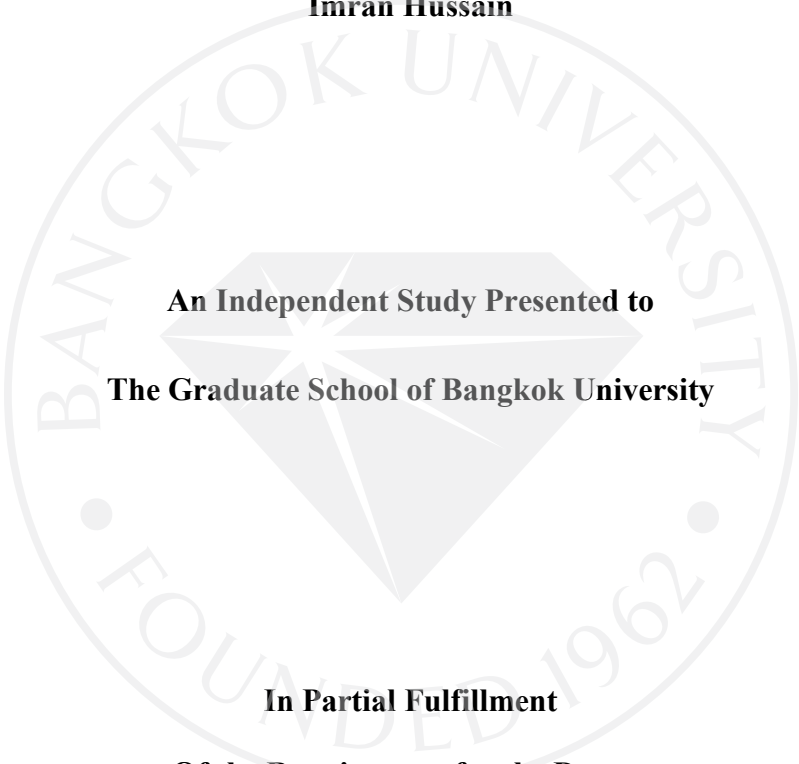


TESTING FOR ARBITRAGE OPPORTUNITIES  
WITHIN THE FOREIGN EXCHANGE MARKET



**TESTING FOR ARBITRAGE OPPORTUNITIES WITHIN THE FOREIGN  
EXCHANGE MARKET**

**Imran Hussain**



**An Independent Study Presented to  
The Graduate School of Bangkok University**

**In Partial Fulfillment  
Of the Requirement for the Degree  
Master of Business Administration**

**2009**



© 2009

**Imran Hussain**

**All Right Reserved**

**This Independent Study has been approved by  
the Graduate School  
Bangkok University**

Title: TESTING FOR ARBITRAGE OPPORTUNITIES WITHIN THE FOREIGN  
EXCHANGE MARKET

Author: Mr. Imran Hussain


Independent Study Committees:

Advisor




(Dr. Andrew R. Criswell)

Field Specialist



(Dr. Sansanee Thebpanya)



(Sudarat D. Chantrawanakul, Ph.D.)

Dean of the Graduate School

June 20, 2009

Hussain, Imran. Master of Business Administration, June 2009, Graduate School,  
Bangkok University

Testing For Arbitrage Opportunities within the Foreign Exchange Market (51 pp.)

Advisor of Independent Study: Andrew R. Criswell, Ph.D.

### **ABSTRACT**

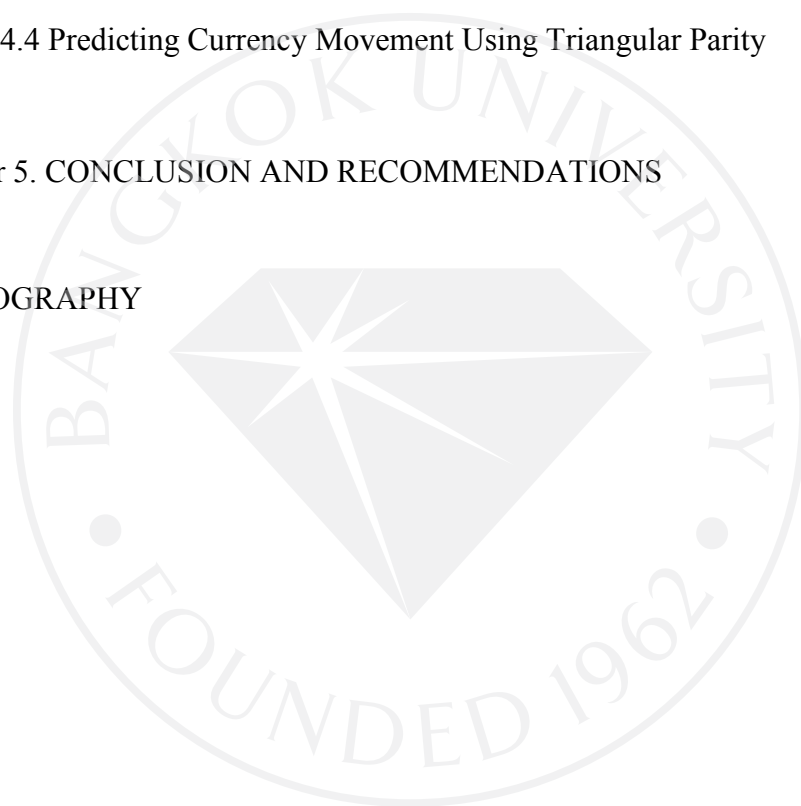
This study aims to determine whether or not arbitrage opportunities exist within the retail foreign exchange market and how the number of opportunities compares to those found within the interbank foreign exchange market. The concept of triangular arbitrage is used within this study to identify potential arbitrage opportunities. This study makes use of minute frequency data obtained from a retail foreign exchange broker involving the US dollar, Euro and Japanese Yen. This study covers a one week period from 4<sup>th</sup> to the 10<sup>th</sup> of April 2009, over which arbitrage opportunities are tested for using the triangular arbitrage trade strategy. This study also tested to see if triangular parity is a good predictor of future currency movement.

This study finds that some arbitrage opportunities do exist within the retail foreign exchange market, however the returns of these opportunities suggests that the retail foreign exchange market falls in line with the efficient market hypothesis. This study finds that arbitrage opportunities in the form of triangular arbitrage are more common within the interbank market than the retail market. This study also finds that triangular parity is not a good predictor of currency movement.

## TABLE OF CONTENTS

	Page
Abstract	iv
Chapter 1. RESEARCH PROPOSAL	1
1.1 Background & Statement of Problem	1
1.2 Objective of Study	4
1.3 Intention and Reason for Study	5
1.4 Benefits of Research	6
Chapter 2. LITERATURE REVIEW	7
2.1 Introduction	7
2.2 Foreign Exchange Markets	7
2.3 Foreign Exchange Quotes and Currency Valuation	9
2.4 Technology & Market Efficiency	11
2.5 Arbitrage	12
2.6 Different Forms of Foreign Exchange Arbitrage	13
2.7 Triangular Parity	14
2.8 Triangular arbitrage	17
2.9 Trading Platforms & Forex Data Feeds	20
2.10 Alpari & Meta Trader 4	22
Chapter 3. RESEARCH METHODOLOGY	24
3.1 Introduction	24
3.2 Data	24
3.3 Construction of Bid-Ask Quotes	26
3.4 Testing for Triangular arbitrage and Currency movement	26

3.4.1 Triangular Arbitrage	26
3.4.2 Testing for Currency movement using Triangular parity	30
3.5 Hypothesis	31
Chapter 4. DATA ANALYSIS & DISCUSSION	32
4.1 Retail Market Results	32
4.2 Interbank Market Results	34
4.4 Predicting Currency Movement Using Triangular Parity	39
Chapter 5. CONCLUSION AND RECOMMENDATIONS	45
BIBLIOGRAPHY	49



**LIST OF TABLES**

	Page
Table 1. Sample Data	25
Table 2. Bid-Ask Spread Scenario for Retail & Interbank Segment	29
Table 3. Triangular Arbitrage Opportunities within Retail Foreign Exchange Marke	32
Table 4. Arbitrage Opportunities within Interbank Segment - Scenario 1-3	34
Table 5. Arbitrage Opportunities within Interbank Segment - Scenario 4-5	36
Table 6. Descriptive Stats - Showing Difference Between Predicted & Actual Close Rates	39
Table 7. Descriptive Stats for Currecny Movement	39



**LIST OF FIGURES**

	Page
Figure 1. Chart Showing How Triangular Arbitrage Opportunities Vary As Different Levels of Bid-Ask Spreads are Used	38
Figure 2. Chart Showing the Average Return per Dollar Investment as Spreads Increase	38
Figure 3. Chart Showing The Relationship Between The Predicted EUR/JPY Value and The Actual EUR/JPY & The Subsequent Currency Movement	42
Figure 4. Chart Showing The Relationship Between The Predicted EUR/JPY Value and The Actual EUR/USD & The Subsequent Currency Movement	43
Figure 5. Chart Showing The Relationship Between The Predicted EUR/JPY Value and The Actual USD/JPY & The Subsequent Currency Movement	44

## CHAPTER 1

### RESEARCH PROPOSAL

#### 1.1 Background and Statement of Problem

The foreign exchange market is considered to be the largest market of any type. According to the Bank for International Settlements (2009) the foreign exchange market is the most actively traded market in the world, with a daily trade volume in excess of \$3.2 trillion. The foreign exchange market has no physical location as such instead it is defined by its participants and its three major trading centers situated in London, New York and Tokyo. The foreign exchange market connects all forms of institutions from large investment banks to government and private commercial banks via a network of technology. Not only is the foreign exchange market extremely liquid, it is also considered to be highly efficient and in line with the efficient market hypothesis.

Before the establishment of retail foreign exchange brokers such as Oanda Currency Services and The Alpari Group, engaging within foreign exchange trading was an expensive prospect. Foreign exchange trading required one to invest in an expensive electronic platform upon which a number of data feeds could be monitored and traded. Having invested in a trading platform, one would then need to enter within an agreement with foreign exchange brokers or interbank counterparties to get access to the data feed upon which the trading will be conducted. The costs mentioned so far represent only the fixed costs, variable costs would include the bid-ask spreads, commission and trading fees. These variable costs would vary depending on the currency pairs involved and the volume of the trade. This combination of fixed and variable costs made the market inaccessible to the small retail level trader. However

over the past decade retail foreign exchange brokers have made it possible for the retail level trader to engage the foreign exchange market using fixed cost free trading solutions.

These fixed cost free or minimal fixed cost trading solutions make use of freely available trading platforms in conjunction with retail foreign exchange brokers, such as Oanda Currency Services or The Alpari Group. These retail foreign exchange brokers provide their clients with data feeds free of cost for use in their trading. Though the retail level trading solution being discussed is fixed cost free, the fixed cost do not simply disappear instead they get absorbed within the variable costs. Oanda Currency Services and The Alpari Group claim to charge no commissions or trade fees, this would stipulate that they must be incorporating all of their costs within the bid-ask spreads. If all the costs associated with running the trading platform, data feeds, commissions and trade fees are incorporated within the bid-ask spreads then one would assume that the spreads of such a solution would be prohibitively high for any arbitrage based trading activity.

The foreign exchange market is considered to be in line with the efficient market hypothesis, which would stipulate the absence of any arbitrage opportunities. Numerous studies have been conducted looking for arbitrage opportunities within the foreign exchange market. Studies by Frenkel and Levich (1975 & 1977), Taylor (1987 & 1989), Rhee and Chang (1992), and more recently Batten and Szilagyi (2006) and Akram, Rime, and Sarno (2008) look for arbitrage opportunities in the form of covered interest arbitrage. More recent studies by Aiba, Hatano, Takayasu, Marumo and Shimizu (2002, 2003), Aiba and Hatano (2004), Marshall, Treepongkaruna, and Young (2008), and Fenn, Howison, McDonald, Williams, and Johnson (2009) have

used triangular arbitrage to identify positive arbitrage opportunity while making use of high frequency data sets. All of these studies have shown that even after taking into account transaction costs that a number of arbitrage opportunities exist. The findings of these studies indicate that at least on paper using empirical testing, arbitrage opportunities can be found in the foreign exchange market at the interbank level.

