call option early right before the stock goes ex-dividend. This has been shown in several studies, e.g. [Merton(1973b)]. The trader can additionally gain the dividend – which he would not obtain if he simply sold the option. [Klemkosky and Resnick(1979)] point out that dividend adoption is only necessary for option contracts with dividend payments before their expiration date. In their paper they account for early exercise incentives by deriving early exercise conditions. Then the synthetics which satisfy these conditions are eliminated. [Klemkosky and Resnick(1979)] investigate options on-exchange traded at the Chicago Board Options Exchange, the American and the Philadelphia Stock Exchange. Hence, their data set does not suffer from the insufficiencies the off-exchange data has. All in all, their results are in consistence with the put-call parity theory.

[Nisbet(1992)] further extends the analysis of early exercise incentives due to non-dividend payout protection. She additionally incorporates transaction costs following the approach of [Gould and Galai(1974)]. As the first author [Nisbet(1992)] analyzes put-call parity on a European option by investigating the London Traded Options Market (LTOM)[8] and is one of the first studies on put-call parity on European option exchanges. Her results show that violations on put-call parity are unlikely to represent exploitable inefficiencies in the market when transactions are incorporated. Furthermore, transaction costs make early exercise less likely.

The following two papers analyze parity models for index options instead of single stock options. However, their approach has important implications for our methodology. [Finucane(1991)] investigates put-call parity for a three-year sample of transactions in OEX options on the S&P 100. He shows that the put-call parity measure, in the presence of market frictions, contains information concerning future returns of the underlying asset. The option quotes and index data is taken from 1985 to 1988 – incorporating the October program trading crash in 1987.[9] Interestingly, all of the extreme deviations from put-call parity occur in this month. Thus, his analysis provides first evidence for declining valuation efficiency in volatile markets. [Mittnik and Rieken(2000)] are the first to investigate put-call parity for DAX index options traded at the DTB, the predecessor of Eurex. They apply a two step methodology which separates the theoretical parity model from the "real world", where transaction costs might eliminate potential profit opportunities: first, the parity model test (a linear regression approach following [Stoll(1969)] without transaction costs)[10] and second, the efficiency test (incorporation of

[5] [Stoll(1969)] differentiates absolute and relative put-call parity. The absolute formulation is presented above whereas the relative formulation $C/S - P/S = i/(1 + i)$ simply states that relative call and put prices should differ by the discounted sure rate of interest. However, this approach is not very convenient for a multiperiod model with differences in strike and stock price.

[6] See [Stoll(1969)] and [Merton(1973a)] for a proof.

[7] Note that put-call parity is a *relative measure* of mispricing. If put-call parity holds, this only means that put prices are fairly valuated compared to call prices. Although this may be true, a general statement on the theoretical option value, as in [Black and Scholes(1973)] and [Cox et al.(1979)Cox, Ross, and Rubinstein], cannot be conducted. However, it seems reasonable to assume that prices are not too far from theoretical values because traders use theoretical models for arbitraging [Figlewski(1989)].

[8] In 1992, the LTOM merged with Liffe which is now owned by NYSE-Euronext.

[9] On Monday, October 19, 1987, the S&P 500 Index fell 20 percent which was one of the largest declines ever recorded. Program trading was blamed for the declines. According to [Kim(2007)] program traders were selling stocks during the market downturn to arbitrage their positions against declines in the index futures.

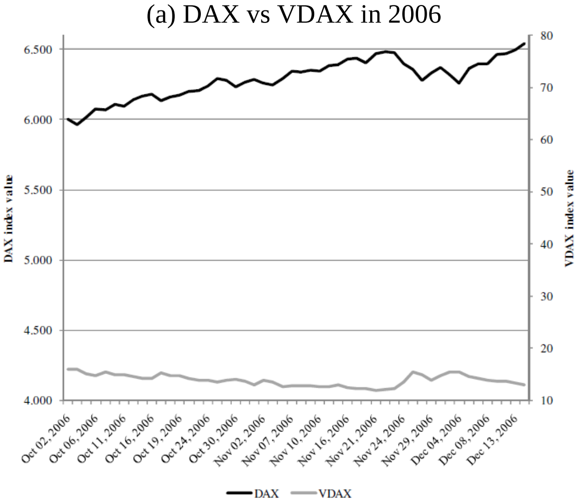
[10] Note that [Mittnik and Rieken(2000)] do not account for early exercise as DAX index options are European type.

transaction costs following [Gould and Galai(1974)]). In constast to our study, [Mittnik and Rieken(2000)] do not add the bid-ask spread to the explicit transaction costs. In sum, their results state that the parity model does not hold due to the continuous overpricing of puts. Transaction costs substantially reduce the profitability of these market inefficiencies.

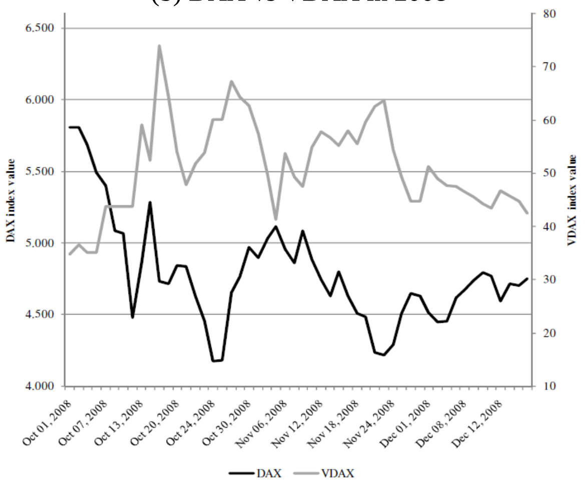
Figure 1. Market conditions

While figure 1a depicts the DAX and the volatility index VDAX from October 2nd to December 14th, 2006, figure 1b shows the development of the indices between October 1st and December 18th, 2008. The VDAX index reflects the implied volatility of the DAX anticipated on the derivatives market. It indicates the expected volatility of the DAX in the next 45 days (in percentage points).

(a) DAX vs VDAX in 2006



(b) DAX vs VDAX in 2008



3 Data

We examine the following two data samples: The first sample covers all trading days from October 2 through December 14, 2006 (stable market environment before the financial crisis), the second captures the trading period from October 1 through December 18, 2008 (highly volatile markets during the financial crisis). In the pre-crisis sample the German stock market rose from 6019 index points to 6611 points. Meanwhile the VDAX[11] was on average 13.9 index points with a minimum of 11.9 and a maximum of 16 index points. During the financial crisis in contrast, the VDAX was considerably higher at 51.1 index points on average: the DAX dropped from 5865 to 4704 index points, with a low of 4014 points and an interim high of 5278 points (see Figure 1).

