PAIRS TRADING : BUILDING TRADING STRATEGIES FOR ASSET PAIRS PRICE DYNAMICS

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İSTANBUL BİLGİ UNIVERSITY

INSTITUTE OF SOCIAL SCIENCES

MASTER OF SCIENCE IN FINANCIAL ECONOMICS

UNDER SUPERVISION OF

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2008

Pairs Trading : Building Trading Strategies for Asset Pairs Price Dynamics

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Approval Date	:	07.08.2008
Number of Pages	:	82

Keywords
1) Pairs Trading
2) Statistical Arbitrage
3) Market Neutral Strategy
4) Hedge Fund

Anahtar Kelimeler
1) İkili Alım/Satım
2) İstatistiksel Arbitraj
3) Piyasa Nötr Strateji
4) Hedge Fon

ABSTRACT

In this thesis, we have studied Pairs Trading, which is a market neutral strategy built over the relative value of two similar assets. The strategy is implemented by identifying two assets whose prices tend to move together in long run and taking inverse positions in these two assets when there is a deviation from the long run relationship. In pairs trading, the trader does not make a bet on the direction of the stock prices, but invests in the condition of the asset prices relative to each other. In this study, we have analyzed the effects of pairs selection, threshold level selection and using bid/ask or low/high prices on the profitability of the strategy for Istanbul Stock Exchange stocks. The main implication of the study is that the portfolio formed with top 5 pairs with the lowest deviation between the normalized prices generates positive return most of the time and shows always the highest performance among the alternative portfolios. The only exception that the portfolio ends in loss is the liquidity crisis scenario where the model uses low/high prices for trade execution. However, the investor should bear in mind that there is no way to build totally risk neutral positions with Pairs Trading Strategy. There always remains the risk of break down of the relationship between the stocks and the liquidity risk that may be encountered in significant market downturns which is more important than the relationship between the stocks.

ÖZET

Bu tez çalışmasında, iki benzer kıymetin göreceli değerleri üzerine kurulmuş piyasa nötr bir strateji olan İkili Alım/Satım Stratejisi incelenmiştir. Strateji, fiyatları uzun dönemde birlikte hareket eden iki kıymetin tespit edilip uzun dönem ilişkisinden sapma olduğunda bu iki kıymette ters pozisyon alınması şeklinde uygulanır. İkili Alım/Satım'da yatırımcı hisse fiyatlarının yönüne değil, kıymet fiyatlarının birbirlerine göre olan konumlarına yatırım yapmaktadır. Bu çalışmada, İstanbul Menkul Kıymetler Borsası hisseleri için hisse seçimi, eşik değeri seçimi ve alış/satış veya en düşük/en yüksek fiyatların kullanımının strateji karlılığına etkileri incelenmiştir. Çalışmanın başlıca sonucu, normalize edilmiş fiyatlar arasında en düşük farka sahip en iyi 5 hisse ikilisi ile oluşturulan portföyün çoğunlukla pozitif getiri oluşturacağı ve alternatif portföyler arasında her zaman en iyi performansı göstereceği yönündedir. Porföyün zarar ile kapandığı tek istisna en düşük/en yüksek fiyatların işlem fiyatı olarak kullanıldığı likidite krizi senaryosudur. Ancak, yatırımcı İkili Alım/Satım Stratejisi ile, tam anlamıyla risk nötr pozisyon oluşturulması imkanının olmadığını göz önünde bulundurmalıdır. Hisseler arasındaki ilişkinin bozulması riski ve hisseler arasındaki ilişkiden daha önemli olan piyasanın ciddi çöküşlerinde yaşanacak likidite riski her durumda var olmaktadır.

To My Family

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor Prof. Dr. Burak Saltoğlu, whose expertise and understanding added considerably to my study. I appreciate his knowledge, assistance and leading comments which helped me a lot in preparing my thesis. I would like to thank the other members of my thesis committee, Assoc. Prof. Dr. Ege Yazgan and Dr. Orhan Erdem for the assistance they provided.

I would like to thank to my mother, father and sister who have never stopped supporting. Their love and belief have been a great encouragement to me in every second of my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1. INTRODUCTION

In this thesis, we have tested the performance of Pairs Trading, a market-neutral trading strategy mainly implemented by hedge funds, on Istanbul Stock Exchange stocks. We have aimed to identify the effects of pairs selection, threshold level selection and using bid/ask or low/high prices on the profitability of the trading strategy.

In section 1, we have first described Pairs Trading Strategy and how the strategy emerged and became popular among the traders. Then, we have tried to understand the basics of market neutral strategies and arbitrage conditions. The main players of Pairs Trading Strategy, Hedge Funds, and the roles they have taken to increase the efficiency in financial markets have been mentioned. However, we have also summarized the biggest crashes of hedge funds in the history, such as LTCM case, which have to be taken into consideration and taken as lesson.

In section 2, we have reviewed the academic studies published about the market neutral strategies. There are many studies about different types of trading strategies those aim to build market neutral or risk-free profit opportunities. The studies cover mainly the stock markets and models are generally based on the price series of the stocks.

Section 3 covers the model we have built, which is mainly a partial replication of the strategy used in the study of Gatev et al. (2006). The model selects the portfolio of pairs according to the deviations between normalized price series of the stocks and opens inverse positions in two stocks when the deviation reaches the predetermined threshold level.

In section 4, we have analyzed the empirical results of the trading strategy and compared the results in terms of portfolios and threshold levels. We have tested the robustness of the performance to transaction costs, which simulates a more realistic scenario. We also

replicated the model for different conditions such as using bid/ask prices or low/high prices in stead of daily close prices.

Although Pairs Trading Strategy is market neutral and expected to return profit with lower risk than traditional buy and hold strategies, there still remains the risk of losing money. The risks with Pairs Trading Strategy are covered in Section 5, which are due to the break down of the relationship between the stocks or market crash which results in the lack of liquidity.

1.1. Pairs Trading and Market Neutral Strategies

Pairs trading is a trading strategy that is built over the relative value of two assets, or a basket of assets, that allows traders profit from the anomalies between these assets' prices. Although the strategy is generally formed to be market neutral by simultaneously buying and selling stocks from the same industry, market neutrality is not a necessity as long as the two stocks those invested have a strong relationship which may give the opportunity of exploiting any deviation from the long run relationship.

Pairs trading is implemented by identifying two assets whose prices tend to move together in long run and building trading strategy to gain profits while there exists a deviation in short run. In pairs trading, the trader does not make a bet on the direction of the stock prices, but exploits the probability of short run divergence.

The investor sells the stock that is thought to be overvalued and buys the other stock simultaneously, which is thought to be undervalued. As long as the strong relationship condition continues, one position should incur loss while the other position yields profit. However, if the relationship between these two stocks converges to equilibrium as expected, the net return of the position will be positive.

The benefit of pairs trading in this situation is that since the value of position in one stock is equal to the value of the position in the second stock, the strategy does not require any financing need, except the trading costs and short selling commissions for the margin account. Therefore, there exists an investment opportunity without any initial capital exposure. In addition, as the strategy is market neutral, the trader concentrates on the relationship between the two stocks instead of general market moves and performance of the strategy does not depend on the market direction.

Combined with fundamental analysis and improved computational and execution skills, pairs trading strategy is valuable for the investors who wants to earn more without betting in the market direction. Moreover, since the strategy can be implemented with a very low capital that will cover the margin maintenance and transaction costs, it is possible to use the advantages of leverage and gain significant profits. However, it is important to bear in mind that although the strategy is named as market neutral or an arbitrage strategy, there still remains the risk of firm specific events or market crashes which will make the investor lose more than a traditional buy and hold investment style. In addition, the relationship between the two assets may not be stable over time and the strategy investing in this relationship may unexpectedly fail.

Strategies like pairs trading are called “market neutral strategies” as these strategies do not bet on the direction of the market by buying or selling one asset and wait for the market to move in favor of the original position. The purpose of market neutral strategies is to find the portfolio of assets that will not be affected from the market movements and return excess profit with lower risk compared to the market.

Pairs trading is a simple form of market neutral strategies that is constructed by using just two securities, consisting of a long position in one security and a short position in another security, in a predetermined ratio. The portfolio is composed of securities having some kind of relationship that makes the securities move in a similar trend. The stocks with common

price dynamics decrease the riskiness of the portfolio return and make the whole investment market neutral.

There are two main types of pairs trading: Statistical Arbitrage Pairs Trading and Risk Arbitrage Pairs Trading.

Statistical Arbitrage Pairs Trading is based on the idea that assets with similar characteristics in terms of price dynamics must be priced similarly. Or, the assets having a relationship between each other that is stable in time should have similar market values. Any deviation from the long run relationship between the assets may be treated as mispricing between the two assets and it may be determined as an indicator to have a long position in the lower priced asset and a short position in the higher priced asset with the expectation of mispricing being eliminated when the relationship returns to its long run equilibrium.

Statistical arbitrage pairs trading can be implemented in different sectors and markets, or even with different assets. Since the strategy depends on the existence of long run relationship between the invested assets and the main determinant of this relationship is the comparison of historical price series of the assets, quantitative analysis of the asset price series is more important than the fundamental specifications of the assets. In addition, the market should allow short-selling and have enough liquidity as lack of these two conditions will make the implementation of statistical arbitrage pairs trading impossible.

Risk Arbitrage Pairs Trading, on the other hand, can be formed in case of a merger or acquisition between two companies. The terms of the merger agreement establish a parity relationship between the values of the two stocks of the two firms involved in the merger. The trade decision can be made for risk arbitrage when there is a significant deviation from the defined parity relationship. Investor analyzes the two securities involved in the merger, buys the lower priced security and sells the higher priced security. As a result, the portfolio

manager invests in the price parity and locks the price difference between the stocks before the merger is finalized.

Risk arbitrage pairs trading is possible when both securities in merger process are publicly traded in the open market while the merger is announced. Since risk arbitrage pairs trading requires understanding the merger process and details of the agreement, it is more than just analyzing the price movements of the stocks and requires additional evaluation skills. The investor should be well informed about fundamentals of the companies attending the merger process and be capable of pricing the whole trade with insights of corporate finance.

The strategies which are searching for a riskless portfolio with positive return over market anomalies ended up in the introduction of the term "arbitrage". There are some conditions to be satisfied to call a strategy as arbitrage. The transaction should have a positive probability of a positive payoff, a zero probability of a negative payoff, and the cost of the transaction should be zero, or at least there should be certain profit that will compensate the transaction costs. Statistical arbitrage pairs trading, on the other hand, is not riskless in general. However, there is positive expected payoff and zero probability of negative payoff only as time approaches infinity.

According to the definition introduced by Hogan et al. (2003), a self financing, zero-cost strategy that satisfies the following four conditions is called Statistical Arbitrage:

1. Discounted profit should be zero at t_0,
2. The expected discounted profit should be positive, or at least be equal to risk-free rate, as time goes to infinity,
3. The probability of having negative expected discounted profit should be zero, as time goes to infinity,
4. A time averaged variance converges to zero when there is positive probability of a loss at every finite point in time, which could be achieved through portfolio rebalancing or

controlling the value of long and short positions to avoid excessive net exposure either long or short, as time goes to infinity.

Although the pairs trading strategy is a statistical arbitrage strategy and it has a positive expected profit as time goes to infinity, the strategy includes the low probability of a huge loss in case the relationship between the pair stocks crashes when the trader is holding a position. Therefore, Holton (2003) described strategies having high probability of making a little money and a low probability of losing a lot as "negatively skewed trading strategies".

The pairs trading strategy is described as market neutral and having a consistent profit performance. However, if the market dynamics change and the long run equilibrium relationship among the stocks disappears, the investment will result in a loss that can be much higher than it is imagined.

The reason for the market neutral strategies being popular among the quantitative traders is that returns of these strategies are independent and uncorrelated with the market regardless of the economic bubbles or downturns. The returns from market neutral strategies are relatively high and constant with lower volatility compared with individual asset price dynamics. Furthermore, the combination of these strategies with traditional investment strategies will help to increase portfolio diversification.

1.2. Emergence of Pairs Trading

Pairs trading emerged in 1980s with the hedging demand of Morgan Stanley's equity block-trading desk (A Demon of Our Own Design, Bookstaber, 2007). The block-trading desk of Morgan Stanley was acting as an intermediary in executing trades on the exchange floor. The desk was executing client block orders and it was also the risk taking division in the equity markets at Morgan Stanley at that time.

In block trading, investors who decided to clear a large block trade have to manage the risk of losing some spread if they go to the market and post their prices direct. The reason for such a loss is that other players in the market who do not have any information about the total size of the order or the reason for the market price move will not be eager to be in the wrong direction in case of a market jump or crash. There will be lack of counter prices to execute the trade. Therefore, the block trade could not be generally executed at the level that the order is given.

In order to eliminate the probability of loss, the institutions were breaking their block trades into a number of smaller trades and trying to execute transactions without losing the liquidity in the market. Or alternatively, the trade was executed through a broker or dealer's block-trading desk and the client was avoiding great losses. The only cost for the institution will be the commission paid to the broker, which is very little compared to the loss probability.

Like all brokers operating in block-trading business, Morgan Stanley was facing the problem of how to execute large block trades efficiently without suffering from the price moves. Once the block-trading desk got the order from the client, the risk of losing from the price movement due to the large size of the block trade was lying with the block-trading desk.

The block-trading desk might have carried the position in the desk's own book, in stead of executing the order immediately and bear the risk of losing the spread. Alternatively, the desk might have an opposite position in a similar stock that would cover the loss of the block trade in case of an unexpected move in the market prices while executing the block trade. As a result, Morgan Stanley block-trading desk analyzed the fundamentals and specifications of stocks and maintained a list of pairs of stocks those were closely related with other stocks in order to have as alternatives for partially hedging positions.

While the block-trading desk was implementing the hedging alternative of having opposite positions in similar stocks in executing block trades, a young programmer, Gerry Bamberger, was assigned to work on the equity trading floor to improve the block-trading desk's ticket entry process. The volume and profit of block-trading desk were increasing and there existed the necessity of having some re-engineering in operational processes to upgrade the business.

While Bamberger was working on the monitoring of the paired hedges as a single entity, he noticed that the stocks in paired hedges include some common behavior trend which makes the stocks follow each other. Thus, he started to think of the pairs not as a block to be executed and its hedge, but as two halves of a trading strategy, which was the first practical attempt of investing in stocks in terms of pairs trading.

According to Bamberger's hypothesis, each stock can be paired with another stock for a reasonable period of time and only company specific information would make both stocks move away from each other. The relative value of the pair would remain unchanged. However, the company specific effects could easily be diversified away by holding many pairs since they would be independent from one company to another.

With the introduction of "Designated Order Turnaround System" (DOT), the first electronic execution system in New York Stock exchange that enables the execution of the orders electronically, block trading desk gained the ability to execute transaction in a couple of seconds. Nunzio Tartaglia, who undertook the responsibility of the desk and continued the implementation of the profit opportunity with pairs trading after Gerry Bamberger, started an automated trading group at Morgan Stanley with the improved speed of execution.

Profits earned by the traders performing pairs trading strategies in the next years took the attention of both the practitioners and the academicians, and there appeared many studies and applications in the financial market about pairs trading.

1.3. Role of Hedge Funds

The main players of market neutral strategies are Hedge Funds, large private capital management firms investing in several asset classes in different markets at a time with the purpose of high profit. Since market neutral strategies require advanced computational, trading, and management skills, the ability to trade in any market without any limitation of time or cost and significant amount of capital, hedge funds are capable of investing in market neutral strategies.

There are different approaches in classification of hedge funds used by Hedge Fund Review, CSFB/Tremont, and Standard & Poor's, which classify the hedge funds in terms of trading styles. One alternative classification is given in the study of Sudak and Suslova, which is summarized in Table 1.1 below.

Table 1.1. Hedge Fund Investment Styles

Long/Short Equity	Event Driven	Relative Value / Market Neutral	Global Asset Allocation
- Value/Growth - Sector - Geographical - Opportunistic - Short Selling	- Merger Arbitrage - Distress Securities - Corporate Restructuring	- Convertible Arbitrage - Fixed Income Arbitrage - Statistical Arbitrage	- Futures Trading - Global Macro - CTA

While long/short equity and global asset allocation strategies mainly invest in directional models involving both long and short positions over short holding periods, event driven strategies aims to benefit from the occurrence of special situations. Relative value / market neutral strategies, on the other hand, are formed to profit on mispricing of related securities of financial instruments. Statistical arbitrage pairs trading categorized as equity market neutral trading style of hedge fund strategies in terms of this classification.

The classification of hedge funds generates the question of what a hedge fund is. The answer for the question will be clear after thinking about what is not a hedge fund. If we screen all the universe of possible strategies that any investor may handle, it is easy to

conclude that the hedge fund strategies actually cover all investment strategies. The difference of the style of a hedge fund from a traditional investor is that a hedge fund will be interested in many investment types with different leverage and risk constraints, in different geographical locations, in the same period of time.

It is difficult to obtain precise data about the activities and profits of the hedge funds. Even the size of investments of hedge funds can not be calculated. Many hedge funds are off-shore funds, which are usually organized under the laws of such regulatory and tax heavens like Cayman Islands or British Virgin Islands and they are not under any obligation to disclose any information about their activities, portfolio holdings or trading strategies. Therefore, available information on hedge funds comes mostly through voluntary disclosure. They do not advertise their trading activities either.

The short term role of the hedge funds, which is emerged with the improvements in capital mobility, is to provide the market with liquidity. The main feature that enables the hedge funds to increase the market liquidity is the acting ability of hedge funds as a market maker. When there is a sharp decrease in price of one stock and hedge funds consider this condition as a price anomaly, they provide purchasing interest and the liquidity of the stock increases. Moreover, as hedge funds decrease the strength of one-sided price impact with increased liquidity, the volatility of the stock price will be lower in the markets where hedge funds are active players.

Compared to the traditional businessman, whose objective is to run a set of assets to generate the best possible results, hedge fund manager can also be classified as a businessman. For example, an entrepreneur will aim to map out a way to effectively allocate capital among the alternatives or a division manager will aim to manage the skills of the workforce as the best way. The hedge fund portfolio manager also aims to identify best opportunities in the market, but the allocation decisions are placed at a more macro level, such as deciding among different companies, asset classes or trading strategies.

Hedge funds are mainly concentrated in skill-based investment strategies with a broad range of risk and return objectives. The main feature of the strategies is the use of investment and risk management skills to search for the market profits regardless of the market direction. The strategies used by hedge funds are mostly based on heavy leverage, short selling, and use of derivatives.

Many hedge fund strategies have the ability to gain excess return with lower risk in both rising and falling market conditions. This is because including hedge funds in investment portfolios provides an efficient diversification that decreases the risk compared to the traditional investment alternatives. Moreover, hedge funds help investors manage their portfolios in a timely manner, without requiring any personal effort to decide about the best market entrance and exit levels.

Having sustainable good performance with high risk adjusted returns are the main strengths of the hedge funds. With the professional management of the funds and pro-active approach in investment style, hedge funds are easy alternatives to invest in for individual investors. Moreover, hedge funds provide the individual investors with greater flexibility of investment instruments which are not available for individual investors with small capital or for those who do not have necessary technological infrastructure.

Although hedge funds provide many opportunities to the individual investors, there are also some weaknesses to be taken for granted. First, hedge funds implement their strategies with their own internal management decisions, which are difficult to be followed by the individual investors who are only shareholders in the investment. Due to the lack of transparency in terms of strategies, the investors might have been sharing a position that is much riskier than they can bear if they are investing on their own. With the additional leverage that hedge funds are generally willing to carry, risk of failure increases and the portfolio performance evaluation becomes much more complex than a single asset investment.

