OPTION MARKET EFFICIENCY AND ARBITRAGE OPPORTUNITIES:

THE CASE OF POLAND

by

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Abstract

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This study is dedicated to investigation of efficiency of an emerging index option market, which is made by testing the put-call parity (PCP) validity during the period from 2010 till 2012. The standard methodology is modified and extended with the help of ex-post arbitrage profits' evaluation, tests for transaction costs' asymmetry, and sensitivity analysis with respect to transaction costs.

On average, reversal arbitrage strategies are proved to be much more beneficial and frequent than conversion ones, indicating that the put options are overpriced in comparison with the identical calls. However, taking into account the amount of real transaction costs, there is a possibility that the index option market will produce almost no arbitrage opportunities, supporting the hypothesis of market efficiency and the validity of the PCP. These results are consistent with the findings of other studies on efficiency of various European index option markets.

In conclusion, it can be stated that the hypothesis of the option market efficiency cannot be rejected in spite of the presence of mispricing signals.

To my family

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Chapter 1

INTRODUCTION

Over the last decades of the twentieth century, financial markets in the advanced economies have made substantial qualitative and quantitative improvements, which consequently turned them into a very sophisticated global system with various complex tools generally called financial derivatives. These financial instruments in the form of futures, forwards, options and swaps provide economic participants with the means of hedging their risks and therefore, enhance their performance, utility and income. This, in turn, stimulates economic growth and ameliorates living standards both in a particular country and in the global economy.

Ever since the foundation of the Chicago Board Options Exchange (CBOE) in 1973, options have become one of the most advanced parts of the derivative markets not only in developed countries, but also in emerging economies. As a result, the question concerning fair pricing and market efficiency deserves closer attention and cannot be overestimated. Fair pricing in this context means that a portfolio which brings to its holder a consistently higher payoff in the future should cost more than a portfolio with a lower-payoff. The violation of this principle implies arbitrage opportunities and leads to market inefficiency.

A great number of empirical investigations show that the assumption of financial market efficiency does not always hold (Grossman and Stiglitz, 1980; Dimson and Massavian, 2000) and there exists a possibility of mispricing and arbitrage. The latest significant example of the market efficiency violation is the Global

Financial Crisis (GFC) of 2008-2009, which stemmed in large part from mispricing of credit derivatives[1].

The presence of arbitrage opportunities in the financial market is a major indicator of its inefficiency (Klemkosky and Resnick, 1979). The notion of arbitrage is closely related to the definition of 'free lunch' and means that economic participants have the opportunity to gain profits on a risk-free basis without involving their own resources (Dybvig and Ross, 1992). Roughly speaking, any possibility of arbitrage and its persistence violates the law of one price, leading to market inefficiency, and, as a result, it takes time for the market to readjust and come to the equilibrium condition of efficiency.

We are interested in testing efficiency of emerging index option markets. More specifically, we are apt to investigate the markets of Ukraine, Russia and Poland due to their relative similarity and geographic proximity. However, as it will be stated later, it is important to have European-type options for our research, while the Ukrainian and Russian markets issue only American style ones. Hence, our main question of research is to test whether the index option market in Poland is efficient. Although the trading volumes in this market are smaller in comparison with the advanced markets of the U.S and Western Europe, there are a number of reasons why it should be individually investigated in more detail.

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[1] In this particular case market inefficiency was induced by a speculative securitization process of poor-quality house mortgages, which led to the issuance of mispriced Collateralized Debt Obligations (CDOs), and bore no relation to option markets. Here the practice of speculation, but not arbitrage became the focal point, underlying that the principal difference between arbitrageurs and speculators lies in the fact that the latter bear a substantial risk, while the position of the former is essentially risk-free. However, even if market inefficiency due to the existence of arbitrage does not have such devastating outcomes for the market, it could hinder the world economic growth substantially.

First, there has been very little research on the topic of emerging option market efficiency (and virtually none on the Polish one), even though the literature on the developed markets is extensive (Klemkosky and Resnick, 1979; Nisbet, 1992; Cavallo and Mammola, 2000; Capelle-Blancard and Chaudhury, 2002, etc.). Also taking into account the fact that different countries have different results in terms of market efficiency and the presence of arbitrage opportunities (Puttonen, 1993; Chesnay, Gibson and Loubergé, 1995; Mittnik and Rieken, 2000; Li, 2006, etc.), the situation on the option market of Poland could stand out from other emerging markets, which implies that a country specific study is needed. Third, economic agents and regulators in this market could benefit from an inquiry into their efficiency for two major reasons. On the one hand, since efficiency in price discovery is a key attribute of a well-functioning securities market, efficient financial markets are conducive to risk hedging, help to allocate capital in the most productive way, reduce transaction costs, and appear to be more convenient in usage (Ackert and Tian, 2000). On the other hand, mispricing and market inefficiency lead to arbitrage opportunities, by taking advantage of which financial market participants could gain some additional profits without bearing any risk.

There exist three approaches investigating option market efficiency. The first one tests efficiency of the option market by comparing the current market prices of options with the computed ones obtained with the help of a theoretical option pricing model (Black–Scholes-Merton, Cox-Ross-Rubenstein, etc.). These models require a great number of assumptions rarely feasible even in the simplified world, which limits and complicates their usage.[2] Originally, the BSM model has to be applied to the stock options, which means that the assumptions imposed should work also for the index options. However, not all such assumptions could

[2] For instance, the celebrated Black–Scholes-Merton model assumes that the prices have to follow a Geometric Brownian motion with constant drift and volatility (Black and Scholes, 1973), which hardly corresponds to the facts.

be extended in such a way that will allow the BSM model being used for pricing of index options.[3] As a result, a great number of studies (Chaudhury, 1985; Chesnay, Gibson and Loubergé, 1995; Capelle-Blancard, 2001, etc.) point out that it could be difficult to apply the BSM model of index option pricing and obtain precise and meaningful results in presence of infrequent trading and non-constant volatility.

The second approach examines the possibility of obtaining profits using the predictability of implied volatility. As an advantage of this method, we can set aside the fact that there is no need in exogenous prediction of returns volatility of the underlying asset (Capelle-Blancard, 2001). However, Canina and Figlewski (1993) conduct research on S&P 100 index options and find out that option prices cannot predict the future realized volatility, while Day and Lewis (1992) reach opposite conclusions about the same instruments. Also it should be mentioned that Schmitt and Kaehler (1996) study the German index market (DAX) and figure out that the model based on the historical volatility of this index gives higher profits than the implied volatility one.

The third approach rests on testing the put-call parity (PCP) and option price boundary conditions. [4] Using this methodology, we can estimate the price of a put option from the known price of the corresponding call option and some other market variables, and vice versa. Hence, in case of substantial market price

[3] For example, it can be considered that the stock prices are lognormally distributed, but the index, which is equal to the sum of stocks' market values, does not have such a distribution (Chesnay, Gibson and Loubergé, 1995). This undermines the validity of using the BSM model in valuation of the index option prices. Furthermore, the research conducted by Evnine and Rudd (1985) and Cotner and Horrell (1989) show that the BSM model with constant variance exhibits pricing biases, which only partially diminish due to the incorporation of stochastic volatility (Sheikh, 1991).

[4] In accordance with the PCP model, there exists a specific deterministic relationship between call and put option prices with the same maturity date and strike price, which is based on the evidence that one of these options and their underlying asset (index) could be matched in such a way as to produce opportunities for losses or profits to the remaining instrument (Klemkosky and Resnick, 1979).

deviations from the estimated parity price, market participants can take advantage of the existing arbitrage opportunities. This mechanism works in the following way: If the call option is overpriced, market agents will have strong incentives to sell it, take a long position in the underlying asset and buy the corresponding put option. After these transactions the obtained difference could be deposited in the bank and overall rate of return would be higher than the risk-free one. Analogously, if participants know that the put option is overpriced, they will sell it, take a short position in the underlying asset and purchase the corresponding call option, earning more than the risk-free profit (Klemkosky and Resnick, 1979).

The major advantage of this approach to analyzing market efficiency, which distinguishes it from the other two ones, is that it is model-free in the sense that no assumptions about the distribution of the underlying asset have to be made and therefore, its conclusions are not sensitive to the choice of the model and its appropriateness (Capelle-Blancard and Chaudhury, 2002).