Eurex issues only American type stock options on DAX constituents. To minimize biases from the parity model of [Stoll(1969)], we chose underlyings without dividend payments in the sample periods. Ex-dates are obtained from Reuters and cross checked with Bloomberg. [Merton(1973b)] shows that for calls early exercise is not favorable when the stock does not go ex-dividend. In consequence, we assume that there are no early exercised calls in our data samples. However, we exclude puts for which early exercise could have been favorable[12]. Table 1 presents the chosen firms for the two samples and some of the options' characteristics:

• Group 1. The underlyings of the ten most traded non-financial stock options on DAX constituents without dividend payments. As a reference point we choose the total trading volume in the 2006 sample period.

• Group 2. The options of the financial services stocks in the DAX (composition as of 2006). Group 2 was subject to a short selling restriction during the financial crisis. The ban was introduced by the Bundesanstalt für Finanzdienstleistungsaufsicht (BaFin) on September 22, 2008 in order to avoid excessive price movements[13].

[11] The VDAX reflects the implied volatility of the DAX. It indicates the expected volatility of the DAX in the next 45 days (in percentage points).

[12] According to [Cox et al.(1979)Cox, Ross, and Rubinstein], early exercise becomes more likely if the put is deep-in-the-money and the interest rate is high. During the volatile trading days in 2008 there might be puts which meet these conditions. That means, the time value does no longer compensate the minimum risk-free rate. Consequently, early exercise could be favorable. Therefore we exclude irrational put prices from the observations. Our approach is presented in the next section.

[13] BaFin only restricted naked stock shorts. In addition, the ban is not valid for lead broker and market maker. The restriction is expected to last until January 31, 2010.

Table 1. Sample characteristics

The table presents the number of traded option contracts in the observation time frame, the corresponding trading volume, and the daily average market capitalization of the underlyings. While group 1 consists of the ten most traded non-financial stock options on DAX constituents, group 2 comprises of all options of financial service companies listed in the DAX. We show the descriptive values for the sample periods between October 2nd to December 14th, 2006 under stable market conditions and October 1st to December 18th, 2008 in highly volatile markets.

October - December 2006				*October - December 2008*			
	Traded contracts (millions)	*Volume (billion EUR)*	*MCap underlying (billion EUR)*		*Traded contracts (millions)*	*Volume (billion EUR)*	*MCap underlying (billion EUR)*
Group 1: Most traded non-financials							
Dt. Telekom	5.90	7.90	58.54	Dt. Telekom	6.72	7.62	48.12
Daimler Chrysler	3.88	17.10	44.75	Daimler	2.10	6.25	23.87
Siemens	1.74	12.47	63.75	Siemens	1.93	10.36	42.82
RWE	0.85	6.93	44.91	E.ON	1.71	5.08	56.57
Infineon	0.83	0.79	7.28	BASF	1.15	3.22	23.85
E.ON	0.81	7.78	65.96	Bayer	1.07	4.67	31.91
Bayer	0.73	2.86	30.55	RWE	1.01	6.58	34.60
Dt. Post	0.52	1.15	26.18	Infineon	0.79	0.25	1.65
BASF	0.51	3.45	34.35	Lufthansa	0.50	0.63	5.05
Lufthansa	0.40	0.73	8.41	Dt. Post	0.49	0.59	12.92
Mean	1.62	6.12	38.47	**Mean**	1.75	4.52	28.14
Group 2: Financials							
Allianz	8.74	12.56	62.57	Allianz	10.39	8.15	30.52
Münchener Rück.	3.29	4.13	28.96	Münchener Rück.	6.13	6.50	21.18
Dt. Bank	1.44	14.10	51.27	Dt. Bank	2.53	9.23	17.25
Commerzbank	0.78	2.20	18.23	Commerzbank	1.18	1.37	5.99
Dt. Börse	0.13	1.57	13.05	Dt. Börse	0.21	1.32	11.06
Hypo Real Estate	0.12	0.56	6.38	Dt. Postbank	0.12	0.27	3.16
Dt. Postbank	0.03	0.17	10.00	Hypo Real Estate	0.08	0.10	0.86
Mean	2.07	5.04	27.21	**Mean**	2.95	3.85	12.86

The options are issued on the 17 underlying stocks, both before and between October and December 2006 (2008), and have the expiry date December 15, 2006 (respectively December 19, 2008). For the risk-free interest rate, the EURIBOR one month yield is chosen[14]. We retrieve our data directly from the TAQTIC data service operated by Securities Industry Research Centre of Asia-Pacific (SIRCA). SIRCA provides Reuters trade and quote data for a wide number of stock and derivative exchanges. We calculate the current midpoint at the end of every one minute interval as a representative for every stock option and its underlying [Nisbet(1992)]. For every interval, we choose the current at-the-money option for the respective stock (see [Mittnik and Rieken(2000)] or [Klemkosky and Resnick(1979)]). It captures the highest trading volume and is most liquid. Thus, transaction costs are assumably the lowest for these options. We clean our data samples according to the following filters: the first and last five minutes of the trading day are excluded to avoid biases from the opening and closing procedures. In addition, we do not consider the expiration dates of the DAX stock options. The stock data is cleaned for opening, closing and intraday auctions and volatility interruptions. We excluded 159 observations from 2006 and 34 observations from the 2008 sample due to early exercise. Potential mistrades are not identified because the number of mistrades occurring at Eurex is very small.

[14] The EURIBOR in Europe or the T-Bill in the US are commonly used in academic papers, e.g. [Mittnik and Rieken(2000)] and [Nisbet(1992)].

4 Methodology

Our approach is oriented at Mittnik's and Rieken's methodology [Mittnik and Rieken(2000)]. In addition, we account for early exercise as stock options on DAX constituents are American type [Klemkosky and Resnick(1979)]. The first subsection discusses our extended version of Stoll's put-call parity model [Stoll(1969)]. The second subsection depicts our two-step approach in detail: Firstly, we compare the theoretical arbitrage potential in a stable and a highly volatile market by testing put-call parity on one minute intervals. Violations of put-call parity thereby indicate that prices of calls are not correct relative to put prices. These deviations are theoretical arbitrage opportunities. Secondly, we examine the exploitability of these mispricings by taking transaction costs into consideration ("practical" arbitrage potential).