Pairs trading is one of the strategies that hedge funds mainly implement to gain profit. Since hedge funds have the ability to invest in many different markets or assets at a time without capital limitation or constraints for executing trades, statistical features of asset prices can be exploited efficiently by the hedge funds with better results than individual investors.

Although hedge funds are active in market neutral strategies, such as pairs trading, these strategies result in market disasters many times as the strategies do not bet in market direction but are much sensitive to market crashes. In case of a market downturn or unexpected circumstances, the funds are facing high losses that may result in the liquidation of the fund.

Ineichen (2001) summarized the hedge fund stories in his article those ended in high loss and had negative effects over the whole market. The table shows that although the hedge fund strategies of fixed income arbitrage, long/short equity, and relative value are seemed to be risk neutral and hedged, they do not guarantee a safe close of the positions in case the conditions are against the initial transaction.

Table 1.2. List of Hedge Fund Losses with Market Neutral Strategies

Case	Strategy	Year	Loss (US$ mio)
Askin Capital Management	Fixed income arbitrage	1994	420
Vairocana Limited	Fixed income arbitrage	1994	700
Fenchurch Capital Management	Fixed income arbitrage	1995	N/A
LTCM	Fixed income arbitrage	1998	3600
Manhattan Investment Fund	Long/short equity	1999	400
Ballybunion Capital Partners	Long/short equity	2000	7
Maricopa Investment Corp.	Long/short equity	2000	59
Cambridge Partners, LLC	Long/short equity	2000	45
Ashbury Capital Partners	Long/short equity	2001	40
ETJ Partners	Relative Value	2001	21

Long Term Capital Management (LTCM) case is the most important story with the amount of loss being the highest and the story of LTCM became a good example for the investors with the lessons to be learned from this experience.

LTCM was founded by John Meriwether, bond trader of Salomon Brothers, in 1994 and the hedge fund aimed to profit from the combination of the academicians' quantitative models and the traders' market judgment and execution capabilities. Being the partners from both academic world, such as Nobel-prize winning economists Myron Scholes and Robert Merton, and the real players in economy like David Mullins, a former vice-chairman of the Federal Reserve Board, the hedge fund was well qualified for generating profit.

LTCM concentrated on convergence trading, which involves finding securities those are mispriced relative to one another, buying the low priced security and selling the high priced one. The hedge fund defined four main types of trades to invest in:

1. Convergence among U.S., Japan, and European sovereign bonds;
2. Convergence among European sovereign bonds;
3. Convergence between on-the-run and off-the-run U.S. government bonds;
4. Long positions in emerging market sovereigns, hedged back to dollars.

As the deviation between these pairs is small, the hedge fund invested in highly leveraged positions in order to have a significant profit. Since the fund managers modeled the trades with highly correlated assets, they thought the risk to be minimal. However, declaration of moratorium by Russia was not a situation that had been foreseen by the hedge fund and the models was running without taking into consideration the extreme cases that may affect the correlation relationship between the pair securities.

The main subject that caused the real problem for LTCM was other than Russian moratorium. With the emergence of Russia's default on its government obligations, flight to liquidity across the global fixed income markets started soon. Investors shifted their capital into U.S. Treasury market. Furthermore, the investors was putting the money only into the most liquid market, which are the most recently issued, on-the-run, treasury bonds.

All these conditions made the spreads between pairs which LTCM invested in become wider dramatically. LTCM failed to satisfy its margin maintenance and lost substantial amounts of the investors' equity capital. The spread of negative effects into the global market was avoided by the rescue plan of Federal Reserve and the equity of LTCM was sold to leading U.S. investment and commercial banks as the return of $ 3.6 billion capital they had used for the rescue plan. After the recovery, the portfolio gained 13% and was unwounded over the following months (Safranov, 2005).

2. LITERATURE REVIEW

Pairs trading is one of Wall Street's quantitative methods of speculation which dates back to mid-1980s (Vidyamurthy, 2004). The process of pairs trading is implemented by identifying pairs of assets whose prices tend to move together and building trading strategy to gain profits while there is a deviation in this interaction between the asset prices.

With the use of historical descriptive statistics of securities in making trading decisions, many different strategies had been introduced and implemented to gain excess profit over traditional buy and hold strategies. Being one of these new attempts, pairs trading strategy is mainly built over the fundamentals of the notion of cointegration (Engle and Granger, 1987) and the law of one price (Ingersoll, 1987). Besides, basics of the strategy are closely linked to relative value strategies (Jagedeesh and Titman, 1967), contrarian strategies (De Bondt and Thaler, 1985), and cointegration based strategies (Alexander and Dimitriu, 2002).

Hogan et al. (2003) empirically investigated whether momentum and value trading strategies constitute statistical arbitrage opportunities by using monthly equity returns data of all stocks traded on the NYSE, AMEX, and NASDAQ between January 1965 and December 2000. The strategies have been also evaluated in terms of robustness to transaction costs, margin requirements, liquidity buffers, and higher borrowing rates.

While implementing the momentum strategy, they set a formation period and a holding period and they long the top returning stock and short the lowest returning stock for the formation period and hold this pair position during the holding period. The same formation and holding periods are used for the value strategies in pairs selection process. However, the criteria to select the stocks to be invested are fundamental characteristics of the companies such as book-to-market, cash flow-to-price, or earning-to-price ratios of the holding period. The hypotheses they have tested are that the incremental profits from the

strategy must be statistically greater than zero and the time-averaged variance of the strategy must decline to zero as time approaches infinity.

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With momentum strategies, for 14 of the 16 portfolios evaluated, the point estimate for the mean is greater than zero at 10% significance level, and the point estimate for the growth rate of variance is less than zero, which are consistent with statistical arbitrage. Value strategies, on the other hand, tests positively for statistical arbitrage at the 5% level for all observation with the sales growth based value strategy. Moreover, the test results are concluded to be robust to transaction costs and margin account costs.

In another study built with the basics of momentum strategies, Larsson et al. (2002) tested a market-neutral statistical arbitrage model using the most liquid stocks from Swedish market over the period 1995 to 2001. The study used momentum techniques to create the list of stocks that exhibit the strongest comovement relationship by forming a ranking among the stocks according to criteria of the stocks such as cumulative return during prior 6 month period, book-to-market ratio, magnitude of price change during increase in trade volume, one year ahead expectations of cash flow changes, and market capitalization. Then, they constructed equally weighted long and short positions by using this ranking.

There are 4 main risk controls in the model of Larsson et al. (2002) which are implemented during the trading period. First, every time a portfolio is formed, the best 4 candidates for inclusion are compared and the stock that will result in the lowest portfolio risk is picked according to the variance-covariance matrix calculated. Second, the stocks having price lower than 3 Swedish Krona are banned in the model as these stocks often move in large discrete steps. Third, stop-loss level for a portfolio is set to 20% of the maximum value during the holding period. The final risk control becomes effective when market-to-book value has doubled or halved in the last year for more than 4 stocks in a sector. Then, the strategy is not implemented in this sector with the expectation that when the valuations deviate too much from fundamental value, prices start to converge again.

It is concluded with the study of Larsson et al. (2002) that there exist both theoretical and empirical evidences about the improved performance with pairs trading strategies those studied in literature. The suggested model yields 39.8% annual return without any risk control, while simplistic price momentum strategy yields 19.8% annually. In addition, the negative impact on return of including transaction costs is outweighed by the lower risk provided with the pairs trading strategy. However, it is mentioned that the results in most academic studies are not based on a methodology realistic enough to measure the performance available to investors in reality.

Sudak and Suslova carried forward the study of Larsson et al. (2002) and tested the momentum effect on the European markets by replicating the pairs trading on the Swiss, French, and German and elaborated a portfolio optimization strategy.

The portfolio formed with the model is composed of two sub-portfolios formed on the basis of the cumulative return of the shares during the formation period. While the first sub-portfolio is long on the 5 highest returning stocks, the other sub-portfolio is short on the 5 lowest returning stocks. Without analyzing the price movement of the stocks during the trading period, a zero cost portfolio is constructed with the 10 selected stocks such that the portfolio has the lowest variance between long and short positions.

The study of Sudak and Suslova proved that it is possible to outperform the market using behavioral statistical arbitrage strategy and portfolio optimization techniques. The best results were observed on the Swiss market, where the degree of outperformance of the strategy comparing to the index is the largest, compared to French and German markets. While annualized return over the trading strategy is 21.8% for Swiss market, German, France and U.K. markets result 8.25%, 7.42%, and 10.9% annual returns, respectively. However, Sudak and Suslova made the conclusion that there is no common model of pairs trading strategy that can be applied for all the global markets, since specifications of the markets, number of active participants and stocks are the main determinants of the efficiency of any model.

Pairs trading strategy generally implemented in stock markets as the connection between the stock prices are more obvious without any maturity or coupon discrepancies. However, Nath (2003) decided to analyze another asset class and examined the implementation of pairs trading strategy in the highly liquid secondary market for U.S. Treasury securities, which is predominantly an over-the-counter market.

For each security, the sum of the square of the daily difference in normalized prices of the securities is calculated first. The normalization of prices for each security is done by subtracting the sample mean of the training period, and dividing by the sample standard deviation over the training period. During the trading period, a pair is opened for trading when the distance widens to reach a trigger level defined as a percentile of the empirical distribution of distances observed over the training period.

The results of Nath (2003) show that the simple pairs trading strategy performs well relative to various benchmarks and using different measures of performance. The strategy formed with trade opening trigger of 15^{th} percentile and stop loss trigger of 5^{th} percentile yields 2.05% without transaction costs, and 1.43% with transaction costs, while the benchmark portfolio returns 1.41% on average.

Hong and Susmel (2004) studied pairs trading strategies for 64 Asian shared listed in nine different market, Hong Kong, India, Indonesia, Israel, Japan, Korea, Philiphines, Thailand, and Taiwan, and listed in the U.S. as American Depository Receipts (ADRs). Since ADRs represent warehouse receipts for foreign underlying shares that have been deposited in a custodian bank on behalf of U.S. investors, ADRs and their underlying shares are expected to have a high correlation relationship. Therefore, they have been selected as possible pair alternatives.

The strategy formed in the study involves a short position in ADR shares in the U.S. market and a long position of underlying shares in the Asian market. The reverse possible is not taken as an alternative as it is not possible to short sell shares in the Asian market. Another

drawback of the study is that Asian markets and the U.S. market have no overlap in trading hours.

Although there are some drawbacks of the strategy due to having separate markets for pairs trading, the strategy returns 33.8% for a conservative investor willing to wait for a one-year period. For an investor intending to trade more frequently with holding period of 3 months, the return decreases to 8.5% with a lower standard deviation achieved.

There are many similar studies on arbitrage opportunities over pairing local stocks and their ADRs trading in U.S. market. Rabinovitch et al. (2003) studied Chilean and Argentine markets using a non-linear threshold model. Koumkwa and Susmel (2005), on the other hand, investigated the convergence between the prices of ADRs and the prices of the Mexican traded shares using a sample of 21 dually listed shares. Both studies concluded that while the mean returns are the same for paired stocks, the distributions of the returns are significantly different and the arbitrage opportunity can be exploited depending on the transaction costs implied on the markets.

In one of the most reviewed studies about pairs trading in literature, Gatev et al. (2006) examined pairs trading strategy for daily stock price data between 1962 and 2002 for U.S. equity market. They selected stocks that are close substitutes according to a minimum-distance criterion as pairs.

The first step of the study was normalizing the price series of stocks by fixing the reference point as the first day of formation period for each stock. Then, they calculated the spread between the normalized price series. The stocks with minimum deviation have been selected which was determined according to the sum of squared deviations between the stock prices during the pairs formation period.

During the trading period, position is opened with the stocks when prices diverge by more than two historical standard deviations as estimated during the formation period. The position is unwounded at the next crossing of the prices or at the last day of trading period.

A fully invested portfolio of the five best pairs earned an average excess monthly return of 1.31%, and a portfolio of the 20 best pairs 1.44% per month. They have concluded that these excess returns are large in economical and statistical sense and suggested that pairs trading strategy is profitable.

Although there has been lower profit performance of pairs trading in recent years, the study of Gatev et al. (2006) assigned this situation to increased hedge fund activity. Hedge funds make use of the profit opportunity as soon as it emerges. They concluded that although raw returns have fallen, the risk adjusted returns have continued to persist.

In another study, Perlin (2007) investigated the profitability and risk of the pairs trading strategy for Brazilian stock market. The data used in the study categorized in three different frequencies, daily, weekly, and monthly between the periods of 2000 and 2006. The data is normalized by following similar steps with Nath (2003) and all price series of stocks are brought to the same standard unit before trading period.

It is concluded with the study that the pairs trading strategy was able to beat a properly weighted naïve portfolio in most of the cases. Such result is more consistent for the daily frequency in the interval of standard deviation threshold of 1.5 and 2.0 and also for the monthly frequency in each tested intervals of standard deviation threshold levels. Excessive returns with pairs trading for daily frequency can reach up to 129.26% with 1.6 standard deviation threshold. The strategy will hold a position in the market for 71.11% of days and 100% of the observations beat the random portfolio.

A multivariate version of pairs trading has also been studied by Perlin (2007) who suggested creating an artificial pair for a stock based on the information of many assets,

instead of just one. The study was held in Brazilian equity market with daily data from 2000 to 2006 for 57 assets and concluded that the multivariate pairs trading was able to beat the market return and random trading alternatives. However, since the model forms an artificial pair with many assets, it is not practical to invest in this artificial pair due to transaction costs resulting from too many trades to execute for just one trade signal.

The artificial pair is composed of all stocks available in the market by using one of the formation processes: ordinary least squares, equal weights, or correlation weighting. The best performing case is the correlation weighting, which yields 111.81% total excess return during the trading period. However, other cases, ordinary least squares and equal weights, return 50.33% and 58.08% with 2.0 standard deviation threshold on average. The main conclusion after the profitability analysis is that the proposed version of pairs trading performs significantly better than chance and provides positive excessive returns after transaction costs.

In addition to the studies on trading process of the pairs trading strategy, there are some sources in literature aiming to improve the performance of the whole strategy. For example, the article of Huck (2008) concentrates on the pairs selection process in stead of trading model and proposes a new method that uses multiple return forecasts based on bivariate information sets and multi-criteria decision techniques. Using artificial neural networks, the method outputs a ranking that helps to detect potentially undervalued and overvalued stocks. Applied to S&P 100 index stocks, the model provides promising results in terms of excess return and directional forecasting.

While the deviation between the paired stocks is detected with purely statistical consideration in the studies of Gatev et al. (2006) and Nath (2003), Do et al. (2006) proposed a general approach to model relative mispricing for pairs trading purposes in a continuous time setting. The relative pricing between two assets is formulated as a continuous time model of mean reversion and with this formulation, the stochastic residual

spread is calculated between the pairs. Empirical results of the study shows that mean reversion is captured significantly with the stochastic residual spread model.

Apart from the studies on empirical analysis about pairs trading strategies, there are other sources of reference those only studied the implementation of the pairs trading without any empirical results. Herlemont (2004) studied the implementation of a trading strategy by investing in stocks those have similar market betas with the expectation of the stock that is bought will outperform the stock that is sold. Herlemont (2004) had some constraints in his trading strategy such as investing in stocks operating in same sector and seeking for very low beta differences between the stocks invested in. With these constraints, he aimed to build a portfolio which is market and sector neutral.

In the book of Vidyamurthy (2004), processes for both statistical arbitrage pairs trading and risk arbitrage pairs trading are covered. The statistical arbitrage strategy implemented in the book is based on cointegration framework, and determines the step without empirical results. First, the candidate list of potentially cointegrated stock pairs is formed using a distance measure between the stocks. The distance measure is the absolute value of the common factor correlation between the two stocks. Then, the model executes the trades when the predetermined threshold level is breached. The book also discusses various classes of spread dynamics and possible ways to model them.

Although the pairs trading strategy is simple and widely implemented by traders and hedge funds, published research about the subject is limited. Studies mainly focus on the stock markets and models are generally based on the price series of the stocks. It is possible to have empirical studies on European markets and some works on Asian Markets, which are mainly evaluating ADRs and their local pairs. As hedge fund activities increase rapidly and global markets are more affected from each other, it is expected to have more studies on emerging markets in the future.

3. METHODOLOGY

The implementation of our pairs trading strategy has two separate stages. First, we form pairs to be used in the strategy over 100 business days (formation period). Then, we execute the trades in the next 402 business days (trading period). Formation period and trading period cover years 2006 and 2007.

We have collected daily close, bid, ask, low and high prices of the publicly traded securities in Istanbul Stock Exchange National 30 Indices between the years 2006 and 2007. The data was retrieved from the database of Bloomberg Professional Service and non-trading days for the stock exchange have been eliminated.

Since it is better to have sufficiently long sample of stocks with full price history, we have eliminated the stocks with missing price information. With this elimination, we can guarantee that the stocks selected as the candidates for pairs trading are liquid or at least continuously publicly traded for a sufficient long period of time. The number of stocks matching this criterion is 25 among 30 stocks of ISE National Index.

One difficulty in selecting the pairs for investing is that the number of alternatives to be evaluated is too high. For a traditional trade of single asset long or short strategy for 25 possible assets requires evaluation of 25 assets separately and finding out the best alternative regarding the predetermined rules. For pairs trading, on the other hand, 25 assets mean 300 different pairs and the number of alternative investments increase exponentially with the number of assets, such as the number of alternative pairs is 4950 with 100 assets. Since it is not easy to run different tests for many alternative pairs at a time while the observations the trader testing are still changing over time, computer aided systems are invaluable for pairs trading.

3.1. Pairs Formation

In pairs formation period, we first normalize each stock price series to be able to compare the stock price series with each other. The reference point for normalization process is the first day of the pairs formation period. After the normalization process, the scale for the price series will be similar and the start point for all normalized price series will be equal to 1, which facilitates the comparison of the normalized price series.

For two stocks X and Y, with price series P_x and P_y, normalized price series will be calculated as:

$$\widetilde{P}_{x,t} = \frac{P_{x,t}}{P_{x,o}} \text{ and } \widetilde{P}_{y,t} = \frac{P_{y,t}}{P_{y,o}},$$

where $P_{x,0}$ is the price of X and $P_{y,0}$ is the price of Y at the first day of the pairs formation period.

After normalizing the price series, we have to select a criterion to determine the spread between the stock prices. We calculate the deviation ($\widetilde{d}_t$) between the normalized price series of X and Y which gives us the dispersion between the stocks with the reference point being the first day of the pairs formation period. Deviation between the normalized stock price series is calculated by subtracting the two normalized prices from each other.

$$\widetilde{d}_t = \widetilde{P}_{x,t} - \widetilde{P}_{y,t}$$

Then, in order to define the magnitude of the dispersion between the price series, we calculate the sum of squared deviations for the formation period between the two stocks' normalized price series,

$$ssd_{x,y} = \sum_{t=1}^{F} \left(\tilde{d}_t\right)^2$$

where F is the number of formation days selected in the model. We have used 100 days as the pairs formation period.

Pairs are formed with the securities those minimizing the sum of squared deviations with the hypothesis that these two stocks will be the best matching pairs having the most similar price movements. As we aim to exploit the deviation between the price series of similar stocks, having pairs with lowest deviation among each other will increase the probability of retaining the relationship in the long run.

3.2. Trading Period

After forming all available pairs with the stocks in our sample set, we begin to execute trades according to predetermined criteria. We will set the rules for entrance and exit signals and the transactions will be held after an objective process that depend only to price dynamics of the stocks, which is free of any personal intervention.