At the same time, there are several assumptions behind the PCP approach, and some of them are quite strong. The basic PCP relation assumes that there are no transaction costs, dividend payments, taxes and short-sales restrictions, lending rates are equal to the borrowing ones, and options and the underlying assets are traded synchronically (Cremers and Weinbaum, 2007). However, the PCP analysis can be easily extended in such a way that allows relaxing some of these assumptions (Cavallo and Mammola, 2000; Mittnik and Rieken, 2000; Li, 2006, etc.).[5] Thus, we will use the PCP model for investigating efficiency of the Polish index option market.[6]

[5] One assumption that cannot be relaxed is that options are not exercised prior to maturity, which means that this approach cannot be used for American-type options.

[6] The WIG20 options are the European ones (can be exercised only on the expiration date).

The major hypothesis consists in inefficiency of the Polish index option market, which means that the expected results are likely to reject the PCP validity. Our preliminary proposition is based on the results of testing the Polish index futures market efficiency (Bialkowski and Jakubowski, 2008), which state that the market has strong persistence of arbitrage with average pricing errors of 64 min, whereas advanced markets suffer from at most 5 min lags. Hence, taking the index futures market of Poland as a 'benchmark'[7], it can be supposed that its option market is probably less efficient than the advanced ones. However, it can be noted that this juvenile market could reveal more efficiency than it is expected, since there has been done a lot for its development and volumes traded have been growing substantially for the last several years.

The dataset used consists of daily data on the WIG20 index call and put options and daily WIG20 index values, daily data of interest rates (WIBOR), and the information concerning transaction costs on the Polish index option markets, which is taken from the official sites of the WSE and CBonds.

This thesis has the following structure. The second chapter represents literature review concerning testing option market efficiency hypothesis and estimating frequency of arbitrage opportunities on different index option markets. The third chapter sheds light on the methodology applied. The fourth chapter is dedicated to the description of the dataset used in this research, while the fifth chapter is devoted to the empirical results. The sixth chapter represents the thesis' conclusions.

[7] Polish index futures and options have the same underlying asset – the WIG 20 index.

Chapter 2

LITERATURE REVIEW

The most outstanding and celebrated approach in investigating and measuring arbitrage opportunities, which is the PCP model originally developed by Stoll (1969), has been widely used in the majority of research and studies dedicated to testing option market efficiency. This initial model introduces the assumptions mentioned before with the one exception: There is no distinction between American and European options. This means that the American options are treated in the same manner as the European ones and the PCP approach could be applied. Taking into consideration this concept, a great number of empirical studies apply the PCP to American options on the U.S. stocks and indices (Stoll, 1969; Gould and Galai, 1974; Klemkosky and Resnick, 1979; Evnine and Rudd, 1985; Chance, 1987; Ronn and Ronn, 1989, etc.). The results of their studies turn out to be quite controversial: Significant and rapid violations of the PCP are observed in the form of options mispricing and at the same time the PCP is not rejected. This inconsistency can be explained by the fact that the options investigated are the American-style ones and could be exercised at any date before the maturity. Conducting research on the relationship between put and call prices, Merton (1973) proves that due to the fact that the possibility of the options' early exercise could not be disregarded, even if some attempts to account for this are made, the PCP cannot be tested for American options. Therefore, the outcomes obtained in these studies are difficult to interpret, since there is no proper way to evaluate if the violations of the PCP are present as a consequence of market inefficiency or early exercise.

Although Klemkosky and Resnick (1979) also mark out different frameworks for American and European options treatment, the research made by Kamara and Miller (1995) is a watershed event in this area. Their study is based on investigation of the European index options (S&P 500), which eliminate the problem of early exercise, and the findings suggest that the PCP violations are significantly smaller and less rapid than those, which are deduced from American options research. The authors point out that in the previous research the presence of market inefficiency could be related to the effect of early exercise. These results convince other scientists to apply the PCP approach only to European options in order to achieve reasonable outcomes. Furthermore, according to this research, in most cases the existed mispricing appears due to substantial liquidity risk, but not market inefficiency. Generally, the S&P 500 option market proves itself as an efficient one, which differs from the Chesney et al. (1994) conclusions that imply the prevalence of relative put overpricing and, as a result, inefficiency of the Swiss index option market.

The most recent market efficiency studies examine the Italian index (MIB30) option market (Cavallo and Mammola, 2000; Brunetti and Torricelli, 2003), the German index (DAX) option market (Mittnik and Rieken, 2000), the French index (CAC 40) option market (Capelle-Blancard and Chaudhury, 2002), the Japanese index (Nikkei 225) option market (Li, 2006), and others. Almost all these research cannot reject the hypothesis of efficiency of the corresponding markets, but the efficiency extent and its implications differ across the studies.

Capelle-Blancard and Chaudhury (2002) figure out that the French index option market reveals a higher extent of efficiency in comparison with the more matured and advanced U.S. index option market (S&P 500). The Italian market turns out to be more efficient than the French one, but with the similar systematic patterns of the PCP violations, while the S&P 500 has absolutely different patterns explained by institutional and cultural dissimilarities of these markets. Also the authors emphasize that the possibility of arbitrage opportunities increases in the active trading periods and there appears to be no evidence of the efficiency amelioration due to the entry into the Eurozone.

As has been mention before, the findings from the Italian option market prove its efficiency as a whole, assigning to retail operators only 2% of profitable hedges among all the investments, whereas institutional operators get profits in 5% and 6% of the cases (Cavallo and Mammola, 2000). The Japanese index option market is also proven to be efficient with 2.74 % of profitable hedges (Li, 2006), although the frequency of arbitrage opportunities happens to be lower than expected, since other related studies demonstrate 9.5% (Lee and Nayar, 1993) and 4.34% (Fung and Mok, 2001) of profitable cases.

The German index option market stands aside from the other markets, since the PCP is rejected according to the statistical approach. The regression analysis determines that the put options are overpriced in comparison with the corresponding call ones, which reflects the presence of PCP violations and indicates the market inefficiency (Mittnik and Rieken, 2000). However, accounting for the short-selling restrictions in Germany, which preclude from execution of a short-hedge strategy, the overall conclusions are different from the statistical ones and indicate that the efficiency is present in the market. Also this research relaxes one crucial assumption concerning the dividend payments: Since the underlying asset is a performance index, payments of dividend on it can be neglected. On the contrary, it could be assumed that the market participants have perfect foresight concerning dividend payments (Capelle-Blancard and Chaudhury, 2001).

A great number of studies point out that transaction costs (commissions, bid-ask spreads, etc.) weaken the possibility of taking advantage of arbitrage opportunities, that's why the absence of transaction costs is one of the strongest assumptions of the PCP approach. However, the extended PCP models relax this assumption, since they could take these costs into account. For instance, the German (Mittnik and Rieken, 2000) and the French (Capelle-Blancard and Chaudhury, 2002) index option markets experience abrupt decrease in arbitrage opportunities in case of all the transaction costs being considered. The Italian market study is also consistent with the results above mentioned and claims that substantial mispricing sizes and violations of the PCP cannot be exploited recognizing all transaction costs (Cavallo and Mammola, 2000). By contrast, investigation into the Japanese index option market reveals that only a small share of investment is profitable, if transaction costs are low, and, on average, the size of arbitrage opportunities becomes larger with incorporation of the actual transaction costs in the model (Li, 2006).

The results concerning the relative profitability of short and long arbitrage strategies also differs across markets. Li (2006) indicates that the average long arbitrage strategy is more beneficial compared to the short one in the Nikkei 225 option market. It should be noted that the short strategies are more frequent compared to the long ones, which implies that the PCP violations stem from overpriced puts and underpriced calls (Li, 2006). However, the index option markets of Europe and the U.S. declare the opposite findings with reference to strategy profitability: The short arbitrage strategy is more advantageous than the long one. On average, the short strategy outperforms the long one by approximately 10% of the cases (Cavallo and Mammola, 2000; Capelle-Blancard and Chaudhury, 2001; Ackert and Tian, 2001; Brunetti and Torricelli, 2003).