4.1 The put-call parity model

The put-call parity model of [Stoll(1969)] is the basis for our extension. [Stoll(1969)] formulates parity for one period with differences in strike price E and stock price S in period two by

$$C - P = S - E / (1 + i).$$

To adapt his model for multiple periods, the parity condition t periods away from expiration date T must be given by:

$$C_t - P_t = S_t - E / (1 + i)^t \quad (2)$$

Where $1 / (1 + i)^t$ is the discount for the "t^{th}" period. For decreasing period size the number of periods tends to infinity: $\lim_{t\to\infty}(1 + i)^{-t} = e^{-it}$. Thus, the last equation for continuous put-call parity is

$$C_t - P_t = S_t - E*e^{-it} \quad (3)$$

This equation is widely used in academic literature, especially since electronic (on-exchange) trading and market data dissemination have made nearly continuous prices available. The equivalent formulation of this equation represents our put-call parity model:

$$C_t - P_t = S_t - E + (1 - e^{-it})*E \quad (4)$$

which breaks down the difference of call price C_t and put price P_t at a point in time t. This difference equals the intrinsic value $S_t - E$ of the option and the (discounted) costs of carrying $(1 - e^{-it})*E$ a trader can gain/must pay for the strike price E. This breakdown is rarely present in reference literature which usually uses form (3). However, equation (4) has the advantage that the source of possible deviations from put-call parity can be assigned to either a mispricing of the option's intrinsic value or a mispricing in the costs of carrying. The latter is dependent on the risk-free interest rate and the time to expiration.

The applicability of the basic model of [Stoll(1969)] for European type options has two major limitations: Firstly, it does not account for dividend payouts and secondly, it does not reflect the possibility of early exercise for American type options. Our study avoids options subject to dividend payments by choosing appropriate time frames without dividends (see section 3). Hence, the fundamentals of dividend adoptions in parity models are not outlined here. Useful discussions on dividend adoptions can be found in [Klemkosky and Resnick(1979)], [Nisbet(1992)] and [Finucane(1991)].

However, early exercise conditions for American options are of more importance for our analysis. Early exercise of calls is not an option for rational investors in the setup of our paper since no dividends occur in the observed time periods[15]. For the put option, we stick closely to the considerations made in section 2 to incorporate the early exercise condition in our parity model [Natenberg(1994)]

putP_t = exercise price E – stock price S_t – cost of carrying $(1 - e^{-it})*E$ + time value.

Early exercise is favorable when the costs of carrying outweigh the time value of the put. If follows directly that the early exercise condition for a put is

$$P_t < E - S_t \quad (5)$$

4.2 Two-step approach

In our methodology, the theoretical arbitrage potential as the deviation from the parity model and the practical exploitability of these mispricings are treated separately in two steps. Firstly, the validity of the parity model is tested. The violations from the model are statistically analyzed and compared among 2006 and 2008 and across the groups in 2008 – without considering transaction costs. Secondly, transaction costs are incorporated and results are compared between the pre-crisis and the 2008 sample[16].

In step one, the validity of the parity model is checked on one minute intervals. We define our linear regression model for equation (4) as follows:

$$(C_t - P_t) = \alpha_0 + \alpha_1 (S_t - E) + \alpha_2 ((1 - e^{-it})*E \quad (6)$$

Where, in a frictionless world, α_0 should be 0, α_1 should be 1 and α_2 should be 1 as well. If this model does not fit statistically, put-call parity would not be valid for the sample in general. As a result, an arbitrage potential exists and the market's valuation function does not work efficiently. Besides this, a well fitting regression model can also provide for considerable profit opportunities. A regression only fits the assumed, in this case linear, functional relationship to the observed data points in the best manner possible.

We analyze and compare the violations and resulting profit opportunities found in step one. As stated in subsection 4.1, a violation from the model like:

$$C_t - P_t > S_t - E + (1 - e^{-it})*E$$

implies that calls are relatively overpriced. In the case that:

$$C_t - P_t < S_t - E + (1 - e^{-it})*E$$

puts are relatively overpriced. For both type of violations we apply the conversion strategy described in section 2 to calculate the resulting profits before transaction costs.

[15] [Klemkosky and Resnick(1979)] provide a mathematical definition of the call option's early exercise condition with dividends.

[16] Similar approaches can be found in [Mittnik and Rieken(2000)], [Klemkosky and Resnick(1979)], [Finucane(1991)] and [Nisbet(1992)].

Step two is the market efficiency analysis. According to [Gould and Galai(1974)], a market can be considered efficient, if no trader can consistently make profits after transaction costs that exceed the risk-free interest. That means that mispricings might not be exploitable if transaction costs are taken into consideration. To examine whether the market is efficient in respect to transaction costs, we apply the conversion strategy to every arbitrage opportunity from step one, i.e. writing the overpriced option and buying the synthetic. Then, we subtract the transaction costs *T*. For an immediately executed conversion strategy *T* is the sum of the full spread of a call and a put at Eurex, the full spread of the underlying at Xetra plus the fixed fees and the interest losses for margin requirements[17]. This may be formulated as:

• When calls are overpriced, the market is efficient if

$$(C_t - P_t) - (S_t - E + (1 - e^{-it})*E) - T \leq 0 \text{ for all } t.$$

• When puts are overpriced, the market is efficient if

$$(S_t - E + (1 - e^{-it})*E) - (C_t - P_t) - T \leq 0 \text{ for all } t.$$

In other words, profits after transaction costs should be zero or negative in a valuation efficient market.

In our paper the transaction costs *T* calculated are the minimum transaction costs a least-cost trader pays. Accordingly, we set a lower boundary for market's valuation efficiency. Within these boundaries arbitrage potential is not exploited as transaction costs outweigh the possible profits. At Eurex the least cost trader is the "Advanced Market-Maker" who profit from fee rebates. To measure the implicit transation costs we use the full quoted spread. In consequence, we neglect the order volume which might have a significant impact on the transaction costs. The Xetra fee is not incorporated because it dependents on the order volume. The order volume, however, is subject to the variable proportion of stocks which need to be sold/bought in order to open/close the synthetic position. Additionally, the opportunity costs due to depositing the margin are neglected as Eurex pays interest on the deposited margin. Hence, the effect on the transaction costs might be rather small compared to fees and spreads. We assume that the conversion position is closed out immediately. Therefore we use the same quotes for purchasing and selling the option and its synthetic to calculate the transaction costs. The total transaction costs *T* subtracted from each observation are: the call spread and put spread from Eurex market, the stock spread from Xetra market plus four times the trading and clearing fees for Eurex. We use the two-step approach to compare the sample from 2006 to the sample from 2008.