We can use either some ratio or difference of the two price series to track the relationship between the stocks. Although we decided to use the difference between the normalized price series of the two stocks, selection of these two alternatives, ratio or difference, can not be concluded as superior to the other since using one of the alternatives will be the result of the subjective preference of the trader.

First, we set the threshold deviation level ($T_{x,y}$) that gives the signal to open a position with the pair stocks. The main determinant of the threshold deviation level is the standard deviation of deviations between the normalized price series ($\tilde{\sigma}_{x,y}$) during the formation period which is calculated as follows:

$$\tilde{\sigma}_{x,y} = \sqrt{\frac{1}{F}\sum_{t=1}^{F}\left(\tilde{d}_t - \bar{d}\right)^2}$$

where F is the number of formation days and $\bar{d}$ is the mean of deviations between the normalized price series during the formation period.

The standard deviation level for the normalized price series of two stocks gives the level where approximately %68 of the observations lies. Therefore, it is possible to have lower or higher standard deviation levels as the threshold level for the strategy. The effects of having different standard deviation threshold levels will be analyzed in the later parts of our study.

The threshold deviation level ($T_{x,y}$) which gives the signal to open a position with the pair stocks is calculated as

$$T_{x,y} = k\sigma_{x,y}$$

where k is the number of standard deviations used in the trading model.

Since the threshold level that will point out the trade signals is set, we can look for the trade signals during the trading period and execute the transactions. Trading decision for each stock is determined according to the comparison of deviation and the threshold level at the end of each day of the trading period.

If $\tilde{d}_t > T_{x,y}$, we sell stock X and buy stock Y with the expectation that $\tilde{d}_t$ will revert to zero in the future. When $\tilde{d}_t$ returns to zero and the deviation between the normalized stock prices disappears, we buy back stock X and sell stock Y. With these two final transactions, the position closes.

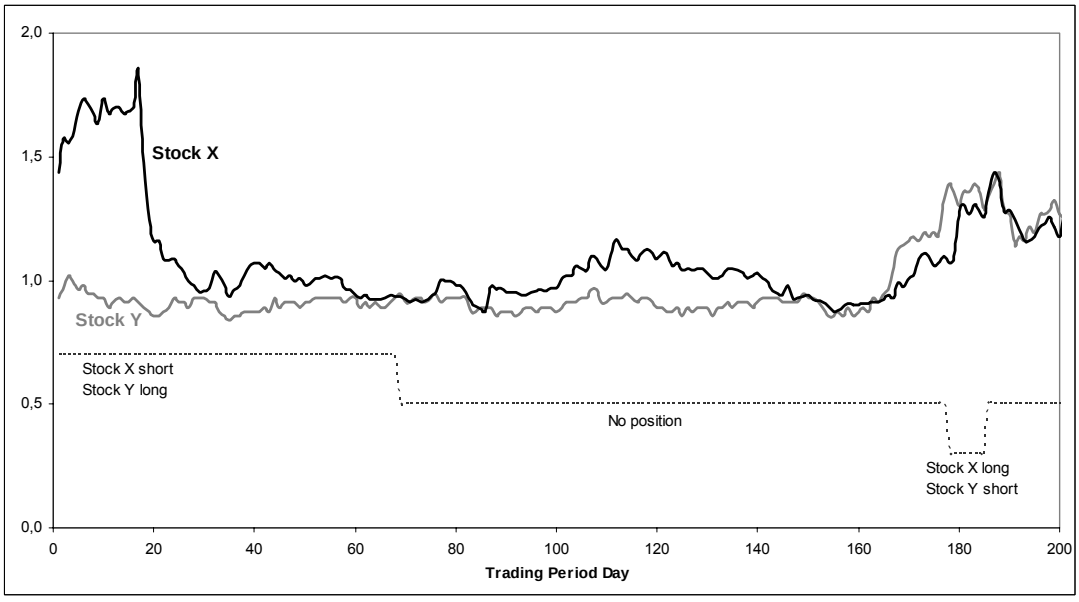
If $\tilde{d}_t < -T_{x,y}$, we buy stock X and sell stock Y with the expectation that $\tilde{d}_t$ will revert to zero in the future. When $\tilde{d}_t$ returns to zero and the deviation between the normalized stock prices disappears, we sell stock X and buy back stock Y. With these two final transactions, the position closes.

During the period where $\left|\tilde{d}_t\right| < T_{x,y}$, we do not hold any position since the deviation is less than the threshold level in absolute terms.

In case there is any position remaining at the end of the trading period, the position is closed at the prices of the last trading day without any comparison of the condition of deviation and the threshold level or inspecting whether the position is in profit or loss.

Figure 3.1 illustrates the pairs trading strategy using two sample stocks. The top two lines are the normalized price series of the two stocks and the bottom line is the state of the position. Number of standard deviations for the threshold level is 2.0 in the sample illustration of the strategy.

Figure 3.1. Sample Pairs Trading Strategy



We start to look for a trade signal and the first trade signal is detected at day 1 of the trading period. The deviation between the normalized prices is 0.507 while the standard deviation for the formation period is 0.123 and the threshold deviation level is 0.246. Stock X is sold and stock Y is bought with the expectation that the deviation will disappear in the future. On day 69 of the trading period, deviation crosses zero, which means the normalized prices of the two stocks become equal. The reverse of the first transactions are executed and stock X is bought back and stock Y is sold and position is closed.

On day 178, the deviation between the normalized prices becomes -0.324, which is lower than -2.0 standard deviation threshold level. This time, stock X is bought and stock Y is sold. 8 days later, on day 186, deviation between the normalized prices of the two stocks crosses zero. The reverse of the first transactions are executed and stock X is sold and stock Y is bought back and position is closed.

The ratio of number of stocks to be bought and sold ($N_{x,y,t}$) with the trade signal is determined by the inverse ratio of the prices of the two stocks which is calculated as:

$$N_{x,y,t} = \frac{P_{y,t}}{P_{x,t}}$$

where $P_{x,t}$ is the price of stock X and $P_{y,t}$ is the price of stock Y at t. Using the ratio $N_{x,y,t}$ makes the value of the investment in stock X and stock Y equal to each other and the position becomes dollar-neutral.

The trading rule we implemented is very simple. We open a long/short position when we detect divergence of the pair prices by a predetermined level. We close the position when the prices revert. As can be observed in the illustration, we do not have any assumption about the direction of the price movement. Therefore, position taken on the stocks is not on the same direction every time.

3.3. Return Calculation

The portfolios of pairs trading are formed by buying one stock and selling the other. Since the values of the investments are same, which means the strategy is dollar neutral; the return over the portfolio is not really the return over the capital invested. The performance of the strategy is calculated as the return over the value of one side of the transaction. Therefore, it is not possible to compare the performance of the pairs trading strategy with a buy and hold strategy, which requires capital to purchase one stock.

The performance of the strategy is considered according to the sum of the returns over the stock bought and sold during the trading period. First, we calculate return over each stock position separately as follows:

$$R_{x,n} = \frac{P^{c}{}_{x,n}}{P^{o}{}_{x,n}} - 1 \text{ and } R_{y,n} = \frac{P^{c}{}_{y,n}}{P^{o}{}_{y,n}} - 1$$

In the equation, $P^{o}{}_{x,n}$ is the position opening price, $P^{c}{}_{x,n}$ is the position closing price of X for the *n*th transaction and $P^{o}{}_{y,n}$ is the position opening price, $P^{c}{}_{y,n}$ is the position closing price of X for the *n*th transaction.

The total return for the pairs is calculated as:

$$R_{x,y} = \sum_{1}^{n} \left(R_{x,n} + R_{y,n} \right)$$

Since the positions are opened when the normalized price deviations are more than the threshold level and closed when the deviation is zero, any position that is closed before the last day of the trading period will result in profit, whether one of the stocks generates loss. Therefore, the condition of having negative return is only possible when the position is still open at the last day of trading period.

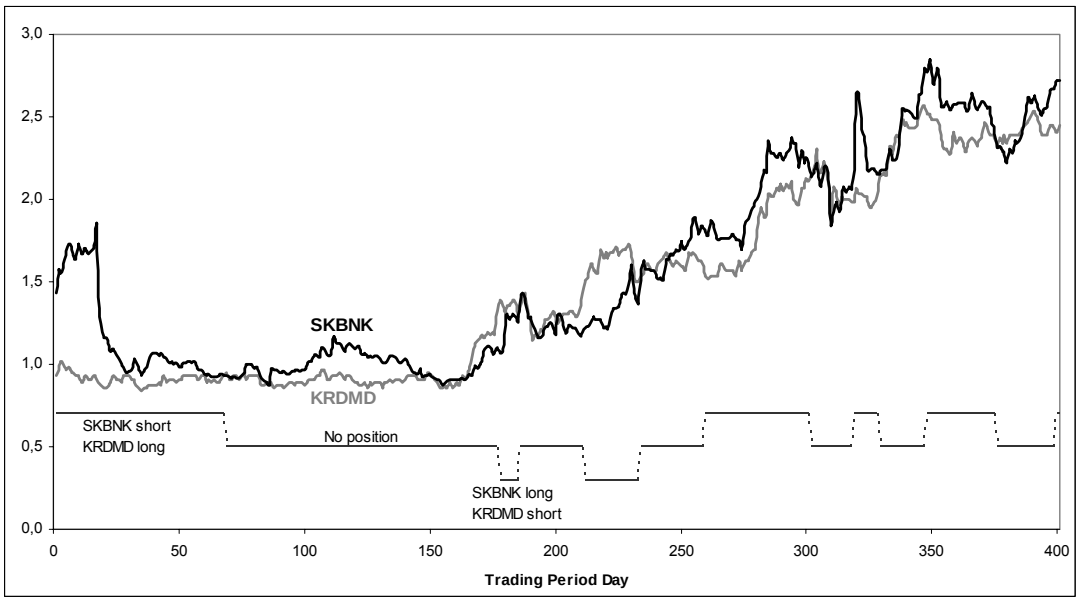
If the position is held on the last day of the trading period, the stock previously bought will be sold. The other stock, on the other hand, will be bought back and the position will be closed at the prices of the last trading day. Since it is possible to have a higher deviation than the threshold level while closing the position, we can encounter loss in one or both stock positions.

3.4. When does the Strategy Win or Fail?

In this part of our study, we analyze two sample pairs, SKBNK-KRDMD and SKBNK-ARCLK. These two sample pairs have low deviations between the stock price series and they are expected to have good performance with the pairs trading strategy.

As shown in Figure 3.2, normalized prices of SKBNK and KRDMD move close to each other during the trading period. Although there is a significant comovement between the normalized price series, they sometimes deviate from each other and provide the trader with the opportunities to trade. The pairs provide 7 trade alternatives during the trading period, which is formed by selling SKBNK and buying KRDMD, or vice versa.

Figure 3.2. Sample Pairs Trading Strategy for SKBNK-KRDMD Pair



The details of the transactions are summarized in Table 3.1, which also includes the level of returns over the stocks for each transaction. In 4 of the transactions, the stocks bought gains value and the stock sold loses value and, as a result, both of the stocks return profits. In 3 of the transactions, one of the stocks results in positive return. The other stock, on the other hand, results in loss. However, the total return over the two positions is still positive as the profit level is higher than the loss. At the end of the trading period, the pair has 138.5% total return over 7 transactions.

Table 3.1. Summary of Trades for SKBNK-KRDMD Pair

Transaction	Day	Action	Price KRDMD	Action	Price SKBNK	Return KRDMD	Return SKBNK	Return TOTAL
1	1	Buy	0,5200	Sell	2,7449			
	69	Sell	0,5300	Buy	1,7870	1,9%	34,9%	36,8%
2	178	Sell	0,7800	Buy	2,0445			
	186	Buy	0,7500	Sell	2,5935	3,8%	26,9%	30,7%
3	212	Sell	0,8400	Buy	2,3284			
	234	Buy	0,8600	Sell	2,9721	-2,4%	27,6%	25,3%
4	260	Buy	0,8600	Sell	3,4642			
	302	Sell	1,2000	Buy	4,0889	39,5%	-18,0%	21,5%
5	319	Buy	1,1100	Sell	4,3000			
	329	Sell	1,2100	Buy	4,1200	9,0%	4,2%	13,2%
6	348	Buy	1,4100	Sell	5,3000			
	376	Sell	1,3000	Buy	4,4200	-7,8%	16,6%	8,8%
7	400	Buy	1,3500	Sell	5,2000			
	402	Sell	1,3800	Buy	5,2000	2,2%	0,0%	2,2%
					TOTAL	**46,4%**	**92,1%**	**138,5%**

As the two stocks have a close comovement relationship and this relationship does not break down permanently during the trading period, the strategy formed with SKBNK and KRDMD is a good example for pairs trading with high return. In addition, having several number of trades executed and closed improves the performance of the pair as any position that is closed during the period results profit.

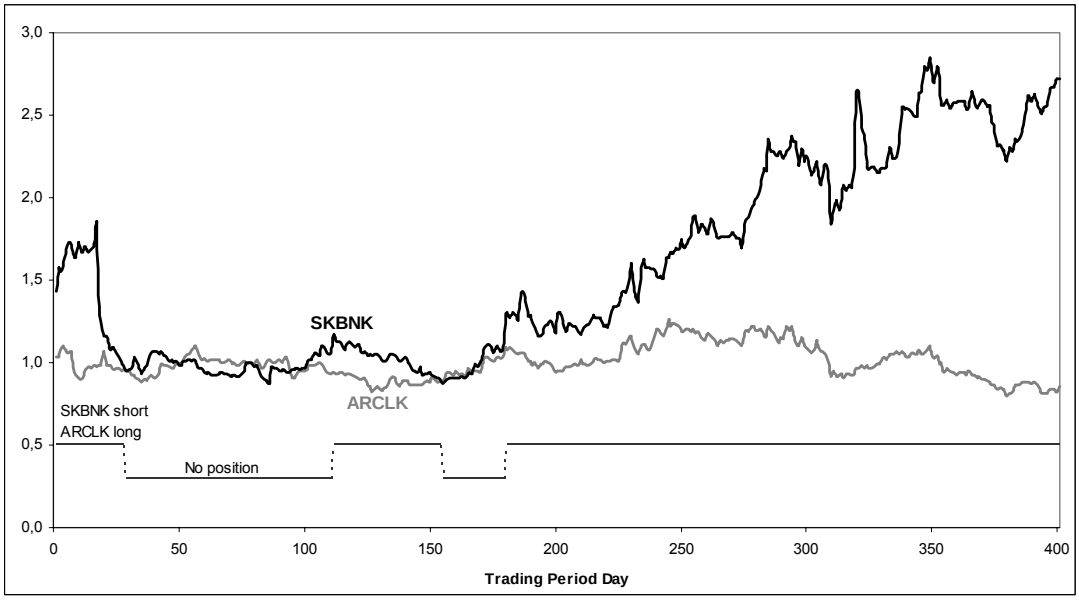
For the second sample pair, SKBNK and ARCLK, the normalized price series have two separate periods with different relationship characteristics. During the first half of the trading period, the price series move very closely to each other and deviate for short

periods. These short period deviations provide two transaction alternatives and both of these positions are formed by selling SKBNK and buying ARCLK.

However, during the second half of the trading period, the deviation between the normalized price series increases steadily and does not revert back. While normalized price series of SKBNK goes higher from the reference point, which is the first day of the formation period, normalized price series of ARCLK reverts to its mean and does not follow the upward move of SKBNK.

The reason for such a break down of the relationship can be fundamental which is due to a firm or sector specific news. Or, it can be only a directional movement of stock prices which can result from difference in transaction volumes of the stocks.

Figure 3.3. Sample Pairs Trading Strategy for SKBNK-ARCLK Pair



Although, first two transactions result in a loss for ARCLK, the profit generated by buying SKBNK outperforms these losses and the pairs have returns of 25.6% and 19.4%. In the 3rd transaction, on day 181 of the trading period, the spread between the normalized price series crosses the threshold level, SKBNK is bought and ARCLK is sold. Since the

deviation after the entrance of the position does not revert back and reach to zero, the position can not be closed until the last day of the trading period. The position is closed at the last day without comparison of the condition of deviation and the threshold level. As a result, final transaction ends in losses of 20.15 and 108.1% for ARCLK and SKBNK, respectively.

Table 3.2 summarizes the transactions with SKBNK and ARCLK pair and the returns over these transactions.

Table 3.2. Summary of Trades for SKBNK-ARCLK Pair

Transaction	Day	Action	Price ARCLK	Action	Price SKBNK	Return ARCLK	Return SKBNK	Return TOTAL
1	1	Buy	9,8000	Sell	2,7449			
	29	Sell	9,0000	Buy	1,8173	-8,2%	33,8%	25,6%
2	112	Buy	8,8500	Sell	2,2338			
	155	Sell	8,3500	Buy	1,6734	-5,6%	25,1%	19,4%
3	181	Buy	10,2000	Sell	2,4988			
	402	Sell	8,1500	Buy	5,2000	-20,1%	-108,1%	-128,2%
					TOTAL	**-33,9%**	**-49,2%**	**-83,1%**

As mentioned above, pairs trading strategy results in profit in case the stock prices deviate form each other for short periods and revert back until the end of the trading period. As long as the stocks have a close price relationship and this relationship does not break down during the trading period, the strategy will be successful in detecting the deviations and profit generating transactions will be executed accordingly.

However, if the relationship between the price series changes significantly during the trading period, the strategy may end in loss as any position that is open at the end of the trading period should be closed.

4. EMPIRICAL RESULTS

In this part of our study, we build the results for the pairs trading strategy. We compare the performance of the strategy for different standard deviation threshold levels and summarize general trading settings such as the number of trades and the number of days in position. Since the assumption of having no transaction costs is not realistic for the strategy, we also analyzed the performance of the strategy after adding the transaction costs. In addition, to simulate the real market conditions as much as possible, we replicate our study with bid and ask prices that will be faced in case of a real transaction. Finally, we simulate a liquidity crisis scenario which uses the daily low and high prices for each stock which can form an idea about what can be the worst condition with the pairs trading strategy.

4.1. Strategy Performance

As the pairs trading strategy aims to gain profit over the relationship between the pair stocks price series, the performance of the strategy is evaluated according to the value added with each transaction. Therefore, the main determinant of good performance is the level of positive return achieved with the pairs trading strategy.

Table 4.1 summarizes the results for the trading period with 2.0 standard deviation threshold level. The results are categorized in 6 groups those composed according to the characteristics of the pairs in terms of sum of squared deviation levels between the normalized price series. While 4 groups consist of top 5, 10, 20 and 50 pairs with the lowest sum of squared deviation ranking, the 5th group has the pairs between 101st and 120th ranking. The last portfolio includes all possible pair alternatives that can be formed with the sample set.

Average return levels show that pairs trading strategy that invests in top 5 pairs earn 22.7% per pair on average during the trading period. In case the number of pairs included in the

portfolio is extended to top 10 pairs, the performance of the strategy decreases. However, the portfolio with top 10 pairs still ends in profit and returns 12.2% on average.