Thus, it can be concluded that despite using the relatively standard approach, a new emerging index option market as a Polish one has additional transaction costs (one of the main distinctions from other markets), since frequent short-selling can be achieved only indirectly via repurchase agreements (repos), which is much more expensive (Bialkowski and Jakubowski, 2008). Repos represent the stocks' sale with an agreement for a seller to buyback the instruments at a specified date. Every market participant who decides to be involved in short-selling for more than one day is obliged to sign a repo contract with a broker. Such contracts are charged by huge commission in amount of approximately 20-25% per year. Thus, it is necessary to extend the methodology to account for different restrictions; however, there is some evidence that the market studied will partly resemble the European ones.

Chapter 3

METHODOLOGY

For our investigation of market efficiency we are going to use the generally acknowledged methodology, which will allow comparing our results with the results obtained by similar studies. This methodology is based on the celebrated efficient-market hypothesis (EMH), which states that financial markets are "informationally efficient" in the sense that given the information available a market agent cannot consistently get returns in excess of average ones on a risk-adjusted basis. Considering the EMH in terms of the PCP condition, this hypothesis implies that call options are efficiently priced relative to identical put options at every time point, and vice versa (Mittnik and Rieken, 2000). At the same time, market efficiency does not imply absolute absence of arbitrage opportunities, just that they are relatively rare, random, and short-lived.

The main objective of our research consists in testing the PCP validity for the Polish (WIG20) index options. There are several versions of the PCP condition for European options that depend on whether the underlying asset pays any dividends. Since most Polish stocks make very small and infrequent dividend payments (Bialkowski and Jakubowski, 2008) we can safely ignore the effect of dividends on the PCP condition. Also, a number of other researchers think that it is quite reasonable to ignore the dividends at all, while studying and analyzing the performance indices (Mittnik and Rieken, 2000).

To test the hypothesis of the Polish index option market efficiency we should examine the PCP violations and find out whether they lead to lucrative arbitrage strategies. This approach is formulated by Stoll (1969) and developed further by

Klemkowski and Resnick (1979), Kamara and Miller (1995), Mittnik and Rieken (2000), Cavallo and Mammola (2000), Capelle-Blancard and Chaudhury (2001), etc. Thus, the fundamental model of the put-call parity condition for European index options could be presented as follows (Li, 2006):

$$C_t + Ke^{-r(T-t)} = P_t + I_t, \tag{1}$$

where C_t – the current market price of a European call index option at time *t*, P_t – the current market price of a European put index option at time *t*, K – the striking price of the call and put options, I_t – the level of the underlying index at time t, *T* – the maturity date, *r* – the risk-free rate.

This relation between put and call option prices follows from the law of one price argument: A portfolio consisting of a European call and a cash position (in the amount Ke^{-rT}) will be worth max(I_t, K) at options' maturity *T*, which also happens to be the value of a portfolio consisting of a European put and one unit of the underlying asset. Therefore, the current values of these two portfolios must also be the same: The PCP condition results. This basic equation ignores transaction costs, which we will consider later.

If the parity condition (1) does not hold, there exist arbitrage opportunities, which could be eliminated by implementing one of the two strategies: a conversion strategy or a reversal one. The conversion strategy is used in cases when the call option is overpriced (the LHS of equation (1) is greater than the RHS), while the reversal one is appropriate for the overpriced put options (the LHS of equation (1) is smaller than the RHS). The mechanism of these strategies is similar. In the conversion (long) strategy, an arbitrageur writes the overpriced call option, borrows cash in amount of $\mathrm{Ke}^{-\mathrm{r}(\mathrm{T}-\mathrm{t})}$ at the risk-free rate and buys the index and the corresponding put index option. This generates a positive immediate cash inflow $C_t + Ke^{-r(T-t)} - P_t - I_t > 0$ and a zero cash flow at the maturity date *T*. The reversal (short) approach consists in writing the overpriced put index option, selling short the underlying index and lending the obtained resources in amount of $-Ke^{-r(T-t)}$ at the risk-free rate, which will produce a positive immediate cash inflow $P_t + I_t - C_t - Ke^{-r(T-t)} > 0$ and a zero cash flow at the maturity date *T* (Mittnik and Rieken, 2000).

Let us incorporate transaction costs into the model, represented by the costs of trading options and the index, denoted by TS_t and TL_t for the short and long-hedge strategies, respectively. A conversion strategy gains profits when $P_t < C_t + Ke^{-r(T-t)} - I_t - TL_t$, while a reversal strategy is profitable if $P_t > C_t + Ke^{-r(T-t)} - I_t + TS_t$ (Mittnik and Rieken, 2000; Li, 2006).

To analyze these relations, Mittnik and Rieken (2000) suggest running a regression of the form:

$$C_t - P_t = \alpha_0 + \alpha_1\left(I_t - Ke^{-r(T-t)}\right) + u_t, \qquad (2)$$

where α_0, α_1 are the constants and u_t is the error term. Assuming no transaction costs, under the null hypothesis of the PCP validity, the coefficients α_0 and α_1 should be zero and one, respectively. However, due to transaction costs, it is natural to expect a non-zero intercept coefficient. This analysis gives us an opportunity to measure the strength of the relationships among the variables underlying the PCP (Li, 2006).

Since possible outliers and violations in disturbances' assumptions could affect the validity of the regression results, a robustness check is quite sensible to implement. According to numerous studies (Rubinstein, 1985; Sheikh, 1991; Mittnik and Rieken, 2000), a non-parametric sign test should be a reasonable tool for robustness analysis.

Sign test is performed in the following way. First, using the PCP equation call market prices are converted into put prices: $P_t^{PCP} = C_t + Ke^{-r(T-t)} - I_t$. Then, the obtained put prices are compared to the market prices of puts, and, under an assumption of the PCP holding, these prices have to be the same $P_t^{PCP} = P_t$. Thus, the probability of finding that the obtained P_t^{PCP} is higher than the market price P_t in every such put-call match should be equal to 0.5 (our H_0 hypothesis). For testing purposes, the random variable *Z* should be generated as follows:

$$Z = \frac{(X - \frac{n}{2} + 0.5)}{\sqrt{\frac{n}{4}}}, \tag{3}$$

where *n* is the number of observations ($n \geq 20$) and *X* is the number of matches that satisfy the inequality $P_t^{PCP} > P_t$.

The variable *Z* follows a standard normal distribution. Hence, after specifying the significance level and finding test statistics, the conclusion of the PCP validity could be made. If the null hypothesis is rejected, this means that the PCP does not hold, which, in turn, indicates significant mispricing.

Since we acknowledge that the strong assumption of no transaction costs does not hold in reality, it is not expected that the intercept estimate in regression (2) is going to be equal to zero. Furthermore, plenty of studies (Mittnik and Rieken, 2000; Li, 2006; Bialkowski and Jakubowski, 2008) empirically prove that transaction costs are asymmetric, which is why we extend our regression model by splitting the whole sample into two parts: The first one consists of overpriced calls, while the second one contains only overpriced puts. Thus, the sample is split based on the sign of the mispricing signal $\boldsymbol{\varepsilon}_t$ calculated as

$$\boldsymbol{\varepsilon}_t = C_t + Ke^{-r(T-t)} - P_t - I_t. \quad (4)$$

The intercept coefficients obtained from different subsamples will be different in signs and magnitudes due to the direction of deals and the asymmetry of transaction costs for long and short index positions.

Let us shed more light on the issue of transaction costs. Getting precise estimates of these costs is quite difficult since they include clearing and trading fees, commissions, cost of repo deals for short index positions, etc. However, we can refer to the available research on the Polish index futures market by Bialkowski and Jakubowski (2008), and extend their general approach to calculating the appropriate transaction costs for the option market deals.

In general, in both conversion and reversal strategies transaction costs arise due to buying and selling operations with two options and buying or selling the index. According to the WSE Rules (Exhibit No.1), the maximum fee on an option deal equals to 1.2 PLN, which means that for establishing any strategy, an agent has to buy and sell an option and pay for that a transaction fee of at most 2*1.2=2.4 PLN.