5 Results

In this section, we present the empirical findings in regard to our two research hypotheses. It is organized as follows: In the first section, we compare violations of the parity model and the resulting profit opportunities across the pre-crisis and crisis samples. Here, the influence of volatility on theoretical arbitrage potential is tested (hypothesis h1). In section 5.2, we incorporate transaction costs in order to verify whether the identified opportunities are practically profitable (hypothesis h2). Finally, we provide robustness checks in the last subsection.

In total 359,397 observations are analyzed for the 2006 sample with 21,141 observations per stock on average. The 2008-sample is even larger with 442,651 observations and on average 26,038 per stock. The higher trading volume in the second data sample is associated with a stronger trading activity during the financial crisis. The difference of put and call prices with the same strike and maturity is the lowest for at-the-money options and optimally zero. As shown in table 2, the mean difference of call and put midpoints is 0.23 Euro in 2006. The standard deviation is 1.80 Euro. Call and put prices are even closer in 2008 with a mean difference of 0.13 Euro and a standard deviation of 0.83 Euro. Besides higher trading activity during the financial crisis, algorithmic trading, facilitated by increasing trading speed and low latency infrastructure, might be a key reason for smaller call-put differentials in 2008 (see [Riordan and Storkenmaier(2008)], [Wagener and Riordan(2009)]).

5.1 The validity of put-call parity

In the first subsection, we present the results of the put-call parity validity tests. We perform regressions for both groups, the most traded (group 1) and the financial services stock options (group 2), as well as on the whole sample from 2006 and 2008. Violations of the parity model are revealed and their resulting profit opportunities are investigated in the second subsection. We compare means on the samples from 2006 and 2008 to show that theoretical arbitrage potential increases in volatile markets. As results for group 1 and group 2 do not differ significantly from the overall samples we only present the results for the overall samples[18].

---

[17] To give an example, in the case of an overpriced call the costs for the conversion are: 1) the call's bid price at Eurex, the ask of the stock at Xetra and the put's ask at Eurex, 2) the fixed trading and clearing fees at Eurex and Xetra and 3) the interest losses for the margins which need to be deposited at Eurex for the open position. To close the position, the transaction costs are: 1) the call's ask price, the bid of the stock and the put's bid as well as 2) and 3) which remain the same.

[18] The results for the individual groups are available from the authors on request.

Table 2. Descriptive statistics

This table presents descriptive statistics for the overall datasets in 2006 and 2008. The overall datsets contain the ten most traded non-financial DAX stock options and the financial services stock options between October 2nd, 2006 to December 14th, 2006 and October 1st, 2008 to December 18th, 2008. We use Reuters DataScope trade and quote data provided by SIRCA to calculate the differences between the put and call price, the violation, and the profit. The violations from the put-call parity are obtained by comparing the difference of call and put prices to the intrinsic value of the option and the costs of carrying. Profits describe the possible earnings by following a conversion strategy. In addition, we compute the quoted spreads as the difference between the best ask and bid of the underlying stocks and of the current at-the-money call and put. The measures are based one minute intervals represented by their last entry and reported in Euros, unless indicated otherwise. Relative violations, profits, and profits after transaction costs (TC) are obtained by dividing absolute values by the strike price of the current at-the-money option. TC are the call and put spread on Eurex, the spread of the underlying on Xetra, and fix trading and clearing fees for Eurex. We present the mean, standard deviation, minimum, and maximum.

Descriptive statistics 2006			***# Obs.:***	359,374
	Mean	***Std. Dev.***	***Minimum***	***Maximum***
call - put	0.23	1.80	-26.97	39.70
violation	0.48	0.42	-9.99	9.98
profit	0.48	0.42	0.00	9.99
spread: stocks	0.04	0.04	0.00	0.94
spread: puts	0.12	0.24	0.00	54.71
spread: calls	0.11	0.23	0.00	54.72
relative violation	0.69%	0.62%	-54.61%	73.95%
relative profit	0.70%	0.62%	0.00%	73.95%
relative profit after TC	0.43%	0.28%	0.00%	1.20%
Descriptive statistics 2008			***# Obs.:***	442,577
	Mean	***Std. Dev.***	***Minimum***	***Maximum***
call - put	0.13	0.83	-31.30	26.49
violation	0.31	0.38	-9.33	8.52
profit	0.31	0.38	0.00	9.33
spread: stocks	0.04	0.05	0.01	1.67
spread: puts	0.24	0.29	0.00	27.62
spread: calls	0.22	0.29	0.00	28.64
relative violation	0.88%	0.74%	-50.48%	60.51%
relative profit	0.90%	0.71%	0.00%	60.51%
relative profit after TC	0.67%	0.46%	0.00%	2.99%

5.1.1 Regression results

As discussed in section 4, we apply a linear regression model using Ordinary Least Squares (OLS) (see equation (6)) to analyze the validity of the parity condition[19]. In section 4 we pointed out that the validity of parity is tested against the coefficients of the regression model. In contrast to other academic papers we split out regression to the intrinsic value and the costs of carrying. Thus, we can identify the crucial factors for potential deviations from parity. In a frictionless world, α_0 should be zero while α_1 and α_2 are one. Then, the regression framework (6) and the parity condition (4) are equal and the regression model fits the put-call parity model. Statistically, the validity of put-call parity is tested on the null hypothesis h0: $\alpha_0 = 0$, $\alpha_1 =1$ and $\alpha_2 =1$ *simultaneously* by using an F-test. The more the regression coefficients deviate from the target values, the worse the valuation efficiency of the market and the more arbitrage opportunities exist.

Table 3 presents the regression results for the overall samples and the subsamples in 2006 and 2008. For both overall samples R^2 is very high (0.996 in 2006, 0.990 in 2008). For 2006 and 2008 h0 is rejected (p-value for the validity of put-call parity below 0.0001), meaning the market did not provide perfect valuation efficiency. However, the deviation of the regression coefficients α_0 and α_1 from the parity model are economically insignificant. They are only different from zero in the third decimal place. For 2008, we even cannot reject at a 95% significance level, that the intercept coefficient α_0 matches the model expectations.

