Triangular Arbitrage in the Forex Market

Emerging versus Developed markets

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Kristian Dukov, Eleni Kyriaki
SUMMARY

Over the last decade, researchers have attempted to show how efficient the markets are by using Fama’s Efficiency Market Hypothesis (EMH). The theory states that an investor cannot increase his returns without taking additional risk. The markets can be efficient in different forms depending on the information included in the traded asset. It is quoted that: "There ain't no such thing as a free lunch”.

However, the topic still remains disputable since researchers have introduced controversial findings after investigating different markets. Overall, emerging markets have been characterized with higher volatility which consequently declares for market imperfections. Commonly, these market inefficiencies are quickly captured by the eye of the investors who are lurking for potential benefits through exploiting them. These are the so called arbitrage opportunities which exist on different level of impact, depending on the attitude of the market.

The existence of arbitrage is clear evidence against Fama’s theory and it has been documented in numerous studies. Unfortunately those events occur rarely and disappear in a matter of seconds, thus; is highly competitive to capitalize. Over the last decade high frequency trading (HFT) became popular on different markets and it allowed traders to make decisions and execute transactions in a matter of milliseconds using algorithms.

The market we are interested in is the Forex market which is a decentralized market where currencies from all over the world are traded. Main participants include multinational banks which rely heavily on HFT. The method used to benefit from inefficiency is called triangular arbitrage and it involves selling and buying 3 sets of currency pairs in times when a parity is violated.

The goal of this study is to answer the following research question, “Is there a difference in triangular arbitrage opportunities between emerging markets and developed ones?” The main objective of this research is to examine how the number of arbitrage occurrences varies considering different market characteristics. Furthermore, the originality of the research stems from the comparison between strategies using currencies from developed economies and emerging ones. Moreover, the additional academic value comes from the analysis of a new dataset that has not yet been examined. Lastly, our results make an empirical contribution into a country’s economy by reducing market inefficiencies and increasing economic stability.

Our sample consists of quantitative data totaling to 2.4 million observations per quotation taken from 2011 and 2013 for currencies picked using a non-probability convenience method based on their property to be converted to EUR and USD currency and availability of information. The research revealed that differences between the two types of market exist, and indicates that the “early” markets possess higher arbitrage activity in contrast to the mature economies. These results should boost the potential for a better trading management and upgrade the profit growth.
Keywords: Efficient Market Hypothesis, Triangular arbitrage, Magnitude, Developed markets, Emerging markets, Forex, Currencies, High Frequency Trading, Arbitrage Opportunities.

ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>Bps</td>
<td>Basis points</td>
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<tr>
<td>CEE</td>
<td>Central and Eastern Europe</td>
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<td>EMH</td>
<td>Efficiency Market Hypothesis</td>
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<tr>
<td>ETF</td>
<td>Exchange -Traded Funds</td>
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<td>EU</td>
<td>European Union</td>
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<td>FX</td>
<td>Forex</td>
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<td>HFT</td>
<td>High Frequency Trading</td>
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<td>OECD</td>
<td>Organization for Economic Co-operation and Development</td>
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Currencies

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<th>Currency</th>
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<td>AUD</td>
<td>Australian Dollar</td>
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<tr>
<td>CAD</td>
<td>Canadian Dollar</td>
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<tr>
<td>CHF</td>
<td>Swiss Franc</td>
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<tr>
<td>CZK</td>
<td>Czech Koruna</td>
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<tr>
<td>DEM</td>
<td>Deutsche Mark</td>
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<tr>
<td>EUR</td>
<td>Euro</td>
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<tr>
<td>GBP</td>
<td>British Pound</td>
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<td>HUF</td>
<td>Hungarian Forint</td>
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<td>JPY</td>
<td>Japanese Yen</td>
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<td>MXN</td>
<td>Mexican Peso</td>
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<td>PLN</td>
<td>Polish Zloty</td>
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<tr>
<td>RUB</td>
<td>Russian Ruble</td>
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<tr>
<td>TRY</td>
<td>Turkish Lira</td>
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<tr>
<td>USD</td>
<td>United States Dollar</td>
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<td>ZAR</td>
<td>South African Rand</td>
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1 Introduction

‘‘It is almost impossible to find an arbitrage opportunity where you make a riskless investment and walk away with abnormal returns’’

- (Damodaran, 2012, p.2).

1.1 Background
Since 1970 researchers were intrigued by Fama’s Efficiency market hypothesis (EMH) and were constantly trying to examine its validity. EMH comes into three forms depending on what information is included in it. When a market is efficient in a weak-form, its prices reflect all the information available in the past prices or returns. Semi-strong form has the prices of financial assets instantly reflecting publicly available information. Lastly, in its strong-form a market is efficient when prices of financial assets reflect even inside information. There are a number of reasons why the EMH will not hold for a certain markets. It can be due to delay of market adjustment when new information is announced (Fama, 1970, p 396), its inaccuracy (Frenkel et al, 2002, p. 415) or the existence of a black market (Diamandis et al., 2007, p. 1).

Currency market stands for one of the most controversial trading places, as referring to the efficiency. Diverse range of studies have been conducted and testify efficient behavior in its weak form, while others represent it as a random walk, voting for inefficiency. The law of one price states that identical goods must have identical prices wherever they trade including the transaction costs (Lamont and Thaler, 2003, p. 191). This clearly confirms that risk-free arbitrage opportunities should not exist. Grossman and Stiglitz (1978, p. 398) have introduced the arbitrage paradox in which, if the markets operate efficiently then there is a massive tendency from the investors perspective to lax their interest, while short-term arbitrage opportunities are created simultaneously.

The foreign exchange market, also known as “FOREX” or “FX”, is a worldwide decentralized over-the-counter financial market for the trading of currencies, which connect buyers and sellers 24 hours a day, five days a week (Levinson, M, 2005, p.14). The FX spot market is often considered one of the deepest and most liquid markets in the world and this can be seen as a reason for the low level of transaction costs (Lopez, n.d.). According to Ickes (2006, p. 2), the main reason for this extensive growth can be considered the rise of the international capital flows. He clearly states that, the international market interactions has developed dramatically especially due to the deficits that some countries face and also, the increase in the international securities markets, where banks are more internationally oriented and bonds are trading more than ever before.

The Bank for International Settlements (2013, p.3) estimates global average daily volume of $5.3 trillion per day in April 2013 dominated by the U.S. dollar (USD), the euro (EUR), and the Japanese yen (JPY). Main instruments that are included in the foreign exchange markets are spot rates, forwards, swaps and options. King and Rime (2010, p. 31) highlights the growth in the spot trading activity which has been driven by the high contribution of small retail investors in electronic execution methods. In the
current research we will investigate the concept of the spot rates, which according to Borio et al. (2007) hold the second position in the most traded instruments (31.3% after swaps with 53.5%). However, Bank for International Settlements (2013, p.8) shows that this percentage has been changed since the first quarter of 2013 with swaps taking the 42 % of the share while spot rates has increased to 38 %.

In the spot rate trading, commodities, indices and currencies are the main exchange tools. In this thesis we will undertake our investigation using currency trading. Cerrato et al. (2009, p.1892) addresses the importance of the exchange rate into the international economy. Since FX transactions facilitates international trade, through the principle of comparative advantage, it has to be beneficial for both parties. Therefore he concludes that exchange rate can influence international competitiveness, growth and inflation through its effect on both import and export prices.

Although finance theory postulates that in well-functioning markets no-arbitrage conditions hold in continuous time, Akram et al. (2005, p. 23) finds that arbitrage opportunities do exist but they disappear instantly. Ito et al. (2012, p.29) have first referred to arbitrage with the diminutive name of “free lunch” and indicated that the probability of disappearance within one second from 1999 (50%) has increased to 2009 (90%). Akram et al. (2005) has also investigated the role of market pace along with arbitrage and indicates, making a reference to FX, that the more liquid and active are the markets, the fewer arbitrage opportunities can be observed, less profit gains and more short-lived arbitrage. Serepka (2012, p. 18) by using linear project method to testify arbitrage, found little evidence of gaining risk-free profits, however, he motivates for further study into the field by searching into higher frequency data.

The advanced technological and computational capacities has emerged a new method of acquiring short term gains through the High Frequency Trading (HFT). High Frequency Trading uses quantitative investment computer programs to hold short-term positions in equities, options, futures, ETFs, currencies, and all other financial instruments that possess electronic trading capability. Recently, the new trading strategy has gained popularity, especially due to the high speed of executions that is provided, which reach the lightning speed. According to Duhigg (2009), this trend has been rising since one software programmer of Goldman & Sachs has been charged of stealing codes related to high speed trading programming. These codes could be used to manipulate financial markets while awarding Goldman & Sachs by generating massive millions of dollars. Easley et al. (2011, p. 127) pointed out another key incidence in the history of HFT, was the so called “Flash Crash”, which took place in the U.S in 2010 and plummeted the market with 700 points (McCrank, 2014) . Kirilenko at al. (2011, p. 19) and Aarheim and Johnsen (2013, p. 10) confirms that since then, only few studies have been undertaken in this field and they mainly concentrate in the equity market.

### 1.2 Contribution

The main participants who intervene in foreign exchange market and take part in speculative transactions are central banks. In general terms, the purpose of using exchange currencies is to buy one’s own currency in order to decrease its supply and increase the value of the currency. This tactic helps the exchange rate within the countries to get stabilized. For instance, it is a usual strategy for the members of European Union to participate in the FX transactions through the Exchange Rate
Mechanism in order to maintain stability in the exchange rates between member states. In the macroeconomic perspective, if the intervention is successful, the value of one's currency against a trading partner may reduce exports and increase imports. This outcome ease persistent trade deficits of the trading partner (Eun & Resnick, 2004, p. 77).

Evidence from Bank for International Settlements (2013) survey shows that the global activity in FX from 2010 to 2013 has been growing significantly up to 19%, comparing to the previous three years 2007 to 2012. The currency composition has changed not only among the most traded currencies but also among the emerging ones. Japanese yen and Mexican pesos have jumped in trading activity, while US dollar holds the first position and EUR the second, displaying a significant decline in comparison with the previous years. Changes in Japanese monetary policy and sovereign debt crisis in Europe in 2010 has provoked the above mentioned changing events. Pukthuanthong and Thomas (2008, p. 72) in an effort to appreciate the reason of the drop in the profitability of the major currencies, they pointed that one hypothesis might be that inefficiency is primarily a characteristic of immature markets.

Bubák et al. (2010, p. 2829), while making a research about volatility into currency exchange rates, states that studies on the emerging markets have not been discussed and it is considered as an “under-researched” field. Furthermore, his results attest the importance of the CE countries, Czech Republic, Poland and Hungary, especially since they have recently entered the European Union (2004). The new EU members committed themselves to adopt the euro upon satisfying the set of Maastricht convergence criteria, one of which is exchange rate stability. Foreign exchange volatility is a measure of currency stability. These economies had fixed rates in the past but due to the monetary policies that have been implemented, they currently have floating rates and as economies grow significantly. Within these currencies, Galati (2000, p. 13) finds that from 1998 to 1999, there is a significant positive correlation between their bid-ask spreads and their volatility. These findings are consistent with Frömmel (2006, p. 16) who, analyzing data from 1994 to 2004 concludes that flexible exchange rate regimes give a boost in exchange rate volatility. Lastly, Bubák et al. (2010, p. 2839) make a reference about the increasing trend of the volatility spillovers, reaching a level of 40% to 80% from 2003 to 2009. However, there is no evidence about arbitrage opportunities into that time-span. Along with the previous reasoning, Turkish lira has been located into G15 major currencies in FX for 2013. It is consider as the most promising emerging markets. Neely & Weller (2013, p. 20) implied that the TRY currency into a portfolio composition in FX revealed the most profitable investment.

The abovementioned challenges have inspired the authors to investigate the existence of triangular arbitrage opportunities in these markets. Aarheim & Johnsen (2013, p. 39), have thoroughly analyzed triangular arbitrage, using various strategies and confirmed that arbitrage do exist, however, they suggest further research into the emerging markets. As Credit Swiss (2013, p.1) Credit Swiss in its brochure has mentioned that in recent years developed markets show a decline trend in their economic conditions and growth rates. On the other hand, emerging markets have actively entered into the global economy, showing a promising track for financial growth and stability. Consequently, it is pointed that, as it concerns the currency market, while emerging economies strive for fiscal evolution, the easy adaptable monetary policy has lead the developed ones to the
degrade of their economic capacity. Accordingly, we will also make use of the G6 pairs and we use them as a benchmark.

Wickremasinghe (2004, p. 2) investigates the market efficiency in Shri Lanka and points out the influence of the government authorities into the exchange rate volatility. In inefficient markets, investors have more opportunities for profits while in more efficient ones they have limited chance to benefit from abnormal returns. Emerging markets has recently attracted the attention of many scholars and practitioners in an effort to underline the influences and effects of their performance into the FX market. We expect that the findings of our study will provide our investors with better evidence in how to utilize their funds and make higher profits. At the end of this analysis, the traders will have apparent insights about the optimal way they could construct their portfolios. In fact, depending on the type of the investment decision and the computational capacity, one will have the option to choose between a trades in strategies which offer opportunities with higher duration but lower magnitude, while others may prefer to choose the inverse strategy. Lastly, our results will boost massive interbank intervention in FX market, which will enhance economic stability and trading growth.

After a thorough research in previous studies, we have realized that special attention has been paid towards arbitrage occurrences in the major trading currencies. We would like to contribute by fulfilling this gap through an investigation on the volume of arbitrage in the emerging economies, how the triangular arbitrage work in their respective currencies and what is their impact in contrast to the developed ones. In essence, we will analyze the triangular strategies of our data and we will distinguish them between highly traded currencies, which are related with the most developed countries, and currencies from emerging economies.

General studies in arbitrage discusses how triangular arbitrage is to be interpreted in FX, which is extremely popular especially due to its controversial character regarding the efficiency of this particular market. Aiba et al. (2002), Yassini (2010), Aarheim and Johnsen (2013), have examined thoroughly the contribution of triangular arbitrage into the FX market in favor of speculation. While previous research has been done in that field, there is no evidence regarding the last three years. As a consequence of previous research, we would like to display the performance of the abnormal gains and how often they have occurred in comparison with the past.

1.3 Research Question
Based on the background, this research formulates and strives to answer the following research question:

“Is there a difference in triangular arbitrage opportunities between emerging markets and developed ones?”