Table 4.1. Strategy Results with 2.0 Standard Deviation Threshold Level

Pairs Portfolio	**Top 5**	**Top 10**	**Top 20**	**Top 50**	**101-120**	**All**
Average Sum of Squared Deviations	0,26	0,31	0,43	0,71	2,22	5,31
Standard Deviation of Normalized Prices	4,71%	5,03%	5,49%	6,72%	10,59%	10,72%
Number of Pairs	5	10	20	50	20	300
Average Return	22,7%	12,2%	-4,4%	-9,5%	-23,6%	2,5%
Maximum	85,3%	85,3%	85,3%	87,6%	60,5%	138,5%
Minimum	-91,5%	-134,0%	-134,0%	-158,4%	-157,8%	-158,4%
Median	39,6%	39,6%	9,0%	-3,3%	-15,4%	12,2%
Standard Deviation	70,1%	74,0%	63,9%	56,5%	57,9%	53,7%
Skewness	-1,37	-1,14	-0,56	-0,54	-0,58	-0,49
Kurtosis	1,86	0,27	-0,60	0,03	-0,19	-0,03
Observations with return > 0	80%	70%	55%	48%	45%	58%
Observations with return < 0	20%	30%	45%	52%	55%	41%

If the number of pairs is increased further and the portfolio is allowed to include more than 10 best pairs, profitability of the strategy disappears. When the strategy is implemented with top 20 pairs, the strategy returns 4.4% loss on average and with 50 pairs, the loss reaches up to 9.5%. However, if we use all possible pair alternatives for transactions during the trading period, the average return that can be generated becomes 2.5%.

In order to have a better understanding about the performance of the strategy, we compare the results over the portfolios including less diversified pairs with panel data that includes more diversified pairs. The panel data is selected as the portfolio of pairs between the 101st and 120th ranking. The results for the sample sets and the panel data show us that as the deviation between the normalized pair price series increases, the performance of the strategy gets worse. The panel data returns 23.6% loss on average while top 20 pairs has a loss of 4.4% on average. The minimum return observation, on the other hand, is not much lower than the top 20 or top 50 pairs for the panel data.

The skewness level for the return observations becomes closer to zero as the number of pairs included in the portfolio increases. For the portfolios including pairs those are more diversified among each other, the distribution of returns gets more left-skewed. Therefore, it can be mentioned that the probability of having negative results increases with the increase of the average deviation between the normalized prices of the stocks.

In addition, the probability of having observations with positive returns decreases continuously as the deviation of the normalized prices of pairs included in the portfolio increases. While only 20% of the observations for top 5 pairs end in negative returns, the probability of having loss increases to 30% with top 10 pairs. Moreover, the percentage of negative returning observations is 41% or higher for the other 3 portfolios and all pairs portfolio.

As the standard deviation level selected for determining the threshold level may affect the performance results, we reproduce the results for the trading period with 1.0 standard deviation.

Since the standard deviation band that sets the condition to enter and exit the position gets narrower, we expect to observe transactions more frequently. However, having lower threshold levels may decrease the profitability of the strategy as the deviations that is aimed to gain profit will be lower and smaller standard deviation level may prevent us from finding out better profit opportunities.

The return of top 5 pairs with 1 standard deviation threshold level is 38.8% on average which is much higher than 22.7%, the return with 2 standard deviations. The return of top 10 pairs also increases by 15.9%, from 12.2% to 28.1% due to the decrease of the standard deviation threshold level.

The performance of all portfolios increases significantly with 1.0 standard deviation threshold level compared to a higher threshold level. However, the decrease of the

profitability with the increase of the deviation between the normalized price series is still valid. While top 5 and 10 pairs end in positive returns, top 20 and 50 pairs show a worse performance and they have negative returns over the trading period. Moreover, the panel data formed with the pairs between 101st and 120th ranking ends in a loss of 22.9% with 1.0 standard deviation.

Table 4.2. Strategy Results with 1.0 Standard Deviation Threshold Level

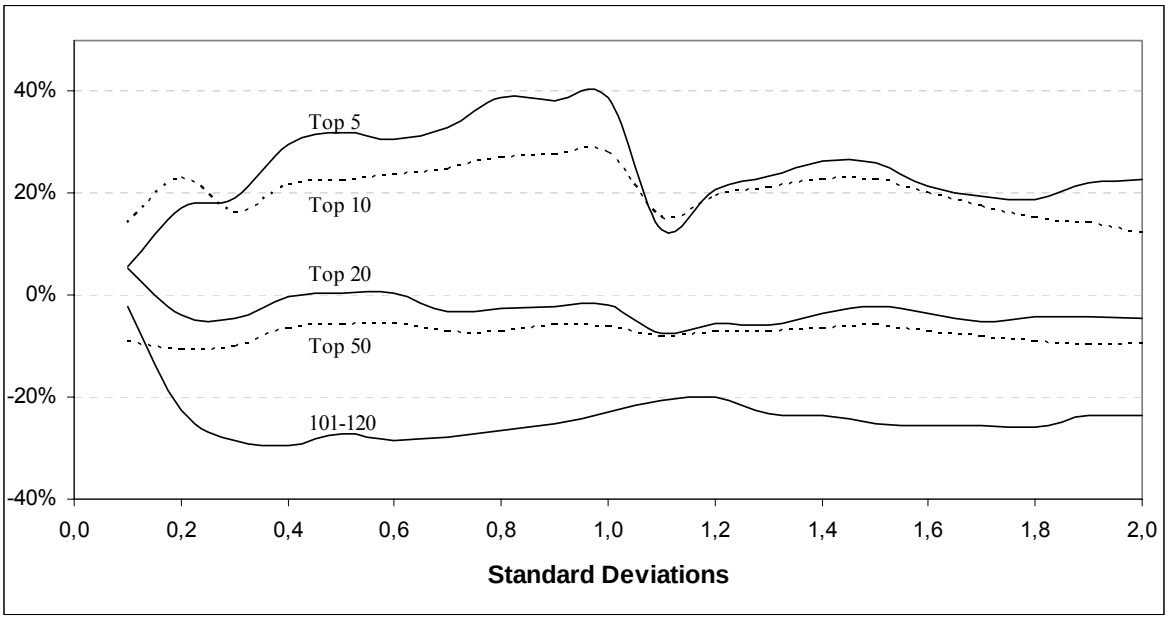
Pairs Portfolio	**Top 5**	**Top 10**	**Top 20**	**Top 50**	**101-120**	**All**
Average Sum of Squared Deviations	0,26	0,31	0,43	0,71	2,22	5,31
Standard Deviation of Normalized Prices	4,71%	5,03%	5,49%	6,72%	10,59%	10,72%
Number of Pairs	5	10	20	50	20	300
Average Return	38,8%	28,1%	-1,9%	-6,1%	-22,9%	3,1%
Maximum	77,0%	80,8%	80,8%	104,7%	87,8%	143,4%
Minimum	11,2%	-145,3%	-145,3%	-160,7%	-156,7%	-160,7%
Median	30,7%	44,4%	10,2%	2,8%	-23,1%	9,3%
Standard Deviation	28,0%	67,2%	65,4%	61,3%	60,7%	56,9%
Skewness	0,59	-2,18	-0,74	-0,54	-0,18	-0,46
Kurtosis	-1,74	5,54	-0,13	-0,02	-0,19	-0,11
Observations with return > 0	100%	90%	65%	54%	30%	58%
Observations with return < 0	0%	10%	35%	46%	70%	42%

Although the skewness for top 5 pairs is the highest among all pairs, all the observations among top 5 pairs result in profit and the standard deviation of the returns in top 5 pairs is significantly lower pointing out a very low risk of return with top 5 pairs. While the percentage of positive returning observations in top 10 pairs is 90%, only 65% of the observations end in profit in top 20 pairs. Similar to the lower profitability results of top 50 pairs and the panel data, the percentage of pairs with positive returns are also lower compared to the portfolios with less deviation.

Figure 4.1 shows average return levels for each portfolio with different standard deviation threshold levels. It can be concluded that independent of the standard deviation threshold level, having minimum sum of squared deviations between the normalized price series as the selection criteria will increase the performance of the strategy. As the average deviation

between the pairs in the portfolio increases, the line showing the performance of the portfolio is plotted lower compared to the other portfolios having pairs with lower deviations between the normalized price series.

Figure 4.1. Average Returns of Pairs Trading Strategies



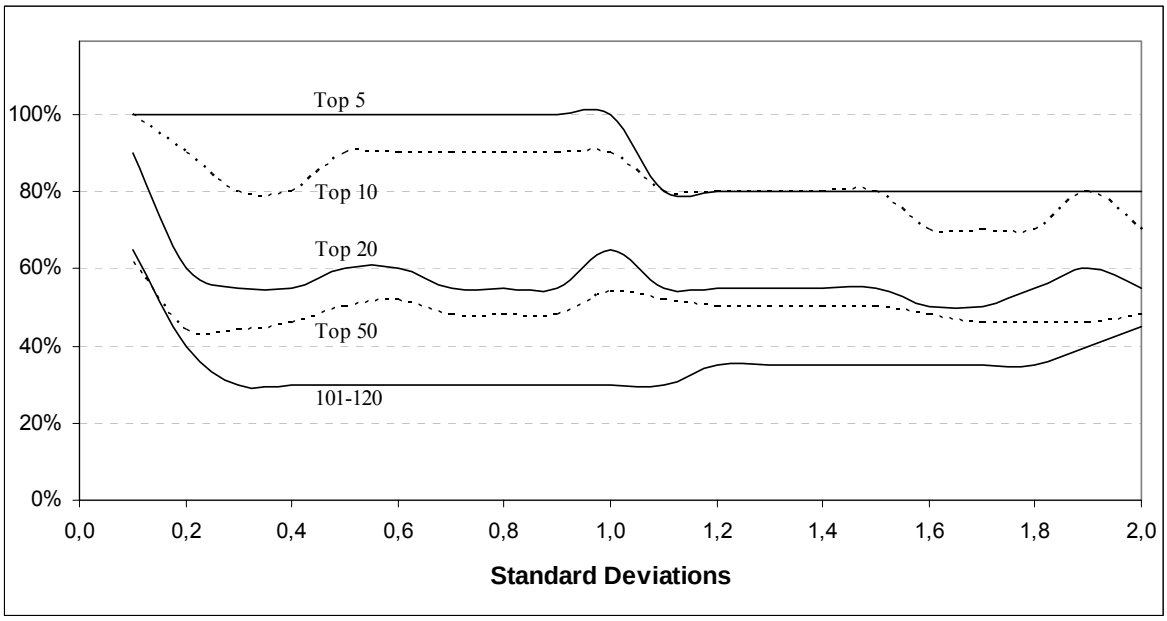
Top 5 pairs is the best performing portfolio in 85% of the observations and top 10 pairs is the best performing portfolio in the remaining 15% of the observations for different standard deviation levels. While top 20 pairs can have positive returns in 15% of the observations, other portfolios formed with pairs with higher deviation result in negative returns for every observation. The ranking of the return levels is not a random process and as the deviation between the normalized price series increases, the return level of the portfolio decreases continuously.

The performance graphs for 5 different portfolios can be divided into 3 subgroups. The first subgroup is composed of top 5 and 10 pair portfolios which generate moderate to high profits. The second subgroup is the portfolios having top 20 and top 50 pairs. Those portfolios have rarely low profits, but frequently losses. The last portfolio, the panel data

always generates high level of loss which is due to higher deviation among the pairs included in the portfolio.

Figure 4.2 shows percentage of pairs with positive return for each portfolio with different standard deviation threshold levels. As the number of pairs included in the portfolio increases, the percentage of pairs with positive returns decreases.

Figure 4.2. Percentage of Pairs with Positive Return



For the portfolios composed of top 5 pairs and top 10 pairs, the percentage of profit generating observations decreases as the threshold level increases more than 1.0 standard deviation. Higher standard deviation threshold also increases the threshold level to be followed in order to execute a trade. However, observing higher deviation between the normalized price series is more risky with the higher probability of being due to a permanent break of the relationship between the stocks. Therefore, increase of threshold level results in the decrease of the percentage of profit generating pairs for the top 5 and top 10 pairs.

For the portfolios with top 20 and top 50 pairs, percentage of pairs with profit decreases up to 0.3 standard deviations. However, the level of profitable pairs stabilizes and does not change evenly with the increase of the standard deviation threshold after 0.3 standard deviations. Therefore, we can conclude that the threshold level has an effect on the percentage of pairs with positive returns for the portfolios with highly deviated pairs.

As the deviation between the normalized price series increases, the percentage of the profitable pairs in the portfolio decreases continuously. It can be also observed over Figure 4.2 that as long as the average deviation between the pairs in the portfolio increases, the line showing the performance of the portfolio is plotted lower compared to the other portfolios having pairs with lower deviations between the normalized price series.

Portfolios of pairs can be divided into 3 subgroups in terms of percentage of profitable pairs in the portfolio. 80% or more observation of the first subgroup, top 5 and top 10 pair portfolios, generate positive returns during the trading period. The second subgroup is the portfolios having top 20 and top 50 pairs. Observations of the second subgroup end in positive return between 40% and 60% of the time. Panel data, which is the last subgroup, has 30% of its observations with profit at the end of the trading period.

After analyzing the performance results for the pairs trading strategy, we can have the following conclusions:

- The lower the deviation between the normalized price series, the higher the profitability.
- The lower the deviation between the normalized price series, the higher the percentage of pairs with positive return.
- The higher the standard deviation for top 5 and top 10 pairs, the lower the percentage of pairs with profit.

- Top 5 pairs is the best performing portfolio 85% of the observations, with the lowest standard deviation of returns and all observations ending in profit for 1.0 standard deviation threshold level.

4.2. Trading Statistics

After comparing the performance level for different portfolios with different standard deviation levels, we analyze the statistics of trades generated with the pairs. Table 4.3 summarizes the number of trades and the number of days the positions are carried for different standard deviation levels.

Table 4.3. Trading Statistics with Different Threshold Levels

	Top 5	**Top 10**	**Top 20**	**Top 50**	**101-120**	**All**
0.5 St. Deviation						
Number of Trades	28	74	120	273	165	1296
Average Number of Trades	5,60	7,40	6,00	5,46	8,25	4,32
Average Days in Position	260	275	313	345	363	359
1.0 St. Deviation						
Number of Trades	24	57	89	199	117	956
Average Number of Trades	4,80	5,70	4,45	3,98	5,85	3,19
Average Days in Position	271	298	333	348	350	351
1.5 St. Deviation						
Number of Trades	21	46	72	157	92	755
Average Number of Trades	4,20	4,60	3,60	3,14	4,60	2,52
Average Days in Position	345	319	335	338	325	331
2.0 St. Deviation						
Number of Trades	17	32	55	116	84	592
Average Number of Trades	3,40	3,20	2,75	2,32	4,20	1,97
Average Days in Position	323	293	315	313	295	304

The strategy generated 28 trades for top 5 pairs during the trading period with 0.5 standard deviation threshold level. Average number of trades for each pairs in this portfolio is 5.60. The investor carries a short position in one stock and a long position in the other stock for 260 days on average for each pair. While average number of trades lies in the range between 5.46 and 8.25, average days in position can reach up to 363 at maximum for different portfolios.

As the standard deviation threshold increases, the threshold level becomes wider and the number of trade signals decreases. Therefore, the average number of trades increases for each portfolio with lower standard deviation thresholds. With 2.0 standard deviation threshold level, the strategy generates 3.40 trades on average for top 5 pairs. However, if the standard deviation threshold level is decreased to 1.5 standard deviation, average number of trades increases to 4.20. Moreover, we can observe 4.80 trades on average if the threshold level gets narrower to 1.0 standard deviation level.

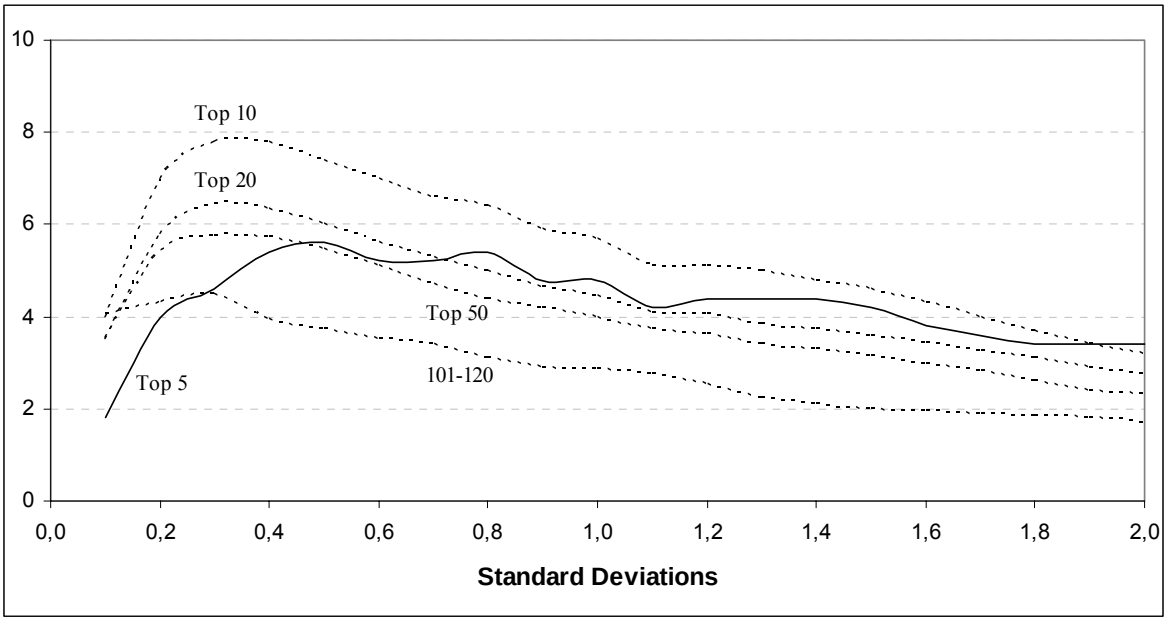
Average days in position is significantly higher for 1.5 and 2.0 standard deviation threshold levels compared to 0.5 and 1.0 standard deviation levels. Higher standard deviation level makes the entrance to the position more difficult as the normalized prices have to deviate with a higher level. However, if the entrance signal is detected and the position is opened, it will take more time of normalized price series to cross each other again. Therefore, the investor will carry the position for longer periods with wider standard deviation bands for top 5 pairs portfolio.

Figure 4.3 shows average number of trades generated with the trading strategy for different standard deviation threshold levels. Apart from top 5 pairs portfolio, average number of trades for the portfolios decreases as the deviation between the normalized price series increases. The pairs with similar price series and lower deviation provide more trade alternatives with temporary fluctuations. Deviation disappears in short periods and the position closes with profit. However, pairs with higher deviations diverge less frequently from each other and the number of trades decreases with increased deviation between the pairs.

For each portfolio, average number of trades increases up to 0.4 standard deviation and starts to decrease steadily with higher standard deviation thresholds. The reason for lower number of trades with higher standard deviation threshold levels is that when the threshold level gets wider, it will be difficult to find out observations with price deviation higher than

the threshold level. Therefore, the number of trades generated with high standard deviation threshold level decreases rapidly and reaches 2 to 3 trades on average for all portfolios.