[19] As we group firms and observe those groups over time, our data is panel data. We obtain our results on pooled data over the respective overall sample and/or group. We also perform single OLS regressions for all firms in the data samples. The results do not differ significantly from the pooled data. In all regressions we use Whites' heteroskedasticity-consistent standard errors to obtain a consistent variance-covariance matrix of OLS estimates [White(1980)].

Table 3. Regression results

The table presents results of regressing the difference of one minute put and call prices on the intrinsic value and the costs of carrying: Call – Put = α_0 + α_1 *instrinsic value + α_2*costs of carrying. The validity of parity is tested against the coefficients of the regression model. This means that in a frictionless world, α_0 should be zero while α_1 and α_2 are one. We present the results for the 2006 sample, consisting of the ten most traded non-financial (group 1) and the seven financial DAX stock options (group 2) in 2006, and accordingly for the 2008 sample. The regression results are also reported separately for each group. In order to calculate the costs of carrying we use the one month EURIBOR as the risk-free interest rate. p-values, based on robust standard errors (White, 1980), are enclosed in parentheses below each regression result.

Regression results 2006						
Sample	***Coefficients***			***R^2***	***Validity of parity***	***# Observations***
	α_0	***α_1***	***α_2***			
All	0.004 <.0001	1.006 <.0001	0.961 <.0001	0.996	2.83E+03 <.0001	359,397
Group 1	0.000 0.5653	1.007 <.0001	0.975 <.0001	0.975	4.16E+02 <.0001	212,517
Group 2	0.009 <.0001	1.006 <.0001	0.950 <.0001	0.999	3.87E+03 <.0001	150,005
Mean	0.005	1.007	0.962	0.987		
Weighted	0.004	1.016	0.973	0.994		
Regression results 2008						
Sample	***Coefficients***			***R^2***	***Validity of parity***	***# Observations***
	α_0	***α_1***	***α_2***			
All	0.000 0.1214	1.006 <.0001	0.785 <.0001	0.990	4.00E+04 <.0001	442,651
Group 1	-0.003 <.0001	1.006 <.0001	0.849 <.0001	0.987	2.74E+04 <.0001	273,170
Group 2	-0.006 <.0001	1.006 <.0001	0.766 <.0001	0.991	2.39E+04 <.0001	169,486
Mean	-0.004	1.006	0.807	0.989		
Weighted	-0.004	1.006	0.817	0.988		

The major deviation from the model is in the coefficient of the costs of carrying for both samples. In 2006 α_2 is 0.961 while in 2008 α_2 is only 0.785. Thus, the deviation from the value implied by parity is rather small in 2006 with around 4% from the parity model coefficient of one. In contrast, the coefficient of 2008 deviates over 20% from the parity model coefficient. The results show that the market's valuation function worked relatively efficient in 2006. The second data sample, taken from a time frame of *higly* volatile markets, show a considerably higher difference. This is mostly due to the heavy underpricing of the costs of carrying in 2008. Which seems reasonable as the intrinsic value of an option is usually a fixed function of strike and stock price. The costs of carrying, in contrast, describe the variable portion of the option price[20]. However, the large difference observed in the costs of carrying coefficients between 2006 and 2008 is evident.

To conclude, we emphasize that put-call parity statistically does not hold in either sample. Nevertheless, the differences between the regression model and the parity model are very small in 2006. For the samples before the financial crisis market's valuation function does not work perfectly efficient but can be considered consistent with the parity model. Considerably lower costs of carrying coefficients in all samples from 2008 indicate a smaller parity model fit in highly volatile markets during the financial crisis.

5.1.2 Violations and profit opportunities

The results in subsection 5.1.1 already indicate that arbitrage potential increases in volatile markets. In this subsection we fortify these findings by comparing the overall sample 2006 and the overall sample 2008[21].

Profits are absolute violations from the parity model. They can be gained by entering into a conversion strategy and closing out when prices returned to fair valuation. There are two ways to measure violations and profit opportunities: either absolute in Euro or relative in percents of the strike price. The explanatory power of the absolute violation is limited due to the differences in strike prices among options for distinct stocks and time frames. A two Euro violation on a strike worth 100 Euro is not

[20] Our results are robust to different interest rates. We also use the EURBIOR three month yield with a similar model fit of the coefficients but a smaller (R^2). But the risk-free interest rates traders use in reality differ from trading desk to trading desk and real circumstances are thus hard to obtain.

[21] For brevity, we do not present our calculations and comparisons for the ten most traded stock options (group 1) and the financial services stock options (group 2) in 2006 and 2008. The results are similar.

comparable to a two Euro violation on a strike worth 20 Euro as returns differ for the same capital investment. Thus, to achieve comparability, we investigate the relative violation in percent of the strike price. Accordingly, the relative profit as a percentage of the strike price states the amount of excess return possible[22]. We test our hypotheses on the mean relative violation and on the mean relative profit, respectively. A lower mean relative violation does not generally indicate that valuation efficiency increases. Imagine a situation where the relative violation is commonly distributed and the amount of overpriced puts and overpriced calls is the same. The mean relative violation would be zero but the valuation is not efficient. In contrast, a lower mean relative profit, as the absolute value of the relative violation, indicates a more efficient market and is zero in the optimal state.

An increase in arbitrage potential should result in higher theoretical profit opportunities. Comparing the relative profit distributions of the overall samples from 2006 and 2008, it is striking that in 2006 the relative profit was mostly on 0.5%, up to 1.5% of the strike price (see figure 2). The mean relative profit of 2006 was 0.70% with a standard deviation of 0.62% of the strike price, see table 2[23].

In contrast, the mean relative profit in 2008 is higher, 0.90%, and the distribution is a wider spread (standard deviation of 0.71%). Over 30% of the observations yield over 1.5% of the strike price as excess return. The highest profit with relevant statistic mass is 2.5% of the strike price in 2008 (see figure 2). However, the overall maximum profit in 2006 is 73.95% and higher than the maximum profit in 2008 (60.51% of the strike price). The tests conducted on the relative profit distributions fortify that the mean relative profit in 2008 is statistically significant and higher than the mean relative profit in 2006 (all p-values below 0.0001 in the t-test and ANOVA results). The mean relative profit in the 2008 sample is 0.2 percent points higher than in the 2006 sample. These results are in line with our regression results since the higher deviation from the parity model in 2008 lead to higher mean profit opportunities.