A point to note is that all of the studies mentioned before were looking for arbitrage opportunities at the interbank level, where the trade sizes would be in the millions. However no study as of yet has looked for arbitrage opportunities at the retail level where the trade sizes are a lot smaller. If arbitrage opportunities have been identified within the interbank segment of the foreign exchange market then it should also be possible to identify arbitrage opportunities within the retail segment of the foreign exchange market.

It could be assumed that conducting trades along the lines of triangular arbitrage would not be possible at the retail level as it requires the use of multiple brokers and extremely low bid-ask spreads. Discussions on online trading forum boards focused on retail foreign exchange trading such as Forex TSD Review and Forex Factory suggests that if the brokers bid-ask spreads are larger than 2 pips then achieving profits via triangular arbitrage is not possible<sup>1</sup>. However at the time of writing this study retail level foreign exchange service providers were advertising bid-ask spreads as low as 0.9 pips<sup>2</sup> for selected major currency pairs. If retail foreign

---

<sup>1</sup> The mentioned forum boards can be viewed using the following links, Forex TSD Review - <http://www.Forex-TSD.com/> and Forex Factory - <http://www.forexfactory.com/> (n.d)

<sup>2</sup> Information regarding the bid-ask spread was obtained from the Oanda Currency Services website <http://fxtrade.oanda.com/>

exchange market makers are offering such low bid-ask spreads then it would be worthwhile investigating whether or not arbitrage opportunities are also present at the retail level of the foreign exchange market.

This study seeks to determine whether or not arbitrage opportunities are present at the retail level when using the bid-ask spreads as provided by a retail level foreign exchange brokers. This study not only looks into arbitrage opportunities at the retail level but also at the interbank level by using a set of assumed bid-ask spread scenarios to emulate the costs that would be faced by a non bank dealer such as hedge fund engaging directly with interbank counterparties.

The specific arbitrage condition that this study tests for is triangular arbitrage. Covered interest arbitrage was not tested for as it requires participation within not only the spot foreign exchange market but also the forward market. Whereas retail level foreign exchange services such as The Alpari Group and Oanda Currency Services provide their clients with access to the spot foreign exchange market, at the time this study was conducted their services did not extend to the forward market. This study uses a set of assumed bid-ask spread scenarios to whether how the number of arbitrage opportunities vary between the retail and interbank segments of the foreign exchange market.

## **1.2 Objective of Study**

It has always been assumed that the high bid-ask spreads associated with retail level foreign exchange trading would make triangular arbitrage infeasible. However with retail foreign exchange service providers quoting bid-ask spreads as low as .9 pips for major currency pairs it can no longer be assumed that the spreads are too

high. This study tests to see whether or not triangular arbitrage opportunities are present at the retail level and compares this to the number of opportunities present when the trader in question is not a retail level trader, but a non bank dealer such as a hedge fund. A hedge fund would deal directly with interbank counterparties instead of an intermediately in the form of a retail foreign exchange broker.

### **1.3 Intention and Reason for Study**

Since their inspection in the “mid- to late- 1990s, the retail foreign exchange market has grown rapidly”, in 2001 daily trade volume amounted to USD 10 billion which represented about .8 percent of the overall foreign exchange market. By 2006 the retail foreign exchange markets daily trade volume had grown by some 500 percent to USD 60 billion, representing 2 percent of the overall foreign exchange market (*Aite Group, 2007*). The retail foreign exchange market is expected to keep growing as people look to “diversify their portfolios” and as they figure out that the retail foreign exchange market yields higher returns than “traditional asset classes”(Aite Group, 2007). Previous studies looking into arbitrage within the foreign exchange market have focused on the interbank segment however no study was found looking for arbitrage opportunities within the retail segment of the foreign exchange market. This study seeks to determine if arbitrage opportunities are present within the retail foreign exchange market and how these opportunities compare to those found within the interbank market. This study back tests for arbitrage opportunities using triangular arbitrage trades based on data obtained from The Alpari Group, a retail level foreign exchange broker.

#### **1.4 Benefits of Research**

As mentioned before previous studies looking into the foreign exchange market have shown that arbitrage opportunities in the form of covered interest arbitrage and triangular arbitrage are present within the interbank segment of the foreign exchange market. However the findings of these studies findings cannot be extrapolated to the retail foreign exchange market due to the different costs scenarios faced by a retail trader engaging the retail foreign exchange market and a non bank dealer directly engaging with interbank counterparties.

This study aims to provide the retail foreign exchange trader with an idea of what type of arbitrage opportunities exist at the retail level and how these compare to the opportunities identified at the interbank level. This should give retail traders a good picture of where they stand in terms of being able to arbitrage their broker and whether or not such trades are worth seeking out depending on their returns.

This study also tests to see if triangular parity upon which the triangular arbitrage trading strategy is based is a good predictor of currency movement. Currently to predict currency pair movement retail traders usually resort to technical analysis of historical data. By testing whether or not the triangular parity relationship between a three currency pair ring can be used in predicting the movement of an individual currency pair will provide traders with an alternative means of analysis. If this test proves to be successful in predicting currency pair movement then it will provide retail traders with a substitute or an alternative to technical analysis which is based on identifying reoccurring trends.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

The concept of arbitrage forms one of the cornerstones of the modern financial theory. It is largely believed that within efficient markets there is no room for arbitrage. The foreign exchange market is considered to be a prime example of an efficient market, yet as mentioned in the previous chapter that there have been a number of studies conducted looking into arbitrage.

This section of the study is dedicated to reviewing the existing literature in the field of arbitrage within the foreign exchange market. It also contains information relating to the retail foreign exchange broker “The Alpari Group” and the freely available trading platform MetaTrader 4. It is this combination of platform and service provider that is used to test whether or not arbitrage opportunities exist within the retail segment of the foreign exchange market.

#### 2.2 Foreign Exchange Markets

When going through any financial textbook one will find references to the fact that the foreign exchange market is the largest market of any type and that it is open for operation in some location around the world all year round (*Eun & Resnick, 2007*). Before proceeding further it is best to define what is meant by the term foreign exchange market. Essentially a “foreign exchange market is a market where a convertible currency is exchanged for another currency or other convertible currencies” (*Wang, 2009, pp.1*). The foreign exchange market is an over-the-counter-market with no physical location as such, instead it connects “traders within the



offices of major commercial banks around the world” who communicate and conduct their trades “using computer terminals, telephones, telexes, and other information channels” (*Grabbe, 1996, pp.87*).

The foreign exchange market is nearly a twenty four hour market because of the fact that business hours around the world overlap. Grabbe (1996) provides a good example explaining how the foreign exchange market is open for operation nearly twenty four hour a day. “When it is 3 P.M in Tokyo it is 2 P.M. in Singapore. When it is 3 P.M in Singapore, it is noon in Bahrain. When is it 3 P.M. in Bahrain, it is noon in Frankfurt and Zurich and 11 A.M. in London. When it is 3 P.M. in New York, it is noon in Los Angeles. When it is 3 P.M. in Los Angeles, it is 9 A.M. the next day in Sydney, Australia” (*Grabbe, 1996, pp.87*). This means that at any given time during a day there will be some activity within the foreign exchange market.

The foreign exchange market is not limited in terms of accessibility to financial professional and full-time traders instead it can be accessed by nearly “anyone, from multinational corporations operating in several countries to tourists travelling across two currency zones” (*Wang, 2009, pp.1*). Therefore a person going to a money changer to get a sum of currency exchanged would also be considered to be engaging the foreign exchange market.

Transactions within the foreign exchange market take one of two forms, spot transactions or forward transactions. A spot foreign exchange transaction involves “the immediate exchange of currencies at the current (or spot) price” (*Saunders and Cornett, 2007, pp. 224*). While a forward transaction involves “the exchange of currencies at a specified exchange rate (or forward exchange rate) based at some specified date in the future” (*Saunders and Cornett, 2007, pp. 224*).

The foreign exchange market can be viewed as a “two-tier market”, where one of the tiers consists of the “wholesale or interbank market” while the second tier consists of the “retail or client market” (Eun & Resnick, 2007, pp. 109). The core of the foreign exchange market is made up by 100 to 200 international banks that collectively form the interbank foreign exchange market. Trades between these banks and non bank dealers such as investment banks, mutual funds and hedge funds account for over 86 percent of the overall foreign exchange trading (Eun & Resnick, 2007, pp. 109-110).

This division of the foreign exchange market can be seen as a value chain of sorts which can be attributed to the variations within the foreign exchange quotes that traders within the two segments receive. In the retail market you have brokers like The Alpari Group who get their data feeds directly from a number of interbank counterparties and then redistribute it to their customer with increased bid-ask spreads.

### **2.3 Foreign Exchange Quotes and Currency Valuation**

A foreign exchange quote is how currencies are valued in the foreign exchange market (Wang, 2009). The “technical way” that the prices of currencies are discussed, is in the form of a ratio (xxx/yyy) denoting the value of the base currency (x) in terms of the asked currency (y) (Rodriguez & Carter, 1976, pp.95). For example the currency pair symbol USD/JPY would denote the value of 1 USD in terms of Yen, this ratio would be considered a direct quotation of the dollar value and in its inverted form (JPY/USD) represents an indirect quote for the value of a dollar. All currencies are valued this way in the foreign exchange market and this leads to an

important point that there is no actual absolute or set value for currencies. Essentially one can only know the value of one currency in terms of another and not by itself. It is this very notion that allows one to predict the value of a currency pair in a three currency pair ring based on the value of the other two currency pairs. This is discussed in more detail later on in this section. In this study the xxx/yyy symbol with the appropriate currency symbols substituted in for x and y, is used while discussing currency pairs.

When trading currencies the bid-ask quotes are displayed to four decimal places, while the currency pairs involving the Yen are quoted to two decimal places. Another term which is commonly used in foreign exchange trading is the pip. A pip is essentially the smallest price increment of currencies. So if the EUR/USD quote changes from .9247 to .9248 then that would represent an incremental increase of 1 pip. When looking at USD/JPY quotes, a one pip increase would increase the quote from 98.02 to 98.03. Oanda Currency Services claim to be the pioneer of the fractional pip or pipettes which is  $1/10^{\text{th}}$  the value of a pip<sup>3</sup>. Therefore a 1.8 pip spread would equate to a premium of 0.00018 when dealing with a non Yen currency pair. For currency pairs involving the Yen like EUR/JPY and USD/JPY 1.8 pips would translate to .018.

The different participants engaging the foreign exchange market do not get access to the exact same bid-ask quotes. Essentially the exchange rates offered to clients engaging the retail foreign exchange market are not the same as those which the banks interchange currency amongst themselves. The rates quoted to retail clients

---

<sup>3</sup> Information was obtained from the Oanda Currency Services website using the following link [http://fxtrade.oanda.com/forex\\_trading/why\\_trade\\_with\\_oanda/spreads/pipettes.shtml](http://fxtrade.oanda.com/forex_trading/why_trade_with_oanda/spreads/pipettes.shtml) Accessed 08/04/2009

are dearer than the interbank rates due to the presence of an intermediary in the form of a retail foreign exchange broker which add on a premium for their service.

Interbank rates refer to the rates at which banks trade amongst themselves and other non bank dealers.