The transaction costs of index trading depend on the type of agent that is why we assume the following four levels of these costs: 1.2%, 0.9%, 0.6%, and 0.3% of the index price (Bialkowski and Jakubowski, 2008). The highest level of transaction costs corresponds to a small private investor, while the lowest one is applied to a large institutional investor, since, on average, the latter one pays lower amount of commissions due to a large size of the fund. Thus, we calculate positive and negative mispricing signals, accounting for these levels of transaction costs.

$$\varepsilon_t^L = C_t + Ke^{-r(T-t)} - P_t - I_t - TC_t^L, \quad (5)$$

where ε_t^L is the amount of mispricing accounting for the transaction costs of level L and TC_t^L is the amount of transaction costs of level L.

Then, we find the percentage of the matched pairs with such positive and negative violations for each of the four levels of transaction costs. The percentage of positive mispricing violations indicates the degree of call overpricing, whereas the percentage of negative mispricing violations - the degree of put overpricing.

Let us consider some econometric problems, which could be encountered in the process of our analysis. Firstly, the possibility of the measurement error is unlikely, since no proxy variables are used. The only approximation being made concerns the interest rates[8], but the induced bias is likely to be negligible, since for the option with less than 1 year to expiration prices are relatively insensitive to interest rate changes (Cox and Rubinstein, 1985). Secondly, serial correlation could be observed, however, the chosen option pairs' contracts differ by maturity dates, strike prices and are diversified across the time interval, which decreases probability of their interdependence. If this problem arises, it will be solved by

[8] Ideally, for each observation (for every option contract) it is preferred to have such an interest rate that completely matches to the time to maturity of the corresponding contract.

the usage of the generalized least-squares (GLS) method, more precisely, the Prais–Winsten and Cochrane–Orcutt test, which allows estimating the parameters in a linear regression model with the serially correlated errors. Thirdly, we should test whether the variance of the residuals is homogeneous with the help of the Breusch-Pagan or the White's tests. If these tests reject the homogeneity assumption, then there exists heteroscedasticity, meaning that the estimates are no longer efficient. In this case, it is reasonable to check the severity of the heteroscedasticity, and then to decide if any correction is needed.

It is also important to mention a serious methodological issue that might affect our results: the problem of non-synchronous trading of puts, calls and the index itself. This problem is frequently solved by matching the option contracts within a one-minute interval in many studies (Li, 2006), but also there is plenty of empirical investigations that test market efficiency by using daily closing prices, lagging the execution till the next trading day (Chesney et al., 1994; Mittnik and Rieken, 2000). The lag of one trading day could be considered as a rather long one, but it is unavoidable in the case of analyzing illiquid markets, where there is not possible to match the options within a shorter interval (Chesney et al., 1994; Li, 2006).

Chapter 4

DATA DESCRIPTION

According to the Federation of European Stock Exchanges (FESE), the Warsaw Stock Exchange (WSE) has one of the highest ranks among the European derivative markets by the contracts trade volumes. The first WSE options based on the WIG20 index[9] were issued on 22nd of September, 2003 and have been traded since then with the constantly growing trading volumes. The options are of the European exercise style, meaning that they could be exercised only at the maturity date. According to the data available[10], in March 2011 the WIG20 options set a historic record for monthly turnover, and the total volume of options traded was equal to 101 465. This is the first time when the mark of 100 000 has been reached since their introduction to the WSE.

For continuous trading, in 2011 the turnover value by premium reached 276.72 million PLN[11] and the corresponding total volume of option trading was equal to 832 106 (an increase of 52.17% compared to 2010). In accordance with turnover volumes of options on different European indices in the first half of 2012, the WIG20 options were ranked 15th with 297 730 items, which was quite similar to the Norwegian (OBX) option trading volume[12]. In contrast, the turnover volumes of the German DAX (2nd place) and French CAC40 (8th place) options constituted 28 267 232 and 2 512 869 items, respectively. However, for the last several years liquidity at the Polish option market has been constantly

[9] There also existed options on the stocks of well-performing Polish companies listed on the WSE.
[10] Trading data and other relevant information are available on the official website of the WSE: www.wse.com.pl.
[11] PLN – Polish Zloty (1PLN≈0.3USD)
[12] 376 267 items

increasing, being supported by the growing number of market makers, who are responsible for making the options more attractive to investors.

Generally, index option contracts have a 1-year maturity and could be exercised only on the 3rd Friday of the corresponding expiry month[13]. Figure 1 shows the annual trading calendar for WIG20 options with the 4 possible expiry months. The 9-letter symbol of each option contract can be decomposed into four parts: the first four letters, OW20, are the same for all index options and stand for WIG20, the next letter denotes the expiration month and a type of the option (see Table 1), the next digit corresponds to the maturity year, and the last three digits contain the exercise price[14]. For instance, OW20L0200 is a call option contract on the WIG20 index that expired on the 3rd Friday of December 2010 and had the exercise value of 2000 PLN.

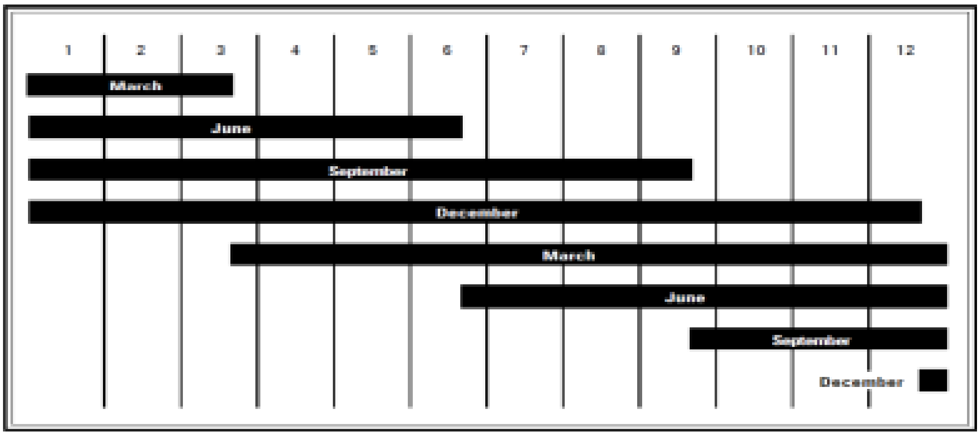

Figure 1. Trading calendar for WIG20 options

As it is common for index options, the WIG20 contracts are priced in index points with strike prices, which could range from 1 100 till 3 300 for different expiry dates. Also index options differ from each other by transaction activity:

[13] The option trading follows the March-June-September-December cycle.
[14] The exercise value is equal to the product of exercise price and multiplier (10 PLN per index point).

The contracts that are the closest to being at-the-money[15] are the most actively traded ones and can have 3 000-5 000 transactions per trading period, while others – only 10-15.

Table 1. Classification of WIG20 options

Option Type / Month	Call Option	Put Option
March	C	O
June	F	R
September	I	U
December	L	X

Following Mittnik and Rieken, 2000; Cavallo and Mammola, 2000; Capelle-Blancard and Chaudhury, 2001 and other authors, initially we intended to use the intraday data on the WIG20 call and put options, the intraday index values (at 1 minute frequency), and daily data on the interest rate (WIBOR) for three years from 2010 till 2012. Such intraday data have been collected[16] for 484 call and put options[17], and included information about the date of a transaction (day, month and year), the time (hours, minutes, seconds), the price and its corresponding volume. Then, we tried to match transactions on otherwise identical put and call options[18], but it appeared that there were no matches within one minute intervals of transactions. Moreover, even within one hour intervals such matches were encountered very infrequently. While using the intraday data would be preferred in very liquid markets, Chesney et al. (1994) and other authors rely on daily closing prices in their research. That is why, in the end we have decided to use end-of-the day data in our research as well.

[15] The option's strike price is the closest to the current price of the underlying asset (value of the index).
[16] The data is available on websites http://www.parkiet.com and http://www.money.pl.
[17] 484 separate files
[18] Identical strike prices and time to maturity (expiration date)

Thus, the data set for our study consists of daily closing prices on the WIG20 index call and put options, daily WIG20 index values, and daily data of the interest rate (WIBOR) from 2010 till 2012. The daily data for index options have been obtained (242 contracts of each type)[19] in the form of 484 separated excel files, which included information about the number of transactions and open positions, volume, different prices, etc. In accordance with the research purposes, for every option we extract only relevant data, which involves such parameters as a strike price, an expiry date and closing prices for each trading day. Taking into account the relative illiquidity of the WIG20 option market, it is sensible to consider only a three-month period prior to maturity, when they are traded most frequently. Hence, every year is divided by 4 subsamples with different contracts traded from January till March, from April till June, from July till September, and from October till December.