1.4 Research objectives
In order to answer the research question as a measure to differentiate between emerging and developed markets, we will use characteristics of the arbitrage opportunities such as number of occurrences, magnitude and mean duration. The main research objective is to examine the arbitrage activity into both developed and emerging markets. Through this
research, traders will be able to conclude whether it is more profitable to take advantage
of arbitrage opportunities using currencies from developed or emerging economies. Another sub-objective is to detect the relationship between the magnitude of arbitrage and the mean duration. Moreover, we will test how this relationship performs in emerging and developed economies comparably. Other objectives would be to find out if the arbitrage opportunities has decreased or increased from 2011 to 2013. In that point, we would like to underline that one would expect a decreasing trend, considering the introduction of high frequency trading (HFT) in FX in 2000.

The EMH suggests that markets are efficient and investors cannot realize abnormal profits no matter if they are using technical or fundamental analysis. One of the objectives of this paper is to present the reader with evidences of such inefficiencies by showing the amount of arbitrage opportunities existing on the market. We expect that there will be currency combinations that will not satisfy the suggested theory. Nevertheless, there are evidences of investors who outperformed a market such as the stock one such as Warren Buffet, Philip Fisher and Benjamin Graham.

1.5 Delimitations of study

The delimitation of this thesis rests on the fact that it will provide information about a specific time-span. Unfortunately, due to the time constraints, the representative data of our study will be constrained into three full weeks of 2011 and 2013. However, Aiba et al. (2002) within a similar research has used data from 8 consecutive weeks, while the time frame can be restricted even more to one month period considering the study of Kollias and Metaxas (2001). Accordingly, our findings may undeniably be considered as a relevant reference of a full year horizon.

Another delimitation is that we decided not to exploit the whole currencies that trade in the FX market but rather, a sub-set of both emerging and developed markets. This choice have been made responsively and due to the time constraints and the lack of visible information from our data stream. Nevertheless, persistent with the analysis in section 1.2, these currencies are of a great importance in the research field and our investigation will definitely bring insights to the finance literature.

1.6 Definitions of concepts

**Arbitrage**

Arbitrage is a result of inefficiency in the pricing of a certain product by the market. It offers a method to exploit those inefficiencies for a short period of time and pocket a risk-free profit. Depending on the market it occurs it can also be explained as a violation of different parities.

For example, in the options market if the following formula is violated:
A person can capitalize on this mismatch by going long on the side with the lower value while keeping the other side short. The technique is similar with other trading tools such as interest rates, forward and currencies. In this report we will focus on the Foreign Exchange arbitrage.

Dubil (2005, p. 13-14) distinguish between 2 types of arbitrage:

**Pure arbitrage** is defined as generating riskless profit by matching current and future obligations to exactly offset each, inclusive of incurring known financing costs. This thesis is focused on this type of arbitrage, since we combine each strategy in order to exactly offset the triangular arbitrage parity. If this parity does not hold, then an arbitrage opportunity occurs. **Relative value** (Statistical) arbitrage is defined as generating profit by matching current and future obligations to nearly offset each other, net of incurring closely estimable financing costs e.g. currencies future market.

Even though the difference might seems minor for the untrained eye, the major difference is that the latter involves some risk taking. Investors try to identify the mismatch through mathematical modeling techniques. There, they expect a favorable change in the price which deviate from the historical one. In general terms, the absence of arbitrage opportunities gives rise to the so-called arbitrage paradox, pointed out by Grossman and Stiglitz (1976, 1980 p. 398). That is, if arbitrage is never observed, market participants may not have sufficient incentives to watch the market, in which case arbitrage opportunities could arise.

**Cross currency or triangular arbitrage**

According to Taylor (2003, p. 28), this is one of the advantages of cross currency trading. It applies mainly to banks and brokers who are set up for the purpose. In simple terms, if the currency that is being traded is EUR/JPY, and a counterparty sells the bank EUR against yen, the bank has the option of either:

1. Selling EUR to another counterparty directly or,
2. Trading out through the dollar, by selling EUR, buying dollars, then, selling dollars and buying yen.

If you can transact at a better rate through using the direct market (through the US dollar), then cross currency arbitrage is possible, sometimes known as triangular arbitrage.
1.7 Research disposition

Chapter 1: Introduction - This chapter aims to present the phenomenon of arbitrage opportunities into the forex currency market due to the existence of market imperfections. After discussing the background of EMH into the FX market and implementing the new trend of HFT, the contribution, main research question and objectives are formulated and explained. In the last part, we indulge the reader into the important concepts of our research by defining arbitrage and triangular arbitrage.

Chapter 2: Theoretical frame of reference – This chapter begins with the introduction of Market Efficiency Hypothesis and how this is implied into the Forex markets, as studied by previous researchers. It is followed by the concepts of arbitrage and high frequency trading and completed by prior evidence of arbitrage in emerging markets. At the end, the set of our hypotheses will be introduced.

Chapter 3: Theoretical Method - This chapter introduces how the authors approach the research proposition. Research paradigm, philosophy, approach and preconceptions are elaborated in order to provide the background so they are capable to critically evaluate and analyze this research.

Chapter 4: Empirical approach- This chapter elaborates the research strategy that has been implemented in this thesis. Clarifications include how we segmented the data and collected them, as well as details about the time horizon, the analysis and the mathematical model we used. Finally, at the end we state the limitations of our study.

Chapter 5: Empirical Findings and Analysis- This part will present the reader with our empirical findings together with their analysis and the implications. The statistical tests conducted on the data and their outcomes will be illustrated. The hypothesis that has derived by the Theoretical Framework Chapter will be addressed and explained one after another.

Chapter 6: Conclusions and suggestions- This chapter is followed by a brief summary of our research. The answer to our research question will be provided base on our empirical findings and analysis. The conclusion contains discussions on the academic and practical contribution towards the arbitrage in Forex and particularly in emerging markets. Moreover, further research suggestions will be stated in the end of the chapter.

Chapter 7: Quality criteria- This chapter presents how we critically evaluate our findings in terms of validity and reliability.
2. Theoretical frame of reference

2.1 Market Efficiency
Market efficiency is defined by how fast, how accurately and what relevant information is absorbed by the market, in particular in the price and the traded volume. In 1970, Fama introduced the concept of three forms of the market efficiency: weak, semi-strong and strong depending on the information included in the price of the financial asset.

When a market is efficient in its weak-form, the current prices incorporate all the information available in the past prices or returns (Fama, 1970, p. 388). In order to test for this form, researchers measure profitability of trading rules used by traders who think they found a predictable pattern. Nevertheless, Fama & Blume (1966, p. 233) tested twenty-four different trading rules and concluded that although some of the filter rules examined can give returns that are higher than buy and hold strategy, after inclusion of transaction costs those profits are eliminated. These results show that filter rules cannot outperform buy and hold strategy when dividends and transaction costs are taken into account (Wijst, 2013, p. 107). Another widely used method to test the weak form efficiency is are the statistical tests for independence. For example, Sharma & Kennedy (1977, p. 404) conducted runs tests where they compared stock market indices of the Bombay, New York and London Stock Exchanges which examine whether an observed sequence of price changes is random. Their finding concludes that there is not a significant difference between the three markets’ behaviours.

Semi-strong form has the prices of financial assets instantly reflecting all publicly available information (Fama, 1970, p. 388). Mackinlay (1997) verified this statement by using event tests with which examines how fast does a new information is being embedded into the price when news such as earnings, dividends, takeover attempts, issuing additional debt or equity have been announced. Fama (1970, p. 388-390) states that all new released information needs to be homogenously interpreted by the investors which makes it impossible to generate abnormal returns. The only ways to do so would be either to have superior interpretation of the same public information or to have an additional one which is not publicly available. Bodie et al. (2011, p. 351) questions the fact that all investors interpret information in the exact same way, which leaves us with the second option and the most superior form, the strong-form of market efficiency, which encompass even inside information when pricing a financial assets (Fama, 1970, p. 388). Given that the strong-form implies that the market is reflective of all information, not only public but also private, the tests for the strong-form involves individuals with excess inside information such as analysts, senior management or other insiders. The strong form of the EMH encompasses both weak and semi strong versions of the EMH.

Even though Fama (1970, p. 388) suggest that might be possible in a perfect market (with no transaction costs) where all information is costless and widely available to all market participants, Bodie et al. (2011, p. 376) question this hypothesis with the fact that insiders have such information at hand long before anybody else on market. Accordingly, in an efficient market, participants cannot use past prices or returns of a financial asset, public information or information available to the insiders of the market to come up with a trading rule which will enable them to beat the market consistently.
This suggests that neither technical analysts nor fundamental can record abnormal returns. Evidences in favour of this hypothesis include Cootner (1961) for the commodity market, Chowdhury (1991) for futures market of nonferrous metals, Buguk et al. (2003) for Istanbul Stock Exchange, Kleiman et al. (2002) for real estate markets and Jennnergren and Korsvold (1974) for the Swedish equity market. Although most of the researches look for long-term relationship, Fama (1991, p. 1607, 1577) stated that the usage of short-horizon event studies is “the cleanest evidence on market-efficiency” together with event studies.

Supporters of EMH argue it is pointless to search for undervalued stocks or to try to predict trends in the market through either fundamental or technical analysis, thus they tend to buy index funds that track overall market performance. The only way an investor can possibly obtain higher returns is by purchasing riskier investments. Nevertheless, investors such as Warren Buffett and Benjamin Graham have consistently outperformed the market over long periods of time in conjunction with the theory which suggests that it is impossible to "beat the market" because assets are always traded at their fair value. Azad (2009 p.334), suggests that one a reason for the success of some forex investors in China, Hong Kong and Malaysia is due to the regulations of those markets applied by the central bank which can limit the scope of foreign banks. Those regulations can result in emergence of a ‘parallel’ or a ‘black’ market and create divergence between the equilibrium rate and the official one (Diamandis et al., 2007, p.1). Another reasons can be in delay with which prices are adjusted to new information (Fama, 1970, p.415) its inaccuracy (Frenkel et al., 2002, p.35) or the distortions in the pricing of capital and risk. (Smith et al., 2002, p.475).

Even though there are evidences supporting the financial theory, EMH is highly controversial and often disputed. For example, Fama & French (1988) found a negative serial correlation in market returns over a period of 3-5 years. Moreover, Lo and MacKinley (1988) reported positive serial correlation in weekly returns. French and Roll (1986) report significant negative serial correlation in daily returns that is “small in absolute magnitude”. Furthermore, Ball (1978) collected 20 empirical studies of share price reaction or the earning announcement. The risk adjusted returns after the announcements were made are non-zero which contradict with the definition of market efficiency given by Kathari (2007, p.4). Watts (1978) is the first researcher who proves that those abnormal returns are due to the market inefficiency and not because of deficiencies in the asset pricing model. Researches of the Option markets conducted by Galai (1978) and Chiras & Manaster (1978) discovered that there is a discrepancy between the price of an option traded on CBOE and the corresponding share on NYSE market. However, those abnormal profits are significantly low and the opportunities can be fully eliminated when taking into consideration the transaction costs.

2.1.1 Evidence about market efficiency in FOREX
Foreign exchange market efficiency has been a disputable topic through several years from the early 70’s. Previous researches tend to oscillate in whether an efficient market exists on FOREX or rather it is an inefficient market. Wickremasinghe (2004, p. 2) states that if a foreign exchange market is inefficient, a model that best predicts exchange rate movements can be developed. Therefore, an inefficient foreign exchange market provides opportunities for profitable foreign exchange transactions. Further, Wickremasinghe & Kim (2014, p. 169) reports that in an inefficient foreign exchange
market, there is always room for the government authorities to effect exchange rates, by reducing exchange rate volatility and evaluating the consequences of different economic policies. Contrary, when the foreign exchange market is characterized by efficient conditions, government does not impede into the market and traders have limited chance to benefit from abnormal returns. Rationally, it seems that there might be a strong argument to believe that emerging markets may be characterized by higher rewarding.

Fama (1984), has extensively investigated six different currencies and concluded in rejection of efficiency hypothesis due to the time varying risk-premium. According to Hsien & Sodoikhuu (2012, p. 216), in that research Fama has used different types of econometric and statistical methods such as OLS estimation which shows the market efficiency hypothesis is not accepted.

Thereafter, a lot of studies have been undertaken for examine the behaviour of the currency market. The results are controversial. Hakkio & Rush (1989) examine the efficiency hypothesis for the UK pound and the Deutsche mark. They find that spot and forward rates within a country are co-integrated, which is consistent with efficiency. Wu & Chen (1998) test the foreign exchange market efficiency for nine OECD countries. Their findings support the hypothesis of foreign exchange market efficiency. Zivot (2000, p.5) tests the foreign exchange market efficiency for the British pound, Japanese yen, and Canadian dollar against US dollar. He finds that cointegration analysis in the first case, estimating a vector error correlation model (VECM), strongly rejects the efficiency hypothesis in all exchange rates. Aroskar et al. (2004) investigate the impact on foreign exchange market efficiency of the European financial market crisis in 1992 by studying pre-crisis, crisis, and post-crisis periods. Meese & Singleton (1982, p. 1033-1034) claim that foreign exchange rates follow a random walk process. McQueen (1992, p.1) and Chow & Denning (1993, p.385) perform a joint variance ratio test and all find evidence supporting the random walk hypothesis in stock prices. But Liu & He (1991, p. 773) and Ajayi & Karemera (1996, p.77) reject the random walk hypothesis in major and Asian foreign exchange rates. A study from Pukthuanthong & Thomas (2008, p. 72) re-examined the weak – form phenomenon within a database or future currencies for 1975-2006. The study included both old and newly liquid currencies and the results are once more controversial. Evidence of weak form of market efficiency do exists through the trends, however, as the traders learn and adapt their strategies these trends are starting to adjust. In the mid-1990s major currencies along with their correspondent exchange rates have loosen value while newly liquid currencies have started adopt major currencies’ characteristics; as were in their early years.

2.2 Evidence about Arbitrage and High Frequency Trading
According to Pukthuanthong & Thomas (2008, p. 72), in the early 70’s, 80’s and 90’s the phenomenon of trading into major currencies and therefore the associated cross exchange rates was a common profitable habit. However, while moving to the recent years, investing in major currencies have yielded poor results. The probability of gains has decreased which indicates that the markets behave in a more efficient form in contrast to the past years of inefficiency. However, there is no significant evidence about the reason of this attitude, but one hypothesis in favour is that inefficiency is benign attribute to the early markets.
High frequency trading (HFT) is the use of a computer driven investment strategy whereby futures, options, equities, currencies and all other financial instruments that is capable in electronic trading are held for a very short period, usually seconds or milliseconds (Brogaard 2010, p.4). Due to the fact that FX has started to obtain a more efficient form than the early past, advanced computing power has created to enable the storage and analysis of large datasets. Institutions are now able to capture the trades, with some exchanges in the FX market now publishing price updates in every 250 milliseconds. In order to capture a fraction of a currency unit on every trade, high frequency traders (HFTs) are in and out of positions thousands or tens of thousands of times each trading day (Huffington Post, 2010). Galati & Bank for International Settlements (2011, p. 1) states that HFT is conducted thousands of time each day, but in small order sizes, low margin, low latency and short risk holding periods. While at first it was operating for the most popular currencies, nowadays, it has been broadened into other currencies with emerging origins.