#### **2.4 Technology & Market Efficiency**

The effect of technology on foreign exchange trading is nicely summed up by Mavrides, who states that “computerized trading is not a simple advancement in FX trading. It is a breakthrough” (*Mavrides, 1992. pp.35*). Flexible exchange rates were first introduced in 1970 and it has been noted that exchange rates since then they have become more erratic and volatile (*Eun & Resnick, 2007*). On the other hand technology has also been attributed with increasing efficiency in the market. While studying the spot USD/JPY market Batten and Szilagyi (2006) find that there has been a “significant decline in the deviations from covered interest rate parity in recent years”, noting that by 2000 the deviations had almost been eliminated (*Batten & Szilagyi, 2008, pp.13*). They attributed this increased efficiency largely to the EBS and Reuters trading platforms.

EBS and Reuters are the platforms of choice within the interbank market. In 2004 the EBS trading platform was involved in over 50 percent of the total daily spot foreign exchange transactions, which amounts to over USD100 billion (*Marshall et al., 2008, pp.6*). While technology has improved efficiency within the interbank market it has also allowed anyone with a bank account, an internet connection and the ability to deposit USD 200, to setup shop as a foreign exchange trader.

Considering that the foreign exchange market is the largest of any financial markets one would assume that it is fairly efficient. A generalized definition of efficiency would have the financial markets being considered efficient only “if the current asset prices fully reflected all the available information”. (*Eun & Resnick, 2007, pp.149*). While the sheer volume of trading taking place would attribute to the volatility of exchange rates with a daily trade volume in excess of \$3.8 trillion, it seems safe to assume that the foreign exchange market is efficient and that any inefficiency in the form of an arbitrage opportunity would be short lived (*Fenn et al., 2009*)

## **2.5 Arbitrage**

The concept of arbitrage is very important in finance as it is widely believed that within an efficient market there will be no regular arbitrage opportunities to exploit. A number of studies of the foreign exchange market test arbitrage strategies whereby one could exploit the perceived inefficiencies of the foreign exchange markets, which according to the definition would be the inability of the market makers to take into account all of the information available into their bid-ask quotes. Studies by Frenkel and Levich (1975 & 1977), Taylor (1987 & 1989), Rhee and Chang (1992), and more recently Batten and Szilagyi (2006) and Akram et al. (2008) look for arbitrage opportunities in the form of covered interest arbitrage. More recent studies by Aiba et al. (2002, 2003 & 2004), Marshall et al. (2008) Fenn et al. (2009) have used triangular arbitrage to identify positive arbitrage opportunity with the use of high frequency data sets. As can be seen from the studies mentioned above, that the

two main area of interest in the field of arbitrage has been triangular arbitrage and covered interest arbitrage.

Arbitrage is an important notion in finance. In this study arbitrage opportunities are identified using the triangular arbitrage trading strategy. Before proceeding further, it is best to define what arbitrage means within the context of this study. "An opportunity for arbitrage consists of transactions in which no money can be lost and some can be earned in certain states of nature" (*Demange & Laroque, 2006 pp.31*). According to this definition if one would be able to take a position in a market and then be able to hold onto it while waiting for that "certain state of nature", then one would essentially be exploiting an arbitrage opportunity. Another definition of arbitrage defines it as "the simultaneous purchase and sale of a commodity or asset in different markets with the sole intent to make profit from the differences in buying and selling prices" (*Clark & Ghosh, 2004 - Page 1*). This study will be going with the first of the two definitions given here.

## **2.6 Different Forms of Foreign Exchange Arbitrage**

Within the context of foreign exchange market arbitrage takes three main forms; location based arbitrage, triangular arbitrage and covered interest arbitrage (*Madura, 2006*). Each of these three forms of arbitrage tries to exploit a different parity relation which governs the foreign exchange market.

Location based arbitrage takes advantage of local banks mispricing of the bids-ask quotes within a certain geographic area, whereby one bank bid would be lower than the other banks ask quote allowing one to buy the currency from one bank and sell it to another bank for a profit (*Ryoo, 2006*). Ryoo (2006) in his study tests for

arbitrage opportunities across different banks in the form of location based arbitrage and finds that arbitrage possibilities do exist, however they are short lived and the number of opportunities decrease with higher bid-ask spreads.

Triangular arbitrage looks to exploit any differences within the cross exchange rates and those that are calculated from the quoted spot rates (*Marshall et al., 2008*). This concept will be studied in some more detail later on.

The final form of arbitrage mentioned is covered interest arbitrage within which zero risk profit can be obtained using a combination of spot and forward transactions in the case of interest rate parity not holding (*Batten & Szilagyi, 2006*). If interest rate parity is not holding then one could borrow money in one country, invest it in another and come out with a profit after paying back the interest and transaction costs (*Batten & Szilagyi, 2006*). This study will be focusing mainly on the triangular arbitrage as an indicator for market efficiency using the USD, EUR, JPY currency ring.

## 2.7 Triangular Parity

In order to explain triangular parity it is best to look at an example. Assume we have three variables  $x = 2$ ,  $y = 5$  and  $z = 8$  which will form our ring (any three random number can be used for this example). If we were to express these variables in the form of fractions or ratios then we would get the following:

$$\begin{aligned} x/y &= .4 \\ y/z &= .625 \\ z/x &= 4 \end{aligned}$$

The values that are assigned to these variables are the result of a relationship within the fractions. If we take the product of all three fractions then we should end up with a value of 1. This relation between the fractions allows us to determine the value of any one of the three fractions, owning that we know the vales of the other two. We know that  $(x/y) * (y/z) * (z/x) = 1$ , therefore we can rearrange the equation to derive the value of  $z/x$  using the values for  $x/y$  and  $y/z$ .

$$\begin{aligned}
 1 &= (x/y) * (y/z) * (z/x) \\
 z/x &= 1 / ((x/y) * (y/z)) \\
 &= 1 / ((.4)*(.625)) \\
 &= 1 / .25 \\
 &= 4
 \end{aligned}$$

The same logic can be applied to the forex quotes to determine if the market for a ring of currencies is performing efficiently or not. In an efficient market we should get the same value in the market as is indicated by the calculation with the currency pairs. If we substitute x,y,z with currencies and the fractions with their corresponding foreign exchange quotes then we can determine whether a currency pair is overvalued or undervalued. This information can then be used to predict currency movement, at least in theory that is. This is explained with the aid of an example below. The data used is in this example actual daily forex averages from 01/05/2009, which was obtained from Oanda data services<sup>4</sup>.

Three currencies, x= USD, y= Euro & z= JPY and there corresponding exchange rates obtained from Oanda Data services (daily averages from 01/05/2009)

---

<sup>4</sup> The data was obtained from the Oanda Currency Services website using the following link <http://www.oanda.com/convert/fxhistory> Accessed 01/05/2009.



$$\begin{aligned}
 x/y &= \text{USD/Euro} = 0.7188 \\
 y/z &= \text{Euro/JPY} = 127.90 \\
 z/x &= \text{JPY/USD} = 0.0108950
 \end{aligned}$$

Therefore :

$$\begin{aligned}
 \text{JPY/USD} &= 1 / ((\text{USD/Euro}) * (\text{Euro/JPY})) \\
 &= 1 / ((0.71880) * (127.8970)) \\
 &= 1 / 91.9281 \\
 &= 0.0108780 \text{ (this means that JPY/USD is overvalued)}
 \end{aligned}$$

$$\text{USD/Euro} * \text{Euro/JPY} * \text{JPY/USD} = 1 \text{ [In Theory]}$$

However in reality this is not the case:

$$(0.71880) * (127.8970) * (0.01089500) = 1.0160$$

According to our calculation this ring of currencies is not efficient as the overall value is in excess of the anticipated value 1. One could infer from this value that this ring of currency pairs is overvalued. This is important because this equation can be used to determine the efficiency of a currency ring at any given moment in time. Essentially this approach makes use of triangular parity and was used by Choi & Yoon in their (2007) study, where they attempt to extrapolate the arbitrage strategy to more than three currencies. Mavrides (1992) also states that the parity condition that links all three currency pairs is as follows,  $x/y = (x/z)(z/y)$ . This means that we can determine any missing rate as long as we have at least two rates and hence test to see if the actual market quotes are in line with those of our calculation.

A major component of this study is the triangular arbitrage trade, as such studies focused on triangular arbitrage trades are overviewed and their key findings discussed below.

## 2.8 Triangular Arbitrage

Triangular arbitrage is based on the exploitation of the misalignment of exchange rate quotes (*Clark & Ghosh, pp.1*). The triangular arbitrage framework has been the focus of a number of different studies as mentioned before. The triangular arbitrage trade consists of three separate individual trades conducted at the same time in other words simultaneously. Essentially what one is doing is buying and selling a currency based on the quotes of the other currencies (*Marshall et al. 2008 pp.11*).

Triangular arbitrage was used by Frenkel and Levich in their 1975 study to determine the transaction costs “associated with covered interest rate parity” (*Frenkel and Levich, 1977*). However much of the earlier work on arbitrage focused on the interest arbitrage in the form of covered interest arbitrage. This is most likely because of a lack of data and technology required to engage within triangular arbitrage which requires the simultaneous opening and closing of trade’s. Barker (2007, pp.4) states that “through the mid-1990’s, the foreign exchange was primarily reliant on phone-based technology”. Therefore in order for a client to deal in the foreign exchange market they “would phone a bank with whom it had a line of credit and ask for a two-sided price, i.e., a bid and offer on the specified amount of foreign exchange to be transacted” (*Baker, 2007 pp.4*). Therefore as high frequency data was not easily available, triangular arbitrage opportunities could not be tested for. However as can be inferred from the number of studies mentioned before that this is no longer the case and as such recently triangular arbitrage has been the focus of a number of studies. In this section we consider some of the more recent arbitrage studies as they focus on triangular arbitrage.

To recreate a triangular arbitrage trade three bid-ask quotes are required. An example of triangular arbitrage opportunity is provided below using data from Marshall et al. (2008 pp.27). The three currencies pairs being looked into are EUR/CHF, EUR/USD and USD/CHF, below is an example of how a triangular arbitrage trade would be conducted.

Currency Pair	Bid	Ask	Quote
EUR/CHF	1.5555	1.5566	1
EUR/USD	1.3541	1.3550	2
USD/CHF	1.1410	1.1420	3

	Initial Investment	= 100,000 Euro
Trade 1.		
	Sell Euro for Swiss Franc @ Bid - $100,000 * 1.5555$	= 155,550
Trade 2.		
	Buy USD using Swiss Franc @ Ask - $155,550 * (1/1.142)$	= 136,208.4
Trade 3.		
	Buy Euro using USD @ Ask - $136,208.4 * (1/1.355)$	= 100,522.8
	Net Profit or Arbitrage	= 522.8 Euros

Marhsall et al. (2008) in their study state that exploitable arbitrage opportunities do exist within the foreign exchange markets. Their study made use of binding bid-ask quotes of the tick frequency from the EBS platform. They tested for arbitrage opportunities using triangular arbitrage trades. Their study finds that arbitrage opportunities are present throughout the day and that the size of the opportunities is “time-varying”. Their study also finds that that the size of the

arbitrage opportunities decrease when the bid-ask spread is smaller and also when there is an increase in the number of quotes received (ie. increased liquidity).

Aiba et al. (2003) in their study using high frequency data show that not only do triangular arbitrage opportunities exist but that there is a direct correlation between the three currency pairs within the spot market. One would assume that triangular arbitrage opportunities would be relatively short lived however Aiba et al. (2002,2003) while examining the JYP/USD, USD/EUR and JPY/EUR spot market find numerous arbitrage opportunities which add up to 90 minutes in any given trading day, with the longest arbitrage opportunity open for a thousand seconds at a time.

Akram et al. (2008) in their study using tick frequency data obtained from the Reuters platform test for both one-way and two-way arbitrage in real time. Their findings suggest that there are in actual fact numerous “short-lived arbitrage opportunities” in real time to be exploited (*Akram et al, 2008 pp.29*). One might assume that most of these would not be economically significant but they explicitly state that the sizes of these opportunities are “economically significant” (*Akram et al, 2008 pp.29*). Their study also suggests that these opportunities are usually open for long enough that traders can take advantage of them.