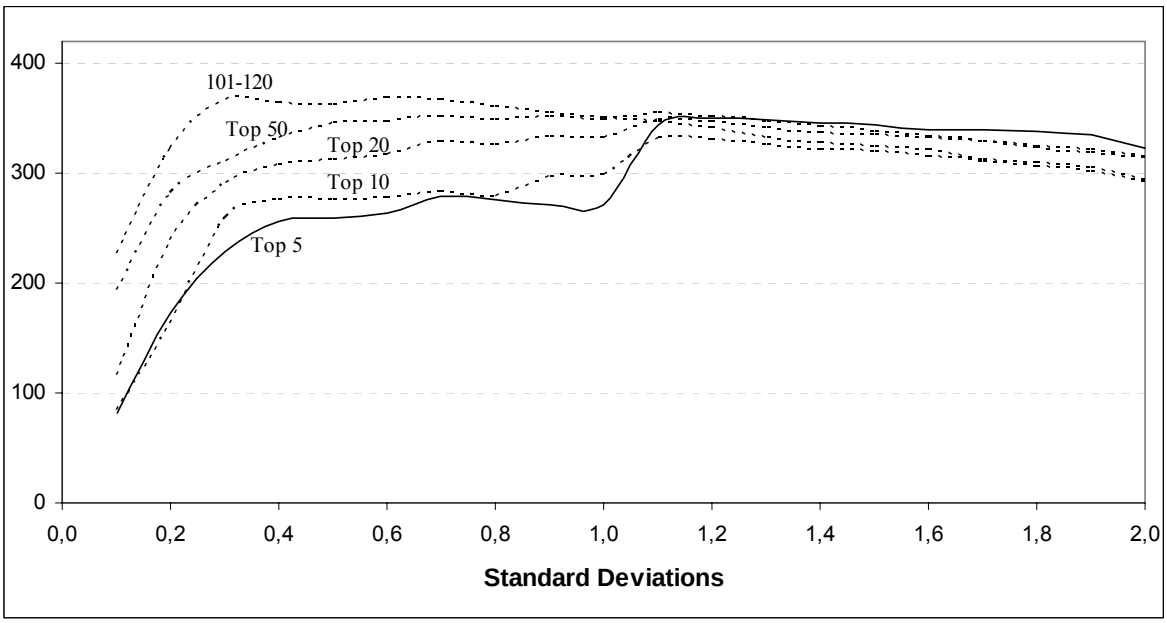
Figure 4.3. Average Number of Trades



Top 5 pairs portfolio is distinguished from other portfolios on the plot of the average number of trades executed. The number of trades is lower than other portfolios up to 0.3 standard deviation threshold level. However, average number of trades reaches its highest level for other portfolios with 0.4 standard deviation level. Top 5 pairs portfolio has the highest number of trades with 0.5 standard deviation, which is equal to 5.60. Moreover, average number of trades for top 5 pairs does not decrease rapidly and regularly as the standard deviation threshold level increases.

As the standard deviation level increases, the average number of days in positions also increases. With higher standard deviation threshold levels, the trading signals are more difficult to encounter. Similarly, when higher threshold level is reached and the normalized price series deviate from each other, it takes more time to revert to zero and the position is held longer periods.

Figure 4.4. Average Number of Days in Position



When we compare the portfolios, we observe that the portfolio composed of pairs with higher price deviations stay for longer periods in position on average as it takes longer time for the normalized prices revert to each other due to having higher dispersion on average.

After analyzing the trade statistics for the pairs trading strategy, we can have the following conclusions:

- The higher the standard deviation threshold level, the higher the number of trades generated.
- Except for top 5 pairs, the lower the deviation between the normalized price series, the higher the average number of trades.
- The higher the deviation between the normalized price series, the higher the number of days in position.
- All portfolios have the maximum number of trades between 0.3 and 0.5 standard deviations.
- All portfolios stay between 300 and 350 days in position with higher than 1.0 standard deviation levels.

4.3. Transaction Costs

Until this part of the study, we assumed that there is no transaction cost over the transactions executed for each stock. However, this is not a realistic assumption and we also have to include transaction costs and regenerate the strategy performance results.

In general, the transaction cost is 0.3% of the trade value per each transaction[1] for each stock. The transaction cost is charged as a percentage of the value of the transaction, whether you buy the stock or sell it. Therefore, the price of the stock is considered as 0.3% higher when the trade requires the stock to be bought and as 0.3% lower when the stock is sold.

Table 4.4 summarizes the results of the strategy after deducting 0.3% of the trade value for each transaction for 2.0 standard deviation level. The profits generated after 0.3% transaction cost are 17.9% and 7.8% for top 5 and top 10 pairs, respectively. The portfolios including pairs with higher deviations result in negative returns which may reach up to 26.1% for the panel data.

Table 4.4. Strategy Results after 0.3% Transaction Cost with 2.0 Standard Deviations

Pairs Portfolio	**Top 5**	**Top 10**	**Top 20**	**Top 50**	**Top 101-120**	**All**
Average Return	17,9%	7,8%	-8,3%	-12,7%	-26,1%	-0,3%
Maximum	77,7%	77,7%	77,7%	83,0%	56,7%	131,6%
Minimum	-94,1%	-136,4%	-136,4%	-160,6%	-160,1%	-160,6%
Median	35,5%	35,2%	6,2%	-5,7%	-16,8%	9,3%
Standard Deviation	68,0%	72,4%	62,8%	55,5%	57,5%	53,1%
Skewness	-1,45	-1,19	-0,60	-0,59	-0,60	-0,52
Kurtosis	2,17	0,37	-0,58	0,09	-0,17	-0,03

0.3% transaction cost is the general market application and this ratio is mostly valid for individual investors. However, as the pairs trading strategy is a hedge fund strategy and it is executed with leverage in high volumes, it is possible to have lower transaction costs.

[1] Ata Online Yatırım Merkezi – Phone execution, Ak Yatırım Menkul Değerler A.Ş. – Middle size client

Therefore, we also calculate the performance of the strategy with 0.1% transaction cost[2] per each trade for each stock.

Table 4.5 summarizes the results of the strategy after deducting 0.1% of the trade value for each transaction for 2.0 standard deviation level. The profits generated after 0.1% transaction cost are 21.1% and 10.7% for top 5 and top 10 pairs, respectively. The portfolios including pairs with higher deviations result in negative returns which may reach up to 24.5% for the panel data.

Table 4.5. Strategy Results after 0.1% Transaction Cost with 2.0 Standard Deviations

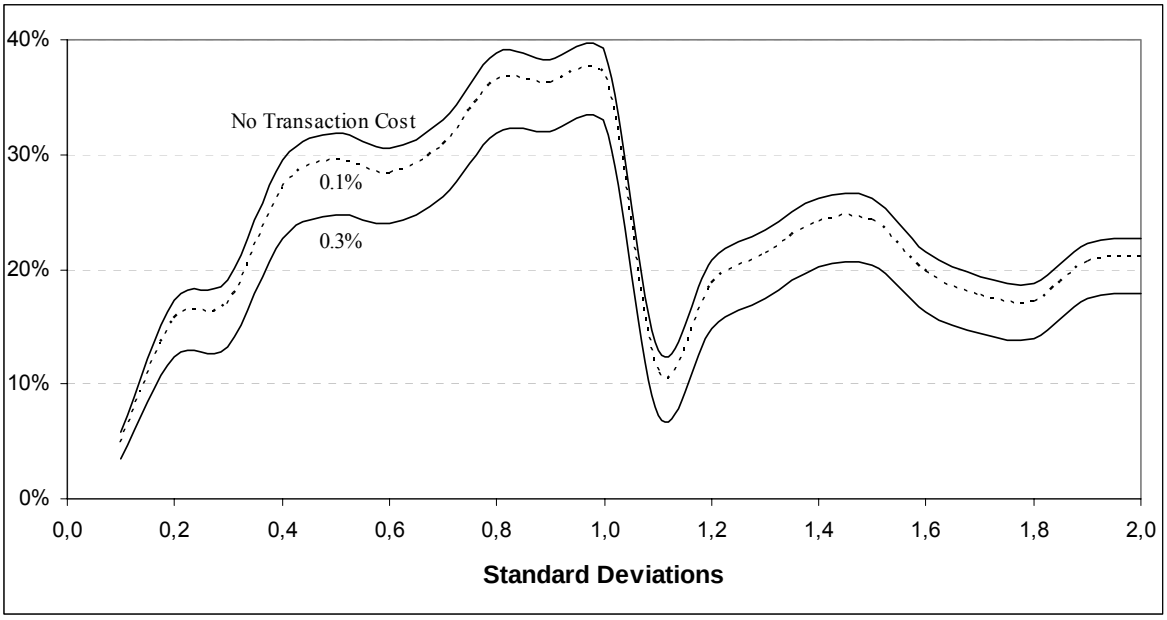
Pairs Portfolio	**Top 5**	**Top 10**	**Top 20**	**Top 50**	**Top 101-120**	**All**
Average Return	21,1%	10,7%	-5,7%	-10,5%	-24,5%	1,6%
Maximum	82,8%	82,8%	82,8%	86,1%	59,2%	135,6%
Minimum	-92,3%	-134,8%	-134,8%	-159,1%	-158,6%	-159,1%
Median	38,2%	38,1%	8,1%	-4,1%	-15,9%	11,5%
Standard Deviation	69,4%	73,5%	63,6%	56,2%	57,8%	53,5%
Skewness	-1,40	-1,16	-0,57	-0,55	-0,59	-0,50
Kurtosis	1,96	0,31	-0,60	0,05	-0,18	-0,03

Figure 4.5 compares the average return for top 5 pairs for different standard deviation threshold levels before and after the transaction costs. The profitability for all standard deviation threshold levels decreases since the transaction cost increases the prices of the stocks bought and decreases the prices of the stocks sold, and has a negative effect on the return levels.

Although 0.1% transaction cost decreases the return of the strategy, the observations for top 5 pairs have profit for each standard deviation level. Moreover, top 5 pairs portfolio still ends in positive returns in case the transaction cost is applied as the market average level of 0.3%, without any discount due to the volume traded.

[2] Akbank Türk A.Ş. – Private banking, Raymond James Securities Turkey – Internet execution

Figure 4.5. Average Return for Top 5 Pairs after Transaction Costs



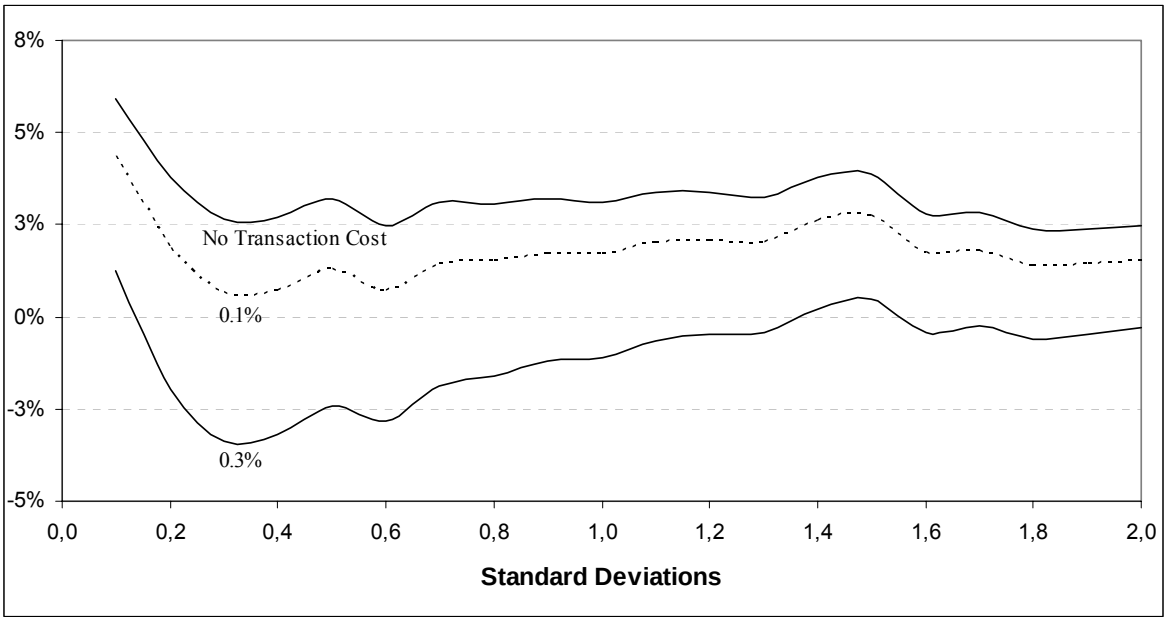
Since the transaction cost depends on the number of trades executed, the decrease in the return is not reflected as a parallel shift of the performance line for all threshold levels after adding the transaction cost. While three lines plotting the return series are very close to each other between 0.9 and 1.1 standard deviations threshold levels, the spread gets wider for the lower and higher standard deviation levels. For the standard deviation threshold levels generating more trades to execute, the transaction cost increases and the spread between the return lines increases.

When we compare the results for all pairs portfolio before and after having additional transaction costs, we observe that the decrease in the return level is higher for the lower standard deviation threshold levels as the number of trades is higher with a narrower standard deviation threshold level. As the number of trades change with the standard deviation, the burden of transaction costs also change and the decrease of the average return is not a parallel shift of the line showing the performance without the transaction costs.

Although having transaction cost has a negative effect on performance of all pairs portfolio, 0.1% transaction cost is low enough to have positive returns with all pairs for each standard

deviation threshold level. 0.3% transaction cost, on the other hand, makes the performance of the strategy decrease more and only 15% of the observations left with a positive return after adding transaction costs.

Figure 4.6. Average Return for All Pairs after Transaction Costs



As it is summarized with Table 4.6, returns of the portfolios decrease by 0.8 to 1.6% with 0.1% transaction cost and by 2.5% to 4.8% with 0.3% transaction cost per trade. The most negatively effected portfolio with the additional transaction costs is the top 5 pairs. Average return generated for top 5 pairs decreases by 1.6% and 4.8% with 0.1% 0.3% transaction costs, respectively. However, top 5 pairs portfolio is still the best performing portfolio among all portfolios.

The magnitude of the negative effect decreases as the pairs forming the pairs show higher deviation. While the return of the top 20 pairs decreases by 1.3% to 3.8%, panel data composed of pairs between 101st and 120th ranking lose 0.8% to 2.5% of its profit with the transaction costs.

Table 4.6. Decrease in Strategy Returns after Transaction Costs

	Top 5	Top 10	Top 20	Top 50	101-120	All
0.1% Transaction Cost						
Average Return	-1,6%	-1,4%	-1,3%	-1,1%	-0,8%	-0,9%
Maximum	-2,5%	-2,5%	-2,5%	-1,5%	-1,3%	-2,9%
Minimum	-0,9%	-0,8%	-0,8%	-0,7%	-0,7%	-0,7%
Median	-1,4%	-1,4%	-0,9%	-0,8%	-0,5%	-0,7%
Standard Deviation	-0,7%	-0,5%	-0,4%	-0,3%	-0,1%	-0,2%
0.3% Transaction Cost						
Average Return	-4,8%	-4,3%	-3,8%	-3,2%	-2,5%	-2,8%
Maximum	-7,6%	-7,6%	-7,6%	-4,6%	-3,8%	-6,9%
Minimum	-2,6%	-2,4%	-2,4%	-2,2%	-2,2%	-2,2%
Median	-4,2%	-4,3%	-2,8%	-2,4%	-1,5%	-2,9%
Standard Deviation	-2,1%	-1,6%	-1,2%	-0,9%	-0,4%	-0,6%

After having the performance results for the pairs trading strategy, we can have the following conclusions:

- The lower the standard deviation, the higher the number of trades and the higher the negative effect of the transaction cost over the performance.
- Top 5 pairs portfolio is still the best performing portfolio after adding the transaction costs.
- Top 5 pairs portfolio generates positive returns for each standard deviation threshold level, with either 0.1% or 0.3% transaction costs.
- All pairs portfolio generates positive returns for each standard deviation threshold level with 0.15 transaction cost. However, if the transaction cost is increased to 0.3%, only 15% of the observations generate profit.

4.4. Bid-Ask Spread

In the previous parts of the study, the results are generated with assumption that any trade signal is executed with the daily close prices. However, the price of buying and selling any stock will be different in practice as there is a bid-ask spread for each stock that is the difference between the price levels to buy and sell in the market.

In order to understand the effects of bid-ask spread on the performance of the strategy, we have to use different prices for the inverse transactions for each stock. In stead of using only one daily close price, we have collected both bid and ask price series for each stock during the trading period. From these price series, we use the ask price for the stock when the trading signal indicates to buy and use the bid price for the stock when the trading signal indicates to sell.

Since there is a spread for each transaction to be faced with bid/ask prices, it is expected that performance of the pairs trading strategy will decrease. Table 4.7 summarizes the performance of the strategy with 2.0 standard deviation threshold level after using bid and ask prices in stead of daily closing prices.

Table 4.7. Strategy Results by using Bid/Ask Prices with 2.0 Standard Deviations

Pairs Portfolio	**Top 5**	**Top 10**	**Top 20**	**Top 50**	**101-120**	**All**
Average Return	14,8%	5,1%	-13,0%	-16,7%	-29,3%	-3,4%
Maximum	74,1%	74,1%	74,1%	80,1%	54,7%	123,3%
Minimum	-95,9%	-137,7%	-137,7%	-162,4%	-159,8%	-162,4%
Median	32,2%	31,7%	-3,6%	-12,4%	-22,8%	5,4%
Standard Deviation	67,2%	71,5%	63,5%	55,4%	56,7%	53,0%
Skewness	-1,46	-1,21	-0,55	-0,56	-0,55	-0,55
Kurtosis	2,20	0,42	-0,73	0,03	-0,19	-0,08
Observations with return > 0	80%	70%	50%	40%	40%	54%
Observations with return < 0	20%	30%	50%	60%	60%	45%

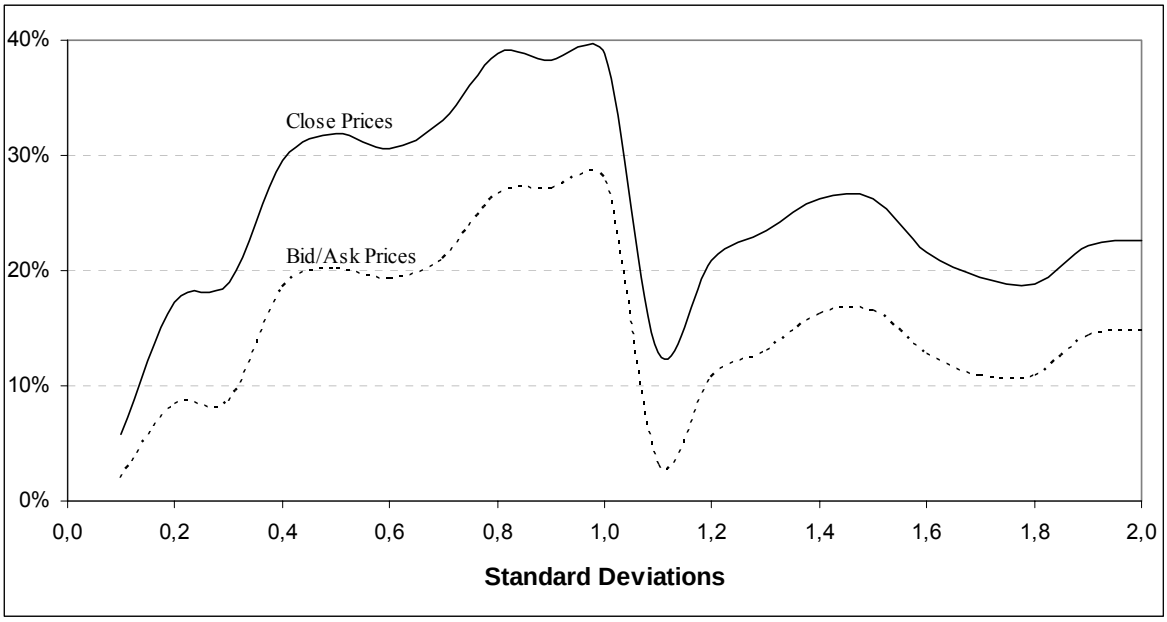
The average profit level for top 5 and top 10 pairs are 14.8% and 5.1%, respectively. Although these two portfolios still generate positive returns, the downfall of the performance is significant. For the other portfolios, on the other hand, the loss levels are 13.0% and 16.7% for top 20 and top 50 pairs with bid and ask prices, respectively.