2.2.1 Arbitrage in Forex
Galant & Dolan (2007, p. 4) found evidence that the major volume of trading in currencies is based on speculation. Traders use buy (long) and sell (short) positions to make quick profits. These gains are derived from minute-to-minute, hour-to-hour and day-to-day fluctuations. Estimates shows that 90 percent of daily trading volume is due to speculation. In that point, considering the spot currency trading only, which is 75 percent in volume, is operating for the so called “major currencies”, which are represented the world’s largest and most developed economies.

Akram et al. (2005, p. 16) explains that in order to exploit an arbitrage opportunity, a trader needs to undertake three deals virtually simultaneously and as fast as possible. Otherwise, there is a risk that prices of one or more instruments move such that an apparent arbitrage opportunity disappears before the trader has been able to seal all of the three deals. He declares that there are electronic trading systems such as Reuter’s, which allow traders to undertake almost simultaneously deals with up to four counterparts. Alternatively, according to his research, virtually simultaneous trading in the money markets and the swap markets can be accomplished through tight cooperation between money market dealers and swap market dealers, which seems to exist in a typical dealing room.

The most current research in triangular arbitrage in the FX market has been done by Ito et al. (2012) who investigated JPY within a twelve year time span. “Free lunch” is the phrase they used to define the arbitrage phenomenon and they present two different ways to measure it. Either by triangular arbitrage or negative spreads, whereas the first method is the most commonly used. Finally, the study reveals that the number of arbitrage opportunities seems to be higher in active markets where the volatility is greater. Fenn et al. (2008) finds similar trends while Marshall et al. (2008) denotes different results.

2.3 Triangular arbitrage
In our thesis, we investigate the triangular arbitrage occurrence within the spot foreign exchange market. We make use of the bid/ask prices of diverse amount of pairs, in a regular and in a reverse order. However, FX market tends to be extremely liquid and price updates occur in a really high frequency. For someone to make such an analysis of
large data, powerful with huge capacity datasets are needed. Time of transaction through different currencies is a matter of a great importance, especially for someone who wants to define profitability. Due to the high frequency trading, some deals are able to be executed but some others not because of the change of the price during the transaction intervals.

Kollias and Metaxas (2001, p. 439) examined for how long the triangular arbitrage occurrences are able to give abnormal profits. Accounting for executed dates they found evidence of profitable delays of 0 to 120 seconds. Accordingly, Aiba et al. (2002, p.472) shows that an investor need 0 to 9 seconds to carry out the transaction, while to be profitable the execution delay reaches up until 4 seconds. However the duration within the seconds varies since there are researchers who use indicative data to fulfil their studies.

The most recent research about triangular arbitrage has been conducted for USD/JPY, EUR/USD and EUR/JPY in 2012 for 12 time period time from 1999 to 2010, valuing per tick-data derived from the EBS platform owned by ICAP group. As it has already mentioned, Ito et al. (2012, p. 51) also shows that arbitrage occurrences do exist but in a decreasing scale than the past, lasting only for few seconds. They first introduce the arbitrage, named as a “free lunch” trading strategy and they divided it into negative spreads between a currency pair and triangular arbitrage within three different currencies. They concluded that negative spreads are happening less than triangular arbitrage occurrences.

2.4 Bid/ Ask quotation

Additionally, it is necessary to be aware of the difference between the indicative and executable quote prices. Fenn et al. (2008, p. 2) states that an indicative bid/ask price is a quote that gives a valid at which a trade can be conducted. The trader can choose either to trade in the indicative price or in the executable which is the actual price; while they differ with each other by few basis points. In this particular thesis, the spot prices are considered executable and have been taken place through the free set of database which was provided online. Further researches have been undertaken for applying both indicative and executable prices. Aiba et al. (2002, p. 470) made a study of indicative quotes within 8 weeks in 1999 of EUR/USD-JPY/EUR strategy. They found proof that arbitrage opportunities exist in the currency market and are evident 6.4% of the time; thus 90 minutes per day. Additionally, Kollias & Metaxas (2001, p.441) examined 24 different strategies using indicative quotes over one month period in 1998. They found evidence that some strategies shows arbitrage occurrences within two hours and the mean duration oscillates between 14 and 12 seconds. However, Fenn et al. (2008, p. 7) by using executable prices in two different exchange pairs in a weekly basis over the period 10/02/2005–10/27/2005, concludes that the arbitrage occurrence in FX is possible but it stands less than 1 sec. The longer the waiting period, the less frequent the probability of profit. Significant is the fact that in high liquidity seasons arbitrage is more likely to arise due to the misprice of the rate, but it can adapted quickly for correction. Pointing out the importance of this distinguish, we will make use of the executable quote prices as we refer to historical executed data.
2.5. Previous studies in testing the profitability in emerging markets

Galati (2000, p.13) was the very first who made a study about the relationship between trading volumes, volatility and spreads in foreign exchange market. His research contributed into the emerging market countries, making a use of a new data set of seven different currencies. The empirical microstructure literature has typically found a positive correlation between volumes and volatility in “normal” periods, however, in cases that volatility rises audibly there is a negative impact in their trend. Consistently, the relation between volatility and spreads is also positive, which makes the moving trend among the three variables identical.

Burnside et al. (2007, p. 1) compared a carry trade of a payoff between two different portfolios, one for developed country currencies and one for emerging country currencies. Their findings are consistent with the hypothesis that emerging markets have higher spreads, since as they found, bid-ask spreads (difference between ask and bid price) are two to four times larger in emerging markets than in developed countries. A recent study of Neely et al (2013, p. 20) shows exactly the same behaviour. Comparing two portfolios between major and emerging markets the results showed that when only non-emerging market currencies are used, about half of the 10- strategy and 50-strategy portfolios earn negative excess returns in the final sample (2000-2012) and none of the portfolios earn statistically significant positive Sharpe ratios (measuring risk-adjusted performance). Pukthuanthong (2006, p. 6), is also consistent with this approach and indicates that while trading in majors has been proved unprofitable, there is another group of currencies that traders hope to implement trend following techniques for profits, the “exotics”.

Mwangi & Duncan (2012, p. 182) investigates the existence of arbitrage opportunities in the Mombasa spot market. Arbitrage opportunities do exist into that market from the trade interplay between Kenyan Shilling, US Dollar and Euro. He also, found that currencies which were occasionally traded such as Australian Dollar, Japanese Yen and Canadian Dollar appear to generate more arbitrage opportunities meaning that they were relatively inefficiently priced. The triangular arbitrage analysis shows that cross rates including shilling generated numerous arbitrage occurrences and it clearly stated that such levels of arbitrage margins are attractive to arbitrageurs.

This paper will attempt to analyse the currencies of CEE countries PLN, CZK and HUF and inspect if there are any arbitrage opportunities into these markets and to conclude if there are more arbitrage opportunities of the cross rates in these emerging markets than in more developed ones. Frömmel (2006, p. 16) indicates that there is a correlation between the changes in the regimes and monetary policies of Central and Eastern European Countries with the changes in the exchange rate arrangements. More specifically, the sharp changes into the flexibility of the exchange rate regimes leads to an increase in the exchange rate volatility.

2.6. Hypotheses
Consistently with the relevant research, as it has been analysed and described above, we would like to introduce the reader to our set of hypotheses.
The introduction of EMH in 1970 has driven various researchers to examine the efficiency within different markets. Although, most researches has endorsed the efficient characteristics of the markets, the continuous existence of arbitrage opportunities declare the appearance of market imperfections. Particularly in Forex, a trader can capitalize on those inefficiencies by executing simultaneously three trades using a trading platform. At the completion of the third trade, the opportunity has been exploited and the profit secured. We, therefore, expect to find triangular arbitrage opportunities throughout the trading day. Thus this leads us to the first test with the null hypothesis stated in negation.

**H1a. There are triangular arbitrage opportunities on the FOREX.**

We investigate this by considering whether the arbitrage opportunities reverse from zero. In that case, the null hypothesis is in favour to the alternative, stated above, that makes the FX market efficient as suggested by Fama (1970) and it will be in line with other researches of the FX market made by Akram et al (2005), Fong et al. (2009) and Marshall et al. (2008)

If this hypothesis is supported and the triangular arbitrage does exist on Forex then, persistent with the abovementioned literature findings in the emerging markets, someone would expect that the emerging economies have a higher likelihood of arbitrage observation than developed economies. Therefore, a sub-hypothesis continues as a sequel:

**H1b. Triangular arbitrage opportunities occur more in emerging markets than in the developed ones.**

Secondly, according to Aarheim & Johnsen (2013, p. 37) after an analysis of 11 pairs in seven consecutive years, they concluded that the proportion of arbitrage is decreasing throughout the years. This is consistent with the investigation of Ito et al. (2012) in three currency pairs for 12 year period of time. It shows that the number of “free lunch” opportunities has dramatically decreasing over time. This has led us to formulate our final hypothesis.

**H2. The arbitrage opportunities decrease over time.**

Secondly, Fenn et al. (2008 p.9) has found that the magnitude of arbitrage in basis points increase when the number of those opportunities decrease. Along with the magnitude, another metrics that also decrease for some currencies is the mean duration. For example, the mean duration of arbitrages using JPY currency with 0.5 basis points (bps) magnitude was 3 seconds whereas the one with a difference of 9 bps disappears after only 1 seconds. However, this may not hold for all currencies. CHF had an opposite effect: half a basis point opportunity remains profitable for 1.5 seconds, but another with 6 basis points of magnitude remains longer (2.3 seconds). The last finding is consistent with Kollias & Metaxas (2011, p. 439) who investigated 24 arbitrage relationships and found that there is a positive relationship between the magnitude and the duration of the mispricing. Accordingly, the following hypothesis needs to be investigated in conjunction with the null hypothesis.

**H3a. There is a positive relationship between magnitude and mean duration of triangular arbitrage**

If the test reveals that we reject the null hypothesis, then that gives us sufficient statistical evidence to conclude that there is a relationship between magnitude and mean
duration. Consistent with the previous analysis in chapter 2.5, one would expect that in emerging economies the correlation between duration and magnitude would be stronger. This leads to our last hypothesis which is stated as follows:

**H3b. The relationship between the magnitude and the duration of the arbitrage opportunities is stronger in the emerging markets than in the developed.**
3. THEORETICAL METHODOLOGY

In this chapter, we describe the research philosophy, approach and design behind our study. Furthermore, we will discuss the rationale for choosing it and describe the methodology of the study. In this section we will discuss the methodology of the research. As a starting point we use the articles of Aiba et al. (2002), Marshall et al. (2008), Fenn et al. (2008) and Ito et al. (2012) discussed in the theoretical review. Further, we address how to calculate triangular arbitrage as well as our assumptions and rationale behind choosing these methods.

3.1 Research paradigm

**Ontology** describes the nature of reality and whether social can be considered as objective entities or as social construction build up from the perception and actions of social actors (Bryman, 2008, p. 18). This term include two different views, objectivism and subjectivism. If an objective view is accepted, the researcher believes that social entities are external to the social actors (Saunders et al., 2009, p. 110) which will create less bias (Flowers, 2009, p. 2). However, the subjectivism view states that we have to explore social actors’ motivations in order to understand their actions. Since there are thousands participants in the Forex market with different motivation of trading, it’s impossible to take those into account. Thereby, we consider the market as a tangible entity, combining all individuals. In addition, we assume that there is only one observable reality making objectivism more suitable in the context of our research. We prefer to take the view that objective aspects are more important than the way investors and traders themselves perceive a phenomena such as arbitrage. Those social actors may have different interpretations of the phenomena depending on their own view of the world leading to different results as suggested by Saunders et al. (2009, p. 111). Although both aspects of ontology can be accepted as producing valid knowledge, in the context of our research we are interested in the end product of actors’ actions which is the arising arbitrage opportunities rather than their motives and intentions therefore finding objectivism as more suitable aspect.

3.2 Philosophy

**Epistemology** is concerned with the nature and scope of knowledge. It questions what is regarded as knowledge and how it can be acquired (Bryman, 2008, p. 13). According to Poetschke (2003, p. 2) knowledge can be acquired either by observing without interference or by being subjective and assume that observations are affected by social construction of reality
Even though previous researchers do not discuss the applied research philosophy explicitly, it was evident that they used positivism. We also think that in this context it is the most appropriate one since we study the observable social reality, the Forex, from a stance of a natural scientist so we can draw law-like generalizations (Remenyi et al., 1998, p. 32). As suggested by Saunders et al. (2009, p. 113) only observation of the phenomena, that is the existence of triangular arbitrage, can be used to produce data which will be later used to support/ reject hypotheses developed from existing theory. We as researchers are external to the process thus having little influence or being influenced by the subject of the research (Remenyi et al., 1998, p. 33), i.e. we cannot change the fact that EUR/ USD rate at a given time was 1.3456. This acts in favor of this philosophy combined with its highly structured methodology described by Gill & Johnson (2002, p. 65) which facilitates replication suggesting that if another researcher run the same test in the same conditions he will come up with the same result.

There are also other approaches that could have been applied. The realism philosophy, which advocates that objects are independent of the human mind and senses, show us reality (Saunders et al. 2009, p. 114) i.e. what you see is what you get. Although realism can also be used as a philosophical position when investigating the arbitrage phenomena by using the understanding of the social structure and social conditioning in order to generate knowledge (Saunders et al., 2008, p. 115), we decided to use positivism since we are not interested in trying to understand the social actors independently in the knowledge derivation process (Dobson, 2002) but the arbitrages as a result.

Philosophy such as interpretivism suggests that a researcher should understand the difference between humans as social actors (Saunders et al., 2009 p. 116). They also suggest that each (business) situation is a combination of different individuals and circumstances coming together at a specific time and that this method is most useful when conducting a research in organizational behavior, marketing or HR management. Since this philosophy is more situational, different in each context, and trying to describe what is happening with this reality we think that it’s more applicable in
qualitative research which is not our case since we are not interested in those differences.