Fenn et al. (2009) investigate triangular arbitrage opportunities within foreign exchange market with the use of high frequency executable price data. Their study finds that arbitrage opportunities do exist but the window of opportunity open for a fairly short period and produce very small returns.

It can be seen from the existing literature that triangular arbitrage opportunities do exist in real time and that at least some of them are economically

significant. This study will be making use of one minute currency pair data collected from The Alpari Groups historical databank to test for triangular arbitrage opportunities within both the retail and the interbank segments of the foreign exchange market.

## **2.9 Trading Platforms & Forex Data Feeds**

Trading in the foreign exchange market has evolved with technology over time, where before the market was a “broker driven over the-counter-market”, it has now shifted to an electronic trading format (*Marshall et al., 2008, pp.4*). In order to trade in the foreign exchange market one can adopt a number of different service providers and platforms. Usually one is required to install a platform upon which the trading will take place and then separately get a data feed. In the interbank market we have the two big platforms that dominate, EBS and Reuters. Both EBS and Reuters platforms come with their own data feeds. These are expensive options which are not meant for the retail market. However non bank dealers such as hedge funds would have the capital to make use of this trading platform. The fixed cost of setting up and running the EBS platform back in 2006, in Australia was AUD 64,440 with the hardware and installation costing AUD 9,000 and a monthly data subscription charge of AUD 4,620 (*Marshall et al., 2008, pp.7*).

With the EBS or Reuters traders get access to data feeds compiled directly from the top interbank market makers. Because of this fact the bid-ask spreads using either EBS or Reuters trading solutions would be small relative to those found in the retail market. On top of the fixed cost the EBS trading platform also have a variable cost component which traders need to take into consideration. EBS charges its

customers a nominal trade fee depending on the volume of trade which would amount to a few dollars for every million. For example for the first billion a trade fee of USD 7.50 per million is imposed (*Marshall et al., 2008*).

In the retail market the trading platforms and the data feeds are much cheaper. An example of a retail level trading platform would be NeoTicker, which is a paid platform which requires the user to select their own data feed. The onetime cost of buying and installing the platform is quoted at USD 1,297. So this gives you the platform but no data feed. Data feeds costs vary depending on the broker in question, for example the services of IQFeed would cost USD 50 in terms of start-up fees and the basic feed would cost USD 60. The basic feed however does not included foreign exchange quotes and getting access to the forex data would cost an additional another USD 50 on top of the USD 60 per month. This amounts to total fixed cost of USD 1,320 just for the data feed excluding any setup and trade costs.

Recently however another option has become available, whereby the trader pays nothing for the platform or the data feed. The Alpari Group has their own trading platform MetaTrader 4 and also provides their client with a free data feed for use in their trading activities. With this retail trading solution there are no trade fees or commissions to be taken into account, as all their costs are included in their bid-ask spreads. This study focus on The Alpari Group and MetaTrader 4 combination of trading within the retail foreign exchange market as this option represents one the cheapest and readily accessible for anyone looking to trade foreign exchange. The Alpari Group also provides an extensive databank of historical foreign exchange data. The data used within this study was attained from this very databank.

## 2.10 Alpari & Meta Trader 4

The Alpari Group was formed in Russia back in 1998. It is a fairly popular foreign exchange trading option at the retail level. Their website claims in 2008 monthly trading volume exceeded USD 60 billion and that they have over 100,000 live accounts<sup>5</sup>. In order to get an indication of size the Alpari operation we can compare its trade volume to that of the EBS platform. In 2006 the EBS platform was noted to have a daily trading volume of USD 145 billion (*Marshall et al. 2008 pp.6*). This means comparatively the Alpari trading services represent less than 1.5 percent of the trading volume seen by the EBS platform.

The Alpari Groups counterparties include interbank market makers such as UBS, Goldman Sachs and Currenex, with their prime broker being The Deutsche Bank. As it can be seen The Alpari Group makes use of a number of interbank market makers to derive their own data feed. It could not be confirmed whether they are making use of either the EBS or Reuter's platform to conduct their own trading. The data feed that The Alpari Group provide to their retail customers are essentially a compilation of their own data feeds, whereby they make use of the best rates available to them, on top of which they charge their customers a premium in the form of the bid-ask spread. Essentially if lower bid-ask spreads are used then the data feed provided by Alpari would provide a good indication of the bid-ask quotes that are available to non bank dealers dealing directly with interbank counterparties.

---

<sup>5</sup> Information about the Alpari Group was obtained from the The Alpari Group website using the following link [http://www.alpari-idc.com/en/about\\_alpari/index.html](http://www.alpari-idc.com/en/about_alpari/index.html) (accessed April 8th, 2009)

The Alpari Group offers its retail customers three types of accounts, Demo, Micro and Classic. All accounts face the same spreads with the lowest spread being 1.8 pips for the EUR/USD. A full summary of their spreads for major currency pairs can be found using this following link<sup>6</sup>. The spreads which are of interest to us with regards to this study are as follow; EUR/USD 1.8 pips, EUR/JPY 3.5 pips and USD/JPY 2.8 pips. The Alpari Micro account allows traders the option of trading 29 currency pairs where as the Classic account provides the additional ability to trade silver and gold. The Alpari Group offers a maximum leveraging of 1:500. The Micro account has a limit of 2 open positions while the Classic account does not have any limitations as to the number of open positions. The minimum deposit for the Micro account is \$200 while the Classic requires a minimum deposit of \$500. The Alpari Group states that they have no commission charges as “transaction costs are incorporated into the bid/ask spread”<sup>7</sup>.

The Alpari Group recommends that the MetaTrader 4 trading platform be used for its Classic trading accounts. The website for MetaTrader 4 describes the platform as “a free-of-charge program specially designed for online trading in the Forex market<sup>8</sup>”. They do also provide trading platforms for smart phones and PDAs at an additional cost.

---

<sup>6</sup> Information regarding the spreads was obtained from The Alpari Groups website using the following link [http://www.alpari-idc.com/en/trading\\_accounts/spreads\\_margins.html](http://www.alpari-idc.com/en/trading_accounts/spreads_margins.html) (accessed April 12th, 2009)

<sup>7</sup> Information regarding the spreads was obtained from The Alpari Groups website using the following link [http://www.alpari.co.uk/en/trading\\_accounts/index.html](http://www.alpari.co.uk/en/trading_accounts/index.html) (accessed April 8th, 2009)

<sup>8</sup> Information regarding the MetaTrader 4 platform was obtained from the MetaTrader 4 website using the following link <http://www.metatrader4.com/traders/> (accessed April 8th, 2009)



## CHAPTER 3

### RESEARCH METHODOLOGY

#### 3.1 Introduction

In this study arbitrage opportunities are tested for using triangular arbitrage trades involving the following three currency pairs, EUR/JPY, EUR/USD, and USD/JPY. This study looks to identify the number of arbitrage opportunities within both the retail and interbank segments using quantitative analysis. This study seeks to establish whether or not triangular parity can be used to predict currency movement. This section of the study overviews the data used within this study, the set-up of the triangular arbitrage trades and the triangular parity based currency movement test.

#### 3.2 Data

The data used in this study was obtained from The Alpari Groups historical data archives<sup>9</sup>. It was chosen because the data was considered to be of good quality and because it was freely available for download. The information regarding the bid-ask spreads that was used within the calculation of triangular arbitrage trades was obtained from The Alpari Groups website. According to their website The Alpari Group employs two different sets of bid-ask spreads depending on whether it is morning (starting from 8:00AM) or night (starting from 22:00 PM)<sup>10</sup>. The currency data provided by The Alpari Group came in two frequencies, minute and daily rates.

The one minute foreign exchange data Alpari bank data quotes the following

---

<sup>9</sup> The data used within this study can be downloaded using the following link: <http://www.alpari-idc.com/en/dc/databank.php>

<sup>10</sup> This information regarding the spreads was retrieved using the following link: [http://www.alpari-idc.com/en/trading\\_accounts/spreads\\_margins.html](http://www.alpari-idc.com/en/trading_accounts/spreads_margins.html)

information, the open quote, high quote, low quote and the close quote for a given minute. The data also includes an indication of trade volume.

For this study the one minute frequency data was downloaded for the following three major currency pairs; USD/JPY, EUR/USD and EUR/JPY. This ring of currency was chosen as it is one of the most liquid rings and because this ring has been used in pervious triangular arbitrage studies by Aiba et al. (2002 & 2003), Aiba & Hatano (2004), Fen et al. (2009) and Marshall et al. (2008). The data used in this study represents the most recent data that was available at the time that this study was being conducted. A time frame of one week was used to test for arbitrage opportunities starting on 4<sup>th</sup> April, 2009 and ending on 10<sup>th</sup> April, 2009. A sample of the original data is provided below; the currency pair in question is EUR/JPY.

Table 1: Data Sample

Date	Time	Open	High	Low	Close	Volume
2009.04.06	0:02	135.57	135.57	135.56	135.57	5
2009.04.06	0:03	135.58	135.58	135.57	135.57	4
2009.04.06	0:04	135.58	135.63	135.57	135.6	8
2009.04.06	0:05	135.61	135.7	135.61	135.69	14

The original data downloaded from The Alpari Groups historical databank was in the .hst format, which required the data to be opened in MetaTrader 4 platform.

From MetaTrader 4 the data was exported in the .csv format so that it could be used for the purpose of empirical analysis. The data points for the three major currency pair were filtered so that all the quotes would be matched according to their time stamp.

After the filtering process was complete, the final data set contained a total of 6,160 one minute data point for each of the three major currency pair.

### 3.3 Construction of Bid-Ask Quote

In order to test for arbitrage opportunities using triangular arbitrage trades, bid ask quotes were required. The bid and ask prices were derived using the close quote from each of the one minute data points. The bid-ask quotes are generated using the close quotes and a spread value of  $\times$  as was used by Batten & Szilagyi (2008):

$$\text{bid quote} = \text{close quote} - .5x$$

$$\text{ask quote} = \text{close quote} + .5x$$

### 3.4 Testing for Triangular Arbitrage and Currency Movement

This study tests for two things, arbitrage opportunities within the retail and interbank segments of the foreign exchange market and currency movement using the theory of triangular parity. Exactly how these trades and tests are conducted is discussed in some detail below.

#### 3.3.1 Triangular Arbitrage

This study makes use of the theory of triangular arbitrage as described in chapter two to determine if an arbitrage opportunity is present while making use of one minute Alpari foreign exchange data. A number of assumed bid-ask spread scenarios are used to replicate the costs associated with trading within retail and interbank segments of the foreign exchange market. The currency ring involving EUR/USD, USD/JPY & EUR/JPY is used to test for triangular arbitrage opportunities. This specific ring of currency pairs can be traded in six different ways,

depending on the currency one starts with. Provide below is a list of all possible trades using our specified currency ring.

### **USD based**

*USD->JPY->EUR->USD* - Buy JPY using USD, buy EUR with JPY, buy USD with the EUR

*USD->EUR->JPY->USD* - Buy EUR using USD, buy JPY with EUR, buy USD with the JPY

### **EUR based**

*EUR->USD->JPY->EUR* - Buy USD using EUR, buy JPY with USD, buy EUR with the JPY

*EUR->JPY->USD->EUR* - Buy JPY using EUR, buy USD with JPY, buy EUR with the USD

### **JPY based**

*JPY->USD->EUR->JPY* - Buy USD using JPY, buy EUR with USD, buy JPY with the EUR

*JPY->EUR->USD->JPY* - Buy EUR using JPY, buy USD with EUR, buy JPY with the EUR

When trading the currency rings it is essential to buy using the bid quote and sell at the ask quote. This would mean that in order to trade the *EUR->USD->JPY->EUR*, the following trades would need to take place.