With the use of bid and ask prices for during trading period, both the return levels and the percentage of observations with positive return decrease. The decrease of the percentage of profit generating pairs can be observed more drastically for the portfolios composed of

pairs with higher deviation. The percentage for top 50 pairs decreased from 48% to 40% with bid and ask prices compared to daily close prices.

Figure 4.7 shows the comparison of the performance of top 5 pairs for different standard deviation levels while using close prices and bid/ask prices. The return of the strategy decreases significantly with bid/ask prices for top 5 pairs. However, the strategy is still profitable for each standard deviation threshold level.

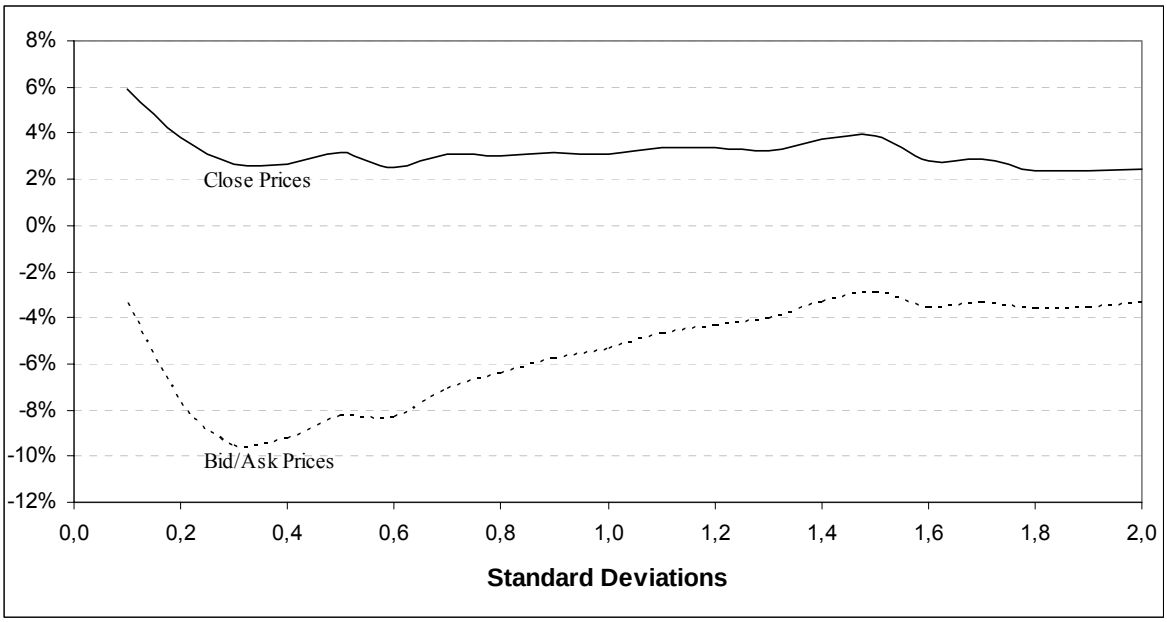
Figure 4.7. Average Return for Top 5 Pairs by using Bid/Ask Prices



The spread between the return line with daily close prices and bid/ask prices is not equal in all standard deviation levels. The level of this spread is both affected from the liquidity conditions of the market and the number of trades executed. In an illiquid market with very few number of buyers and sellers, the bid/ask spread will be wider and the cost over the return will be higher. Moreover, as much trades as you execute, the frequency you have to incur the bid/ask spread will increase and the performance of the strategy will decrease more.

Figure 4.8 shows the comparison of the performance of all pairs for different standard deviation levels by using daily close prices and bid/ask prices. While the portfolio composed of all pairs results in profit for all standard deviation levels by using daily close prices of the stocks, the performance of the strategy decreases by using bid/ask prices. Moreover, the average return of the portfolio turns into negative for all standard deviation levels.

Figure 4.8. Average Return for All Pairs by using Bid/Ask Prices



The spread between the return lines of close prices and the bid/ask prices is higher for lower standard deviation levels. As mentioned in the previous sections, a narrower standard deviation threshold level will facilitate to encounter position entrance signals since the normalized prices of the pairs can deviate in a narrower band easily. Then, the strategy with lower standard deviation threshold level will generate more trades and the spread between bid and ask prices should be incurred more frequently. Therefore, performance will decrease more significantly with narrower threshold bands.

As shown in Table 4.8, using bid/ask prices during the trading period in stead of daily close prices decreases the return of the portfolios between 5.7% and 8.6%. However, the

riskiness of the portfolio returns also decrease as the standard deviation of returns is lower with bid and ask prices.

The most negatively effected portfolio is top 20 pairs, but the magnitude of decrease in returns does not fluctuate heavily and we can not have a direct conclusion about whether bid/ask spreads have more significant effect over a specific portfolio.

Table 4.8. Decrease in Strategy Returns by using Bid/Ask Prices

	Top 5	**Top 10**	**Top 20**	**Top 50**	**101-120**	**All**
Average Return	-7,8%	-7,1%	-8,6%	-7,2%	-5,7%	-5,8%
Maximum	-11,2%	-11,2%	-11,2%	-7,5%	-5,8%	-15,2%
Minimum	-4,4%	-3,6%	-3,6%	-4,0%	-2,0%	-4,0%
Median	-7,4%	-7,9%	-12,6%	-9,1%	-7,4%	-6,8%
Standard Deviation	-2,9%	-2,6%	-0,5%	-1,0%	-1,2%	-0,8%

After having the performance results for the pairs trading strategy with bid and ask prices, we can have the following conclusions:

- Top 5 pairs returns profit for each standard deviation threshold level when the bid ask prices are used in stead of daily close prices.
- Although all pairs portfolio have positive return with daily close prices, it is not possible to have profit on average with bid and ask prices for all standard deviation threshold levels.
- Performance of the portfolio decreases as the pairs included in the portfolios deviate more from each other.
- There is not a direct relationship between the magnitude of negative effect with bid/ask prices and the standard deviation threshold level as other variables like the number of transactions are also important.

4.5. Liquidity Crisis Scenario

In the previous sections of our study, we have shown that the probability of having positive returns is high by using top 5 pairs in terms of sum of squared deviations between the normalized price series if the pairs trading strategy is implemented in a market that has daily liquidity for stocks. In addition, although having transaction costs or using bid/ask spread have significant downward effect on the performance, top 5 pairs portfolio still conserves the positive performance for each standard deviation threshold level.

However, the risk behind the pairs trading strategy is lack of liquidity in the market. In case the position is open and the investor is long in one stock and short in the other when the liquidity is lost, the cost of closing out the positions will be huge. The transactions will be held in any possible prices available in the market and the investor will have to carry the burden due to lack of liquidity.

In order to analyze the results of such a liquidity crisis, we built a simple scenario that uses daily low prices to sell the stocks and daily high prices to buy the stocks. Although daily low and high prices are used as the only prices available in the market in the liquidity crisis, it may even not be possible to find these prices since the liquidity crisis makes both the stock and cash market to disappear immediately.

Table 4.9 summarizes the performance of the strategy with 2 standard deviation threshold level after using daily low and high prices in stead of daily close prices. As the spread between daily low and high prices is much higher compared to bid/ask spread implemented in the previous section, the performance of the pairs trading strategy is expected to be much worse.

All portfolios return heavy negative losses during the trading period with daily low and high prices. Although top 5 pairs is still the best performing portfolio, it ends in 28.1% loss

and there is no observation among top 5 pairs that has positive return. The loss can reach up to 48.3% as the deviation between the price series increases.

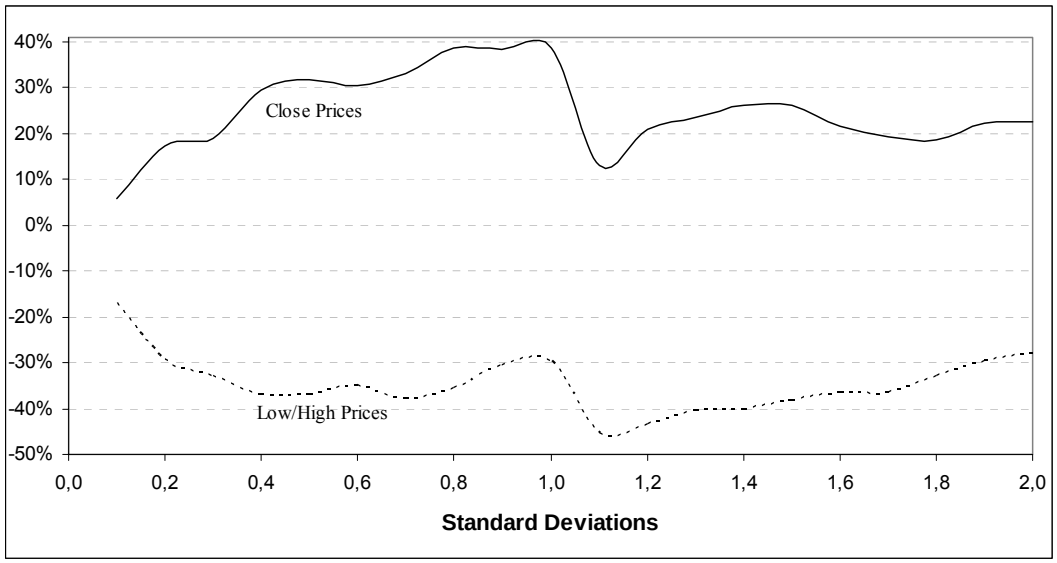
Table 4.9. Strategy Results by using Low/High Prices with 2.0 Standard Deviations

Pairs Portfolio	**Top 5**	**Top 10**	**Top 20**	**Top 50**	**101-120**	**All**
Average Return	-28,1%	-32,0%	-44,0%	-40,9%	-48,3%	-25,1%
Maximum	-4,0%	16,8%	16,8%	27,4%	27,4%	72,5%
Minimum	-106,7%	-145,0%	-145,0%	-168,9%	-171,4%	-171,4%
Median	-8,8%	-10,8%	-35,5%	-31,5%	-30,7%	-15,6%
Standard Deviation	44,1%	52,9%	49,5%	45,9%	56,0%	49,7%
Skewness	-2,19	-1,52	-0,81	-0,91	-0,69	-0,73
Kurtosis	4,83	1,35	-0,40	0,38	-0,41	-0,06
Observations with return > 0	0%	20%	15%	16%	15%	36%
Observations with return < 0	100%	80%	85%	84%	85%	64%

It is possible to have profit generating observations with low and high prices as 36% of the observations in all pairs have positive returns. In addition, the maximum return is 16.8% for top 10 and 20 pairs and 72.5% for all pairs. However, the observations with positive returns can not offset the loss incurred over the other pairs included in the portfolios.

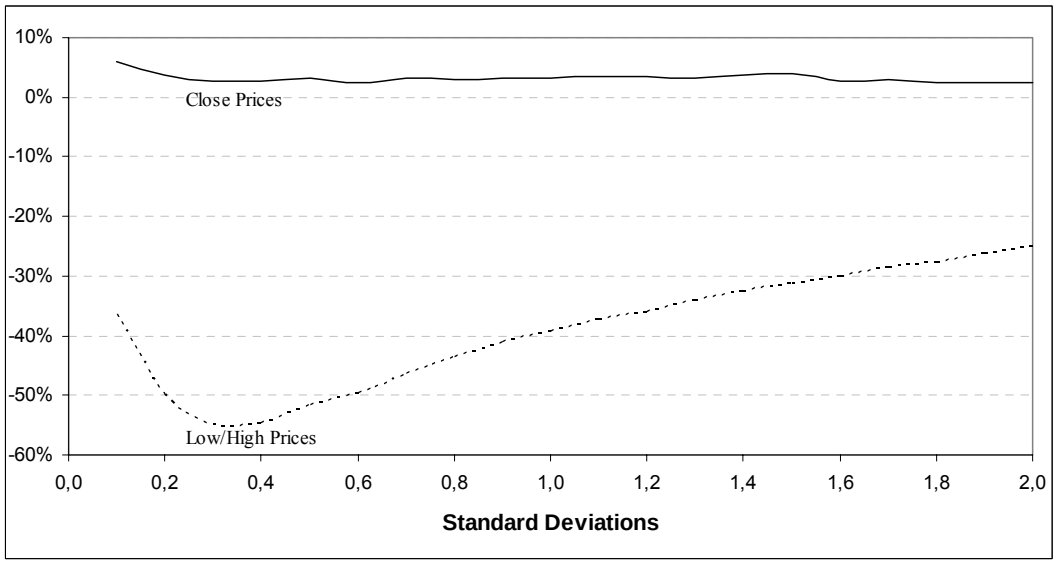
As shown in Figure 4.9, top 5 pairs returns negative results in each standard deviation threshold level. The loss can reach up to 45.3%, which can be observed with 1.1 standard deviation level, which is also the threshold level that has the worst performance with daily close prices.

Figure 4.9. Average Return for Top 5 Pairs by using Low/High Prices



The lowest loss that can be achieved with all pairs portfolio is 24.9%. The best performance, which is still a heavy loss, is observed at 2.0 standard deviation level. The worst performance with 54.8% loss is observed at 0.3 standard deviation level. While the return with daily close prices is over zero for each standard deviation level, it is not possible to have profit on average with low and high prices.

Figure 4.10. Average Return for All Pairs by using Low/High Prices



When we compare the performance of the portfolios at 2 standard deviation level for the liquidity crisis scenario, we can conclude that lack of prices at the market makes the strategy totally fail. Average return decreases by 50.8% for top 5 pairs, and by 44.1% for top 10 pairs. The maximum return that can be observed is -33.1% for any pair alternative.

Table 4.10. Decrease in Strategy Returns by using Low/High Prices

	Top 5	**Top 10**	**Top 20**	**Top 50**	**101-120**	**All**
Average Return	-50,8%	-44,1%	-39,6%	-31,4%	-24,7%	-27,6%
Maximum	-89,3%	-68,6%	-68,6%	-60,1%	-33,1%	-66,0%
Minimum	-15,3%	-11,0%	-11,0%	-10,5%	-13,5%	-13,0%
Median	-48,4%	-50,4%	-44,6%	-28,3%	-15,3%	-27,9%
Standard Deviation	-25,9%	-21,1%	-14,4%	-10,6%	-1,9%	-4,0%

We can have the following conclusions according to the performance results for the pairs trading strategy with daily low and high prices, which is the scenario generated for liquidity crisis:

- There is no observation with positive return at the end of the trading period.
- Although the downward shift of the return series with daily low and high prices is not a parallel shift of the return series with daily close prices, the spread between the series is very high for all standard deviation threshold levels.

5. RISKS WITH PAIRS TRADING STRATEGY

Pairs trading is basically a market neutral strategy in terms of being long in one asset and short in another asset with the same amounts of capital which makes the investment dollar-neutral. The strategy does not bet on the market direction but just hold the position with the expectation of spread reverting to its mean. However, it is not possible to avoid systematic market risk totally by having long and short position.

Since the characteristics and the market betas of the assets are different from each other, there remains the market risk and investment is exposed to the direction of the market. Even though it is still risky to invest in such a strategy, the risk being involved can be ignored compared to the position that is held by holding one asset, or shorting one asset by its own.

The portfolio composed of long and short positions in two assets can be market neutral in terms of beta or sector. However, mismatches on other important factors like market capitalization, liquidity or value/growth ratios may result in different risk exposures from long and short positions. One simple precaution for eliminating mismatch of stocks is to avoid having negatively correlated stocks in long and short portfolios. Stocks having strong negative correlations among each other are expected to have totally opposite characteristics, which can be determined as lacking comovement between the selected pairs.

As the pairs trading strategy is formed with the expectation of pair stocks to be a hedge for each other, the riskiness of the portfolio should be lower compared to the traditional directional trading. However, the strategy is riskier than directional trading for the extreme cases, as each trade consists of two positions hold in two different assets. If the position goes against the investor's direction, which is the reversion of the price relationship to its long run equilibrium, there is double the exposure of a traditional directional trade.

Besides the riskiness of the strategy for a standalone portfolio, any general drastic price move will spread over the market rapidly and the effects of having quantitative managed portfolios such as pairs trading end in heavy losses for the hedge funds.

Khandani and Lo (2007) reviewed the performance of long/short equity strategies during the last decade and analyzed the profitability of the strategies during August 2007. Financial markets faced a sharp decline in August 2007 due to the negative news about U.S. sub-prime mortgage market. Although long/short equity strategies are expected to be market neutral and many hedge funds have portfolios investing mainly in exchange traded equities which constitute the primary market, these hedge funds were among the players who have lost the most during the second week of August 2007 and Khandani and Lo (2007) attempted to identify the reasons for such heavy losses.

On August 7th and 8th, there were no signs of any market turmoil as S&P 500 index gained 0.62% and 1.44% each day and CBOE Volatility Index (VIX) decreased by 1.04 and 0.11. However, on August 9th, all the markets suffered extreme losses. S&P 500 index was down 2.95% and VIX jumped by 5.03.

Although the reason for such extraordinary return pattern is not clear as the activities of hedge funds are not disclosed publicly, one explanation suggested with the study is that there existed a large-scale strategy liquidation and the market move was the temporary price impact resulting from that large and rapid unwinding of more quantitative equity market-neutral portfolios.

According to the assumption of the study, one large-scale market neutral strategy generated a trigger that made the portfolio to be unwounded. However, the price impact of the execution of the close out resulted in extra margin maintenance necessity for other smaller sized portfolios of different hedge funds and they also had to have inverse positions in their illiquid portfolios. The losses spread over the whole hedge fund market due to the snowball effect of the unwind process.

The unwind process and the risk reduction of the hedge funds were mainly achieved by August 9th, and the resulting cumulative price impact of the previous three days have created even stronger trading signals for the long/short equity strategies. The price impact of August 7-9 was so severe that it drew the attention of new investors who recognized that the closing prices on August 9th were temporarily out of equilibrium and it can be exploited by buying securities at artificially deflated prices. Therefore, the downward turmoil disappeared quickly, the stock indices gained value and the VIX index decreased in August 10th.

A similar market condition has been experienced on August 17, 1998 with the Russian default on government bonds. The event of default caused a global flight to quality and credit spreads widened significantly which generated extreme losses for fixed income arbitrage hedge funds.