To conclude, in the context of our research being objective, independent of the social actors and being able to draw credible conclusions by observing the phenomena under question (occurrence of triangular arbitrage), all those characteristics motivate us to prefer positivism as our research philosophy. Although (Bunge, 1996) criticize this approach as heavily dependent on existing theory and crate barriers for defining the research, since our study relies on observable historical data and we do not have an influence to change the information, we find positivistic approach suitable in terms of making computations and analysis (Broberg & Lindh, 2012 p. 10). This choice influenced our research in a way that we will draw conclusions only of the events that series of actions resulting to market inefficiencies rather than the reasons. Nevertheless, it is possible conduct a research where we examine the reasons for those events using a realism philosophy aspect but since the arbitrage opportunities has a short duration it might be impossible to examine the sentiments of the social actors. Rather than either using interpretivism and studying the Forex market from direct experience, or relying on our senses through realism we make use of natural science in the form of mathematical and statistical modelling, thus choosing positivism.

3.3 Approach

The next layer in the “research onion” shows that a research has to follow a specific research approach. Since we are using positivistic philosophy employing a deductive approach can be seen as a natural step to follow. Testing an existing theory is a central point in the deductive approach and there is already an extensive body of research with the field of arbitrage. After a thorough theory review, we found a research gap that should be fulfilled. To do so, we deducted hypotheses deriving from the theory which are measurable predictions of outcomes. These hypotheses are tested during our empirical research with a sufficient amount of data and after analyzing it we can support or reject the hypothesis. The last step in this process is to verify our findings, discuss final conclusions and present them to our audience.

On the other end of the spectrum, we have the inductive approach where the aim is to formulate new theory based on observations. The approach is commonly used in in-depth interviewing or more qualitative approaches (Bryman & Bell, 2011, p. 11-12). In our case this would mean that we will base a new theory about arbitrage opportunities by taking into account the results from empirical studies, fully neglecting theory such as EMH.

The next step in the research is to choose a research design. As you can see from Figure 2, a researcher can choose between qualitative, quantitative or a mixture of both. Since we are not coming up with new theory, but using an established one in order to assess our data the approach employed in this research will be deductive or more precisely quantitative non-experimental (observational). The theoretical framework behind arbitrage-free model and triangular arbitrage is already defined by other scientists and widely applied in different contexts. Researchers such as Fenn et al. (2008), Aiba et al.
(2002) and other used that theory and methodology into a certain context depending on the data they want to draw conclusions.

3.4 Pre-Conception
Before getting familiar with this paper the readers are introduced to the background of the researchers to understand our reasoning of choices and the degree of writer’s preconception. The authors of this thesis have completed Bachelors in Business Administration, earning the needed knowledge for executing research in this field. Furthermore, participating in numerous activities such as financial internships and online classes only developed and nurtured our interest. A main contribution to choosing this topic is the course Investments that we have studied in the course Financial Management where the authors first heard about a put-call parity of the option market. After further dialogue with the lecturer it became clear that there is lack of evidence describing characteristics of such phenomena such as duration, magnitude and reasons for existence. Since both researchers share a common interest in the financial world we decided to investigate this subject further attempting to add value with their findings after identifying the research gap.

Being students in the Master of Finance program we have been exposed to studies that mostly used a positivist philosophy. This might have influenced our decision to use this approach as well as we feel more comfortable following this set of assumptions regarding how we perceive the world.

3.5 Theoretical framework – Evaluation of sources
As mentioned by Simon and Goes (2011 p.1) the purpose of the theoretical framework is that a researcher does not solely rely on personal instincts or guesses but rather on theories and credible studies. And since the research is following a deductive approach, a main component of it is the collection of such theories and publications which are the starting point of formulating hypotheses. The success of the research is dependent on how thorough the researchers are at this stage and the quality of the gathered academic work.

During our Literature/ Theoretical review we have used data sources in order to acquire enough background knowledge. We have used academic articles, and journals available at the Umeå University library and Diva Database. In our search, some of the keywords used were spot rate, High Frequency Trading, FX market, emerging countries, arbitrage, foreign exchange markets, and efficient market hypotheses etc. Up-to-date sources were used during the review and they have been seen as more credibility compared to researches executed right after the publication of EMH theory. The implementation of new technology could have been captured in the recent researches but not in the ones dating back in 1980s when it was questionable whether computers can make decisions in a matter of milliseconds thus decreasing their validity.

The sources used in the research are considered to be reliable since they are collected and distributed from established journals such as Journal of Economic Literature, Journal of Business and more. Furthermore, those are being reviewed by peers and used in other researches which speaks for their truthfulness. The authors of the paper avoided
secondary references as being object of misinterpretations and decided to examine the conclusions of the original authors. Although the articles can still include human biases and opinion, chances are it will not cause a distortion of our research. Especially since we use a wide variety of articles. However, by using certain articles and textbooks we are still a possible subject of the human biasness, since we are exposed to the personal opinion of the authors.
4. Practical Approach

Here we explain the reasons behind convenient sampling, why we have chosen those currencies and time horizon. We discuss the different data analysis methods and our rationale of using correlation when investigating the relationship between magnitude and duration and descriptive statistic when it comes to comparing the numbers of arbitrage opportunities. In addition, we show the mathematical model employed in order to identify the arbitrage opportunities and their magnitude. Lastly, we show how different hypothesis will be tested for significance and we present the limitations of our study.

4.1 Data Segmenting / Sampling Method and Sample selection

According to Saunders (2009, p. 210-213), a sample is a section of population that is chosen by researchers for research investigations. The main advantage of sampling is the cost reduction created by gathering data from small group and drawing conclusion that is applicable for the whole population. Although Saunders et al. (2007, p. 212) suggest that using a census from the whole population would generate the most accurate results, it might not be applicable in our case due to certain limitations as time, high number of combination, computational power and availability of data. However, by using sample from the population and a statistical models we can generalize for the whole population and our findings can still be valid up to a certain confidence interval.

The population of the research can be formulated as all currency pairs traded on the FOREX market. Although there are more than 80 pairs, our decision to use Euro as domestic currency (that is our starting currency into which we will capitalize our profit if any) and use U.S. Dollars as a “transitional” limits the number of pairs to 42. Since one of the objectives of the research is to identify the difference between using currencies from developed countries and ones of emerging economies, our sample will be include representatives from those two groups. The former group overlaps with the so called Majors which are the most traded currencies on the market and includes EUR, USD, JPY, GBP, CAD, AUD and CHF. In this paper six major currencies have been included. This means that there are eight different strategies of using triangular arbitrage. We have chosen these currencies due to the fact that they are classified as most traded currencies, they are coming from developed countries and also previous researches have used them as benchmarks. For example the GBP, CHF and JPY currencies have been used in arbitrage research by Aarheim & Johnsen (2013) in addition to Fenn et al. (2008) with CHF and JPY currencies, and lastly Aiba et al. (2002) investigate the arbitrage opportunities on the FOREX market using JPY.

The currencies classified as emerging include CZK, PLN and HUF has been selected since they are being part of the alliances such as Visegrad Group which is an alliance preparing countries for their European integration. Even though these currencies are in a process of covering the Maastricht convergence criteria they are still reluctant towards adopting the common European currency (Lovas, 2014) a number of researchers have examined their volatility (Frömmel, 2006, p. 16), bid-ask spread (Galati, 2000, p. 13) and currency risk premia (András, 2010, p.5).In addition, TRY is included in our
research due to the fact it is seen as one of the most promising currencies together with Egypt, Poland, South Africa and South Korea (Goh, 2008 p. 15). As suggested by Neely & Weller (2013, p. 20) the TRY currency is one of the most profitable on FX market.

When choosing a sampling method, we have used a combination of purposive and convenience sampling. Our choice for of developed currencies was entirely on purpose since we needed a benchmark and those currencies meets our criteria. For selecting currencies which will be used in the formation of emerging strategies we used firstly convenience sampling to limit ourselves of using currencies present on Histdata.com website. Furthermore, we have decided to focus on countries that are part of the Visegrad Group and they have not entered into Euro, and also TRY from Turkey, which cover our previous criteria. This means that we use non-probability convenience sampling and according to (Lucas, 2014 p. 399) such samples can lead to bias by picking some kinds of respondents and avoid others. However, we think that in our research the sample and its diversity still make the sample representative and in line with our research question. Currencies from developed countries cover most of the research population of currencies and for emerging ones, although it is limited with regard to generalization for the whole population, the findings are still valid for a subgroup such as emerging European countries.

Moreover, the rise of electronic trading platforms, the increase in trading volume, and the high level of activity in FX and international capital markets demands then use of high-frequency, real-time quotes to characterize the properties of arbitrage opportunities. Finally, it is also important to have a sufficiently long sample to draw general conclusions and gain statistically reliable results. Our data set possesses these characteristics to a large extent, mainly because such data have been unavailable freely to researchers before 2010. The move to electronic trading platforms in the 1990s has made it possible to obtain long data samples of real-time quotations for rigorous empirical work.

4.2 Time-Horizon
According to Saunders et al. (2009, p.155), the time horizon of a research can be either cross-sectional or longitudinal depending on the observed time. The authors explain that if we study a phenomena in particular time it is probable that our research will be cross-sectional. On the other hand, a longitudinal study examines changes or development over time.

Our research will study and analyze tick data for publicly traded currency pairs during the years of 2011 and 2013. In order to cover the whole period we have divided they year into 3 groups each including 4 months. This save us time compared to an analysis on a quarterly basis and yet give us more findings than simply semi-annual analysis. In addition, the full second week of each period (weeks 6, 23, 40 for 2011 and 6, 23, 41 for 2013) is observed since it covers a period of 5 days consecutive 24 hours of trading. Similarly to Aiba et al (2002) who used 8 consecutive weeks of observations. The dataset consists of 2.4 million observations per currency pair which is in accordance with other researches such as Fenn et al’s (2008) dataset of 5.2 mil per strategy, Marshall et al. (2008) of 2.7 mil quotes and Akram’s (2008, p. 12) 2.5 mil observations.
Nevertheless, since one of the objectives of the research is to investigate whether there is a decrease in the number of arbitrage opportunities, we decided to utilize the historical data from 2011 and 2013 not take into account 2012’s in order to cover a bigger time span. The motivation behind this decision is the more coverage utilized compared to using two consecutive years. In addition, we hope that by doing so we can distinguish trends more easily and still generate statistically relevant results. This is why a longitudinal research is more appropriate for investigating trends than cross sectional which only present us with a snapshot of the current situation.

4.3 Data collection technique

In order to answer the research question and meet the objectives of the research it is essential to collect data of foreign currencies and analyze it. However depending on the frequency of the data, convenience and period under observation, one can choose from a range of providers.

The one that cover our requirements is the database of Histdata.com. It offers historical data on a second basis for 66 currency pairs since 2000. The data is available free of charge and its format is consistent making it easy to employ and refine into more usable form since it only includes a timestamp and last change in the quotation of that currency.

Because there is a mismatch between the timing of those changes, one is required to generate a file which fills the periods between those changes, making it easier when comparing with multiple currencies. For example if the EUR/USD bid at point of time 0015 was 1.3608 and the next change occurred at 0019 an issue arises when a comparison is made with another currency which had a different time of change. This is why it is required to generate a table where all quotations are aligned and the gap between the changes filled with the last known value.

4.4 Data analysis

Saunders et al (2009, p.139) suggests that depending on the purpose of the study a research can be exploratory, descriptive or explanatory. According to Robson (2002, p. 59) and Collis and Hussey (2009, p. 5) exploratory research seeks new insights is to analyze the ideas and patterns or hypothesis instead of verifying the theory using hypothesis.

Robson (2005, p. 59) explain a descriptive study as one that portray an accurate profile of event or situation. Since we want to make a profile of an event i.e. triangular arbitrage, but also establish a causal relationship between variables (Saunders et al., 2009, p. 140) our study will be descripto-explanatory. An explanatory characteristic is also incorporated since we are interested to establish a causal relationship between variables when testing the last 3 hypothesis related to Seasonality of occurrence on a monthly basis, correlation between Magnitude and Duration, and year to year changes.

When analyzing data one researcher can use different method such as quantitative, qualitative or a combination of both methods. The choice depends on the nature of the
study and its objectives. Since one of the objectives of the research is to show how often arbitrage on FX market exists it involves analysis of quantitative data in a systematic and replicable manner that seeks to quantify content in terms of predetermined categories (Bryman & Bell 2011, p. 291), the research method employed is quantitative analysis. We find this method suitable since we deal with comparison and analysis of numerical data in order to explain an event (i.e. arbitrage opportunities). Moreover, adding the fact that our research philosophy is positivism and our approach is deductive a quantitative method is appropriate. The benefits of this method also include high level of reproducibility, allowing other researchers to obtain same results using the same data.

There are different quantitative methods that can be used when analyzing numerical data. One such approach is the descriptive statistics which enable you to describe and compare numerical variables. It focuses on two aspects: central tendency (mode, mean and median) and dispersion (range, quartiles and coefficient of variance) (Saunders et al., 2008, p. 444).

Mean is the average and it is the most popular measure in fields such as business, engineering and computer science. It is best used when there are no extreme values. It is unique - there is only one answer and is useful when comparing sets of data. However a disadvantage it that it can be affected by extreme values (outliers). Other measure of central tendency is the median whose main advantage is the robustness to outliers. In addition, similar to the mean, there is only one answer and can be used to compare data. Unfortunately it is not as popular as the average as it does not take all the data into account. An advantage of the mode is that it can be used with non-numeric data or when we want to identify which is the most popular item. Extremes values do not affect the mode but when no values repeat the mode is every value in this data set which makes it difficult to interpret and compare. Using such analysis we can present the readers with variables such as the mean duration of arbitrages and median about the number of occurrences of arbitrage.

Another type of analysis that took place in the research was the strength of relationship test using Pearson’s product moment correlation coefficient when we examine the relationship between the magnitude and duration of arbitrage opportunities. Furthermore, a similar test was also used when comparing the correlations of two different groups of our sample. The advantages of this analysis is that it allow us to seek for linear relationship between two variable and how a change in one of them will affect the other (Saunders et al., 2008, p. 459). However, we cannot say anything about whether one caused the other. This method does not allow us to come to any conclusions about cause and effect.

4.5 Mathematical model

We would like first to introduce the practical formulation of the exchange rates. An exchange rate represents the number of units of one currency that can be exchanged for a unit of another. There are two ways to express an exchange rate between two currencies (e.g., the US Dollar USD and the Euro EUR). One can either write EURUSD or USDEUR. These are reciprocals of each other, if the exchange rate S is the price for
one EUR in USD ($S = \frac{USD}{EUR}$) and the exchange rate $S'$ is the price for one USD in EUR ($S' = \frac{EUR}{USD}$), then ($S = \frac{1}{S'}$) must hold. It is mandatory to use the domestic currency in the numerator while using the foreign one in the denominator, by stating it this way the origin of the trade and the desirable execution is indicated.