Trade 1. USD bought @ bid

Trade 2. JPY bought @ bid

Trade 3. JPY sold for EUR @ ask

If the other EUR based ring (*EUR->JPY->USD->EUR*) is traded, then it will be as follows.

Trade 1. JPY bought @ bid

Trade 2. JPY sold for USD @ ask

Trade 3. USD sold for EUR @ ask

As has been mentioned in chapter 2 before that indirect quotes for our three major currency pairs are not available, as such this study utilizes the inverse function of the direct quotes to form the indirect quotes for JPY/USD, JPY/EUR and USD/EUR. Below we provide an example of exactly how the six different trades between the three currency pairs are calculated, where x represents the initial capital outlay.

$$USD \rightarrow JPY \rightarrow EUR \rightarrow USD: (x * (USD/JPY_{bid}) * (1/(EUR/JPY_{ask})) * (EUR/USD_{bid})) -x$$

$$USD \rightarrow EUR \rightarrow JPY \rightarrow USD: (x * (1/(EUR/USD_{ask})) * (EUR/JPY_{bid}) * (1/(USD/JPY_{ask}))) -x$$

$$EUR \rightarrow USD \rightarrow JPY \rightarrow EUR: (x * (EUR/USD_{bid}) * (USD/JPY_{bid}) * (1/(EUR/JPY_{ask}))) -x$$

$$EUR \rightarrow JPY \rightarrow USD \rightarrow EUR: (x * (EUR/JPY_{bid}) * (1/(USD/JPY_{ask})) * ((1/(EUR/USD_{ask})))) -x$$

$$JPY \rightarrow USD \rightarrow EUR \rightarrow JPY: (x * (1/(USD/JPY_{ask})) * ((1/(EUR/USD_{ask})) * (EUR/JPY_{bid}))) -x$$

$$JPY \rightarrow EUR \rightarrow USD \rightarrow JPY: (x * (1/(EUR/JPY_{ask})) * (EUR/USD_{bid}) * (USD/JPY_{bid})) -x$$

Having established exactly how the triangular arbitrage trades are computed within this study, it is important to define what amounts to an arbitrage opportunity. If any trade returned a value  $>0$  after taking into account the initial capital outlay and all costs then it is considered that the trade represented an arbitrage opportunity. In order to test for arbitrage at the retail level, The Alpari Group bid-ask spreads were employed within the bid-ask quotes calculation. When testing for arbitrage opportunities at the interbank level, we viewed The Alpari Group not as a market maker but instead as a non bank dealer, a hedge fund to be more specific. Therefore while testing for arbitrage opportunities at the interbank level this study employed five different spread scenarios to reflect the relatively lower bid-ask spreads within the interbank market when compared to the retail market.

When viewing The Alpari Group as a non bank dealer the historical data represented the best rates available to The Alpari Group from its various interbank counterparties. As a hedge fund The Alpari Group would face spreads which are much lower than those faced by its retail customers for reasons discussed in chapter two. The five different bid-ask spread scenarios employed in this study are displayed in table 2 below.

Table 2: Bid-Ask Spread Scenario for Retail & Interbank Segment

Currency Pair	Bid-Ask Spread Scenario					
	Retail Market Trader	Hedge Fund				
		HF1 @ 25% of Retail	HF2 @ 33% of Retail	HF3 @ 50% of Retail	HF5 @ 66% of Retail	HF5 @ 75% of Retail
EUR/JPY	0.038	0.0095	0.01254	0.019	0.02508	0.0285
EUR/USD	0.00018	0.000045	0.0000594	0.00009	0.0001188	0.000135
USD/JPY	0.028	0.007	0.00924	0.014	0.01848	0.021

At the retail level, all the transaction costs associated with foreign exchange trading were said to be incorporated within the bid-ask spreads. However this is not the case with the interbank segment, where the additional variable cost component of trade fees has to be taken into consideration. In chapter two it was mentioned that using the EBS trading platform, a trader faces a nominal trade fee based on the volume of a trade. For a trade of up to a million USD EBS charges a fee of USD 7.5. It is for this reason that when calculating triangular arbitrage within the interbank market that a total trade fee of USD 22.5 is included. A triangular arbitrage trade consists of three separate trades conducted simultaneously; therefore the trade fee of 7.5 is multiplied by three to give 22.5. For instance the  $USD \Rightarrow JPY \Rightarrow EUR \Rightarrow USD$

trade would be calculated in the following manner, where x represents the initial capital outlay of 1 million.

$$(x * (\text{USD/JPY}_{\text{bid}}) * (1/(\text{EUR/JPY}_{\text{ask}})) * (\text{EUR/USD}_{\text{bid}})) - (x + 22.5))$$

### 3.3.2 Testing for Currency Movement using Triangular Parity

The second part of this study tests whether or not triangular parity within a three currency pair ring can be used to predict future currency movements. To test for this the open and close quotes were used. The process used to compute this currency movement has already been described in chapter two. An example is provided here to reiterate the point. To test if  $\text{USD/JPY}^A$  (actual close rate) was overvalued or undervalued, we first need to establish a value  $\text{USD/JPY}^P$  (predicted close rate) using triangular parity.

$$\text{Step 1. } \text{EUR/JPY} * \text{EUR/USD} = \text{USD/JPY}^P$$

$$\text{Step 2. } \text{USD/JPY}^A - \text{USD/JPY}^P = x$$

If the sum of step two was positive then the actual close price was deemed to be overvalued relative to the predicted close price. This meant that in the subsequent data point we would expect that the currency pair would depreciate in line with the law of one price. If the sum of step two was negative than it was assumed that the actual quote was undervalued and as a result the subsequent currency data point  $\text{USD/JPY}^{A+1}$  (the open quote for the next minutes data point) would show signs of appreciation. This appreciated and depreciation was tested for using the third and final step, where  $\text{USD/JPY}^{A+1}$  represent the next minutes open quote.

$$\text{Step 3. } \text{USD/JPY}^{A+1} - \text{USD/JPY}^A$$

The next minutes open quote is used because in theory the close quote of the preceding data point and the open quote of the next data point would constitute two continuous ticks of data. If the sum of step three was positive then the currency pair in question was recorded as having appreciated and was considered to have depreciated if the sum was negative. If a currency pair was overvalued according to our calculation and the next data point showed that the currency pair has depreciated then it meant that the currency pairs were acting in line with the predictions of triangular parity and vice versa.

### **3.4 Hypothesis**

Based on what has been discussed so far this study sets out four hypothesis which are as follow:

- H1: Triangular arbitrage is not possible at the retail level.
- H2: The number of triangular arbitrage opportunities registered will increase as spreads are lowered.
- H3: The average return per unit of initial currency outlay will decrease as spreads are increased.
- H4: Triangular parity is an effective indicator of future currency movement.



## CHAPTER 4

### DATA ANALYSIS & DISCUSSIONS

#### 4. Introduction

The results of the empirical analysis are presented in a series of tables and figures below.

#### 4.1 Retail Market Results

Table 3: Triangular Arbitrage Opportunities within Retail Foreign Exchange Market

Spread Scenario : Retail Market Trader	Currency Ring					
	<i>USD-JPY- EUR-USD</i>	<i>USD-EUR- JPY-USD</i>	<i>EUR-USD- JPY-EUR</i>	<i>EUR-JPY- USD-EUR</i>	<i>JPY-USD- EUR-JPY</i>	<i>JPY-EUR- USD-JPY</i>
Total Number of Trades	6,160	6,160	6,160	6,160	6,160	6,160
Number of Arbitrage opportunities "> 0"	7	44	7	44	7	44
Average Amount	8.7210	12.2665	8.7210	12.2665	8.7210	12.2665
Max Amount	20.5049	52.0809	20.5049	52.0809	20.5049	52.0809
Percentage of Total Trades Returning Positive for Arbitrage	0.1136	0.7143	0.1136	0.7143	0.1136	0.7143

In hypothesis H1 it was stated that there would be no real triangular arbitrage opportunities to exploit within the retail foreign exchange market. Given the spreads employed by The Alpari Group it was determined that out of 12,320 possible trades using a USD, EUR or JPY based ring, only 51 arbitrage opportunities were identified. Of these 51 opportunities the maximum amount of arbitrage profit identified was USD 12.2665 with an initial capital outlay of USD 100,000. This meant that the most profitable arbitrage opportunity yielded a return of a mere return of 0.0521 cents to

the dollar. Out of the 12,320 possible USD based trades only 0.4140 percent of the trades returned positive for arbitrage.

It is noted that the direction within which the currency rings were traded also made a difference in terms of arbitrage. Trading USD-JPY-EUR-USD resulted in 7 arbitrage opportunities with the mean return per dollar of 0.012 cents; whereas the USD-EUR-JPY-USD trade resulted in 44 positive arbitrage opportunities with a mean return of 0.0087 cents to the dollar. Seeing that the most profitable arbitrage opportunity witnessed only produced a return of only 0.0521 cents to the dollar and with only 0.4140 percent of all trades resulting in positive arbitrage opportunities, it is safe to assume that there are no worthwhile triangular arbitrage opportunities to be found within the retail segment of the foreign exchange market. This alludes to the fact that the retail segment of the foreign exchange market falls in line with the efficient market hypothesis.

As is witnessed in table 3 that a USD, JPY or EUR based ring produces the same results, the reason for this can be found within the original equations used to calculate the triangular arbitrage trade.

$$USD \rightarrow JPY \rightarrow EUR \rightarrow USD: (x * (USD/JPY_{bid}) * (1/(EUR/JPY_{ask})) * (EUR/USD_{bid})) -x$$

$$EUR \rightarrow USD \rightarrow JPY \rightarrow EUR: (x * (EUR/USD_{bid}) * (USD/JPY_{bid}) * (1/(EUR/JPY_{ask}))) -x$$

$$JPY \rightarrow EUR \rightarrow USD \rightarrow JPY: (x * (1/(EUR/JPY_{ask})) * (EUR/USD_{bid}) * (USD/JPY_{bid})) -x$$

$$EUR \rightarrow JPY \rightarrow USD \rightarrow EUR: (x * (EUR/JPY_{bid}) * (1/(USD/JPY_{ask})) * ((1/(EUR/USD_{ask})))) -x$$

$$JPY \rightarrow USD \rightarrow EUR \rightarrow JPY: (x * (1/(USD/JPY_{ask})) * ((1/(EUR/USD_{ask})) * (EUR/JPY_{bid}))) -x$$

$$USD \rightarrow EUR \rightarrow JPY \rightarrow USD: (x * (1/(EUR/USD_{ask})) * (EUR/JPY_{bid}) * (1/(USD/JPY_{ask}))) -x$$

If we closely examine the trades then we find that the product of the USD-JPY-EUR-USD, EUR-USD-JPY-EUR and the JPY-EUR-USD-JPY, trades are all the same. The same is the case with the USD-EUR-JPY-USD, EUR-JPY-USD-EUR and JPY-USD-EUR-JPY, Therefore while discussing the arbitrage opportunities within the interbank market only the USD based ring trade results will be shown.

#### 4.2 Interbank Market Results

In the hedge fund scenario we employ five different bid-ask spread scenarios. In the first scenario we assume that the non bank dealer can trade within the interbank market at  $\frac{1}{4}$  the spreads faced by its retail customers.