Looking at the relative violations, it is striking that in 2006 almost only calls are overpriced. 357,747 overpriced calls were found compared to only 1,627 overpriced puts. That is, 0.0045 puts per call (the ratios are shown in table 4). In 2008, this general tendency continues and yet a lot more overpriced puts can be found (0.0322 puts per call). The mean relative violation in 2006 is 0.69% of the strike price compared to 0.88% mean relative violation in 2008. Our tests verify that the difference in the means is statistically significant.

To conclude, the hypothesis that theoretical arbitrage potential increases during volatile markets is broadly supported by our data set. The possible excess returns were considerably higher in the 2008 sample than in the 2006 sample. The mean relative profit was significantly higher during the financial crisis.

5.2 The market efficiency test

Our analyses indicate that the Eurex market for DAX stock options is not perfectly valuation efficient and considerable profit opportunities existed during both sample periods in 2006 and 2008. The results show that deviations from the put-call parity model are even higher during the financial crisis in 2008. In this section we test the exploitability of arbitrage opportunities by incorporating transaction costs. Transaction costs are subtracted from every profitable conversion opportunity. We consider spreads and trading fees as transaction costs as depicted in section 4.

Similar to step one, we compare the total samples of 2006 and 2008 using the mean relative profit after transaction costs. Figure 3 depicts our results. The mean relative profit after transaction costs in 2006 is 0.43% of the strike price. 198,016 observations of the total 359,374 violations show a profit greater or equal to zero. In 2008, only 49,179 observations of the total 442,577 violations yield a positive payoff after transaction costs. Still, the mean relative profit of these conversions is 0.67% and thus higher than in 2006 (see table 2). The difference is statistically highly significant (all p-values below 0.001). The maximum profit in 2008 is 2.99% of the strike and therefore more than twice the maximum of 1.2% in 2006. The results for group 1 and group 2 in 2006 and 2008 are similar to the overall sample results.

One reason for the small number of profitable conversions after transaction costs in 2008 seems to be larger spreads in the Eurex option market during the financial crisis. As shown in table 2, the mean option spreads doubled from 0.12 Euro for puts and 0.11 Euro for calls in 2006 to 0.24 Euro and 0.22 Euro respectively in 2008. Meanwhile, the mean stock spreads remained constant at 0.04 Euro. In relative terms (i.e., spread by stock price) the stock spreads widened also during the financial crisis as the shares lost in value[24]. Consequently, the implicit transaction costs reduce the majority of arbitrage opportunities in 2008. Larger spreads are a well known phenomenon in volatile market environments. Eurex market makers quote in a broader range as volatility and uncertainty rise [Schwartz and Francioni(2004)].

---

22 Note that the excess return can be considered as the additional interest possible on the riskless interest rate at the market.

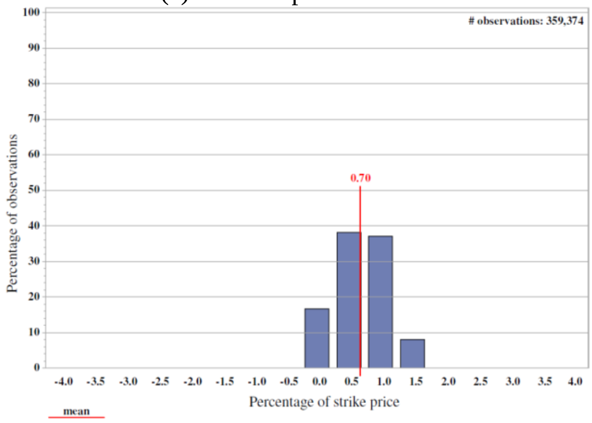
23 The absolute profit in the data sample of 2006 is higher than in 2008. One explanation might be the strong decline in stock prices and in consequence the lower level of strike prices. This is another reason why the relative view is more appropriate.

24 Eurex is obliged to issue new options with at-the-money strike prices when markets move away from the existing strike prices. As we always choose at-the-money options, we automatically incorporate the relative view for options.

Figure 2. Relative profits

Profits are absolute values of violations from the put-call parity model. A violation from parity occurs when either a call or a put is overpriced. Relative profits are obtained by dividing the absolute values by the strike price of the current at-the-money option. We present the distribution of relative profits for the overall datasets between October 2nd to December 14th, 2006 under stable market conditions and October 1st to December 18th, 2008 in highly volatile markets.

(a) Relative profit in 2006



(b) Relative profit in 2008

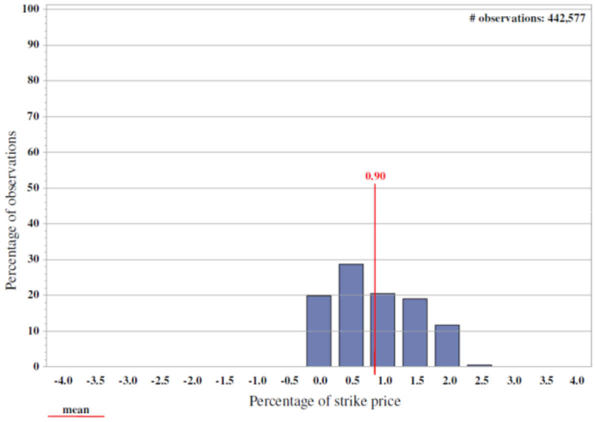


Table 4. Ratio of overpriced puts to overpriced calls

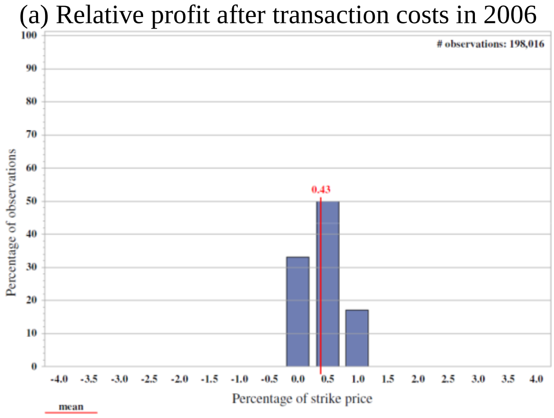
This table presents the absolute number of overpriced calls and puts, the ratio of overpriced puts to overpriced calls, and the number of correctly priced options according to the put-call parity model. We present the results for the overall datasets in 2006 and 2008 as well as for the ten most traded non-financial DAX stock options (group 1) and the DAX stock options of financial service provider (group 2) in 2008.