Further, in order to identify the possibility of arbitrage opportunity, one should compare simultaneously the currency pairs. If there is a price deviation this suggests that there is a possibility to capitalize risk-free profit. In order to quantify the existence of triangular arbitrage opportunities we use the following quantity:

$$y(t) = \prod_{i=1}^{3} r_i(t)$$

(1.1)

Where $r_i(t)$ denotes each currency rate at time $t$ on a second basis. A triangular arbitrage opportunity exists whenever the rate product $y(t)$ is greater than 1.

Since there are three currencies involved, two different strategies of execution depending on the order of execution can be applied. For example, a trader can change not only from EUR to USD to GBP and then back to EUR but also vice versa. This gives a trader higher chances to observe an opportunity since there are six quotations and only a small violation in one of them is needed to make a strategy profitable. The first rate product of our example using one of the strategies is as follows:

$$y_1(t) = \left( \frac{EUR}{USD_{bid}(t)} \right) \times \left( \frac{USD}{CHF_{bid}(t)} \right) \times \left( \frac{1}{CHF_{ask}(t)} \right)$$

(1.2)

The second possible arbitrage strategy in the reverse directions is:

$$y_2(t) = \left( \frac{1}{EUR} \right) \times \left( \frac{1}{USD_{ask}(t)} \right) \times \left( \frac{EUR}{CHF_{bid}(t)} \right)$$

(1.3)

Those two rate products determine all possible combination using those currencies.

The objective of these equations is to find if that parity holds. Considering that in our study we investigate our data in a second basis, each time that the parity is violated must be recorded. This analysis should conducted in a regular basis with all different datasets from all different strategies. Moreover, we will calculate the number of arbitrages by testing if the product of exchange rates for each second is greater than 1 or not. If it is greater than 1 we will make use of a formula which will count how many times this...
4.5.1 Significant test

The significance test examines if a relationship within variables is determined by something else than a mere luck. All our hypothesis were tested using one or two sample t-test. The T-test is the most widely used test when testing for relevance of the null hypothesis (Studenmund, 2011, p. 128). When doing so, one can choose from a significance levels $\alpha$ ranging between 0.1 and 0.01 depending on the field of study. In the financial field, it is a general practice to apply significance levels $\alpha = 0.05$, therefore we have decided to use it in our research.

**Hypothesis 1b using independence t-test**

In order to show that arbitrage opportunities occur more on the emerging market we formulate the following statement which will be tested using independent two sample t-test. When conducting t-test researchers choose between a one-sided and two-sided test, depending on the alternative hypothesis (Studenmund, 2011, p. 122-123).

**Null hypothesis:** $\mu$ (emerging) $\leq \mu$ (developed)

**Alternative hypothesis:** $\mu$ (emerging) > $\mu$ (developed)

Since we are examining a hypothesis in such a way that values can take place on both sides of the null hypothesis we will use one sided test with significance level of $\alpha = 0.05$. The t-test will be equal to:

$$t = \frac{\mu_{emerging} - \mu_{developed}}{est. \sigma_{emerging-developed}}$$

(2.1)

In order to arrive to the estimation of variance of the standard deviation of the sampling distribution of sample-mean differences ($est. \sigma_{emerging-developed}$) we firstly estimated the variance of the source population by using the following formula (Lowry, 2013):

$$s_p^2 = \frac{SS_{emerging} + SS_{developed}}{(N_{emerging} - 1) + (N_{developed} - 1)}$$

(2.2)

$$est. \sigma_{emerging-developed} = \sqrt{\frac{\frac{s_p^2}{N_{emerging}} + \frac{s_p^2}{N_{developed}}}{2}}$$

(2.3)

**Hypothesis 2 Decreasing rate of number of arbitrages**
To test our hypothesis whether the number of arbitrages is decreasing in 2013 compared to 2011 we will use a dependent one pair t-test because we are testing the same sample repeatedly.

Our hypothesis is that the arbitrage opportunities in 2013 has decreased compared to 2011. This can be formulated as:

**Null hypothesis**: \( \mu_d \geq 0 \) Where \( \mu_d = \mu_{2013} - \mu_{2011} \)

**Alternative hypothesis**: \( \mu_d < 0 \)

\[
t = \frac{\bar{x}_d - 0}{S_d / \sqrt{n_d}}
\]

(3.1)

Where \( \bar{x}_d \) the average of the difference is, \( S_d \) is the standard deviation and \( n_d \) is the number of sample differences. We use one tail t-test since we have a directional hypothesis.

**Hypothesis 3a Correlation testing using one sample one tail t-test**

The main objective of the research is identify is there a relationship between the magnitude of the arbitrage opportunities and their duration. Although Fenn et al. (2008, p. 9) researched this subject related to two JPY transactions and two CHF transactions, the evidences show controversial finding. Thus we would like to test if there is in fact such a link and if there is a difference between developed and emerging currencies.

Since we are working with samples by obtaining different samples we might calculate another correlation thus drawing a different conclusion. We want to generalize and draw a conclusion about the linear relationship of the population hence, we will use t-test for testing the population correlation coefficient.

**Null hypothesis** Ho: \( \rho \leq 0 \)

**Alternative hypothesis** Ha: \( \rho > 0 \)

Formula used for calculating correlation coefficient:

\[
r = \frac{1}{n-1} \sum \left(\frac{X - \bar{X}}{S_x}\right) \left(\frac{Y - \bar{Y}}{S_y}\right)
\]

(4.1)

When comparing the correlation between two sample groups we have to test if it is significant and to eliminate the possibility that such difference arise by luck. To do so we will test for significance of the difference between two correlation coefficients. It will test the hypothesis one correlation coefficients obtained from independent sample is stronger than another one, known as Fisher’s r-to-z transformation (J. Cohen & P. Cohen, 1983)
Formula used for calculating test-statistic:

\[ t = \frac{r}{\sqrt{\frac{1-r^2}{n-2}}} \]  

(4.2)

The obtained test statistic is used to calculate the P-value which answers the question "how likely is it that we’d get a test statistic \( t^* \) as extreme as we did if the null hypothesis were true?" The P-value is determined by referring to a \( t \)-distribution with \( n-2 \) degrees of freedom. If the P-value is smaller than the significance level \( \alpha \), we reject the null hypothesis in favor of the alternative. We can conclude that "there is sufficient evidence at a significant level \( \alpha \) that there is a relationship in the population magnitude and duration." If the P-value is larger than the significance level \( \alpha \), we fail to reject the null hypothesis.

**Hypothesis 3b Magnitude and duration difference between emerging and developed**

Similarly to the previous hypothesis we have to quantify the correlation coefficient between magnitude and duration but only this time it be separated into 2 samples: emerging and developed countries. Furthermore we would test if the arbitrages using emerging currencies has a stronger relation between magnitude and duration compared to strategies using developed currencies. Thus we formulate the following hypothesis:

**Null hypothesis:** The relationship between the magnitude and the duration of the arbitrage is weaker in the emerging markets than in the developed

\[ |\rho| \text{ (emerging)} \leq |\rho| \text{ (developed)} \]

**Alternative hypothesis:** The relationship between the magnitude and the duration of the arbitrage opportunities is stronger in the emerging markets than in the developed

\[ |\rho| \text{ (emerging)} > |\rho| \text{ (developed)} \]

In order to compute p-value and compare it with level of significance \( \alpha \) one has to obtain the difference between the two correlations.

\[ z = \frac{z_{\text{developed}} - z_{\text{emerging}} - 0}{\sigma_{z_{\text{developed}} - z_{\text{emerging}}}} \]

(5.1)

Where \( z_{\text{developed}} \) the first correlation is transformed to \( z \) and \( z_{\text{emerging}} \) is the second correlation transformed into \( z \), 0 is the value specified in our null hypothesis and \( \sigma_{z_1 - z_2} \) is the standard error of the difference between \( z \) s in the formula:

\[ \sigma_{z_{\text{developed}} - z_{\text{emerging}}} = \sqrt{\frac{1}{N_{\text{developed}} - 3} + \frac{1}{N_{\text{emerging}} - 3}} \]

(5.2)
Where $N_{\text{developed}}$ the sample is size of the first sample and $N_{\text{emerging}}$ is the sample size for the second sample.

Fisher r to z Transformation formula is required since sampling distribution of Pearson’s r is not normal the sample correlations are transformed to Fisher’s z’s (Jane, 2013).

\[
    z = \frac{1}{2} \ln \left( \frac{1+r}{1-r} \right)
\]

(5.3)

The final step is to find the probability value of z using the formula:

\[
    P(Z \leq z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} e^{-\frac{u^2}{2}} du
\]

(5.4)

A comparison with the significance level $\alpha$ is needed to identify whether the results are significant or not.

4.6 Software used

In order to analyze a dataset with such high quantities, we had to use a combination of Microsoft Excel and R programming language. The latter was needed to overcome the software limitation when applying the mathematical model, sorting the results and testing our hypothesis. Using this software and functions, such as “run length encoding” (rle), we were able to measure the durations of each arbitrage. In addition when calculating the correlation and testing for its significance we used the cor.test function. The variables studied here were computed using the data points gathered from the Histdata database and then, these were processed using R software which remains as one of the most prominent tools for statistical analysis within the academic research community (Crawley, 2007, viii). Due to the lack of experience in this software, we are relieved that the statistical department gave us an advice of how to compile the data in R. We find this program is suitable for our needs since it is available for free. After the analysis has been made conclusions were drawn using tables and graphs created in Excel.

4.7 Limitations

The limitation of this thesis rests on the fact that it will provide data from restricted period of time. Under this study, the time horizon will be six weeks, in which half are attributed in 2011 and the rest in 2013. Data for many currencies were not available in Histdata.com before 2010 and thus, the application of this particular boundary occurred as a consequence. Moreover, we decided to distinguish the two periods of the study in one week per quarter, because we faced the problem of the technology and time
limitation. Our data has to be scrutinized tick–by-tick which demands a high computational capacity and/or a long time span. Unfortunately, due to the time constraints, the authors were unable to conduct a longitudinal study that would provide further data regarding the number of arbitrage occurrences and the level of decrease/increase in frequency.

Our analysis in arbitrage in FX spot market is limited to two bilateral exchange rates e.g. USD/CHF (United stated Dollar) and EUR/CHF. Our decision is constant with the fact that the Dollar and Euro are considered the principals when it comes for triangular arbitrage and the most competitive currencies in the world. However, with the recent rapid growth in Asia, one may expect that Japanese Yuan would be the most traded currency in the near future. This may affect the duration and the validity of our research, but is totally valid as long as the leading currencies remain the same. Additionally, we would like to investigate further emerging economies, which has been extremely popular the recent years, such as Mexican Peso (MXN) and South Africa Rand (ZAR). Unluckily, we were not able to be provided with such information, since the sources from Histdata are limited to certain pairs.

We could also provide a more complete picture by making use of transaction costs. For each transaction to be made, a small transaction fee has to be paid. Even though those costs on the Forex market are less significant compared to other markets, they are still important and should be taken into account when executing a trade. Their use could affect the decision of an investor since he is facing the risk of cost which would constraint the strategies and minimize the profitable arbitrage occurrences. The most of the researches take into consideration transaction costs, however this is not applicable for our research. Such data is not widely available and costly to obtain. For example, Data provider such as Tickdata.com offer such information for the price of $15,750.00. Since we cannot afford nor make estimates, transaction costs are ignored and the parity should hold.

The last limitation is the lack of volumes of trading within each pair, which are needed to clarify further our results. Aarheim & Johnsen (2013, p. 20) indicate the importance of the volumes for measuring the number of arbitrage observations, as making them more “realistic”. Using volumes, all the roundtrips that the number of trading remains the same, are measured as one occurrence, however in our case we cannot exclude the number of arbitrage which its trading size is the same since we only face values and the trading quantities are unknown.
5. Empirical Findings and Analysis

5.1 Arbitrage in the Forex market

In this section we present and analyze the findings of our research. The focus of our analysis is divided into two main parts. We will first show that arbitrage opportunities arise in Forex market by counting the number of observations and continuously we will provide insights in triangular arbitrage by detecting the difference between emerging and developed markets. Secondly, we will also refer to the relationship between the magnitude and the mean duration of the arbitrage, as; the more the waiting period of arbitrage observations the more profit you can earn which is counterintuitive and not anticipated.

The selected roundtrips will be compared with each other yearly which will allow us to investigate if the number of arbitrage has increased or decreased throughout the years. However, willing to make our analysis more thorough we will provide more information about each trading week in our appendices (see appendix 1-4). As it has been mentioned in chapter 4.3, we have used a timeframe in which for 2011 and 2013, week 6, 23, 40 and 6, 23 and 41 respectively, belongs to February, June and October. Finally, as mentioned above all the currencies contain the best bid and best ask quotes, while we do not make use of volumes when we count the number of arbitrage opportunities.

5.2 The occurrence of arbitrage

We start our analysis with the first four strategies with their reverse roundtrips which are referring to the developed countries. Moreover, the last four with their reverse roundtrips are attributed to the emerging market currencies. All discussed descriptive statistics such as median, mean, maximum and minimum are on weekly basis whereas the number of arbitrages is on a yearly basis.

5.2.1 Arbitrage in developed market currencies

**EUR/USD - USD/JPY - EUR/JPY**

We will first start our examination with the roundtrip of the most traded currency in the Forex market.

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>95</td>
<td>19</td>
<td>32</td>
<td>75</td>
<td>1</td>
</tr>
<tr>
<td>2013</td>
<td>68</td>
<td>6</td>
<td>23</td>
<td>58</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 1: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/USD - USD/JPY - EUR/JPY (without volume). *weekly.

Table 1 depicts that the number of arbitrage opportunities has decreased throughout the years, from 2011 to 2013. There was a downgrade of 28% in the arbitrage occurrences. This result is consistent with what Ito et.al (2012, p. 41) and Fenn et al. (2008) have identified for the particular roundtrip. With a longer period of time, they found a huge decrease in the number of opportunities. Furthermore, Aiba et al. (2002, p. 470) and...
Marshall et al. (2008, p. 16) have found that arbitrage opportunities for this particular strategy are “persisting throughout the entire day”. As we can observe in appendix 1, week 40 of 2011 had the highest number of observations in contrast to the rest of the weeks. Significant is the fact that the same week in 2013 had the lowest number while the highest was in June (week 23). Additionally, we can see from the table above that the difference between mean and median is closer in 2011 which means that in 2013 more outliers were existing. As we have stated in chapter 4.4, the median is a more stable measure. That means that it will not be affected of any interruptions e.g. outliers in our case. These extreme occurrences are reasonable to exist since we do not consider volumes, and there is room for possible outliers and/or market imperfections.