Following the PCP literature, our research focuses on the so-called at-the-money (AM) contracts, which are traditionally the most liquid ones. At-the-money options are contracts with strike prices that are closest to the contemporaneous WIG20 index values. More specifically, options are defined to be at-the-money, when the moneyness coefficient, $m = \frac{I_t}{Ke^{-r(T-t)}}$, belongs to a narrow interval around 1: $0.98 \leq m \leq 1.02$.

We also need the data on the WIG20 index daily closing prices from 2010 till 2012. The WIG20 index represents 20 most liquid and capitalized local companies listed at the WSE, which come from different industries (software, finance and insurance, chemistry, real estate, energy, food, mining, oil and gas, media and telecommunication). This stock market index is weighted by capitalization and recognized as a 'benchmark' for the security market of Poland.

[19] Data are available on website http://www.gpwinfostrefa.pl.

Table 2 contains basic descriptive statistics of the WIG20 index over these three years and by quarters.

Table 2. Descriptive statistics for the WIG20 index

Year/ quarter	Number of observations	Min	Max	Mean	Standard deviation
2010	253	2 173.25	2 787.09	2 492.93	147.79
1st quarter	63	2 173.25	2 506.24	2 375.42	97.91
2nd quarter	61	2 270.13	2 604.76	2 431.94	97.51
3rd quarter	66	2 270.52	2 615.22	2 469.76	85.11
4th quarter	63	2 609.15	2 787.09	2 693.77	56.05
2011	251	2 089.84	2 932.62	2 573.30	272.66
1st quarter	63	2 641.83	2 828.42	2 733.16	45.78
2nd quarter	61	2 782.83	2 932.62	2 868.14	39.82
3rd quarter	65	2 101.23	2 820.08	2 454.22	230.76
4th quarter	62	2 089.84	2 414.62	2 245.6	86.78
2012	248	2 035.80	2 602.51	2 290.02	110.86
1st quarter	64	2 126.71	2 390.27	2 288.33	65.66
2nd quarter	60	2 035.8	2 300.97	2 183.71	78.23
3rd quarter	63	2 114.51	2 417.32	2 273.66	77.99
4th quarter	61	2 310.25	2 602.51	2 413.24	82.10
2010-2012	752	2 035.80	2 932.62	2 452.84	224.20

According to Table 2, it can be noted that in the 3rd quarter of 2011 the WIG20 index decreased sharply by approximately 720 index points, which constituted almost a 26% drop. Such turmoil could exacerbate efficiency of the Polish market and increase arbitrage opportunities. Also, as can be observed from Figure 2, the

WIG20 index is quite volatile, which reflects relatively high uncertainty of pricing and leads to larger mispricing errors (Draper and Fung, 2002). This underlines the importance of market efficiency and arbitrage opportunities estimation.

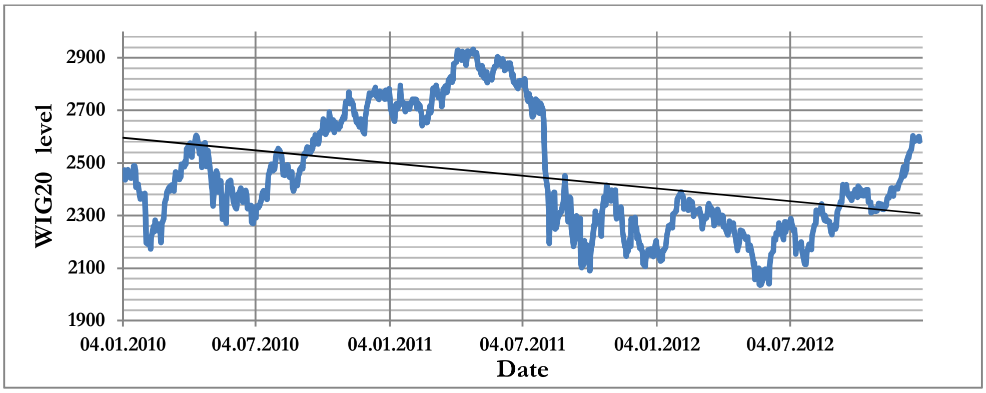

Figure 2. Index Chart for the WIG20

At first, we combine the data for all options with the same maturity date into one subset, which includes the above mentioned parameters[20]. Then, the information concerning the WIG20 closing prices and interest rates for every trading day is added to the data. Here the questions arise: What the main difference among the interest rates is and how these rates should be matched to our dataset.

The daily data on the interest rates is represented by Warsaw Interbank Offered Rate (WIBOR), which constitute the independent reference rates estimated by Reuters on the basis of interbank deposit rates of 16 heading local commercial banks with best reputations and highest levels of activity. Specifically, these banks are selected in terms of their share in the cash and derivative instruments market of Poland.

[20] There are 12 such subsets in total for 3 years.

The WIBOR rate is computed for overnight, 1-week, 2-week, 1-month, 3-month, 6-month, 9-month, and one year tenors every day at 11.00am. Hence, in our analysis it is sensible to use the interest rates which are matched to the time to expiration of index options. Therefore, the 1-month WIBOR rate is applied for maturity less or equal to one month, and the 3-month WIBOR – for maturity from one till three months.

Table 3 represents descriptive statistics of WIBOR rates from 2010 till 2012. As can be noted, the interest rates for all maturities are relatively similar and quite stable, which entitles us to expect that such interest rate stability could positively affect efficiency of the Polish index option market, reducing the amount and size of mispricing errors. If interest rates are very unstable, prices of put and call options are likely to incorporate this uncertainty, which can create arbitrage opportunities and pricing inefficiencies. For instance, in 2000-2002 the WIBOR rates were in the range of 6.88% and 19.62%, when Bialkowski and Jakubowski (2003) found that the Polish index futures market was relatively inefficient.

After adding the WIBOR rates into our datasets, it is necessary to match these rates to the corresponding time to maturity of options, which gives us the opportunity of finding the moneyness coefficient for each pair of options for every trading day. Then, we need to choose only one option pair per day, whose moneyness coefficient is closest to 1. Since the WIG20 index is quite volatile, at-the-money option pairs can be different for every trading day. Thus, we compute the absolute values of the difference between the moneyness coefficient and 1 for every matched pair for each day. Then, the comparison of these values across pairs is made: A pair with the smallest deviation for a particular trading date is selected for the empirical analysis. Thus, proceeding that way the final dataset is obtained for every working day of 2010-2012. The entire sample includes 640 matched option pairs for three years, approximately 212 pairs annually and 53 pairs quarterly.

Table 3. Descriptive statistics for WIBOR rates

Year	Interest rate WIBOR	Number of observations	Min, %	Max, %	Mean, %	Standard deviation, %
2010	1-month	253	3.6	3.71	3.62	0.017
	3-month	253	3.8	4.27	3.94	0.146
2011	1-month	251	3.65	4.77	4.37	0.363
	3-month	251	3.94	4.99	4.54	0.32
2012	1-month	247	4.22	4.92	4.77	0.156
	3-month	247	4.13	5.14	4.91	0.231
2010-2012	1-month	751	3.6	4.92	4.249	0.53
	3-month	751	3.8	5.14	4.46	0.470

The descriptive statistics for at-the-money WIG20 options with maturities from 16 days till three months is provided in Table 4. As could be seen, the closing prices of options have higher standard deviation in 2011 than in the other ones. This can be explained by the fact that the level of the index dropped by 26% in the 3rd quarter of 2011. Furthermore, we could observe presence of relatively high standard errors for all three years, which means that option prices are quite volatile. Consequently, this speaks about the prospects of arbitrage opportunities; however, in such periods arbitrage activities become more risky due to possible inability of market participants to short-sell or buy the index at a reasonable price.

According to Table 4, it could be noted that the average prices of at-the-money put contracts are higher than the average prices of at-the-money calls, which allow us to make a preliminary conclusion that put options are relatively overpriced. This hypothesis is going to be tested empirically in our research.