Ratio of overpriced puts per overpriced call					
	# Overpriced calls	***# Overpriced puts***	***Puts per call***	***# Correct priced***	***# Observations***
All 2006	357,747	1,627	0.45%	23	359,397
All 2008	428,789	13,788	3.22%	74	442,651
Group 1 2008	265,495	7,628	2.87%	47	273,170
Group 2 2008	163,310	6,151	3.77%	25	169,486

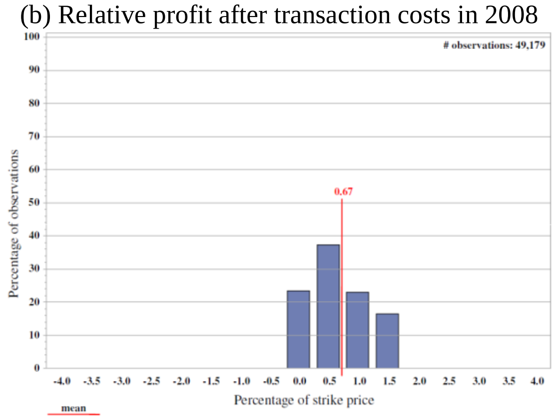
Figure 3. Relative profits after transaction costs

Profits are absolute values of violations from the put-call parity model. A violation from parity occurs when either a call or a put is overpriced. Relative profits are obtained by dividing the absolute values by the strike price of the current at-the-money option. Transaction costs (TC) are the call and put spread on Eurex, the spread of the underlying on Xetra, and fix trading and clearing fees for Eurex. We only consider the observations where the relative profit after transaction costs is greater or equal to zero. In consequence, we exclude negative profits since a trader would not enter such a conversion. Relative profits are presented for the overall datasets between October 2nd to December 14th, 2006 under stable market conditions and October 1st to December 18th, 2008 in highly volatile markets.

(a) Relative profit after transaction costs in 2006



(b) Relative profit after transaction costs in 2008



Although much less profitable conversions are found in 2008, these conversions yield a higher average payoff after transaction costs are subtracted (0.67% in 2008 compared to 0.43% in 2006). Since only around 11% of all violations can be exploited in 2008, the market is valuation efficient in respect to the boundaries of exploitation set by transaction costs – even during the financial crisis in 2008. The results are mainly influenced by larger spreads in the option market. However, our analyses show that still a small number of profitable conversions could be performed[25].

A comparison of our results to other papers is hardly possible. Either the analyses suffer from a lack of available high frequency data, e.g. [Gould and Galai(1974)], or the authors investigate absolute violations in foreign currencies, see [Nisbet(1992)], [Mittnik and Rieken(2000)], [Klemkosky and Resnick(1979)] and [Finucane(1991)]. As the strike prices vary in general, it is impossible to compare absolute violations when analyzing single stock options (see section 5.1). Nonetheless, we find support for the results of [Gould and Galai(1974)], [Nisbet(1992)] and [Mittnik and Rieken(2000)]: After incorporating transaction costs, seemingly profitable conversions are unlikely to represent exploitable inefficiencies of the market.

5.3 Robustness checks

To make our results robust, the impact of a short selling restriction on the valuation efficiency is examined. Bundesanstalt für Finanzdienstleistungsaufsicht (BaFin) restricted short sells for eleven stocks of the financial service industry on September 22, 2008 in order to avoid excessive price movements. By the time we wrote the paper the restriction was still in place. We conduct an additional comparison across the two groups in 2008 to assess whether the restriction leads to a decrease in valuation efficiency. The most traded stock options (group 1) are compared to the financial services stock options (group 2) during the financial crisis. We use t-tests with robust standard erros and ANOVA to compare the mean differences of the violations in group 1 and group 2. As for the conversion of puts the stock needs to be sold short, the short selling restriction should yield significantly more overpriced puts in the sample of group 2 (see section 2). In consequence we expect a larger amount of overpriced puts in group 2 compared to group 1.

We find that the means of the relative violations in group 2 are and lower than in group 1. Table 5 shows that the relative violation in group 1 is 0.90% while it is 0.84% of the strike price in the financial services stocks[26]. Although more overpriced calls are found, the ratio of puts per call is 0.0377 in group 2 and higher than in group 1 (0.0287). So the lower mean relative violation is due to more overpriced puts, i.e. due to opposed violations.

Our results indicate that the short selling ban affects the valuation efficiency. However, only around one percent point more overpriced puts per call are found. Hence, the influence of the restriction seems to be rather small. This might be explained by the fact that the short selling restriction is not valid for Eurex market makers. They are responsible for the majority of the quotes at Eurex.

6 Conclusion

In our paper we provide evidence that the Eurex market for DAX stock options is less valuation efficient during the financial crisis in 2008. Even so, we find considerable arbitrage potential in stable and volatile markets in 2006 and 2008. A linear regression approach is applied to identify crucial factors for deviations from efficient valuation by using the put-call parity model. The results show that option prices in 2006 are economically consistent with the parity model. In the 2008 sample we find more deviations due to misvalued costs of carrying. We find support for our hypothesis that theoretical arbitrage potential increases in volatile markets by comparing the resulting profit opportunities of 2006 and 2008. In accordance with our regression results, the mean profit is higher during the financial crisis and statistically significantly different from 2006. Almost all of the profit opportunities are due to overpriced calls. The extent to which the violations in our samples yield practicall exploitable profit opportunities is considerably reduced by incorporating transaction costs. The Eurex option market is valuation efficient given the boundaries for exploitation set by transaction costs as only a few profit opportunities remain profitable when transaction costs are considered.

Finally, we address limitations of our work. The interest rate we use, although chosen with care and in accordance to other researchers, might not match the interest rate traders use in reality. As most of the arbitrage potential is due to the mispricing of the costs of carrying, our results could be biased if the risk-free interest is different. More importantly, we do not investigate the duration of the arbitrage opportunities. Consequently, no statement can be made on whether the mispricings existed only for a few seconds or continuously, in maximum to expiration. In the first case, arbitrageurs would have been able to exploit the mispricings and the market would return to an efficient valuation afterwards. In case of a continuous mispricing, arbitrageurs could not exit their conversion strategies with profit and market prices would not have reflected fundamental values at all. Thus, the investigation of the duration of arbitrage potential would be an interesting extension of our study.