**EUR/JPY - USD/JPY - EUR/USD**

This is the reverse strategy of the first roundtrip above which include the same currencies but the order of execution of the transactions is different.

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>265</td>
<td>56</td>
<td>88</td>
<td>204</td>
</tr>
<tr>
<td>2013</td>
<td>67</td>
<td>12</td>
<td>22</td>
<td>52</td>
</tr>
</tbody>
</table>

*Table 2: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/JPY - USD/JPY - EUR/USD (without volume).* weekly.

Similar with the ordinary strategy, the reverse also testify the decline in the number of arbitrage occurrences. In 2011 were 265 incidences and until 2013 they have been decreased to 67, a downturn of 75%. Aarheim & Johnsen (2013, p. 29), by measuring the weekly median, had also found evidence for this decrease through the years from 2003 to 2007. In table 3, we can see that the median is also decreasing through the years which also implies the drop in the amount of arbitrage. The spread between the median and the mean has also decreased from 2011 to 2013 by 75%. This suggest that the outliers were less in 2013 which makes the distribution smoother. Once more, as we can observe from appendix 2, October had the most observations in 2011, while it was June in 2013. The reverse strategy had better chances for profits in contrast to the ordinary.

**EUR/USD - GBP/USD - EUR/GBP**

The second most traded currency in the FX market is GBP, if we exclude EUR and USD since we interfere it into the strategy.

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>246</td>
<td>40</td>
<td>95</td>
<td>240</td>
</tr>
<tr>
<td>2013</td>
<td>17</td>
<td>70</td>
<td>5</td>
<td>80</td>
</tr>
</tbody>
</table>

*Table 3: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/USD - GBP/USD - EUR/GBP (without volume).* weekly.

Similar with the preceding analysis, for this strategy we can conclude, that the amount of arbitrage has declined from 246 in 2011 to 17 in 2013. This is a decrease of 93% between the intervals of two years. Aarheim & Johnsen (2013, p. 27) found a similar trend in the number of arbitrage from 2003 to 2007. Marshall et al. (2008, p. 16) have found that triangular arbitrage opportunities exist for this strategy throughout a whole day for the year 2005. By looking in the table 4, the maximum was 240 with a median
of 40 in 2011 and it drops to 80 in 2013 with a median of 70. This indicates a significant number of outliers in 2011, while they have been decreased notably in 2013. From appendix 1 we can detect that October shows higher number of arbitrage occurrences for 2011 and June for 2013 respectively.

**EUR/GBP - GBP/USD - EUR/USD**

This is the reverse strategy from the previous one with the same currency.

<table>
<thead>
<tr>
<th>Year</th>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>213</td>
<td>24</td>
<td>71</td>
<td>184</td>
<td>5</td>
</tr>
<tr>
<td>2013</td>
<td>35</td>
<td>9</td>
<td>12</td>
<td>22</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 4: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/GBP - GBP/USD - EUR/USD (without volume). *weekly.

Table 4 shows that the level of arbitrage was low in 2013 in contrast to 2011. There was a downturn of 84%. Our findings are consistent with Aarheim & Johnsen (2013, p. 27) where they also found a decline in the trend for six sequential years. The maximum for 2011 was 184 while the median was 24 which clearly shows the presence of extreme occurrences. The difference between median and mean for 2011 can confirm this argument once more. However, for 2013 the extremes are not so significant and the spread between mean and median has decreased in the amount of 93%. We can observe from appendix 2 that this roundtrip follows a similar trend as prior where February had the greatest number of arbitrage in 2011 while it was June for 2013.

**EUR/USD - USD/CHF - EUR/CHF**

This the original roundtrip of the third most traded currency in the FX market excluding EUD and USD.

<table>
<thead>
<tr>
<th>Year</th>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>286</td>
<td>40</td>
<td>95</td>
<td>240</td>
<td>6</td>
</tr>
<tr>
<td>2013</td>
<td>159</td>
<td>70</td>
<td>53</td>
<td>80</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 5: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/USD - USD/CHF - EUR/CHF (without volume). *weekly.

Similar to the Table 5, Table 6 indicates the same trend in the number of arbitrage observations. There is a decline of 44%, since in 2011 the occurrences were 286 while in 2013 there was a drop to 159 occurrences. Our findings are expected and persistent with both Fenn et al. (2008, p. 12) and Marshall et al. (2008, p. 29). The first one has presented the decline of the number of risk-free profits in four weeks interval and the latter has found evidence of arbitrage activity through a full year in 2005. Again, we can see that the spread between median and mean has been increased throughout the years, but also the difference between the maximum and the median, which indicates that in 2013 the number of arbitrage were more normally distributed. Finally, the results, according to appendix 1, show that the maximum for 2011 was in October while for 2013 was in June.

**EUR/CHF - USD/CHF - EUR/USD**

This is reverse roundtrip strategy of the previous.
Table 6: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/CHF - USD/CHF - EUR/USD (without volume). *weekly

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>123</td>
<td>41</td>
<td>69</td>
<td>13</td>
</tr>
<tr>
<td>2013</td>
<td>126</td>
<td>35</td>
<td>91</td>
<td>0</td>
</tr>
</tbody>
</table>

In this table, there is an unexpected increase in the number of arbitrage opportunities, contrary to the preceding roundtrips. However the raise was small by 2.5%. Nevertheless, Aarheim & Johnsen (2013, p. 31) has shown a vast decreasing tendency throughout six sequential years. The increased number of arbitrages can be explain with the fact that we do not make use of volumes, so the number in some cases may be unrealistic. The median and the mean have the same figure which reveals the absence of the outliers in this strategy. As we can observe from the appendix 2 the number of arbitrage for both years is changing in a logical manner through the weeks, without any extreme spreads between the maximum, mean and median. Having a look in appendix 2, the numbers display a maximum in October for 2011; thus, the same characteristic in June for 2013. As in the ordinary strategy, the magnitude is more normally distributed than the previous strategies with their roundtrips.

**EUR/USD - AUD/USD - EUR/AUD**

That is the fourth most traded currency in FX market, excluding EUR and USD.

Table 7: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/USD - AUD/USD - EUR/AUD (without volume). *weekly.

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>176</td>
<td>11</td>
<td>165</td>
<td>0</td>
</tr>
<tr>
<td>2013</td>
<td>40</td>
<td>16</td>
<td>24</td>
<td>0</td>
</tr>
</tbody>
</table>

From the table above, we can see that the possible risk-free profits have been eliminated, since the number of arbitrage has decreased from 2011 to 2013 by 77%. The difference between the median and the mean has decreased from 48 in 2011 to 3 in 2013. The maximum was 165 in 2011 while in 2011 it drops to 24, which indicates that the outliers were much less for 2013. However, there was an entire week in June for both 2011 and 2013, where no arbitrage observations. As in the previous strategies, appendix 1 shows that for 2011 week 40 had the more arbitrage activity and week 23 in 2013 respectively.

**EUR/AUD - AUD/USD - EUR/USD**

This is the reverse roundtrip of the AUD previous strategy.

Table 8: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/AUD - AUD/USD - EUR/USD (without volume). *weekly.

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>2473</td>
<td>59</td>
<td>824</td>
<td>15</td>
</tr>
<tr>
<td>2013</td>
<td>80748</td>
<td>24</td>
<td>26916</td>
<td>80722</td>
</tr>
</tbody>
</table>

Consistent with table 6, table 8 shows a dramatic rise in the number of arbitrage in 2013 in contrast to 2011. This ascent is represented by the outstanding change of 3 165%.
However, according to Aarheim & Johnsen (2013, p. 28), there might be several reasons for that. Firstly, the years might be influenced by extreme conditions which could easily be seen by looking in the difference between the median and the mean in both years. Secondly, as reported by the superiors, testing the median can give us a more realistic picture, since they are not affected by the outliers. It can be seen that the median is decreasing by 59%. Nonetheless, making use of volumes and considering more weeks and months could enhance the assertion of our description. Once more, it can be seen from appendix 2 that, for 2011 there is a spike in the number of arbitrage occurrences in October while in June for 2013.

5.2.2. Arbitrage in emerging market currencies

**EUR/USD - USD/HUF - EUR/HUF**

This strategy contains a trade through an emerging market economy.

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>25675</td>
<td>138</td>
<td>9558</td>
<td>28470</td>
</tr>
<tr>
<td>2013</td>
<td>260</td>
<td>115</td>
<td>87</td>
<td>145</td>
</tr>
</tbody>
</table>

Table 9: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/USD - USD/HUF - EUR/HUF (without volume). *weekly.

The table above, similar to the majority of the strategies, confirms the decreasing number of arbitrage per year. Particularly, in this example, the drop were 110 times less in 2013 than in 2011. The extreme conditions in this currencies were mass and it is clarified by observing the deference between the mean and the median. There was a difference of 9 420 occurrences in 2011, while the maximum was 28 470, however, the difference has shorten in 2013 to 28 observations, making the distribution well standard. Once more, appendix 3 points out that October was the most active month for 2011 and June for 2013. Significant is the fact that there was a full week in October without any incidences of risk free profits.

**EUR/HUF – USD/HUF – EUR/USD**

This is the reverse strategy of the preceding one.

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>8702</td>
<td>52</td>
<td>2901</td>
<td>8609</td>
</tr>
<tr>
<td>2013</td>
<td>408</td>
<td>31</td>
<td>136</td>
<td>373</td>
</tr>
</tbody>
</table>

Table 10: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/HUF – USD/HUF – EUR/USD (without volume). *weekly.

Along the ordinary strategy, the reverse one indicates a downturn of 95 % in the number of arbitrage. As previously, in 2011, the mean and the median were driven by large outliers, while in 2013 the number of the median through the years and the spread between the mean and the median has merged notably. In this strategy results are similar as previous (see appendix 4) with October having the most occurrences in 2011 and June in 2013.
EUR/USD - USD/CZK - EUR/CZK

This roundtrip, contains a trade in CZK, which applies for an emerging market currency.

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>519</td>
<td>107</td>
<td>316</td>
<td>96</td>
</tr>
<tr>
<td>2013</td>
<td>53399</td>
<td>19420</td>
<td>29485</td>
<td>4494</td>
</tr>
</tbody>
</table>

Table 11: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/USD - USD/CZK - EUR/CZK (without volume). *weekly.

Table 11 shows that the arbitrage is moving upwards in 2013 in an extent of 102 times mere in contrast to 2011. In general, such a number is impossible to appear in such a great extent and in that point we would like to outline the importance of volumes into these kind of investigations, where the results would conducted with further accuracy. The increase in the median reached an increase of 18 049% in 2013, if we compare it with 2011. However, the spread between the mean and the median is not excessive which means that the occurrences were better distributed.

EUR/CZK - USD/CZK - EUR/USD

The reverse roundtrip including CZK is examined below.

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>142</td>
<td>60</td>
<td>82</td>
<td>0</td>
</tr>
<tr>
<td>2013</td>
<td>82617</td>
<td>20452</td>
<td>56384</td>
<td>5771</td>
</tr>
</tbody>
</table>

Table 12: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/CZK - USD/CZK - EUR/USD (without volume). *weekly.

Once more, we can see from table 12 that the number of arbitrage opportunities has increased tremendously in 2013, by 580 times less, in contrast to 2011, with a lot of extreme incidences. However, it can be seen from the Appendix 4, week 40 in 2011 did not present any single arbitrage opportunity. For 2013, the biggest activity is presented in October, while the existence of outliers is apparent.

EUR/USD - USD/PLN - EUR/PLN

This strategy holds the third currency of the emerging market economies that we will investigate.

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>7897</td>
<td>651</td>
<td>7155</td>
<td>91</td>
</tr>
<tr>
<td>2013</td>
<td>1728</td>
<td>388</td>
<td>1275</td>
<td>05</td>
</tr>
</tbody>
</table>

Table 13: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/USD - USD/PLN - EUR/PLN (without volume). *weekly.

It can be seen from the table 13, that Polish Zloty strategy shows a decreasing levels of arbitrage in 2013 compared to 2011. This change is up to 78%, while looking in the spread between the mean and the medium the extremes are more in 2011 than in 2013. As it can be seen from the appendix 3, the number of arbitrage changes irregular which
testifies the presence of extreme conditions. Also, as previous strategies, in 2011 October experiences higher activity, however, for 2013 February was more active in contrast to the rest.

**EUR/PLN - USD/PLN - EUR/USD**

This roundtrip is the reverse roundtrip of EUR/USD - USD/PLN - EUR/PLN.

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>3120</td>
<td>400</td>
<td>1040</td>
<td>2702</td>
</tr>
<tr>
<td>2013</td>
<td>2004</td>
<td>425</td>
<td>668</td>
<td>1561</td>
</tr>
</tbody>
</table>

*Table 14: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/PLN - USD/PLN - EUR/USD (without volume). *weekly*

Table 14 shows that the number of arbitrages in this strategy is declining by 36%. Here, the outliers are a lot in both years, with October holding the most occurrences in 2011. However, aligned with the ordinary strategy, appendix 4 depicts that February is the month with the most arbitrage observations. The extremes here are in a high frequency as previously.

**EUR/USD - USD/TRY - EUR/TRY**

This is the last roundtrip of the most traded currencies of the emerging markets.

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>15624</td>
<td>20</td>
<td>5208</td>
<td>15598</td>
</tr>
<tr>
<td>2013</td>
<td>973</td>
<td>11</td>
<td>324</td>
<td>962</td>
</tr>
</tbody>
</table>

*Table 15: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/USD - USD/TRY - EUR/TRY (without volume). *weekly.*

Table 15 depicts as the rest of the strategies the drop in the number of opportunities for profits without risk by 94%. The spread between the mean and the median is tremendous for 2011, counting for 5188 opportunities difference but in 2013 is limited to 313, which means that the outliers has been eliminated for the last month. More occurrences have been observed in October for 2011 and in June for 2013 (Appendix 3).

**EUR/TRY - USD/TRY - EUR/USD**

This is the reverse strategy from the previous roundtrip.

<table>
<thead>
<tr>
<th>N. of Arbitrages</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>1697</td>
<td>0</td>
<td>566</td>
<td>1697</td>
</tr>
<tr>
<td>2013</td>
<td>114441</td>
<td>25882</td>
<td>38147</td>
<td>86174</td>
</tr>
</tbody>
</table>

*Table 16: Shows the No. of triangular arbitrage opportunities, as well as the descriptive statistics, for EUR/TRY - USD/TRY - EUR/USD (without volume). *weekly.*

The last table shows an acute upward trend in the number of arbitrage which counts for 67 times increase. This is consistent with the exceptions that we have noticed previously. As it can be seen from the appendix 4, for 2011 there were full two weeks in February and October where no arbitrage opportunities were existed. However, in 2013
the number of extreme conditions was really high, exclusively in June and October. Consequently with the ordinary strategy, in 2011 the trend was characterized by smooth movements but in 2013 we can observe extreme magnitudes in a range of 12.2 and 14.2 bps.