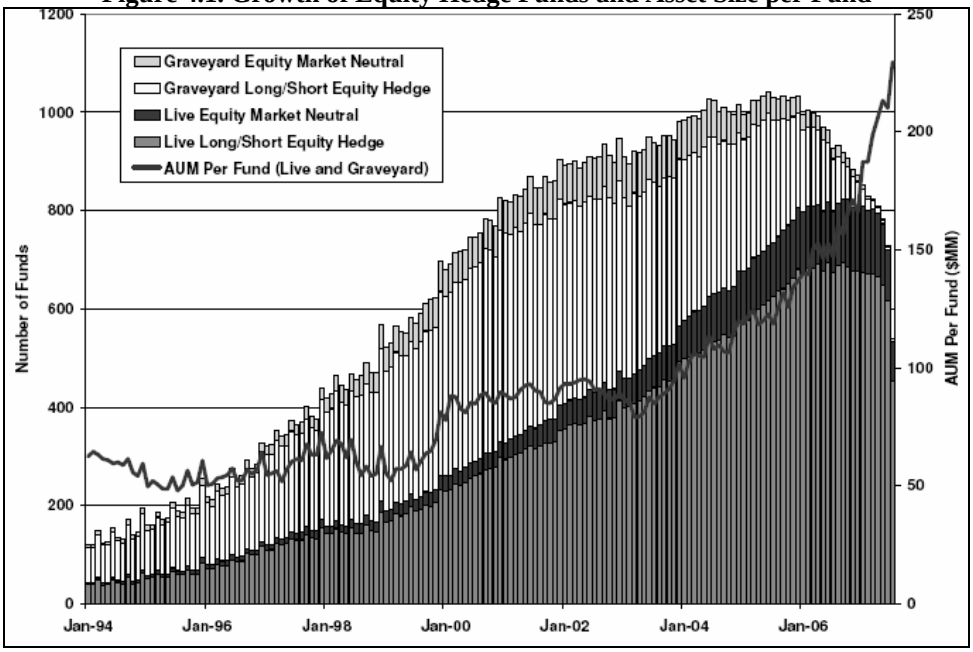
Although the August 1998 mechanism, starting from the unwinding of illiquid portfolios for margin requirements and ending in further losses, was similar to the scenario observed in August 2007, Khandani and Lo (2007) mentioned that the turmoil in financial markets had little or no effect on the performance of the market neutral strategies during August 1998.

The main differences between the period of August 1998 and August 2007 are summarized as follows:

- Asset size devoted to long/short equity strategies increased,
- The profitability of quantitative equity market neutral strategies declined due to increasing competition and technological advances,
- Equity market volatility declined,
- Leverage increased to maintain the levels of expected returns required by hedge funds,
- Financial markets lack the information about how crowded the long/short equity strategies had become and could not understand the risks with the market downturns.

As Figure 4.1 implies, both the number of equity-market neutral and long/short equity hedge funds have grown rapidly over the last years. Moreover, average asset size per funds has increased exponentially. With the increased number of hedge funds and the asset sizes, financial markets became more vulnerable to the activities of hedge funds.

Figure 4.1. Growth of Equity Hedge Funds and Asset Size per Fund



The simultaneous increase in the number of hedge funds in the market and average asset size per fund resulted in greater competition with the help of advanced computational technologies. Increased competition inevitably reduced profitability of the strategies implemented by such funds. In order to compensate the reduced profitability of the strategies, hedge funds have increased the leverage in their strategies. Although the size of the portfolios held by the hedge funds seems to be manageable in terms of market risk exposed, the size of the positions is often considerably larger than the amount of collateral due to the leverage.

The study of Khandani and Lo (2007) also showed that the correlations among the various different hedge fund categories have increased in the last years. As a result, the higher the

correlation among the strategies, the more destructive the effects of any market turmoil over the whole financial market since the liquidation process spreads more rapidly.

Any market neutral portfolio is formed to have positive expected return as time goes to infinity. However, regardless of the portfolio's expected return during normal market conditions, if a rapid and large unwind process is faced, all such portfolios experience losses. The magnitude of loss will be directly proportional to the size and speed of unwind process. Therefore, the losses are the results of the liquidation of quantitatively constructed portfolios rather than the defectiveness of the quantitative strategy.

In addition, with the market neutral strategies attracting high capital inflows due to the excess profitability opportunities, the risk term in the strategy becomes an endogenous element and is affected drastically with the capital flows. The historical estimates of volatility and price impact can not be the accurate risk measures as the risk exposure changes with the market dynamics. Therefore, it is not possible to use standard models such as Value-at-Risk and the assumptions of normal distribution in risk management.

Moreover, as the extreme observations, which are the tail events in the probability distribution, are rare with the selected top 5 pairs according to the pairs selection criteria, the trading model is subject to large estimation error. Therefore, the peso problem, which is mentioned by Bondarenko (2003), arises when an event that is rare and did not happen during the sampling period happens in the trading period. While the model built with the use of historical prices does not have any market crash scenarios in the sample set and the model did not undertake the results of any such extreme observations, it is still possible to have unexpected market moves, which are actually the main risks with the pairs trading strategy.

Besides the risks included in the model, the risk of asset specific events still remains with pairs trading, that is, any change in fundamentals of the asset, or any other change in the market conditions that will affect one of the assets in the pairs may result in new long run

equilibrium to be formed. Alternatively, the prices may never mean revert again and the pair relationship may never be observed again among the two assets.

We can conclude that although the strategy is profitable in all cases of convergence of prices to the long run equilibrium and the portfolio is market-neutral, pairs trading strategy involves risks due to breaking up of the long run relationship of the stocks and disappearing of liquidity in the market. With higher number of hedge funds using market neutral strategies and the increased leverage of these hedge funds, the effects of any unexpected market turmoil results in the fail of the strategy rapidly. Therefore, any position held in pairs trading strategy should be closely monitored and risk management rules should be set without relying on the market neutrality.

6. SUMMARY

In this thesis, we have tested the performance of Pairs Trading, a market-neutral trading strategy mainly implemented by hedge funds, on Istanbul Stock Exchange stocks. We have tried to identify the effects of pairs selection, threshold level selection and using bid/ask or low/high prices on the profitability of the trading strategy.

We have replicated the study of Gatev et al. (2006) and built a trading strategy that will invest in the price deviations of pairs of stocks relative to each other, instead of the market direction. We calculated the difference between the normalized price series of stocks and tried to detect the deviations from the long run relationship between pairs of two stocks, which is pointed out with standard deviation of the difference during the pairs formation period.

According to the empirical results of the pairs trading strategy, having portfolios of stocks those have the lowest deviation between the normalized price series improves the profitability of the strategy. While top 5 pairs portfolio has 22.7% return during the trading period, portfolios formed with highly deviated pairs of stocks can not beat the performance of top 5 pairs. In addition, the probability of having profit generating observations is higher with the portfolios having low deviation between the normalized price series.

When we use wider standard deviation bands as threshold levels for entrance, the number of transactions decreases. It is observed that maximum number of trades is reached between 0.3 and 0.5 standard deviations for all portfolios. In addition, with wider standard deviation bands, if the entrance signal is detected and position is opened, it will take more time of normalized price series to cross each other again. Therefore, the position is carried for longer periods with higher standard deviation bands.

If we include transaction costs and regenerate the strategy performance results, return levels decrease depending on the number of transactions. Return of the top 5 pairs portfolio

decreases to 21.1% with 0.1% transaction cost per leg, and to 17.9% with 0.3% transaction cost per leg. While top 5 pairs portfolio is still the most profitable portfolio after incurring transaction costs, all pairs portfolio ends in loss with 0.3% transaction cost at the end of the trading period.

The models in the literature implementing pairs trading generally use daily close prices of stocks. However, it is not easy to execute trades at close prices every time in practice. Therefore, in order to generate more realistic results, we analyzed the strategy results by using bid/ask prices during the trading period. The results show that average return of the portfolios decreases by 6-9% with bid/ask prices. Top 5 pairs portfolio, on the other hand, is still generating positive returns and the performance of the portfolio is robust to bid/offer spread.

As the main risk with the pairs trading strategy is the lack of liquidity of the stocks in case of a rapid market change, we built a simple scenario that uses daily low and high prices as the only available prices in the market in a liquidity crisis. With low and high prices, all portfolios return heavy negative losses during the trading period. Although top 5 pairs is still the best performing portfolio, the portfolio ends in 28.1% loss and there is no observation among top 5 pairs that has positive return.

With the increase in number of hedge funds and the asset size devoted to market neutral strategies, highly leveraged portfolios of these funds invested in different sectors and lacking the information about how crowded the hedge fund market had become, the effects of any market movement against pairs trading strategy spreads over the market easily. Regardless of the pairs trading portfolio expected return during normal market conditions, if a rapid and large unwind process exists, all such portfolios experience heavy losses. Therefore, these losses should be concluded as the results of the liquidation process of such quantitative portfolios rather than the defectiveness of the quantitative trading strategies.

Pairs trading is classified as a market neutral strategy. However, it is not possible to avoid systematic market risk totally. The portfolio composed of long and short positions in assets can be market neutral in terms of beta or sector. However, mismatches on other important factors like market capitalization, liquidity or value/growth ratios may result in different risk exposures from long and short positions. Therefore, the risk of asset specific event still remains with Pairs Trading. Moreover, the investor should be aware that the model is formed with the historical price series of assets and the model will be efficient as long as history repeats itself.

7. CONCLUSION

The study results shows that pairs trading strategy generates profit by using stocks from Istanbul Stock Exchange. However, although the strategy is named as statistical arbitrage strategy, the risk of the position ending in loss can never be dismissed.

The main implication of the study is that the pairs selection process based on the deviation between the normalized price series of stocks improves the performance of the strategy. As we have observed with the trading model results, top 5 pairs according to the pairs selection criteria generates the highest profit among the alternative pairs. The only exception that the portfolio ends in loss is the liquidity crisis scenario where the model uses low/high prices for trade execution.

The investor should bear in mind that there is no way to build fully hedged and totally risk neutral positions with Pairs Trading Strategy as there always remains the risk of break down of the relationship between the stocks. In addition, liquidity risk that may be encountered in significant market downturns is more important than the relationship between the stocks. Any liquidity crisis will make the whole strategy meaningless and result in a heavy loss, which has been mainly experienced with the global crisis cases of hedge funds.

We have studied performance of the trading strategy for daily observations. However, having intraday price data may provide more information about the robustness of the quantitative model and can be the subject of further researches. In addition, it will be informative to analyze the effects of price volatility during the trading period over the performance of the strategy as we only used historical prices in building our trading model.

As a final word, pairs trading strategy based on the pairs selection criteria that will capture the deviation between the price series combined with fundamental analysis to detect capture any unanticipated market crash will be the best decision for success.

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8. APPENDICES

A.1. Table of Stocks

TICKER	NAME	INDUSTRY SECTOR	INDUSTRY GROUP
AKBNK	AKBANK TAS	Financial	Banks
AKGRT	AKSIGORTA	Financial	Insurance
ARCLK	ARCELIK AS	Consumer, Cyclical	Home Furnishings
AYGAZ	AYGAZ AS	Consumer, Cyclical	Distribution/Wholesale
DOHOL	DOGAN SIRKETLER GRUBU	Diversified	Holding Companies-Divers
DYHOL	DOGAN YAYIN HOLDING	Communications	Media
ECILC	ECZACIBASI ILAC SAN VE TIC	Consumer, Non-cyclical	Pharmaceuticals
EREGL	EREGLI DEMIR VE CELIK FAB	Basic Materials	Iron/Steel
GARAN	TURKIYE GARANTI BANKASI	Financial	Banks
HURGZ	HURRIYET GAZETECILIK	Communications	Media
ISCTR	TURKIYE IS BANKASI-C	Financial	Banks
ISGYO	IS GAYRIMENKUL YAT O	Financial	REITS
KCHOL	KOC HOLDING AS	Diversified	Holding Companies-Divers
KRDMD	KARDEMIR KARABUK DEMIR C	Basic Materials	Iron/Steel
MIGRS	MIGROS TURK TAS	Consumer, Non-cyclical	Food
PETKM	PETKIM PETROKIMYA HOL AS	Basic Materials	Chemicals
PTOFS	PETROL OFISI AS	Consumer, Cyclical	Retail
SAHOL	HACI OMER SABANCI HOLDING	Diversified	Holding Companies-Divers
SISE	TURK SISE VE CAM FAB	Consumer, Cyclical	Housewares
SKBNK	SEKERBANK	Financial	Banks
THYAO	TURK HAVA YOLLARI AO	Consumer, Cyclical	Airlines
TSKB	TURKIYE SINAI KALK BANK	Financial	Diversified Finance Service
TUPRS	TUPRAS-TURKIYE PETROL R	Energy	Oil&Gas
ULKER	ULKER BISKUVI SANAYI AS	Consumer, Non-cyclical	Food
YKBNK	YAPI VE KREDI BANKASI	Financial	Banks

A.2. Sample Trade Statistics

	KRDMD vs SKBNK	ARCLK vs SKBNK
Standard Deviation Threshold	2	2
Standard Deviation	12,33%	11,25%
Sum of Squared Deviations	11,577	5,437
Sum of Deviations	-31,737	-20,454
Average	-0,317	-0,205
Minimum	-0,531	-0,429
Maximum	0,000	0,027
5% Quantile	-0,511	-0,383
95% Quantile	-0,045	-0,019
Standard Deviation	0,123	0,113
Number of Trades	7	3
Total Days in Position	180	292
Maximum Days in Position	68	221
Minimum Days in Position	2	28
Average Days in Position	25,7	97,3
Standard Deviation of Days in Position	23,1	107,4
Stock 1 Return	46,35%	-33,91%
Stock 2 Return	92,15%	-49,22%
Total Return	138,50%	-83,13%
Maximum Return for One Trade	36,82%	25,63%
Minimum Return for One Trade	2,22%	-128,20%
Average Return for One Trade	19,79%	-27,71%
Standard Deviation of Returns for One Trade	12,35%	87,08%

A.3. Performance of the Strategy

		Top 5	Top 10	Top 20	Top 50	101-120	All
	Average Sum of Squared Deviations	0,26	0,31	0,43	0,71	2,22	5,31
	St.Dev. of Normalized Price Deviations	4,71%	5,03%	5,49%	6,72%	10,59%	10,72%
	Number of Pairs	5	10	20	50	20	300
	Average Correlation	0,83	0,82	0,80	0,70	0,43	0,39
0.5 STANDARD DEVIATION	Average Return	31,9%	22,6%	0,5%	-5,7%	-27,3%	3,2%
	Maximum	81,6%	81,6%	81,6%	102,1%	80,5%	155,7%
	Minimum	9,8%	-138,4%	-138,4%	-164,5%	-179,5%	-179,5%
	Median	17,5%	28,4%	10,5%	0,8%	-29,8%	9,0%
	Standard Deviation	30,2%	63,6%	65,9%	62,7%	65,7%	60,2%
	Skewness	1,53	-2,00	-0,81	-0,52	-0,35	-0,47
	Kurtosis	1,89	4,96	-0,23	-0,20	0,13	-0,07
	Observations with return > 0	100%	90%	60%	50%	30%	55%
	Number of Trades	28	74	120	273	165	1296
	Average Number of Trades	5,60	7,40	6,00	5,46	8,25	4,32
	Average Days in Position	260	275	313	345	363	359
1.0 STANDARD DEVIATION	Average Return	38,8%	28,1%	-1,9%	-6,1%	-22,9%	3,1%
	Maximum	77,0%	80,8%	80,8%	104,7%	87,8%	143,4%
	Minimum	11,2%	-145,3%	-145,3%	-160,7%	-156,7%	-160,7%
	Median	30,7%	44,4%	10,2%	2,8%	-23,1%	9,3%
	Standard Deviation	28,0%	67,2%	65,4%	61,3%	60,7%	56,9%
	Skewness	0,59	-2,18	-0,74	-0,54	-0,18	-0,46
	Kurtosis	-1,74	5,54	-0,13	-0,02	-0,19	-0,11
	Observations with return > 0	100%	90%	65%	54%	30%	58%
	Number of Trades	24	57	89	199	117	956
	Average Number of Trades	4,80	5,70	4,45	3,98	5,85	3,19
	Average Days in Position	271	298	333	348	350	351
1.5 STANDARD DEVIATION	Average Return	26,2%	22,6%	-2,4%	-6,0%	-25,3%	3,9%
	Maximum	90,5%	91,5%	91,5%	109,7%	56,5%	130,4%
	Minimum	-88,0%	-141,8%	-141,8%	-156,0%	-157,1%	-157,1%
	Median	54,1%	57,8%	6,7%	-1,0%	-23,4%	10,1%
	Standard Deviation	70,1%	79,2%	69,5%	61,5%	58,6%	55,9%
	Skewness	-1,39	-1,35	-0,45	-0,35	-0,47	-0,45
	Kurtosis	1,80	0,87	-0,76	-0,14	-0,30	-0,14
	Observations with return > 0	80%	80%	55%	50%	35%	57%
	Number of Trades	21	46	72	157	92	755
	Average Number of Trades	4,20	4,60	3,60	3,14	4,60	2,52
	Average Days in Position	345	319	335	338	325	331
2.0 STANDARD DEVIATION	Average Return	22,7%	12,2%	-4,4%	-9,5%	-23,6%	2,5%
	Maximum	85,3%	85,3%	85,3%	87,6%	60,5%	138,5%
	Minimum	-91,5%	-134,0%	-134,0%	-158,4%	-157,8%	-158,4%
	Median	39,6%	39,6%	9,0%	-3,3%	-15,4%	12,2%
	Standard Deviation	70,1%	74,0%	63,9%	56,5%	57,9%	53,7%
	Skewness	-1,37	-1,14	-0,56	-0,54	-0,58	-0,49
	Kurtosis	1,86	0,27	-0,60	0,03	-0,19	-0,03
	Observations with return > 0	80%	70%	55%	48%	45%	58%
	Number of Trades	17	32	55	116	84	592
	Average Number of Trades	3,40	3,20	2,75	2,32	4,20	1,97
	Average Days in Position	323	293	315	313	295	304

A.4. Average Return of Portfolios

Standard Deviation	Top 5	Top 10	Top 20	Top 50	101-120	All
0,1	5,7%	14,2%	5,2%	-9,1%	-2,2%	5,9%
0,2	17,3%	23,0%	-3,8%	-10,8%	-22,8%	3,8%
0,3	19,0%	16,2%	-4,7%	-10,0%	-28,5%	2,6%
0,4	29,5%	21,9%	-0,3%	-6,6%	-29,6%	2,7%
0,5	31,9%	22,6%	0,5%	-5,7%	-27,3%	3,2%
0,6	30,5%	23,7%	0,3%	-5,4%	-28,6%	2,5%
0,7	33,0%	24,8%	-3,2%	-7,1%	-27,8%	3,1%
0,8	38,8%	27,1%	-2,4%	-7,0%	-26,4%	3,1%
0,9	38,3%	27,6%	-2,3%	-6,0%	-25,3%	3,2%
1,0	38,8%	28,1%	-1,9%	-6,1%	-22,9%	3,1%
1,1	12,9%	15,2%	-7,6%	-8,3%	-20,5%	3,4%
1,2	20,8%	19,5%	-5,5%	-7,2%	-20,1%	3,4%
1,3	23,4%	21,2%	-5,7%	-7,0%	-23,2%	3,3%
1,4	26,2%	22,7%	-3,6%	-6,4%	-23,7%	3,8%
1,5	26,2%	22,6%	-2,4%	-6,0%	-25,3%	3,9%
1,6	21,6%	20,1%	-3,5%	-7,3%	-25,6%	2,8%
1,7	19,4%	17,4%	-5,1%	-8,2%	-25,7%	2,8%
1,8	18,8%	15,3%	-4,1%	-9,2%	-26,0%	2,4%
1,9	22,2%	14,1%	-4,2%	-9,9%	-23,5%	2,4%
2,0	22,7%	12,2%	-4,4%	-9,5%	-23,6%	2,5%