Table 4. Descriptive statistics for at-the money (AM) WIG20 options

Year	Option type	Number of observations	Min, PLN	Max, PLN	Mean, PLN	Standard deviation, PLN
2010	Call	214	19.9	180	76.37	28.45
	Put	214	24.65	195	95.58	30.96
2011	Call	214	18	187	73.82	36.02
	Put	214	29	180	89.46	33.52
2012	Call	212	19.7	160.2	61.84	20.26
	Put	212	18.05	170.4	73.56	27.11

As it has been mentioned before, the Polish companies pay dividends very rarely. There were no dividends paid by the companies included in the WIG20 index from 2010 till 2012.

Chapter 5

EMPIRICAL RESULTS

The PCP is investigated using statistical tests (regression and nonparametric approaches), evaluation of the ex-post arbitrage profits, tests for transaction costs' asymmetry, and sensitivity analysis with respect to transaction costs.

5.1 The PCP statistical tests

The results of regression (2) are reported in Table 5. According to the standard methodology, the regression equation should be estimated by the ordinary least squares (OLS) for every dataset. However, after testing the error terms for serial correlation[21], we identify presence of autocorrelation in each of our subsamples, including the whole sample. As has been mentioned before, usage of the generalized least-squares method could solve this problem: More specifically, we have to run the Prais–Winsten and Cochrane–Orcutt regression.

Our null hypothesis is that the PCP is valid, implying that coefficients a_0 and a_1 are equal to 0 and 1, respectively. According to the obtained results, it can be stated that the regressions have reasonable fit, especially taking into account a relatively small number of observations in the data samples. As can be seen, for every subsample and the whole sample the estimated intercepts (a_0) are negative and significantly different from 0[22], which means that, on average, at-the-money puts are overpriced relative to calls. The scale of such overpricing substantially differs among the periods under consideration. Thus, for the entire sample the average magnitude of overpricing is equal to 16.89 PLN, while it is as high as

[21] We use the Durbin-Watson *d* statistic

[22] Except for the 1st quarter of 2010 and the 1st and 4th quarters of 2012

44.01 PLN in the 3rd quarter of 2012, and virtually zero in the 1st quarter of 2010 and 2012 and in the 4th quarter of 2012.

Table 5. Regression tests of the put-call parity

Sample period	Sample size	α_0 (se) [23]	α_1 (se)	R^2	t-test $\alpha_1 = 1$	F-test (joint)[24]
2010	214	-13.75**[25] (1.664)	0.971** (0.026)	0.8744	0.2660	0.0000
1st quarter	53	-3.488 (2.509)	0.939** (0.056)	0.8463	0.2861	0.2774
2nd quarter	52	-32.107** (1.924)	0.993** (0.053)	0.8825	0.8903	0.0000
3rd quarter	55	-11.441** (1.965)	1.032** (0.05)	0.8894	0.5188	0.0000
4th quarter	54	-8.286** (2.139)	0.95** (0.04)	0.9167	0.2168	0.0008
2011	214	-19.78** (2.359)	1.005** (0.035)	0.7990	0.8737	0.0000
1st quarter	54	-4.54** (1.483)	0.927** (0.044)	0.9165	0.1158	0.0073
2nd quarter	53	-26.6** (7.41)	1.097** (0.029)	0.9646	0.0017	0.0001
3rd quarter	53	-40.88** (3.865)	0.887** (0.092)	0.6916	0.2321	0.0000
4th quarter	54	-5.38** (2.266)	1.013** (0.082)	0.7451	0.8778	0.0686
2012	212	-17.678** (2.981)	0.964** (0.039)	0.7374	0.3711	0.0000
1st quarter	54	0.115 (1.903)	1.018** (0.045)	0.9069	0.6809	0.9166
2nd quarter	52	-18.437** (2.089)	0.891** (0.074)	0.7506	0.1505	0.0000
3rd quarter	51	-44.005** (7.686)	1.049** (0.125)	0.6348	0.6949	0.0000
4th quarter	55	-2.113 (1.305)	0.96** (0.09)	0.6811	0.6621	0.2548
2012-2012	640	-16.89** (1.366)	0.984** (0.018)	0.8144	0.4069	0.0000

[23] Standard errors
[24] H_0: $\alpha_0=0$ and $\alpha_1=1$
[25] A double asterisk denotes significance at 1% level.

As to slope coefficient α_1, the hypothesis that it is equal to 1 cannot be rejected at any standard significance level for each subsample, as well as for the entire sample. However, we observe one exception in the 2nd quarter of 2011 (α_1=1.097), which could be explained by a significant drop in the value of the underlying asset exactly at that time. As has been stated before, such huge decrease of the WIG20 index could distort efficiency of the market, which is proved by the regression analysis.

Joint F-test (α_0=0 and α_1=1) suggests that we cannot reject the validity of the PCP for the 1st quarter of 2010, the 1st and 4th quarters of 2012 at any standard significance level and for the 4th quarter of 2011 at the 10% significance level. This means that in these quarters there is no significant mispricing happened, which is quite doubtful since we have not accounted for transaction costs. However, for the whole sample and the remaining quarters we reject the hypothesis of the PCP validity at the 5% significance level.

Also we conduct the Breusch-Pagan test for heteroscedasticity, which does not reject the homogeneity assumption for every subsample and the whole sample. This means that the estimated coefficients are efficient and there is no need in any corrections.

To test for systematic biases, distortive effects of outliers and disturbance assumption violations, the non-parametric sign test has to be implemented. It is less powerful than the executed above F-test, but it works as the robustness check. The sign test makes emphasis on the number of violations rather than their magnitude. Thus, if we have few outliers with huge magnitudes, we cannot surely reject the hypothesis of market efficiency, while as a standard regression approach would do it. According to the described methodology, the test is conducted and the results are shown in Table 6.

Table 6. Non-parametric tests of the put-call parity

Sample period	Number of matched pairs	X[26]	Z[27]	PCP validity[28]
2010	214	40	-9.091	Reject
1st quarter	53	22	-1.098	Do not reject
2nd quarter	52	0	-7.072	Reject
3rd quarter	51	6	-5.663	Reject
4th quarter	54	12	-3.946	Reject
2011	214	41	-8.954	Reject
1st quarter	54	16	-2.857	Reject
2nd quarter	53	2	-6.593	Reject
3rd quarter	53	1	-6.868	Reject
4th quarter	54	22	-1.224	Do not reject
2012	212	58	-6.525	Reject
1st quarter	54	26	-0.136	Do not reject
2nd quarter	52	2	-6.518	Reject
3rd quarter	51	5	-5.601	Reject
4th quarter	55	25	-0.539	Do not reject
2010-2012	640	139	-14.269	Reject

[26] The number of matches that satisfy the inequality $P_t^{PCP} > P_t$

[27] A random variable that follows a standard normal distribution

[28] At the 5% significance level

According to the results of the sign test, it can be concluded that the PCP validity is rejected for every quarter and the whole sample, except for the 1st quarter of 2010 and 2012 and the 4th quarter of 2011 and 2012. Thus, we could state that these four quarters experience no significant mispricing. These results are strongly supported by the regression tests conducted before.

However, we should not conclude that the obtained results of the joint test of the PCP validity have much implication against the Polish index option market efficiency. This can be justified by the fact that we do not account for transaction costs, which are present in reality. Hence, much more attention has to be paid to the estimate of the slope coefficient (a_l), which should be equal to 1 if the market is efficient. In our case, the slope coefficients for effectively all data sets[29] satisfy this condition, suggesting that we cannot reject the efficiency of the WIG20 option market.

5.2 The ex-post arbitrage profits and strategies

Let us consider the frequency of mispricing signals for every quarter, as well as for the whole sample. For each option pair, we have to calculate the cash flow $\boldsymbol{\varepsilon}_t$ $= C_t + Ke^{-r(T-t)} - P_t - I_t$, which indicates the mispricing signal with the assumption of no transaction costs. If $\boldsymbol{\varepsilon}_t$ is equal to zero, then this option pair is priced efficiently at time *t*. However, if $\boldsymbol{\varepsilon}_t > 0$, the call option is overpriced and, a long-hedge[30] portfolio can be used to make arbitrage profits. Conversely, if $\boldsymbol{\varepsilon}_t < 0$, the mispricing signal tells us that a put option is overpriced, leading to implementation of a short-hedge[31] strategy. The empirical distributions of this variable for every subsample and the whole sample are represented in Figure 3.