Table 4: Arbitrage Opportunities within Interbank Segment - Scenario 1-3

Spread Scenario : Hedge Fund	Currency Ring					
	HF1 @ 25%		HF2 @ 33%		HF3 @ 50%	
	USD-JPY- EUR-USD	USD-EUR- JPY-USD	USD-JPY- EUR-USD	USD-EUR- JPY-USD	USD-JPY- EUR-USD	USD-EUR- JPY-USD
Total Number of Trades	6,160	6,160	6,160	6,160	6,160	6,160
Number of Arbitrage opportunities "> 0"	69	2996	35	2,069	18	727
Average Amount	72.6961	63.2711	101.8875	56.5835	113.0649	53.4317
Max Amount	446.8637	760.7935	418.6669	732.7918	358.7513	673.2908
Percentage of Total Trades Returning Positive for Arbitrage	1.1201	48.6364	0.5682	34.0260	0.2922	11.8019

When testing for arbitrage opportunities within the interbank market the trade sizes employed were USD 1 million and a trade fee of USD 22.5 was taken into consideration as mentioned previously in chapter three. The USD-EUR-JPY-USD

trade shows that out of the 6,130 possible trades, 2,996 came back positive for arbitrage. This means that nearly 50 percent of all trades returned positive for arbitrage. The most profitable arbitrage opportunity netted a return of 0.0761 cents per 1 USD in capital outlay while the mean arbitrage opportunity produced a return of 0.0063 cents per 1 USD in capital outlay. It is highly unlikely that nearly 50 percent of the USD-EUR-JPY-USD trades would come back positive for triangular arbitrage therefore we can assume that non bank dealers would be facing a bid-ask spread higher than  $\frac{1}{4}$  the retail spreads.

In scenario two the non bank dealer bid-ask spreads is factored in at  $\frac{1}{3}$  of the retail brokers bid-ask spreads. Scenario two just like scenario one produces an abnormally high percentage of trades returning positive for arbitrage at just over 34 percent of the time using the USD-EUR-JPY-USD trade. Would the market allow for such a high number of arbitrage opportunities, it is highly unlikely. Abia et al. (2002) found that arbitrage opportunities exist for only 6.4 percent of the time; therefore it can be safely assumed that spreads faced by non bank dealers are higher than  $\frac{1}{3}$  those employed by retail brokers.

One thing to note is that when testing for arbitrage opportunities at the interbank level we include a USD 22.5 trade fee. This trade fee would decrease the number of trades returning positive for arbitrage and also increase the mean return, as it eliminates lower value trades from the equation. This is believed to be the case with regards to the higher average returns in scenario two while trading USD-JPY-EUR-USD.

In scenario three the bid-ask spreads employed are  $\frac{1}{2}$  those faced by The Alpari Group retail customers. This increase of spread has a significant effect on the

total number of trades returning positive for arbitrage. The USD-EUR-JPY-USD which in the previous two scenarios had returned an abnormally high number of arbitrage opportunities, this time round returned positive for arbitrage at just over 11.8 percent. This figure seems to be more realistic. The average arbitrage trade return was just over 0.0012 cents to the dollar while the most profitable arbitrage opportunity netted 0.067 cents per 1 USD in initial capital outlay. It would not be surprising if the actual bid-ask spreads faced by a non bank dealer such as a hedge fund directly engaging the interbank market are close to half those faced by a retail customer.

The reason for this is that had the spreads been lower, then The Alpari Group instead of servicing the retail market as a broker would themselves trade within the interbank market in the guise of a non bank dealer. In scenario three there are still a significant number of arbitrage opportunities to be exploited however The Alpari Group would be better off acting as a market maker, as the arbitrage opportunities are small and they would probably be more profitable trading on behalf of other people.

Table 5: Arbitrage Opportunities within Interbank Segment - Scenario 4-5

<b>Spread Scenario : Hedge Fund</b>	<b>Currency Ring</b>			
	<i>HF4 @ 66%</i>		<i>HF5 @ 75%</i>	
	<i>USD-JPY- EUR-USD</i>	<i>USD-EUR- JPY-USD</i>	<i>USD-JPY- EUR-USD</i>	<i>USD-EUR- JPY-USD</i>
Total Number of Trades	6160	6160	6160	6160
Number of Arbitrage opportunities "> 0"	9	229	8	114
Average Amount	153.2613	65.3970	139.5637	86.4222
Max Amount	302.3633	617.2932	270.6464	585.7960
Percentage Trades Returning Positive for Arbitrage	0.1461	3.717	0.1299	1.85

In scenarios four and five we employ bid-ask spreads which are closer to those seen in the retail market at  $\frac{2}{3}$  and  $\frac{3}{4}$  respectively. In these scenarios' the arbitrage opportunities are dramatically reduced. Going from scenario three to four, the spreads increase by 17 percent, however the total number of arbitrage opportunities with the USD-EUR-JPY-USD trade plummets to 3.7 percent. The average arbitrage trade returned just over 0.0065 cents to the dollar and the most profitable arbitrage opportunity netted 0.0617 cents to the dollar. If we consider that Abia et al. (2002) found arbitrage opportunities 6.4 percent of the time while using high frequency tick data obtained from an information company, it would seem that interbank bid-ask spreads would be between  $\frac{1}{2}$  to  $\frac{2}{3}$  of those that The Alpari group charges its retail customers. After reviewing tables 4 and 5 and looking over the figure 1 it is apparent that hypothesis H2 is supported. In H2 it was stated that as the level of spreads increased the number of arbitrage opportunities would decrease and our empirical analysis find this to be the case.

In hypothesis H3 it states that as the spreads increase the average return of a triangular arbitrage trade will decrease. However as can be seen in figure 2 this is not the case. These results would suggest that as spreads are increased the average returns also increase when considering the interbank segment. This however cannot be the case, one possible explanation which has been discussed before is that because the interbank market scenarios takes into account the additional costs in the form of trade fees USD 22.5. Therefore any arbitrage trade producing profits less than USD 22.50 will not be taken into consideration thereby inflating the mean return figure. According to the findings of this study H3 is rejected.

Figure 1: Chart Showing How Triangular Arbitrage Opportunities Vary as Different Levels of Bid-Ask Spreads are Used

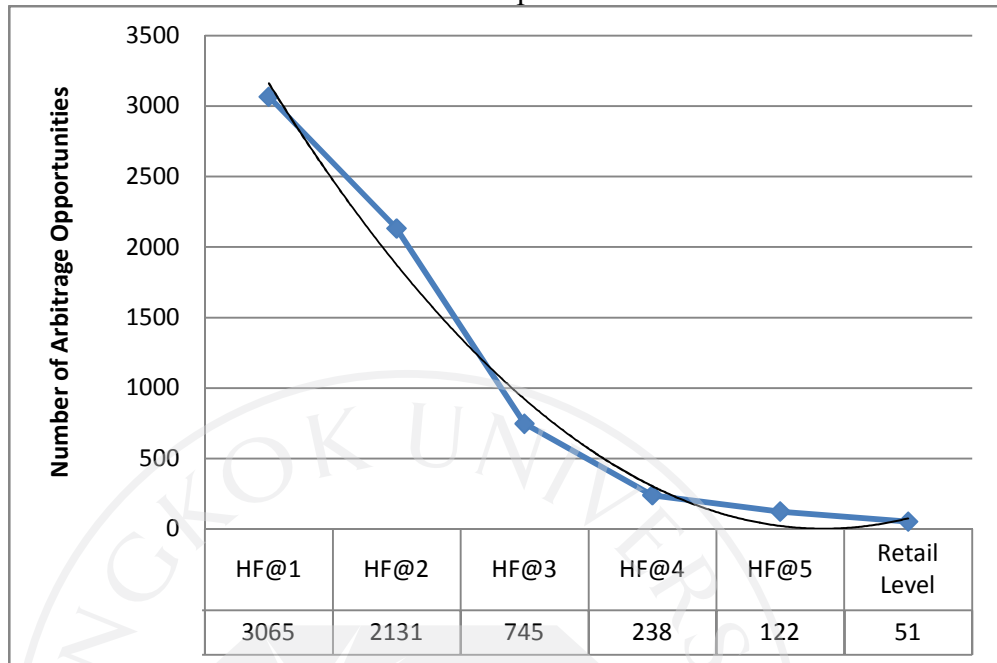
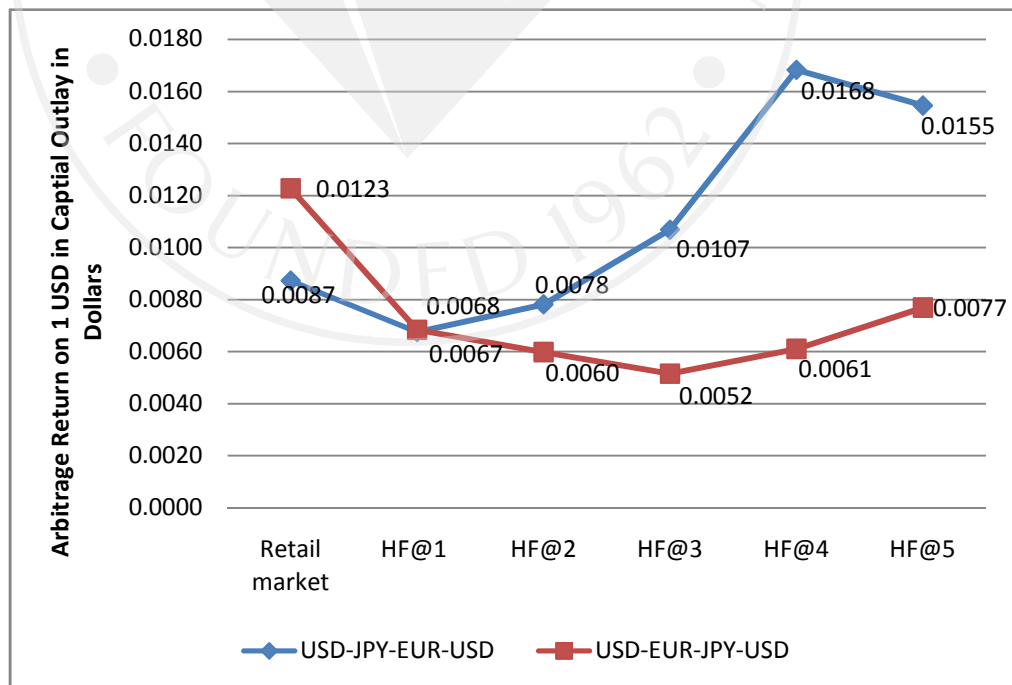


Figure 2: Chart Showing the Average Return per Dollar Investment as Spreads Increase



### 4.3 Predicting Currency Movement Using Triangular Parity

Table 6: Descriptive Stats Showing Difference Between Predicted & Actual Close Rates

<b>Descriptive Stats: Difference Between Predicted &amp; Actual Close Rates</b>			
	<i>EUR/JPY</i>	<i>EUR/USD</i>	<i>USD/JPY</i>
Mean	0.014201332	-0.000141467	-0.010676218
Standard Error	0.000150303	1.497E-06	0.000113168
Median	0.01436	-0.000143182	-0.010794022
Mode	0.01	-1E-04	-0.01
Standard Deviation	0.011795711	0.000117483	0.008881321
Sample Variance	0.000139139	1.38023E-08	7.88779E-05
Kurtosis	5.097291406	5.08206959	5.170484376
Skewness	0.126963601	-0.124480409	-0.123018761
Range	0.189388	0.001885057	0.143466765
Minimum	-0.073376	-0.001155383	-0.087437443
Maximum	0.116012	0.000729674	0.056029322
Sum	87.466004	-0.871297502	-65.75482848
Count	6159	6159	6159

Table 7: Descriptive Stats for Currency Movement

<b>Descriptive Stats: Currency Movement</b>			
	<i>EUR/JPY</i>	<i>EUR/USD</i>	<i>USD/JPY</i>
Mean	-4.87E-06	-5.34178E-06	-4.87092E-06
Standard Error	0.000171944	3.86701E-06	0.000320509
Median	0	1E-04	0
Mode	-0.01	1E-04	0.01
Standard Deviation	0.01349401	0.000121948	0.011144988
Sample Variance	0.000182088	1.48713E-08	0.000124211
Kurtosis	58.64195574	81.49737927	0.876408451
Skewness	-2.256564767	-3.162376832	-0.010309489
Range	0.45	0.0042	0.16
Minimum	-0.32	-0.0032	-0.07
Maximum	0.13	0.001	0.09
Sum	-0.03	0.0087	-0.25
Count	6159	6159	6159

According to our data using triangular parity the EUR/JPY currency pair was on average overvalued by 0.0142 or 1.4 pips. It is noted that the EUR/USD and the



USD/JPY were on average undervalued by 1.4 pips and about 1.1 pips respectively. The range within which the values of the currencies were predicted in terms of pips would be 18.9 for the EUR/JPY, 18.8 pips for EUR/USD and 14.3 pips for USD/JPY.