A.5. Percentage of Observations with Positive Return

Standard Deviation	Top 5	Top 10	Top 20	Top 50	101-120	All
0,1	100,0%	100,0%	90,0%	62,0%	65,0%	67,7%
0,2	100,0%	90,0%	60,0%	44,0%	40,0%	58,7%
0,3	100,0%	80,0%	55,0%	44,0%	30,0%	55,0%
0,4	100,0%	80,0%	55,0%	46,0%	30,0%	53,7%
0,5	100,0%	90,0%	60,0%	50,0%	30,0%	54,7%
0,6	100,0%	90,0%	60,0%	52,0%	30,0%	55,0%
0,7	100,0%	90,0%	55,0%	48,0%	30,0%	55,7%
0,8	100,0%	90,0%	55,0%	48,0%	30,0%	56,0%
0,9	100,0%	90,0%	55,0%	48,0%	30,0%	56,3%
1,0	100,0%	90,0%	65,0%	54,0%	30,0%	57,7%
1,1	80,0%	80,0%	55,0%	52,0%	30,0%	57,0%
1,2	80,0%	80,0%	55,0%	50,0%	35,0%	56,7%
1,3	80,0%	80,0%	55,0%	50,0%	35,0%	57,3%
1,4	80,0%	80,0%	55,0%	50,0%	35,0%	57,3%
1,5	80,0%	80,0%	55,0%	50,0%	35,0%	57,3%
1,6	80,0%	70,0%	50,0%	48,0%	35,0%	58,3%
1,7	80,0%	70,0%	50,0%	46,0%	35,0%	58,3%
1,8	80,0%	70,0%	55,0%	46,0%	35,0%	57,7%
1,9	80,0%	80,0%	60,0%	46,0%	40,0%	58,0%
2,0	80,0%	70,0%	55,0%	48,0%	45,0%	58,0%

A.6. Average Days in Position

Standard Deviation	Top 5	Top 10	Top 20	Top 50	101-120	All
0,1	81,6	84,3	116,8	194,2	227,9	251,8
0,2	172,8	163,1	239,2	281,5	323,2	308,5
0,3	229,4	259,5	290,7	311,5	367,2	337,1
0,4	256,6	275,8	308,4	331,9	364,4	353,1
0,5	259,6	275,4	312,6	345,0	363,0	358,8
0,6	264,2	277,0	316,9	347,7	369,1	360,0
0,7	279,4	283,3	329,5	351,3	367,2	359,0
0,8	275,2	279,0	325,6	348,8	360,3	355,8
0,9	271,4	296,7	333,4	351,9	354,3	353,9
1,0	271,4	298,3	332,5	348,3	350,0	351,3
1,1	344,0	332,2	348,5	354,6	346,6	348,1
1,2	350,2	330,6	346,8	351,5	341,6	344,1
1,3	348,4	326,3	341,7	346,9	332,6	339,9
1,4	346,0	321,7	337,0	342,2	327,1	335,2
1,5	344,8	319,2	334,9	338,0	324,7	331,3
1,6	339,8	315,2	332,5	333,6	321,4	325,4
1,7	339,0	311,3	328,6	328,5	312,9	319,8
1,8	337,6	306,8	325,1	323,3	309,0	315,3
1,9	335,6	301,0	320,9	318,2	305,0	309,7
2,0	323,0	292,7	315,5	313,1	294,9	303,6

A.7. Average Number of Trades

Standard Deviation	Top 5	Top 10	Top 20	Top 50	101-120	All
0,1	1,8	4,0	3,5	3,6	4,1	3,7
0,2	4,0	7,0	5,8	5,4	4,3	4,5
0,3	4,6	7,8	6,5	5,8	4,5	4,7
0,4	5,4	7,8	6,4	5,7	4,0	4,6
0,5	5,6	7,4	6,0	5,5	3,8	4,3
0,6	5,2	7,0	5,6	5,1	3,5	4,1
0,7	5,2	6,6	5,3	4,7	3,4	3,8
0,8	5,4	6,4	5,0	4,4	3,1	3,5
0,9	4,8	5,9	4,7	4,2	2,9	3,3
1,0	4,8	5,7	4,5	4,0	2,9	3,2
1,1	4,2	5,1	4,1	3,7	2,8	3,0
1,2	4,4	5,1	4,1	3,6	2,6	2,9
1,3	4,4	5,0	3,9	3,4	2,3	2,7
1,4	4,4	4,8	3,8	3,3	2,1	2,6
1,5	4,2	4,6	3,6	3,1	2,0	2,5
1,6	3,8	4,3	3,5	3,0	2,0	2,4
1,7	3,6	4,0	3,3	2,8	1,9	2,3
1,8	3,4	3,7	3,1	2,6	1,9	2,2
1,9	3,4	3,4	2,9	2,4	1,8	2,1
2,0	3,4	3,2	2,8	2,3	1,7	2,0

A.8. Average Return of Portfolios with 0.3% Transaction Cost

Standard Deviation	Top 5	Top 10	Top 20	Top 50	101-120	All
0,1	3,5%	9,4%	0,9%	-13,5%	-7,3%	1,2%
0,2	12,4%	14,5%	-11,0%	-17,6%	-28,3%	-2,0%
0,3	13,2%	6,5%	-12,7%	-17,2%	-34,4%	-3,4%
0,4	22,7%	12,2%	-8,3%	-13,7%	-34,8%	-3,2%
0,5	24,8%	13,3%	-7,1%	-12,6%	-32,2%	-2,4%
0,6	24,0%	14,9%	-6,8%	-11,9%	-33,2%	-2,8%
0,7	26,3%	16,5%	-10,0%	-13,1%	-32,3%	-1,9%
0,8	31,9%	19,0%	-8,9%	-12,6%	-30,5%	-1,6%
0,9	32,1%	20,1%	-8,4%	-11,4%	-29,3%	-1,2%
1,0	32,6%	20,9%	-7,7%	-11,2%	-26,8%	-1,1%
1,1	7,2%	8,5%	-13,0%	-13,1%	-24,2%	-0,7%
1,2	14,8%	12,8%	-10,9%	-11,9%	-23,6%	-0,5%
1,3	17,4%	14,7%	-10,9%	-11,5%	-26,2%	-0,4%
1,4	20,2%	16,4%	-8,6%	-10,7%	-26,6%	0,2%
1,5	20,4%	16,6%	-7,3%	-10,1%	-28,1%	0,5%
1,6	16,3%	14,4%	-8,2%	-11,2%	-28,4%	-0,4%
1,7	14,4%	12,1%	-9,5%	-12,0%	-28,4%	-0,2%
1,8	14,0%	10,4%	-8,4%	-12,7%	-28,6%	-0,6%
1,9	17,4%	9,5%	-8,2%	-13,2%	-26,1%	-0,4%
2,0	17,9%	7,8%	-8,3%	-12,7%	-26,1%	-0,3%

A.9. Percentage of Observations with Positive Return with 0.3% Transaction Cost

Standard Deviation	Top 5	Top 10	Top 20	Top 50	101-120	All
0,1	80,0%	90,0%	85,0%	60,0%	65,0%	66,0%
0,2	100,0%	90,0%	60,0%	42,0%	40,0%	57,3%
0,3	100,0%	80,0%	55,0%	42,0%	30,0%	53,7%
0,4	100,0%	80,0%	55,0%	42,0%	30,0%	52,0%
0,5	100,0%	80,0%	55,0%	44,0%	30,0%	52,7%
0,6	80,0%	70,0%	50,0%	44,0%	30,0%	52,3%
0,7	80,0%	70,0%	45,0%	42,0%	30,0%	53,0%
0,8	100,0%	80,0%	50,0%	44,0%	30,0%	52,3%
0,9	100,0%	80,0%	50,0%	44,0%	30,0%	54,3%
1,0	100,0%	80,0%	50,0%	44,0%	30,0%	54,3%
1,1	80,0%	70,0%	50,0%	44,0%	30,0%	55,3%
1,2	80,0%	70,0%	50,0%	44,0%	30,0%	54,7%
1,3	80,0%	80,0%	55,0%	50,0%	35,0%	56,7%
1,4	80,0%	70,0%	50,0%	48,0%	35,0%	56,3%
1,5	80,0%	70,0%	50,0%	46,0%	35,0%	56,3%
1,6	80,0%	70,0%	50,0%	46,0%	35,0%	57,0%
1,7	80,0%	70,0%	50,0%	46,0%	35,0%	55,7%
1,8	80,0%	70,0%	55,0%	46,0%	35,0%	56,0%
1,9	80,0%	80,0%	60,0%	46,0%	40,0%	56,0%
2,0	80,0%	70,0%	55,0%	46,0%	45,0%	56,3%

A.10. Average Return of Portfolios with 0.1% Transaction Cost

Standard Deviation	Top 5	Top 10	Top 20	Top 50	101-120	All
0,1	5,0%	12,6%	3,7%	-10,5%	-3,9%	4,4%
0,2	15,7%	20,1%	-6,2%	-13,0%	-24,6%	1,9%
0,3	17,1%	12,9%	-7,3%	-12,4%	-30,5%	0,6%
0,4	27,2%	18,6%	-3,0%	-9,0%	-31,3%	0,7%
0,5	29,5%	19,5%	-2,0%	-8,0%	-28,9%	1,3%
0,6	28,4%	20,7%	-2,1%	-7,6%	-30,1%	0,7%
0,7	30,8%	22,0%	-5,4%	-9,1%	-29,3%	1,4%
0,8	36,5%	24,4%	-4,6%	-8,9%	-27,8%	1,5%
0,9	36,2%	25,1%	-4,3%	-7,8%	-26,6%	1,7%
1,0	36,7%	25,7%	-3,8%	-7,8%	-24,2%	1,7%
1,1	11,0%	13,0%	-9,4%	-9,9%	-21,7%	2,0%
1,2	18,8%	17,3%	-7,3%	-8,7%	-21,2%	2,1%
1,3	21,4%	19,0%	-7,4%	-8,5%	-24,2%	2,0%
1,4	24,2%	20,6%	-5,3%	-7,9%	-24,7%	2,6%
1,5	24,3%	20,6%	-4,0%	-7,4%	-26,2%	2,7%
1,6	19,8%	18,2%	-5,0%	-8,6%	-26,5%	1,7%
1,7	17,7%	15,7%	-6,6%	-9,5%	-26,6%	1,8%
1,8	17,2%	13,7%	-5,5%	-10,3%	-26,9%	1,4%
1,9	20,6%	12,6%	-5,5%	-11,0%	-24,3%	1,4%
2,0	21,1%	10,7%	-5,7%	-10,5%	-24,5%	1,5%

A.11. Percentage of Observations with Positive Return with 0.1% Transaction Cost

Standard Deviation	Top 5	Top 10	Top 20	Top 50	101-120	All
0,1	100,0%	100,0%	90,0%	62,0%	65,0%	67,0%
0,2	100,0%	90,0%	60,0%	42,0%	40,0%	58,0%
0,3	100,0%	80,0%	55,0%	42,0%	30,0%	54,3%
0,4	100,0%	80,0%	55,0%	46,0%	30,0%	53,7%
0,5	100,0%	80,0%	55,0%	46,0%	30,0%	54,0%
0,6	100,0%	90,0%	60,0%	50,0%	30,0%	54,3%
0,7	100,0%	90,0%	55,0%	46,0%	30,0%	54,7%
0,8	100,0%	90,0%	55,0%	48,0%	30,0%	55,7%
0,9	100,0%	90,0%	55,0%	48,0%	30,0%	56,0%
1,0	100,0%	90,0%	60,0%	52,0%	30,0%	57,0%
1,1	80,0%	70,0%	50,0%	48,0%	30,0%	56,0%
1,2	80,0%	80,0%	55,0%	48,0%	35,0%	56,3%
1,3	80,0%	80,0%	55,0%	50,0%	35,0%	57,0%
1,4	80,0%	80,0%	55,0%	50,0%	35,0%	57,0%
1,5	80,0%	80,0%	55,0%	48,0%	35,0%	56,7%
1,6	80,0%	70,0%	50,0%	46,0%	35,0%	57,3%
1,7	80,0%	70,0%	50,0%	46,0%	35,0%	57,7%
1,8	80,0%	70,0%	55,0%	46,0%	35,0%	57,3%
1,9	80,0%	80,0%	60,0%	46,0%	40,0%	57,3%
2,0	80,0%	70,0%	55,0%	46,0%	45,0%	57,0%

A.12. Average Return of Portfolios with Daily Bid/Ask Prices

Standard Deviation	Top 5	Top 10	Top 20	Top 50	101-120	All
0,1	2,0%	6,6%	-2,9%	-17,4%	-14,1%	-3,3%
0,2	8,4%	9,1%	-18,1%	-24,1%	-35,0%	-7,7%
0,3	8,7%	0,7%	-20,4%	-24,4%	-41,5%	-9,6%
0,4	18,5%	6,7%	-16,5%	-21,2%	-41,3%	-9,3%
0,5	20,1%	8,1%	-15,0%	-19,9%	-38,3%	-8,2%
0,6	19,3%	9,8%	-14,3%	-18,7%	-38,6%	-8,3%
0,7	21,0%	11,0%	-16,4%	-19,0%	-37,9%	-7,1%
0,8	26,7%	13,7%	-15,3%	-18,3%	-36,1%	-6,4%
0,9	27,1%	15,3%	-14,6%	-16,9%	-34,7%	-5,8%
1,0	27,9%	16,0%	-13,4%	-16,2%	-31,8%	-5,4%
1,1	3,2%	4,3%	-18,6%	-18,0%	-28,6%	-4,7%
1,2	10,7%	8,6%	-16,1%	-16,5%	-27,7%	-4,3%
1,3	13,0%	10,4%	-16,0%	-15,8%	-29,6%	-4,1%
1,4	16,2%	12,5%	-14,0%	-15,1%	-30,0%	-3,3%
1,5	16,5%	12,7%	-12,2%	-14,2%	-31,4%	-2,9%
1,6	12,7%	10,7%	-13,2%	-15,3%	-31,5%	-3,6%
1,7	10,9%	8,7%	-14,7%	-16,2%	-31,3%	-3,4%
1,8	10,8%	7,2%	-13,5%	-17,0%	-31,6%	-3,6%
1,9	14,4%	6,8%	-13,1%	-17,4%	-29,0%	-3,5%
2,0	14,8%	5,1%	-13,0%	-16,7%	-29,3%	-3,3%

A.13. Percentage of Observations with Positive Return with Daily Bid/Ask Prices

Standard Deviation	Top 5	Top 10	Top 20	Top 50	101-120	All
0,1	60,0%	80,0%	75,0%	54,0%	65,0%	63,3%
0,2	80,0%	80,0%	55,0%	40,0%	40,0%	55,0%
0,3	80,0%	70,0%	50,0%	38,0%	30,0%	51,3%
0,4	100,0%	80,0%	55,0%	42,0%	30,0%	50,0%
0,5	100,0%	80,0%	55,0%	42,0%	30,0%	50,3%
0,6	80,0%	70,0%	50,0%	40,0%	30,0%	49,3%
0,7	80,0%	70,0%	45,0%	40,0%	30,0%	50,3%
0,8	100,0%	80,0%	50,0%	40,0%	30,0%	49,7%
0,9	100,0%	80,0%	50,0%	40,0%	30,0%	50,3%
1,0	100,0%	80,0%	50,0%	40,0%	30,0%	50,0%
1,1	80,0%	70,0%	50,0%	42,0%	30,0%	52,3%
1,2	80,0%	70,0%	50,0%	42,0%	30,0%	52,3%
1,3	80,0%	70,0%	50,0%	42,0%	35,0%	53,3%
1,4	80,0%	70,0%	50,0%	40,0%	35,0%	53,0%
1,5	80,0%	70,0%	50,0%	44,0%	35,0%	54,0%
1,6	80,0%	70,0%	50,0%	42,0%	35,0%	55,7%
1,7	80,0%	70,0%	50,0%	40,0%	35,0%	54,3%
1,8	80,0%	70,0%	50,0%	40,0%	35,0%	53,3%
1,9	80,0%	70,0%	50,0%	38,0%	40,0%	54,7%
2,0	80,0%	70,0%	50,0%	40,0%	40,0%	54,3%

A.14. Average Return of Portfolios with Daily Low/High Prices

Standard Deviation	Top 5	Top 10	Top 20	Top 50	101-120	All
0,1	-16,9%	-27,6%	-31,4%	-48,0%	-50,9%	-36,3%
0,2	-29,4%	-52,3%	-66,9%	-71,4%	-77,6%	-50,0%
0,3	-32,9%	-71,7%	-77,6%	-75,8%	-87,1%	-54,8%
0,4	-36,9%	-69,2%	-74,9%	-74,4%	-82,3%	-54,6%
0,5	-36,7%	-64,8%	-72,1%	-72,7%	-78,9%	-51,6%
0,6	-34,8%	-59,3%	-66,8%	-68,3%	-77,4%	-49,6%
0,7	-38,0%	-56,3%	-68,5%	-66,1%	-76,4%	-46,4%
0,8	-35,6%	-52,4%	-65,6%	-62,6%	-72,7%	-43,7%
0,9	-30,7%	-48,1%	-62,6%	-60,2%	-68,7%	-41,1%
1,0	-29,6%	-43,9%	-58,2%	-56,9%	-67,0%	-39,4%
1,1	-45,3%	-50,3%	-60,3%	-56,6%	-62,7%	-37,4%
1,2	-43,3%	-48,6%	-59,1%	-55,0%	-61,5%	-36,1%
1,3	-40,5%	-45,6%	-57,1%	-52,2%	-60,1%	-34,1%
1,4	-40,1%	-42,7%	-55,7%	-50,3%	-58,5%	-32,5%
1,5	-38,3%	-41,7%	-53,8%	-48,2%	-57,1%	-31,3%
1,6	-36,6%	-38,8%	-52,1%	-47,6%	-56,6%	-30,0%
1,7	-36,4%	-38,8%	-51,6%	-46,8%	-55,2%	-28,5%
1,8	-32,8%	-36,5%	-49,1%	-45,3%	-54,1%	-27,7%
1,9	-29,8%	-33,2%	-46,1%	-42,8%	-49,8%	-26,2%
2,0	-28,1%	-32,0%	-44,0%	-40,9%	-48,3%	-24,9%

A.15. Percentage of Observations with Positive Return with Daily Low/High Prices

Standard Deviation	Top 5	Top 10	Top 20	Top 50	101-120	All
0,1	0,0%	0,0%	0,0%	2,0%	10,0%	17,7%
0,2	0,0%	0,0%	0,0%	2,0%	5,0%	15,0%
0,3	0,0%	0,0%	0,0%	2,0%	0,0%	14,3%
0,4	0,0%	0,0%	0,0%	0,0%	0,0%	13,7%
0,5	0,0%	0,0%	0,0%	0,0%	0,0%	14,7%
0,6	0,0%	0,0%	0,0%	0,0%	0,0%	15,0%
0,7	0,0%	0,0%	0,0%	0,0%	0,0%	16,0%
0,8	0,0%	0,0%	0,0%	0,0%	0,0%	17,7%
0,9	0,0%	0,0%	0,0%	0,0%	5,0%	20,7%
1,0	0,0%	10,0%	5,0%	6,0%	10,0%	22,0%
1,1	0,0%	10,0%	5,0%	8,0%	10,0%	23,7%
1,2	0,0%	10,0%	5,0%	8,0%	15,0%	25,3%
1,3	0,0%	10,0%	5,0%	10,0%	10,0%	28,0%
1,4	0,0%	10,0%	10,0%	14,0%	15,0%	31,0%
1,5	0,0%	10,0%	10,0%	16,0%	15,0%	31,3%
1,6	0,0%	10,0%	10,0%	16,0%	15,0%	31,7%
1,7	0,0%	10,0%	10,0%	14,0%	15,0%	33,0%
1,8	0,0%	10,0%	10,0%	14,0%	15,0%	33,7%
1,9	0,0%	20,0%	15,0%	16,0%	15,0%	34,3%
2,0	0,0%	20,0%	15,0%	16,0%	15,0%	35,7%