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29 Except for the 2nd quarter of 2011
30 Conversion
31 Reversal

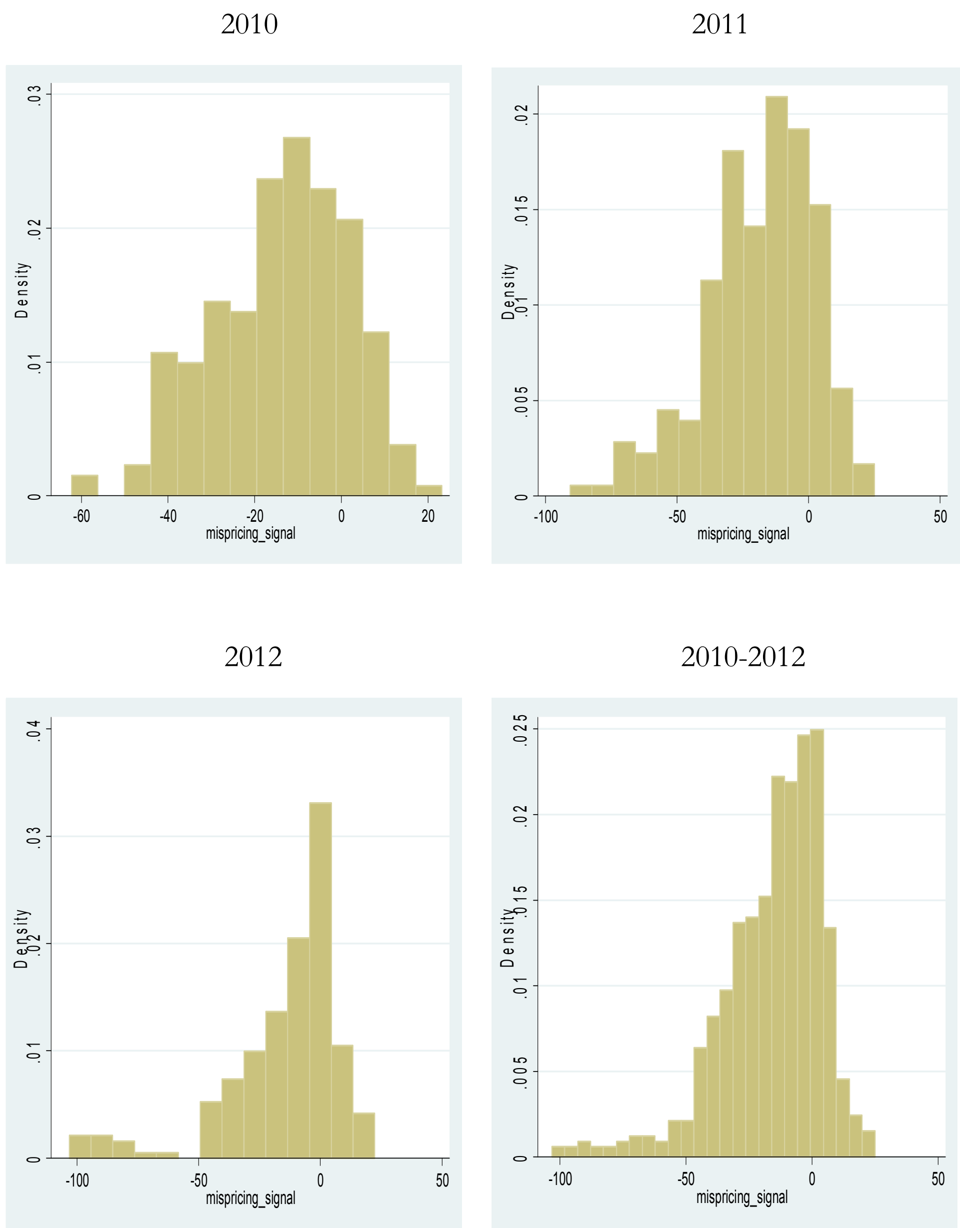

Figure 3. Histograms of the ex-post PCP violations

As can be noted, the histograms for all three years and the whole sample are skewed to the left, meaning that the put overpricing signals are relatively higher and more frequent than such signals of call overpricing. The histograms for 2011, 2012 and the whole period are more pronounced in this respect, whereas the mispricing signals in 2010 seem to be a little bit less skewed. The mispricing results with the assumption of no transaction costs for every year and the entire period are shown in Table 7.

Table 7. Ex-post arbitrage profits and strategies ignoring transaction costs

Parameters	2010		2011		2012		2010-2012	
	Hedge Portfolio		Hedge Portfolio		Hedge Portfolio		Hedge Portfolio	
	Long	Short	Long	Short	Long	Short	Long	Short
Number of signals	40	174	41	173	58	154	139	501
Percentage of pairs, %	18.69	81.31	19.16	80.84	27.36	72.64	21.72	78.28
Mean[32]	6.41	18.46	6.6	24.58	6.02	22.04	6.31	21.68
Standard deviation	4.92	13.2	5.65	18.2	5.5	23.59	5.36	18.74
Min	0.197	0.043	0.172	0.012	0.152	0.107	0.152	0.012
Max	23.296	62.265	25.113	90.669	22.395	103.22	25.113	103.216
F (calculated)	7.198		10.376		18.396		12.224	
F (table)	1.55		1.55		1.44		1.31	

At first, let us consider the whole period from 2010 till 2012. The total amount of mispricing signals are divided into 21.72% of long arbitrage opportunities and 78.28% of short ones, proving that reversal strategies are considerably more frequent. Also, as can be seen, on average, the short arbitrage portfolio with the mean of 21.68 PLN is more profitable compared to the long arbitrage one with

[32] Mean, maximum and minimum are presented in modulus.

the mean of 6.31 PLN. However, since the standard deviation of reversal strategy is significantly higher[33] relative to that of a conversion strategy, it can be concluded that the former one appears to be more risky than the latter one.

Now let us turn to the results of the subsamples. For every year short arbitrage strategies prove to be much more frequent, implying that for all three years it is more common for put options to be overpriced. Furthermore, the reversal strategy, on average, is more beneficial in 2011 with the mean of 24.58 PLN, whereas the lowest mean profit of 18.46 PLN is indicated in 2010. However, these lowest short arbitrage profits have the lowest standard deviation of 13.2 PLN among all the years, seeming to be less risky ones. In contrast, the most risky average reversal profits arise in 2012, having the standard deviation of 23.59 PLN, which is almost two times higher than in 2010. Considering the long hedge portfolio, the mean profits oscillate about 6 PLN over each of three years with the highest standard deviation of 5.65 PLN in 2011 and the lowest of 4.92 in 2010. Thus, we can say that in every year and in the whole period, on average, the conversion arbitrage profits are more stable compared to the reversal ones, having lower extent of deviation, according to the Variance Ratio test.

5.3 The PCP ex-post tests for transaction costs' asymmetry

The standard approach for testing the PCP validity has one strong assumption that is quite unrealistic: market participants bear no transaction costs. However, transaction costs do exist, and, moreover, it has been empirically proven that these costs are asymmetric, which encourages us to extend our regression analysis by dividing each data sample into two subsamples: one with overpriced calls ($\boldsymbol{\varepsilon}_t \geq 0$), and another one with overpriced puts ($\boldsymbol{\varepsilon}_t \leq 0$).

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[33] We use the Variance Ratio test to compare the variability of two strategies. If Fcalc > Ftab, then there is a significant difference between the two standard deviations.