[25] We also considered both negative and positive profit opportunities in our analyses. After incorporating transaction costs the mean relative profit in 2006 is still positive with 0.06% of the strike price. In 2008, the mean relative profit after transaction costs is negative at -1.82% of the strike.

[26] The t-test and ANOVA verify that the difference in means is statistically significant (all p-values below 0.0001).

Table 5. Descriptive statistics of the robustness check

This table presents descriptive statistics for the ten most traded non-financial DAX stock options (group 1) and the financial services stock options (group 2) between October 1st, 2008 to December 18th, 2008. We use SIRCA trade and quote data to calculate the difference between the put and call price, the violation, and the profit. The violations from the put-call parity are obtained by comparing the difference of call and put prices to the intrinsic value of the option and the costs of carrying. Profits describe the possible earnings by following a conversion strategy. In addition, we compute the quoted spreads as the difference between the best ask and bid of the underlying stocks and of the current at-the-money call and put. The measures are based on one minute intervals represented by their last entry and reported in Euros, unless indicated otherwise. Relative violations, profits, and profits after transaction costs (TC) are obtained by dividing absolute values by the strike price of the current at-the-money option. TC are the call and put spread on Eurex, the spread of the underlying on Xetra, and fix trading and clearing fees for Eurex. We present the mean, standard deviation, minimum, and maximum.

Group 1: Descriptive statistics most traded non-financials in 2008			***# Obs.:***	273,123
	Mean	***Std. Dev.***	***Minimum***	***Maximum***
call - put	0.11	0.54	-16.91	17.48
violation	0.25	0.29	-9.33	8.52
profit	0.25	0.28	0.00	9.33
spread: stocks	0.03	0.02	0.01	0.66
spread: puts	0.17	0.20	0.01	27.62
spread: calls	0.16	0.19	0.01	28.64
relative violation	0.90%	0.72%	-50.48%	45.89%
relative profit	0.92%	0.69%	0.00%	50.48%
relative profit after TC	0.68%	0.46%	0.00%	1.80%
Group 2: Descriptive statistics financials financials in 2008			***# Obs.:***	273,123
	Mean	***Std. Dev.***	***Minimum***	***Maximum***
call - put	0.16	1.16	-31.30	26.49
violation	0.41	0.48	-6.43	7.57
profit	0.41	0.47	0.00	7.57
spread: stocks	0.06	0.07	0.01	1.67
spread: puts	0.36	0.37	0.00	17.40
spread: calls	0.32	0.38	0.00	22.00
relative violation	0.84%	0.78%	-47.64%	60.51%
relative profit	0.86%	0.75%	0.00%	60.51%
relative profit after TC	0.65%	0.44%	0.00%	2.99%

References

1. [Bessembinder and Kaufman(1997)] Bessembinder, H., Kaufman, H. M., September 1997. A Comparison of Trade Execution Costs for NYSE and NASDAQ-Listed Stocks. Journal of Financial and Quantitative Analysis 32 (3), 287–310.
2. [Björk(2005)] Björk, T., 2005. Arbitrage Theory in Continuous Time, 2nd Edition. Oxford University Press, Inc.
3. [Black and Scholes(1973)] Black, F., Scholes, M., May - June 1973. The Pricing of Options and Corporate Liabilities. Journal of Political Economy 81 (3), 637–654.
4. [Cox et al.(1979)Cox, Ross, and Rubinstein] Cox, J., Ross, S., Rubinstein, M., October 1979. Option Pricing: A Simplified Approach. Journal of Financial Economics 7, 229–264.
5. [Fama(1970)] Fama, E. F., May 1970. Efficient Capital Markets: A Review of Theory and Empirical Work. The Journal of Finance 25 (2), 383–417.
6. [Figlewski(1989)] Figlewski, S., December 1989. Options Arbitrage in Imperfect Markets. The Journal of Finance 44 (5), 1289–1311.
7. [Finucane(1991)] Finucane, T., December 1991. Put-Call Parity and Expected Returns. The Journal of Financial and Quantitative Analysis 26 (4), 445–457.
8. [Gould and Galai(1974)] Gould, J. P., Galai, D., July 1974. Transactions costs and the relationship between put and call prices. Journal of Financial Economics 1 (2), 105–129.
9. [Kim(2007)] Kim, K., 2007. Electronic Trading and Algorithmic Trading Technologoy – The Complete Guide. Elsevier.
10. [Klemkosky and Resnick(1979)] Klemkosky, R., Resnick, B., December 1979. Put-Call Parity and Market Efficiency. The Journal of Finance 34 (5), 1141–1155.
11. [Merton(1973a)] Merton, R., March 1973 a. The Relationship between Put and Call Option Prices: Comment. The Journal of Finance 28 (1), 183–184.
12. [Merton(1973b)] Merton, R. C., 1973 b. Theory of Rational Option Pricing. The Bell Journal of Economics and Management Science 4 (1), 141–183.
13. [Mittnik and Rieken(2000)] Mittnik, S., Rieken, S., 2000. Put-call parity and the informational efficiency of the German DAX-index options market. International Review of Financial Analysis 9 (3), 259–279.

14. [Natenberg(1994)] Natenberg, S., 1994. Option Volatility & Pricing. McGraw-Hill.
15. [Nisbet(1992)] Nisbet, M., June 1992. Put-call parity theory and an empirical test of the efficiency of the London Traded Options Market. Journal of Banking and Finance 16, 381–403.
16. [Riordan and Storkenmaier(2008)] Riordan, R., Storkenmaier, A., 2008. Latency, Liquidity and Price Discovery. In: 21st Australasian Finance and Banking Conference 2008. Sydney, Australia. URL http://ssrn.com/abstract=1247482
17. [Schwartz and Francioni(2004)] Schwartz, R. A., Francioni, R., 2004. Equity Markets in Action: The fundamentals of Liquidity, Market Structure & Trading. John Wiley and Sons, Inc.
18. [Stoll(1969)] Stoll, H., December 1969. The Relationship Between Put and Call Option Prices. The Journal of Finance 24 (5), 801–824.
19. [Wagener and Riordan(2009)] Wagener, M., Riordan, R., 2009. System Latency in Linked Spot and Futures Markets. In: Fifteenth Americas Conference on Information Systems. San Francisco, California, USA.
20. [White(1980)] White, H., May 1980. A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. Econometrica 48 (4), 817–838.