5.3 Differences and overall trends of arbitrage occurrences

The table below shows the total number of arbitrage in the two different groups separately. The currencies followed by the figure 1 refer to the ordinary roundtrip, while the ones with the figure 2 to the reverse.

<table>
<thead>
<tr>
<th>Developed Markets</th>
<th>Emerging Markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPY1</td>
<td>163 HUF1</td>
</tr>
<tr>
<td>JPY2</td>
<td>332 HUF2</td>
</tr>
<tr>
<td>GBP1</td>
<td>263 CZK1</td>
</tr>
<tr>
<td>GBP2</td>
<td>248 CZK2</td>
</tr>
<tr>
<td>CHF1</td>
<td>445 PLN1</td>
</tr>
<tr>
<td>CHF2</td>
<td>249 PLN2</td>
</tr>
<tr>
<td>AUD1</td>
<td>216 TRY1</td>
</tr>
<tr>
<td>AUD2</td>
<td>83,221 TRY2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>85,137 Total</strong></td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>10,642</td>
</tr>
<tr>
<td><strong>St. Dev</strong></td>
<td>29,326</td>
</tr>
</tbody>
</table>

*Table 17: Shows the No. of triangular arbitrage occurrences per group for the two years*

The analysis above has been made to find evidence that Forex market can be characterized as an imperfect market, since arbitrage exists and progressively has been analyzed. There is not such a matter of disbelief, since it is a yes or no question, depending on what the triangular arbitrage parity in relation to the bid/ask quotes will show. As we can observe from the table 18 the number of arbitrage opportunities not only occurs but they are more in emerging economies than in developed markets. All in all, emerging markets show better likelihood for riskless profits and give a higher prosperity into the trading world.

In the appendix 5 & 4, we have pinpointed the two different groups of our data for both years. It follows that for 2011 developed economies had a really low level of bursts. In comparison, the occurrences in the emerging markets are diminished gradually but steadily. However, we can observe the unexpected spillovers in some cases. This means that arbitrage was active in this period of time and there was high chance for market makers to make profits. For 2013 the whole picture remains the same in both kind of economies, with the developed ones descending in smoother level than the previous year. However, emerging market currencies are observed to be declining firmly, and once more the whole trend has been characterized by spikes.

The results are consistent with Frömmel (2006, p. 16) who found evidence that there is a positive relationship between the exchange rate volatility and the switches in the exchange rate system and monetary policy in such countries. This means, that for the developed currencies in which the fiscal system is stable the number of arbitrage is calm and the total spikes negligible. In contrast, emerging or “early” economies are represented by irrationality and volatility, which pose the outbursts and consequently the chances of higher profits, more likely to occur.
Significant test

In order to show that the difference between the number of arbitrages in emerging and developed markets is significant, a test of proportions will be used. The total number of arbitrages occurrences and their proportion has been presented in the table 18. We will make a use of two sample t-test with two independent variables and we will test the following hypotheses:

**Ho: Triangular arbitrage opportunities occur less in emerging markets than in the developed ones.**

**Ha: Triangular arbitrage opportunities occur more in emerging markets than in the developed ones.**

The p-value for $t = 838.15$ is $p<0.000001$ which is relatively small number. Comparing it to our level of significance $\alpha= 0.05$ we come to the conclusion that our results are significant, therefore rejecting the null hypothesis in favor of the alternative; the arbitrage opportunities on the emerging market are more than the ones in developed markets.

5.4 Differences over time

The table above shows the change in the number of arbitrage occurrences within all the strategies over the years from 2011 to 2013. The currencies followed by the figure 1 refer to the ordinary roundtrip, while the ones with the figure 2 to the reverse.

<table>
<thead>
<tr>
<th>Currencies</th>
<th>Years</th>
<th>2011</th>
<th>2013</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPY1</td>
<td>2011</td>
<td>95</td>
<td>68</td>
<td>-27</td>
</tr>
<tr>
<td>JPY2</td>
<td>2011</td>
<td>265</td>
<td>67</td>
<td>-198</td>
</tr>
<tr>
<td>GBP1</td>
<td>2011</td>
<td>246</td>
<td>17</td>
<td>-229</td>
</tr>
<tr>
<td>GBP2</td>
<td>2011</td>
<td>213</td>
<td>35</td>
<td>-178</td>
</tr>
<tr>
<td>CHF1</td>
<td>2011</td>
<td>286</td>
<td>159</td>
<td>-127</td>
</tr>
<tr>
<td>CHF2</td>
<td>2011</td>
<td>123</td>
<td>126</td>
<td>3</td>
</tr>
<tr>
<td>AUD1</td>
<td>2011</td>
<td>176</td>
<td>40</td>
<td>-136</td>
</tr>
<tr>
<td>AUD2</td>
<td>2011</td>
<td>2,473</td>
<td>80,748</td>
<td>78,275</td>
</tr>
<tr>
<td>HUF1</td>
<td>2011</td>
<td>28,675</td>
<td>260</td>
<td>-28,415</td>
</tr>
<tr>
<td>HUF2</td>
<td>2011</td>
<td>8,702</td>
<td>408</td>
<td>-8,294</td>
</tr>
<tr>
<td>CZK1</td>
<td>2011</td>
<td>519</td>
<td>53,399</td>
<td>52,880</td>
</tr>
<tr>
<td>CZK2</td>
<td>2011</td>
<td>142</td>
<td>82,617</td>
<td>82,475</td>
</tr>
<tr>
<td>PLN1</td>
<td>2011</td>
<td>7,897</td>
<td>1,728</td>
<td>-6,169</td>
</tr>
<tr>
<td>PLN2</td>
<td>2011</td>
<td>3,120</td>
<td>2,004</td>
<td>-1,116</td>
</tr>
<tr>
<td>TRY1</td>
<td>2011</td>
<td>15,624</td>
<td>973</td>
<td>-14,651</td>
</tr>
<tr>
<td>TRY2</td>
<td>2011</td>
<td>1,697</td>
<td>114,441</td>
<td>112,744</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2011</td>
<td>70,253</td>
<td>337,090</td>
<td>266,837</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>St. Dev</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40,920</td>
<td>16,677</td>
</tr>
</tbody>
</table>
Table 18 shows that in most of the strategies the number of arbitrage is decreasing over the years. Although thorough explanation has been carried in the chapter 5.2.1 for each strategy separately, we would like to underline the overall picture of the two groups together. As it can be seen, in 2013 the total number of arbitrage opportunities has been increased dramatically since 2011. However, in that point, we have to remark the significant impact of the rise in arbitrage observations in several strategies. The reverse roundtrip of AUD, CZK and TRY and the ordinary of CZK have shown an extensive climb who reaches the scale of 58,080% (CZK2). Nevertheless, as it has mentioned in the chapter 4.7 the not existence of volumes can alternate the results. In our case seems more likely that these currencies occur arbitrage with constant number of trading volumes which are not visible to us. Thus, should we not be able to eliminate them, we therefore exclude them from our analysis. At last, we did not removed CHF2 strategy, since the results are not driven by any spikes. Conclusively, we can say that the number of arbitrage over time has dropped, which as it has been discussed earlier through literature review, can be attributed to the introduction of high frequency trading.

**Significant test**

In order to show that the number of arbitrage has decreased over the years, we have to conduct a two-sample T-test analysis. So, we would like to examine the following hypothesis:

*Ho: The arbitrage opportunities increase over time.*

*Ha: The arbitrage opportunities decrease over time.*

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>4390.8125</td>
<td>21068.125</td>
</tr>
<tr>
<td>Variance</td>
<td>61021144.16</td>
<td>1480025720</td>
</tr>
<tr>
<td>Observations</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>-0.22195825</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>-1.972733112</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.03709446</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.753050356</td>
<td></td>
</tr>
</tbody>
</table>

Table 19: Shows the Two-Sample T-test results.

Using Excel’s function we calculate how much is the standard deviation of the last column which gives us t-statistics of -1.972733112. This lead us to a P-value of 0.03709446 and comparing it to our significance level of α=0.05, our conclusion is that the result is significant and thus rejecting the null hypothesis which means the arbitrages in 2013 were less than in 2011. However, we have to add once more that we have
excluded the currencies that have been driven by an increasingly extreme number of arbitrage occurrences.

5.5 The Magnitude and duration of arbitrage opportunities
5.5.1 Developed Market currencies

<table>
<thead>
<tr>
<th>Developed countries</th>
<th>Magnitude</th>
<th>Mean Duration in sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0-1</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>1-2</td>
<td>1.99</td>
</tr>
<tr>
<td></td>
<td>2-3</td>
<td>1.57</td>
</tr>
<tr>
<td></td>
<td>3-4</td>
<td>1.66</td>
</tr>
<tr>
<td></td>
<td>4-5</td>
<td>10.2</td>
</tr>
</tbody>
</table>

Table 20: Shows the range of the magnitude in the number of arbitrage in relation to the mean duration per second for the developed countries in total (2011).

<table>
<thead>
<tr>
<th>Developed countries</th>
<th>Magnitude</th>
<th>Mean Duration in sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0-1</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>1-2</td>
<td>1.99</td>
</tr>
<tr>
<td></td>
<td>2-3</td>
<td>1.57</td>
</tr>
<tr>
<td></td>
<td>3-4</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>4-5</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Table 21: Shows the range of the magnitude in the number of arbitrage in relation to the mean duration per second for the developed countries in total (2013).

Together with the table 20 and table 21, we will try to examine the relationship between the magnitude of the arbitrage opportunities and their mean duration. For 2011, we can observe that the magnitude and duration had an abnormal behavior. As the magnitude increases the mean duration fluctuates controversially. In 2013, we can see a totally different trend. The higher the magnitude the lower the mean duration. However, in both cases, it can be seen that when the magnitude reaches higher levels the duration takes increasingly extreme numbers, especially in 2011.

5.5.2 Emerging market currencies

<table>
<thead>
<tr>
<th>Emerging countries</th>
<th>Magnitude</th>
<th>Mean Duration in sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0-1</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>1-2</td>
<td>1.99</td>
</tr>
<tr>
<td></td>
<td>2-3</td>
<td>1.57</td>
</tr>
<tr>
<td></td>
<td>3-4</td>
<td>1.66</td>
</tr>
<tr>
<td></td>
<td>4-5</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>&gt;5</td>
<td>289.6</td>
</tr>
</tbody>
</table>

Table 22: Shows the range of the magnitude in the number of arbitrage in relation to the mean duration per second for the emerging countries in total (2011).

<table>
<thead>
<tr>
<th>Emerging countries</th>
<th>Magnitude</th>
<th>Mean Duration in sec</th>
</tr>
</thead>
<tbody>
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<td>Range</td>
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<tr>
<td></td>
<td>0-1</td>
<td>2.3</td>
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<td></td>
<td>1-2</td>
<td>1.99</td>
</tr>
<tr>
<td></td>
<td>2-3</td>
<td>1.57</td>
</tr>
<tr>
<td></td>
<td>3-4</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>4-5</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>&gt;5</td>
<td>289.6</td>
</tr>
</tbody>
</table>

Table 23: Shows the range of the magnitude in the number of arbitrage in relation to the mean duration per second for the emerging countries in total (2013).
Table 22 and 23 depict the relationship between the magnitude and the mean duration in emerging economies. In both years we can observe the abnormal deviation, since as the magnitude increases the mean duration either rises or drops. Lastly, there is a significant extreme condition where in 2013, observations with magnitude over 5 bps lasted for almost five minutes.

5.5.3 Differences and overall trends

*Figure 3: Shows the trend of the mean duration and the magnitude in developed markets in 2011 & 2003.*

In the table 20 & 21 we spotted that the relation between magnitude and mean duration is quite irregular and it is rather than obvious to draw specific conclusions. As it can be depicted also from the plot (Figure 3) both of the trends are upward, besides there is a slight difference in the relation between the mean duration and the magnitude overall through the years. Once more, we cannot really estimate general conclusions about the scale of potential profits.

*Figure 4: Shows the trend of the mean duration and the magnitude in emerging markets in 2011 & 2003.*

Consistent with the table 22 & 23, in tables 24 & 25 the duration of arbitrage had a decreasing tendency in relation with the magnitude for 2013. However, Figure 4 shows that for 2011 there was an increasing shift. As in the developed markets, similarly in the emerging ones, to make a conclusive comment would be considered arguable.
However, according to the preceding analysis in the theoretical framework, research shows that there is a consistent positive difference between mean duration and magnitude of arbitrage. Considering that our data has driven by unexpected outliers which were not applicable to eliminate them we are consistent with the prior theory and we believe that there is a positive relationship between the two variables, magnitude and mean duration. After a scrutinized test analysis, we found a significance of our assumption. In Appendix 7 is included a list of outliers which were ignored when calculating the mean of the magnitude. The reasoning behind this decision is that those observations are subject of measurement error arising from the assumption that a price between the end of a trading week and the first change in the next trading day has not changed. For some strategies this delay of adjustment gives arbitrage opportunities of more than 500 basis points. Nevertheless, we observed that such extreme values only take place in week 6 and 23 of year 2011. In addition their duration is no more than 5 seconds with the exception of TRY reverse strategy which had 7 observations.

**Significant test**

Combining all observations for the two years and all currencies we come up with 164 467 observations whose magnitude and duration is included in the scatterplot below:

![Figure 5: Shows the correlation between mean duration and magnitude in both years for all the currency combinations.](image)

In order to show that there is a positive correlation between the magnitude and the mean duration of the number of arbitrage occurrences we will use the correlation test using one tail t-test. Our hypotheses are formulated as follows:

*H₀: There is a negative relationship between magnitude and mean duration of triangular arbitrage*

*Hₐ: There is a positive relationship between magnitude and mean duration of triangular arbitrage*

From the trend line (Figure 5) it is evident that a weak correlation exist. In order to calculate the precise coefficient we use the formula 4.1 from methodology to arrive to the result of \( \rho = 0.032507 \) which means that the correlation between magnitude and duration is weak. The results corresponds with our expectations of positive correlation.
Since the p value of the t statistic is less than our significant level (6.97E-39 < 0.05) the result is significant thus we can reject the null hypothesis and conclude that there are significant evidence for positive correlation between magnitude and duration.