Table 8. Regression tests of the PCP with transaction costs' asymmetry

Sample period	Sample size	α_0 (se)[34]	α_1 (se)	R^2	t-test $\alpha_1 = 1$	F-test (joint)[35]
2010 ($\varepsilon_t \geq 0$)	40	6.34**[36] (0.79)	0.978** (0.028)	0.9696	0.4589	0.000
2010 ($\varepsilon_t \leq 0$)	174	-17.31** (1.42)	0.987** (0.026)	0.8877	0.6547	0.000
2011 ($\varepsilon_t \geq 0$)	41	6.21** (0.73)	0.98** (0.029)	0.9663	0.5103	0.0000
2011 ($\varepsilon_t \leq 0$)	173	-22.18** (2.128)	1.037** (0.031)	0.8688	0.2392	0.000
2012 ($\varepsilon_t \geq 0$)	58	6.26** (0.61)	1.03** (0.027)	0.9628	0.2681	0.000
2012 ($\varepsilon_t \leq 0$)	154	-19.07** (2.71)	0.97** (0.06)	0.6173	0.5910	0.000
2010-2012 ($\varepsilon_t \geq 0$)	139	6.43** (0.412)	0.999** (0.016)	0.9646	0.9793	0.000
2010-2012 ($\varepsilon_t \leq 0$)	501	-19.47** (1.24)	1.005** (0.02)	0.8378	0.7917	0.000

Table 8 shows that the intercept coefficients differ between subsamples and are statistically significant at any standard significance level for both subsamples in every data subset. In particular, we can notice that for every year and for the whole data period the absolute values of α_0 for overpriced puts are higher compared to those corresponding to overpriced calls, supporting our hypothesis of the transaction costs' asymmetry. Furthermore, it should be noted that, on average, the intercept coefficient in the subsample with put overpricing is more than 3 times higher in absolute value compared to the corresponding coefficient in the subsample with call overpricing.

[34] Standard errors

[35] H_0: $\alpha_0=0$ and $\alpha_1=1$

[36] A double asterisk denotes significance at 1% level.

For every subsample the slope coefficient (a_1) is highly significant at any standard significance level and, according to the test for slopes, we cannot reject the hypothesis that they are equal to 1. Hence, since in the presence of transaction costs only the deviation of this coefficient from one can be interpreted as the evidence against market efficiency, we cannot reject the efficiency of the Polish index option market.

5.4 Sensitivity analysis with respect to transaction costs

Let us now discuss in more details the magnitude of transaction costs and their influence on the ex-post mispricing signals. Our goal is to show how different assumptions about transaction costs affect the profitability of conversion and reversal arbitrage strategies and the frequency of their occurrences. In the methodology section we introduced 4 levels of transaction costs, which include a fixed-amount payment of 2.4 PLN plus the specified percentage of the index level (1.2%, 0.9%, 0.6%, and 0.3%). All these values are appropriate to different types of investors, including institutional[37] and individual[38] ones. Such an approach has two main advantages. The first one consists in a possibility to estimate the amount of profitable hedges for market participants with different levels of transaction costs, while the second one lies in the fact that the asymmetry of these costs is demonstrated. Thereafter, it is reasonable to compute the number of mispricing violations accounting for four levels of transaction costs. The obtained results are provided in Table 9.

As can be concluded from this table, the increase in the amount of costs decreases the possibility of overpricing for both put and call options. Naturally, the higher the transaction costs are, the less the possibility of mispricing is, and the more efficient the market is.

[37] Small and large

[38] Retail operators

Table 9. Mispricing violations accounted for transaction costs

Year	Transaction costs / Arbitrage Strategy	Level 1 (0.3%)	Level 2 (0.6%)	Level 3 (0.9%)	Level 4 (1.2%)
2010	Conversion	4.21%	0.47%	0%	0%
	Reversal	55.14%	37.38%	24.77%	14.02%
2011	Conversion	4.21%	1.87%	0%	0%
	Reversal	61.68%	44.86%	32.24%	17.58%
2012	Conversion	5.19%	2.36%	0.47%	0%
	Reversal	46.22%	33.02%	26.42%	18.4%
2010-2012	Conversion	4.53%	1.56%	0.16%	0%
	Reversal	54.37%	38.44%	27.81%	16.72%

Also, it can be seen that there exists a huge difference in the frequencies of mispricing for Level 1 and Level 4 of the transaction costs, especially, it is observable for a reversal hedge strategy in every year and in the whole period. The largest difference in mispricing for short hedge strategies appears in 2011 and is approximately equal to 43%. For long hedge strategies such a decrease constitutes only 5% on average, since the frequency of overpriced calls is significantly lower than the frequency of overpriced puts. One of the possible explanations for this is that investors use index put options as a very convenient and relatively inexpensive way to hedge their positions, leading to higher demand and, consequently, a higher price for put options (Li, 2006). Thus, under Levels 3 and 4 the arbitrage opportunities for long hedge strategies are virtually equal to zero for all the periods.

As has been mentioned before, transaction costs are proved to be asymmetric and differ for various types of market participants. Typically, individual and small institutional investors have a higher level of transaction costs than large institutional investors, implying that the amount of arbitrage opportunities which they could exploit is significantly lower. Concerning the asymmetry of transaction costs, we can say that an investor experiences different levels of transaction costs, depending on the strategy she chooses. For instance, the investor could bear the transaction costs at Level 1 for a conversion strategy, but the usage of a reversal strategy would cost her a significantly greater amount (Level 3 or 4). This is justified by the fact that for the short hedge portfolio, the market participant has to take a short position in the index, which is quite an expensive procedure due to high repo commissions. Thus, we cannot apply the amount of transaction costs of Level 1 to both portfolios, which is consistent with our asymmetry principle. This indicates a much lower difference between the frequencies of two arbitrage strategies in comparison with the case of symmetric transaction costs.

Chapter 6

CONCLUSION

The efficiency of the Polish WIG20 index option market has been studied by testing the PCP validity for each of three consecutive years from 2010 till 2012, as well as for the whole period. For the purposes of our research, we modify the standardly used methodology and extend it with the help of the ex-post arbitrage profits' evaluation, tests for transaction costs' asymmetry, and sensitivity analysis with respect to transaction costs.

Leaving the core of a standard approach unchanged, we conduct the Prais–Winsten and Cochrane–Orcutt regression instead of the simple OLS, paying more attention to the slope coefficient estimate[39] than the intercept one[40], since this test does not account for transaction costs. As a result, the slope coefficients for almost all datasets satisfy the efficiency condition, meaning that there exists no solid evidence against the claim that the WIG20 option market is efficient. Considering the estimates of the intercept coefficients, we find that they have a negative sign for all the subsamples in the case of putting both positive and negative errors together. The negative coefficients imply that at-the-money puts are overpriced to identical at-the-money calls. Applying a non-parametric sign test as model robustness check, we strongly confirm the results obtained.

The same conclusion can be made after evaluating the ex-post arbitrage profits under the assumption of zero transaction costs. For the entire period the short hedge portfolio, on average, is much more beneficial in comparison with the long one (21.68 PLN vs. 6.31 PLN), but it is also considerably riskier, since its

[39] The slope coefficient has to be equal to 1 in the case of market efficiency.
[40] The intercept coefficient has to be equal to 0 in the case of market efficiency and zero transaction costs.

standard deviation appears to be significantly higher relative to that of a long strategy. This outcome is consistent with the results obtained in the Italian, German and French index option markets[41], which means that the Polish market follows a West European trend.

Since we have not accounted for transaction costs in the previous tests, it becomes essential not only to take them into consideration, but also acknowledge that there exists an asymmetry of transaction costs. For this purpose we conduct the PCP ex-post tests for such asymmetry, which shows that the intercept coefficients for overpriced puts are higher than those for overpriced calls[42] (19.47 PLN vs. 6.43 PLN for the entire period), providing evidence for our initial hypothesis.

To extend our research further, the sensitivity analysis with respect to transaction costs is made. The main conclusion is that there exists a negative relationship between the amount of transaction costs, which market participants bear, and the number of long and short arbitrage strategies, which could be implemented. Furthermore, if the transaction costs[43] are relatively high[44], it could be quite possible that there will be almost no arbitrage opportunities, inferring the market efficiency and the validity of the PCP. This result is also similar to the findings from European index option market efficiency studies.

In conclusion, it can be noted that although some mispricing and violations of the PCP are observed, their frequency substantially diminish after accounting for the real transaction costs. Therefore, we can infer that the hypothesis of the Polish index option market efficiency cannot be rejected.

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41 Cavallo and Mammola, 2000; Capelle-Blancard and Chaudhury, 2001; etc.
42 In absolute value
43 Including repo commissions
44 Level 3 for conversion strategies and Level 5 and higher – for reversal strategies

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