Out of these three currencies we see that the least liquid currency pair EUR/JPY is the only one to be overvalued. Also it should be noted that the most liquid currency pair USD/EUR, displayed the smallest variation between the actual closing price and the predicted closing price, with a standard deviation of 0.000117483. Something which presents itself from these tables is that the liquidity of a currency pair will have an effect on how well triangular parity can predict currency movements. It is interesting to note that for all three currencies the mode and median were zero, suggesting that the most common currency movement was no movement.

In terms of correlation, plotting all the graphs for all three currency pair's show no linear correlation in terms of the movement predicted via triangular parity and the actual movement of the currency pair in the next recorded data point. It was assumed that the law of one price would force the small difference between the actual close rates and those calculated using triangular parity to cause a readjustment movement within the next recorded data point. However our empirical results do not find this to be the case. There can be one of two explanations for this; firstly the difference could be so small that it did not result in any currency movement at all. The second explanation would point to a fundamental flaw within the actual test. The way the test was conducted it is assumed that the two currency pairs being used to calculate the predicted close rate were static in nature, as in that they will remain the same (static) in the subsequent data point and that the currency pair being predicted as being dynamic and thereby being able to change in the subsequent data point. The fact

is that all three currency pairs are dynamic in nature. Therefore if a currency pair is deemed to be overvalued then instead of it actually depreciating in the subsequent next data one of the currency pairs used to predict the value could appreciate, thereby bringing the three currency pairs back in line with triangular parity.

Figures 3 to 5 show that two currency pairs cannot really be used to predict the movement of a third currency pair. The differences found were so small that one would require higher frequency tick data to track the actual currency movement. According to the results we are unable to validate the final hypothesis H4, which stipulates that triangular parity can be used to predict currency movement. The average difference between the predicted and actual value was less than 1.4 pips, considering the fact that the data used is from one minute open and close quotes, it could be that the bid-ask spreads would account for this small difference. Technical analysis of Candle-Stick charts would give a better indication of trends and runs of currency pair movement. Triangular parity as used within this study is not a good indicator of future currency movement.

Figure 3: Chart Showing The Relationship Between The Predicted EUR/JPY Value and The Actual EUR/JPY Value & The Subsequent Currency Movement

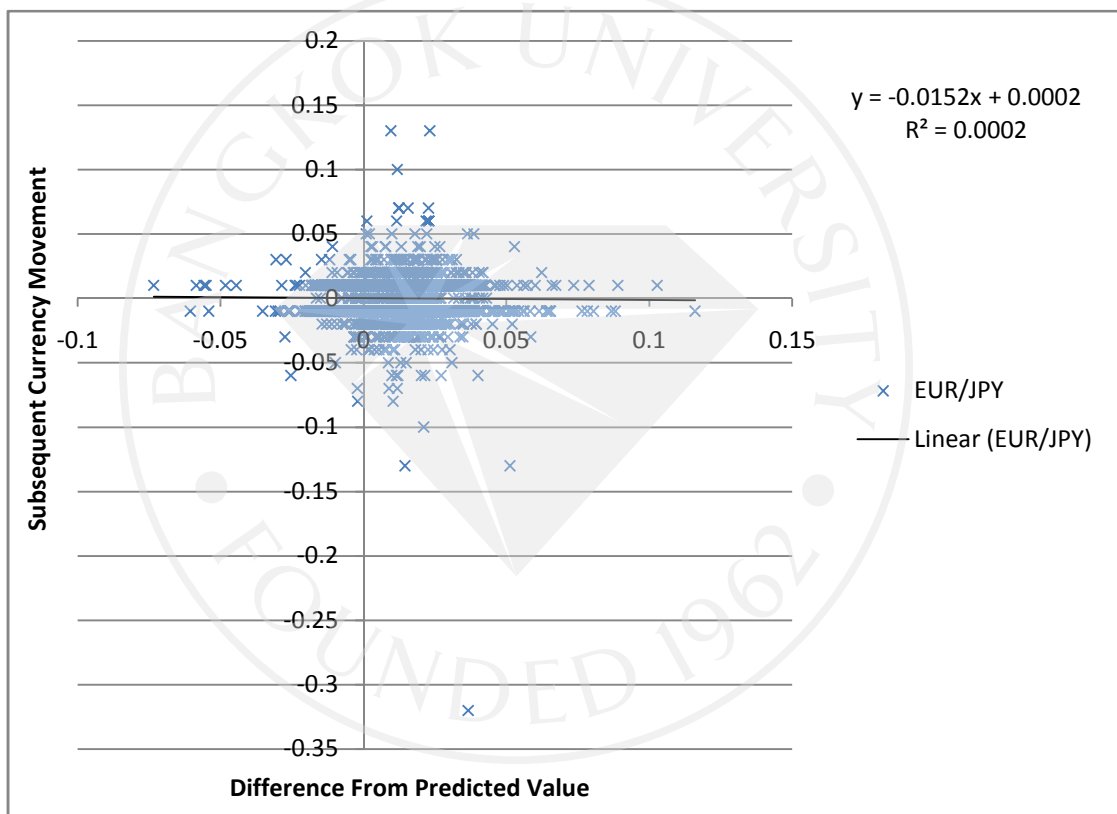


Figure 4: Chart Showing The Relationship Between The Predicted EUR/JPY Value and The Actual EUR/USD Value & The Subsequent Currency Movement

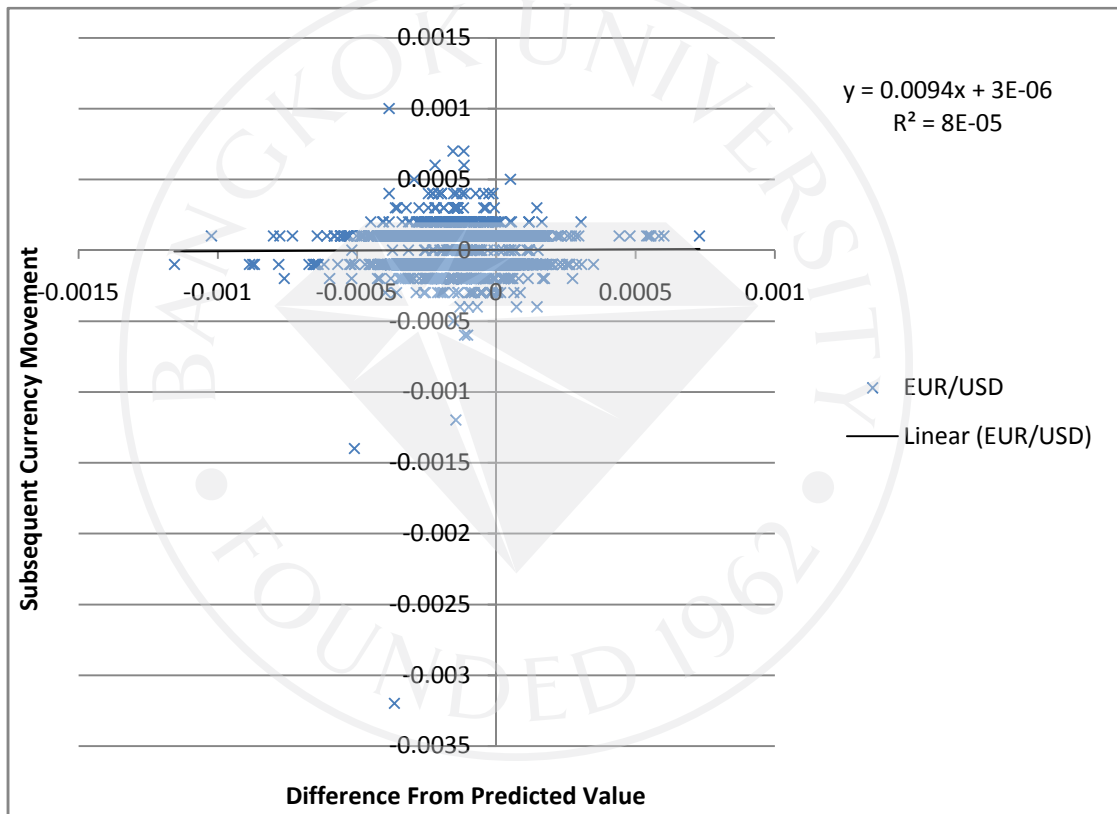
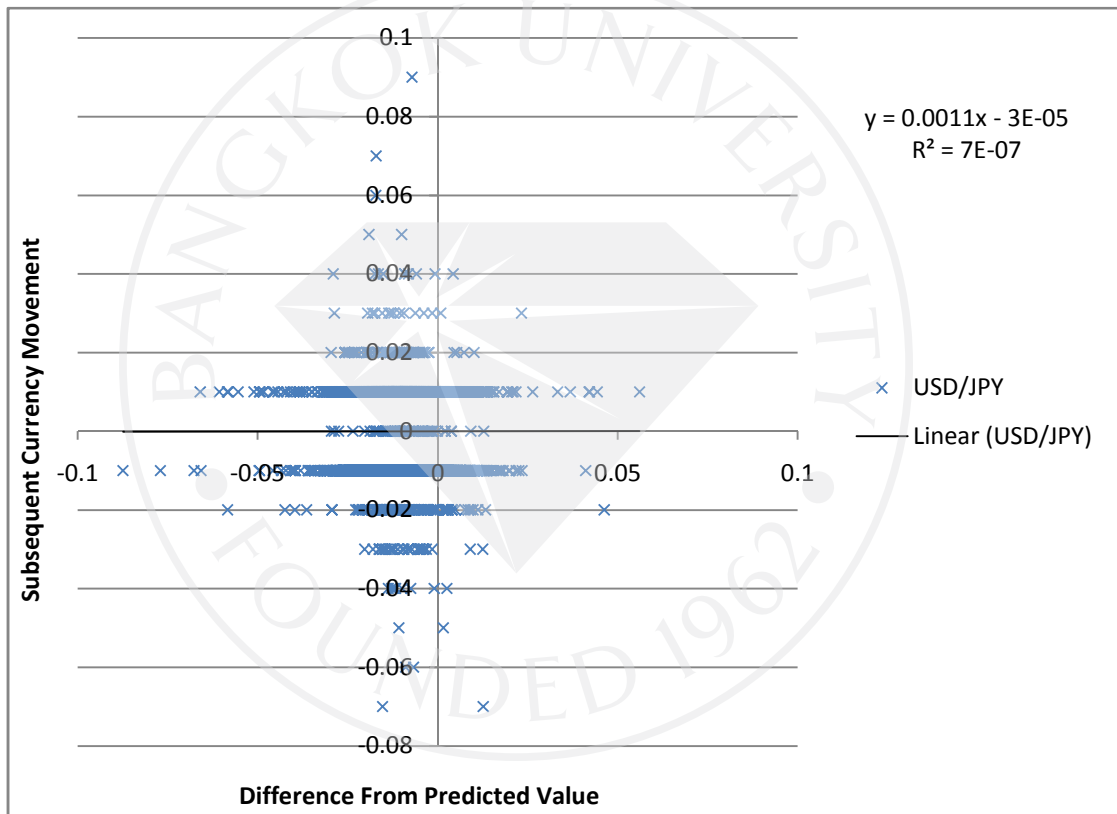


Figure 5: Chart Showing The Relationship Between The Predicted EUR/JPY Value and The Actual USD/JPY Value & The Subsequent Currency Movement



## CHAPTER 5

### CONCLUSION AND RECOMMENDATION

This study seeks to determine whether or not arbitrage opportunities are present within the retail foreign exchange market. Triangular arbitrage trades were used to detect the arbitrage opportunities. It was predicted that the high level of spreads imposed by foreign exchange brokers like The Alpari Group would make the quest for triangular arbitrage futile. Not only did the results indicate that the arbitrage opportunities were very rare but also pointed to the fact they were also not very profitable, with the most lucrative trade netting only USD 12.2665 with an initial capital outlay of USD 100,000.