Secondly, we test if the correlation between magnitude and duration is stronger in emerging than in developed economies. For the first group (developed countries) we resulted with 57 985 observations, while for the second group (emerging) we used 106 483 observations. In order to test the significance of the correlation we will use the correlation test using one tail t-test. Our hypotheses are formulated as follows:

**H₀**: The relationship between the magnitude and the duration of the arbitrage is weaker in the emerging markets than in the developed

**Hₐ**: The relationship between the magnitude and the duration of the arbitrage opportunities is stronger in the emerging markets than in the developed

The relation between the magnitude and the duration within the two discussed samples are plotted in the graphs below:

*Figure 6: Shows the correlation between magnitude and mean duration for the developed market currencies in total years.*

For this group the correlation is $\rho = 0.0121$ arising from 57 985 observations.

*Figure 7: Shows the correlation between magnitude and mean duration for the emerging market currencies in total years.*

The correlation of the same variables but for the arbitrages using currencies from emerging counties is $\rho = -0.05569$ calculated using 106 483 observations. This means
that with the increase of magnitude of the arbitrage opportunities, their duration also decrease.

Since our \( Z \) statistics is \( Z = 13.1458 \) has a \( p \)-value \(< 0.00001 \) it is lower than our significant level of \( \alpha = 0.05 \) making our results significant thus rejecting null hypothesis in favor of the alternative hypothesis which states the correlation between magnitude and duration using currencies from emerging is stronger than developed countries.
6. Discussion and conclusion

“Arbitrageurs keep the markets honest. They bring perfection to imperfect markets as their hunger for free lunches prompts them to bid away the discrepancies that attract them to the lunch counter. In the process, they make certain that prices for the same assets in different markets will be identical.”

– Bernstein, 1992, p. 171

We begin this chapter by recalling out the research question, the objectives and the purpose of conducting this study. Our research has been based upon Efficient Market Hypothesis (EMH) which is related to the various imperfections that have been occurred into the Forex market. Considering different controversial studies and approaches and after an exhaustive empirical analysis, we aimed to answer the following research question:

“Is there a difference in triangular arbitrage opportunities between emerging markets and developed ones?”

Our main purpose with this research was to identify if possible imperfections in the Forex market exist for arbitrage opportunities to arise. The first sub-purpose was therefore to examine both emerging and developed economies and how do they differ by the number of arbitrage occurrences. Moreover, we examined how the trend of arbitrage observations has been changed in magnitude over the years, which is a strong sequence of high frequency trading. Finally, another objective was to test if there is any relationship between the magnitude and the mean duration of the arbitrage since previous researches has shown questionable results. As a consequence, we have set a sub-objective which is to test if the difference between the mean duration and the magnitude is stronger for the emerging markets than the developed ones.

6.1 General Findings

This study made a use of Histdata.com in order to achieve and analyze the findings below. Throughout the whole research we have been investigating the efficiency of the FX market by testing triangular arbitrage opportunities into specific candidate currencies for 2011 and 2013. The main participants of our study have been divided into two groups, the developed markets and the emerging ones. In the first group we considered JPY, CHF, GBP and AUD, while in the second we studied HUF, CZK, PLN and TRY, both in contrast to Euros and US dollars respectively. Overall, our findings show that arbitrage do occur into the FX market for all the triangular roundtrips. Additionally, the separated groups shows a significant difference in the number of occurrence. The results have shown that arbitrage in emerging economies was 2.8 times more active than the developed. In fact, after testing the accuracy of the findings, we concluded that they are defined by significance.
We also examined the trend of the number of arbitrage throughout the years in both groups combined and we concluded that the number of the observations is decreasing. In most of the cases we see a drop between 70% - 90%, while HUF have reached the denoting level of 9 909 %. However, in the analysis of each strategy alone, we came across with some exceptions. The round-trip of AUD, and TRY and both round-trip and ordinary strategy for CZK indicated that the number of arbitrage has increased in a significant level. These results have been driven due to some outbursts, hence we decided to exclude them.

Lastly, we conducted an investigation about the mean duration and the magnitude into the different groups of our study. Our tests showed that there is a significant correlation between the mean duration and the magnitude of the arbitrage. This means that as the number of arbitrage is increasing throughout the year the duration. Along with this finding we also concluded that emerging economies perform with higher duration when arbitrage reaches higher activity.

6.1.1 Academic implications
Our research has contributed into the existing theory by concluding that the impact of arbitrage is higher in emerging than in developed markets and FX market should not be considered efficient. This thesis work extends the findings of Aarheim & Johnsen (2013) who declare the existence of arbitrage through the spot rate currency market and motivate for further analysis in the ‘‘early’’ economies. Moreover, these conclusions have been drawn from a period that has not been studied before in the FX market and thus keeps the research on this area up to date. This is of a great importance since, as we observed, the high frequency trading has diminish the number of occurrences from 2011 to 2013. These findings are consistent with previous studies and we support them with confidence and transparency. Additionally, this research provides insights into the benefits and results by speculating in emerging economies, which are the strong correlation between the duration and the magnitude of the number of arbitrage observations.

6.1.2 Practical implications
In this analysis we have shown that there is still room for exploitation of Forex in the ‘‘early markets’’, since they are characterized by imperfections. Thus, we have practically contributed by suggesting alternative ways that an investor could structure their portfolio in the currency spot market. By segmenting the currencies into two different groups, we raise a new motivation for both private but also institutional investors to structure portfolios or invest on emerging market strategies, thus resulting with higher benefits.

These implications will definitely influence the global economy and the arbitrage itself. The intervention of the banks into the FX market can also lead to the variation of import and exports within the country. So, whereas these countries penetrate successfully into the market could result in increasing their imports and decreasing their exports. However, as long as investors trade in these currencies trying to speculate its deficiencies, the exchange rates are starting to adjust. This means that the exchange rates are fluctuating softer, the currencies accept liquidation and the market performance
is flattened. Thus, arbitrage opportunities are reduced and economic stability and growth is settled.

Finally, we have realized that high frequency trading and its increasing trend is able to change the whole market structure and how it functions globally. In the near future, policy makers will probably requested to adjust their settings and implement new regulations regarding the trading. New York State’s Attorney General Eric Schneiderman already proposed a limits for companies to place their computers in the data centers of exchanges in order to gain unfair technological advancement. (McCrank, 2014)

6.2 Conclusion
Based on the empirical findings and analysis, the authors accept the research proposition. Emerging markets are off interest and, as our findings testify, they possess higher perspective of profitability than the developed ones. The spot market in Forex should be characterized by inefficiency, since imperfections do exist. “Free lunch” is occurring through the different currency roundtrips and room for beneficial trading is wide open. However, we found out that high frequency trading has eliminated the arbitrage observations throughout the years. Lastly, we concluded that there is a positive correlation between the mean duration of an arbitrage occurrence and its magnitude which in emerging market strategies the relation is remarkable stronger.

6.3 Further research directions
The purpose of our research was to find new insights on the subject of arbitrage opportunities that exist in the Forex spot market. The main investigation has been done into the abovementioned currencies which we have divided into two major groups, the emerging ones and the developed. Although extensive research has been conducted in developed market currencies, the field of emerging economies is still untouched. Thus, as presented in our findings such risk-free profit opportunities exist in these markets and awaits to be exploited. The authors suggest that different researchers have to conduct longitudinal studies in order to capture the effect of arbitrage into the emerging markets.

Albeit broad literature exist in major traded currencies, current factors that have been introduced in Forex market, such as algorithmic trading, make them outdated and perhaps not even valid any more. Regarding the advance of technology, it is questionable if individual investors are able to profit by using regular existing methods. So, it is important for studies to incorporate into the field by making use of high frequency trading, the impact in the number of arbitrage and in the total market overall. High frequency trading has also the potential to spread to other traded instruments apart from spot rates, such as commodities (gold, silver, etc.).

We also have restricted ourselves to use specific strategies. However, by studying different currencies, it is possible to find common or contrasting results within the same research subjects, this increasing the transferability of the research. Possible candidacy for such a research are different currencies from emerging countries such as BRL, RUB, INR, CNY (BRIC’s) but also, MXN and ZAR which have gained a great publicity lately, due to their current economic progress.
Finally, as mentioned in the limitations, since we have used data without volumes into consideration, additional studies could include order book information and trading volumes for suggesting more accurate results. By searching different contexts, it is possible to find either common denominators or contrasting results within the same research projects, thus increasing the transferability of the research.
7. Quality Criteria

“Reliability and validity are tools of an essentially positivist epistemology.”
- Watling, 1995, p. 5

The aim of this chapter is to evaluate our research findings, measure their integrity, representativeness, naturalness and trustworthiness. Saunders et al. (2012, p. 192) highlights the importance of a good research design when the possibility of getting a wrong answer is diminished. According to Remenyi et al. (1998, p. 179) the most essential criteria for assessing a research study are validity, reliability, and great accuracy and transparency in order to establish research quality (Golafshani, 2003, p. 599). Validity refers to measures that actually assess what they are designed for (David & Sutton, 2011, p. 268; Ghauri & Grønhaug, 2010, p. 78, Saunders et al., 2012, p. 684; and according to Bryman (2008, p. 32) it is considered as the most important criterion. Reliability describes if the used evidence and the methods are characterized by consistency and stability (Ghauri & Grønhaug, 2010, p. 79; Remenyi, 1998, p. 181). According to David & Sutton (2011, p. 266), reliability is “the degree to which the indicator or test is a consistent measure over time”.

7.1 Validity

The conclusions of a study have to be characterized by integrity in order to be valid. That means that the analysis of the data must have been done in a reasonable way, so that the derived conclusions has arrived logically and in a credible way (Bryman 2008, p. 32). In consistence with Saunders (2012, p. 193), internal validity discuss the causal relationship between two variables and the importance of hypothesis testing and measures if our conclusions hold water. Measurement errors are stated when there is a difference between the actual value and the value as given by the measurement. In our analysis we have investigated the number of arbitrage opportunities by taking directly the quotes of our database in a given time period. Since they are pure numbers the only risk we could face is that they are stated wrongly in our software program, but as it is recognizable and powerful, we accept that risk and we confirm that the provided information is correct.

Our method employed is seen as the only one that can measure triangular arbitrage and has been widely used by academics and traders seeking to benefit from the mispricing. This method rely heavily on price quotations as predictor of arbitrage opportunity and we think that it has demonstrated a sufficient accusation between the two. Nevertheless we should note a discrepancy between the arbitrage concept and the triangular arbitrage opportunity: since a trader has to execute three orders simultaneously, this can create a risk of execution which is in conflict with the risk-free profit.

As suggested earlier in the Metrology chapter, an alternative method using interpretivistic philosophy can be applied which compares the sentiment and the motivation of different traders and the way and timing they analyze new data, although it is arguable how such information can be valid when identifying the magnitude and the duration of arbitrages.
External validity it is according to Bryman (2008, p. 32) important for any line of research project to be able to conclude if they are valid and generalizable. Saunders (2012, p. 194) posts the following question: “Can a study research findings be generalized to other relevant settings or groups?” In our case currencies in the Forex market hold the 95% of the global currency trade which is the reason we can safely say that they are a valid proxy for the global currencies market. Moreover, EUR and USD prevail in the market, as they formulate the majority of the pairs and they are considered to be the most competing currencies overall.

7.2 Reliability
Saunders (2012, p. 192) refers to reliability as whether our data and analysis would be identical if were repeated in a different situation or replicated by another researcher. It answers the question: “Are the results of the study repeatable?” (Bryman, 2008, p. 31) David & Sutton (2011, p. 266) declares that “it is inevitable that the data collected in a measurement tool or indicator will consist of the true measure plus an error measure” Bryman (2008, p.31) states that reliability is more connected with quantitative research. Quantitative researchers are more likely to face issues of whether a measure or indicator is established or not. For our analysis, since we use secondary data, and well established equations for our measurements, it is rather easy to compute the same type of data analysis. We have also described thoroughly how we have formulated our hypothesis and with which criteria we have tested them, consequently we believe that arbitrage happens in a different markets and currencies as well as in a different time span, thus; we think that our research concept is repeatable. Moreover, we have thoroughly described and analyzed our findings and our perceptions, so a researcher can test their results against ours in a correct way. It is therefore, in our point of view, safe to state that our study is also replicable.
8. References


## Appendices

### Appendix 1

**Developed markets arbitrage occurrences per week**

**Ordinary Strategy**

### EUR/USD - USD/JPY - EUR/JPY

<table>
<thead>
<tr>
<th>Week</th>
<th>2011</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
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<td>6</td>
</tr>
<tr>
<td>23</td>
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<td><strong>Total</strong></td>
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<td><strong>68</strong></td>
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### EUR/USD - GBP/USD - EUR/GBP

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</tr>
</thead>
<tbody>
<tr>
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<td>9</td>
</tr>
<tr>
<td>23</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td>40</td>
<td>184</td>
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<tr>
<td><strong>Total</strong></td>
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<td><strong>35</strong></td>
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### EUR/USD - USD/CHF - EUR/CHF

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</tr>
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<td><strong>Total</strong></td>
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<td><strong>159</strong></td>
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### EUR/USD - AUD/USD - EUR/AUD

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</tr>
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<td>24</td>
</tr>
<tr>
<td>40</td>
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<td>15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>176</strong></td>
<td><strong>40</strong></td>
</tr>
</tbody>
</table>
Appendix 2

Developed markets arbitrage occurrences per week

Reverse Strategy

### EUR/JPY - USD/JPY - EUR/USD

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<td>52</td>
</tr>
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<td>40</td>
<td>204</td>
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<td>Total</td>
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<td>67</td>
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### EUR/GBP - GBP/USD - EUR/USD

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<td>23</td>
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<td>40</td>
<td>209</td>
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</tr>
<tr>
<td>Total</td>
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</tr>
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### EUR/CHF - USD/CHF - EUR/USD

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</tr>
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### EUR/AUD - AUD/USD - EUR/USD

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</tr>
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<td>80722</td>
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**Appendix 3**

**Emerging markets arbitrage occurrences per week**

**Ordinary Strategy**

### EUR/USD - USD/HUF - EUR/HUF

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<tbody>
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<td>40</td>
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<td>Total</td>
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### EUR/USD - USD/CZK - EUR/CZK

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### EUR/USD - USD/PLN - EUR/PLN

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### EUR/USD - USD/TRY - EUR/TRY

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Appendix 4
Emerging markets arbitrage occurrences per week
Reverse Strategy

EUR/HUF – USD/HUF – EUR/USD

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EUR/CZK - USD/CZK - EUR/USD

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EUR/PLN - USD/PLN - EUR/USD

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EUR/TRY - USD/TRY - EUR/USD

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Appendix 5:
Total number of arbitrages using currencies from developed markets sorted by magnitude

2011

2013

Developed markets
Appendix 6:
Total number of arbitrages using currencies from emerging markets sorted by magnitude

2011

2013
Appendix 7

Year 2011

Outliers

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