Something which makes the picture even more bleak for the retail trader is the fact that in the real world there are questions as to a retail trader's ability to attain the stated bid-ask quotes due to slippages. Essentially there are questions as to a retail market customer's ability to execute all the trades simultaneously. In the foreign exchange market currency rates change very quickly and by the time a trader is able to identify an arbitrage opportunity and execute the required trades, it could very well be that one of the bid-ask quotes would have changed. This would mean that not only will a valid arbitrage opportunity go unfulfilled but that it could also end up costing the trader.

Trying to attain profits using triangular arbitrage while making use of a single retail broker is simply not possible as the broker would impose spreads which would make it impossible for the traders to profit at the broker's expense. However it would be interesting to note the type of arbitrage opportunities that are present within the

retail market using a multiple broker approach. Though all brokers are essentially redistributing their interbank market data feeds with increased bid-ask spreads, each broker would have established relationships with different interbank counterparties so their actual bid-ask quotes would vary for each currency pair. Also different brokers would have different technological infrastructure in place which would determine how much lag there is between the brokers getting the data from their interbank counterparties and the time it takes them to pass it onto their retail customers. Future research looking into arbitrage in the retail market should be based on a multiple broker approach instead of the single broker approach as adopted within this study.

In the retail market we were dealing with an online broker however in our interbank market analysis we eliminate the broker and directly engage with interbank counterparties. With the bid-ask spreads for a non bank dealer such as a hedge fund figured in at  $\frac{1}{2}$  those faced by The Alpari Groups retail traders, the percentage of arbitrage opportunities found using the two USD based triangular arbitrage trades increased significantly from .8702 percent in the retail segment to 6.0470 percent in the interbank segment. Arbitrage opportunities are much more likely within the interbank market than within the retail market. However with the average return of 0.0052 cents to the dollar and with the most lucrative arbitrage opportunity netting 0.067 cents to the dollar, it can be concluded that there a greater number of arbitrage opportunities identified within the interbank segment relative to the retail segment of the foreign exchange market.

While testing for triangular parity it was found that the predicted values almost never matched the actual recorded value. The finding indicates that the product of the

three currency quotes almost never equals one. This essentially means the ring of currency was consistently either overvalued or undervalued. With the use of 1 minute data this opportunity was consistently present. However triangular parity according to the findings of this study would not prove to be effective in predicting currency movement within a ring of currency pairs for reasons mentioned in chapter four.

According to the finding of this study the number of arbitrage opportunities found increase as the spreads are lowered. The findings also point to the fact that the profitability of a triangular arbitrage trade decreases with lowering spreads. The data used in this study to test for arbitrage opportunities in the interbank segment was obtained via a retail foreign exchange broker. Though different spreads scenarios were employed in order to reflect the lower bid-ask spreads of the interbank segment, in order to get a better indication of the nature of the arbitrage opportunities present in the interbank market would require the use of binding bid-ask tick quotes from a number of interbank players or from an electronic trading platform such as EBS or Reuter. Also within the interbank market the spreads are not static but dynamic in nature, which change according to the liquidity of the currency pair in question.

This study does however provide an indication as to how the numbers of arbitrage opportunities vary when different level spreads are employed. It can be safely concluded that arbitrage opportunities are not only rare but that the return per dollar in initial capital outlay is also very small. Even in the most favorable spreads scenario the most profitable arbitrage opportunity in the interbank segment netted a return of 0.076 cent per dollar in initial capital outlay.



Though this study was unable to validate its hypotheses regarding currency movement and triangular parity it is interesting to note that market quotes for currency pairs are not totally efficient. Very rarely did the product of the three currency pairs equal one, indicating that at most times a ring of currency was either under or overvalued by a small margin. In future studies instead of making use of data at the 1 minute interval, tick frequency data should be used to determine if the product of a ring of currencies pairs is equal to one or not. If product of the currency pairs is still not equal to one on a regular basis's then it would indicate that the foreign exchange market is in fact not efficient, as an efficient market requires that the market prices not be exploited on a regular basis.

Though the notion of arbitrage is simple to follow and understand it is not actually that simple of a concept to exploit. Initially the author of this study figured that with the information lag there had to be some worthwhile arbitrage opportunities within the retail market, but as this study has shown this is not the case and that the retail foreign exchange market falls in line with the efficient market hypothesis. Depending on the costs faced by a non bank dealer the interbank market is not always efficient in terms of the number of arbitrage opportunities, but it is efficient when considering the profitability of these opportunities. If the costs of trading for a hedge fund are half that of a retail trader then there are a significantly greater number of arbitrage opportunities to be exploited within the interbank segment than the retail segment of the foreign exchange market.

## BIBLIOGRAPHY

### Books

Clark, E., Ghosh, D.K. (2004) - Arbitrage, Hedging, and Speculation: The Foreign Exchange Market. Available at <http://books.google.com/books?id=agnVKu6z7TkC&printsec=frontcover> >, Accessed: 14/04/2009

Demange, G., Laroque, G., (2006) - Finance and the Economics of Uncertainty. Available at < <http://books.google.com/books?id=t-2pIXbMYIC&printsec=frontcover&dq=Finance+and+the+economics+of+uncertainty> >, Accessed: 17/04/2009

Eun, C. S., Resnick, B. G, (2007), "International Financial Management", 4th ed., New York, McGraw-Hill.

Grabbe, J. O., (1996), International Financial Markets", 3<sup>rd</sup> ed., New Jersey: Prentice-Hall

Mavrides, M., (1992) - Triangular arbitrage in the foreign exchange market: inefficiencies, technology, and investment opportunities. Available at: < [http://books.google.com/books?id=\\_dr42c712F8C&printsec=frontcover&dq=Triangular+arbitrage+in+the+foreign+exchange+market:+inefficiencies,+technology,+and+investment+opportunities](http://books.google.com/books?id=_dr42c712F8C&printsec=frontcover&dq=Triangular+arbitrage+in+the+foreign+exchange+market:+inefficiencies,+technology,+and+investment+opportunities) >, Accessed 04/04/2009.

Rodriguez, R. M., Carter, E. E., (1976) – "International financial management" , New Jersey, Princeton

Saunders, T., Cornett, M. M., (2007), "Financial markets and Institutions", International 3<sup>rd</sup> ed., New York, McGraw-Hill

Wang, P., (2009) – "The Economics of Foreign Exchange and Global Finance", 2<sup>nd</sup> ed., Available at < [http://books.google.com/books?id=jUvpADVx32gC&dq=Economics+of+Foreign+Exchange+and+Global+Finance&printsec=frontcover&source=bn&hl=en&ei=YawoSs6ROJvU7A0VkyJCQ&sa=X&oi=book\\_result&ct=result&resnum=4#PPP1,M1](http://books.google.com/books?id=jUvpADVx32gC&dq=Economics+of+Foreign+Exchange+and+Global+Finance&printsec=frontcover&source=bn&hl=en&ei=YawoSs6ROJvU7A0VkyJCQ&sa=X&oi=book_result&ct=result&resnum=4#PPP1,M1) >, Accessed: 26/03/2009

### Articles

Aiba, Y., Hatano, N., Takayasu, H., Marumo, K., Shimizu, T., (2002) - "Triangular arbitrage as an interaction among foreign exchange rates. Physica A: Statistical Mechanics and its Applications. 310(3-4), 467-479.

- Aiba, Y., Hatano, N., Takayasu, H., Marumo, K., Shimizu, T., (2003). Triangular arbitrage and negative auto-correlation of foreign exchange rates. *Physica A: Statistical Mechanics and its Applications*. 324(1-2), 253-257.
- Aiba, Y., Hatano, N., (2004). Triangular arbitrage in the foreign exchange market. *Physica A: Statistical Mechanics and its Applications*. 344 (1-2), 174-177.
- Akram, Q. F., Rime, D., Sarno, L., (2008), "Arbitrage in the Foreign Exchange Market: Turning on the Microscope", *Journal of International Economics*, 2008, vol. 76, pp. 237-253
- Bank for International Settlements, "OTC Derivatives Market Activity in The Second Half of 2008," Monetary and Economic Department (May 2009). Available at <<http://www.bis.org>>, Accessed: 15/05/2009
- Batten, J. A. and Szilagyi, P. G., Is Covered Interest Parity Arbitrage Extinct? Evidence from the Spot Usd/Yen (March 12, 2006). Available at <<http://ssrn.com/abstract=890858>>, Accessed: 13/04/2009
- Barker, W (2007): "The global foreign exchange market: growth and transformation", *Bank of Canada Review*, autumn, pp 3–12
- Choi, Y., and Yoon, Y. (2007) - "Arbitrage Strategy with N Currencies," *International Journal of Finance*, Vol. 18, No. 3, pp. 4105-4126.
- Fenn, D. J., Howison, S. D., McDonald, M., Williams, S., Johnson, N. F. (2009), "The Mirage of Triangular Arbitrage in the Spot Foreign Exchange Market". Available at: <[http://arxiv.org/PS\\_cache/arxiv/pdf/0812/0812.0913v1.pdf](http://arxiv.org/PS_cache/arxiv/pdf/0812/0812.0913v1.pdf)>, Accessed: 25/04/2009
- Frenkel, J. A. and Levich, R. M., (1975), "Covered Interest Arbitrage: Unexploited Profits," *Journal of Political Economy*, 83, 325–338.
- Frenkel, J. A. and Levich, R. M. (1977), "Transaction Costs and Interest Arbitrage: Tranquil Versus Turbulent Periods," *Journal of Political Economy*, 85, 1209–1226.
- Marshall, B. R., Treepongkaruna, S. and Young, M. R., (2008) - Exploitable Arbitrage Opportunities Exist in the Foreign Exchange Market – Presented at American Finance Association Annual Meeting, New Orleans, January 2008. Available at <[http://www.docs.fce.unsw.edu.au/banking/seminar/2007/exploitablearbitrage\\_Marshall\\_Sept13.pdf](http://www.docs.fce.unsw.edu.au/banking/seminar/2007/exploitablearbitrage_Marshall_Sept13.pdf)>, Accessed: 05/04/2009
- Rhee, S.G. and Chang, R.P., (1992), "Intra-day Arbitrage Opportunities in Foreign Exchange and Eurocurrency Markets," *Journal of Finance*, 47, 363–379.

Ryoo, H. H., (2006), "Arbitrage Opportunity in the Foreign Exchange Market". Available at < <http://www.business.curtin.edu.au/files/ryoo.pdf>>, Accessed: 28/04/2009

Taylor, M. P., (1987) - Covered interest parity: a high-frequency, high-quality data study. *Economica*, 54 (November), 429-38.

Taylor, M. P., (1989) - Covered Interest Arbitrage and Market Turbulence. *Economic Journal*. 99(396), 376-91

### **Internet**

Aite Group, (2007), "Retail FX: Taking Center in Overall Market Growth." 23 July. Available at < <http://www.aitegroup.com/reports/200707161.php>>, Accessed: 16/04/2009

