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A Model of Currency Forecasting Based on FX Option Market's Perspective

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ABSTRACT

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Traditional currency forecasting methods are mainly based on historical data and market sentiments. In this thesis a new model was developed, in which a currency's price range is predicted based on the market perspectives that could be a useful complementary viewpoint compared to the traditional ones.
The objectives of this study are, firstly, forecasting the price range of EUR/USD in the month of April, and secondly, constructing a new method of foreign exchange forecasting. The view of market on the currency is represented in its option quotes. Under the log-normal distribution assumptions, two important theories used in this work are Garman Kohlhagen model, a Black-Scholes extension for foreign exchange, and Value at Risk.
The model was tested during a short time frame with the currency pair of EUR and USD. It showed a very positive result with accurate prediction. Although the study pointed out some cautions and limitations when implementing this method, the model is still at an immature stage and should be tested more on different currency pairs and time periods.

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PREFACE

I would like to show my gratitude to my thesis supervisor, Mr. Pekka Tervonen and my statistic supervisor, Mr. Simo Määttä, without whom I would not be able to finish this work.

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1 INTRODUCTION

On the attempt to recover from the financial crisis 2007-2008, the Euro zone economy is still facing the risk of slipping back into the recession due to a number of domestic issues such as the Russian - Ukraine conflict, stagnation of the big economies in the area like Germany, France and Italy as well as the unsolved credit crisis in the East (Thompson, 2014). These factors have negatively affected the growth of Europe's economy as well as resulted in the great depreciation of the area's mutual currency. The Euro, for the first time in 11 years, has been shrinking 5 % against the US dollar in the first three month of the year 2015 (Ranasinghe, 2015). The historical fall of Euro raises concerns on what is the future of the currency, will its value continues to drop or will it recover, and how low or high Euro can reach.

Many methods, theories and models used in currency forecasting are based on historical data of the currency, prices of other currencies and commodity, the situation of the economy, society and politics and events or policies of the area. However, the forecasting model in this thesis will take the view of the market on Euro into account when predicting its future movement. By collecting the prices of option on Euro against US dollar, we can see how volatile the currency is under the option market's perspective and get an estimation of the Euro's price range in April 2015.

The thesis aims at two objectives. Firstly, the result of the work will give a concrete estimation of the maximum and minimum rate of Euro can reach in the future. The estimation will then be tested against the actual price of Euro in the market to evaluate the effectiveness and accuracy of the work. In case the exchange rate in real life is close to the estimation, the combination of theories and formulas used in the thesis can be used as a model of currency forecasting and be further tested on different currencies or on longer period of time. Bottom line, the goal of this thesis is trying to construct a new foreign exchange forecasting model that bases on the market's perspective.

The research method used in this study is desk-based, which means all data is already available and can be collected from internet. The theoretical background consists of existing, well-known theories and formulas. It also employs quantitative research method which utilises mathematical techniques.

The thesis consists three main parts. The next four chapters indicate the theoretical framework the study bases on. The hypothesis background will firstly introduce the definition of foreign exchange risk, derivatives and options. It will also emphasise the importance of currency forecasting to the business's well-being. Consequently, Log-normal distribution, Garman Kohlhagen and Value at Risk model will be explained and analysed. The next part indicates the research methods used in this study and lists the stages of the forecasting model. It also shows the assessment method of the model. The final part of thesis will present the results of the model as well as of its assessment process. According to the collected results, the model's errors will be analysed and its drawbacks as well as cautions of using will be concluded.

2 FOREIGN EXCHANGE RISKS AND OPTIONS

This chapter will define the risk deriving from the foreign exchange market, what is used to measure risks as well as which tools are employed to eliminate and avoid them.

2.1 Foreign Exchange Risk and the Need of Currency Forecasting

In finance theory, risk is defined as the unforeseen changes of financial variables may lead to either positive or negative results. Financial risks are categorised into interest rate risk, currency risk, equity risk and commodity risk (Jorion 1997, 63). Foreign exchange risk or currency risk is a type of financial risk that derives from the change of currencies' value. Currencies' value are presented in form of exchange quote, or their prices against each other (Baettig, 2013). For instance: EUR/USD = 1.10 (Bloomberg, 2015), the quote means that in order to buy 1 Euro, people need to pay with 1.10 US Dollar and they will receive the same amount of US Dollar when selling 1 Euro. The movement of currencies' prices also results in the change of assets' value. Consider an US-based investor in EU bond for 1 million Euro. At the time when 1 Euro still costs 1.5 US Dollar, his asset worth 1.5 million US Dollar. However after the exchange rate falls down to 1.1, his asset lose its value worth of 0.4 million US Dollar. Needless to say, the fluctuation of currency's exchange rate can have some majorly impacts on the well-being of business.

Risk or in this case, unexpected changes in currency rate, is not the only cause for losses. Financial failure also derives from the exposure of asset to the exchange rate risk. While the movement of currency is uncontrollable, firms can fully decide on how much of their asset is exposed to the volatility. This can be done with the help of foreign exchange derivatives (Jorion 1997, 64).

As uncertainty is one of the biggest causes of fear, human-beings have always subconsciously try to define, shape and form what they are not acquaintance with as a mean to eliminate the feeling of insecurity. Especially to future, people, being unable to know what are their risk ahead of time, are constantly trying to predict it (Ropeik, 2011). This can explain why there is such a big need and demand for currency forecasting. The threat that foreign exchange risk can cause to firms is undeniable and companies therefore have to use derivatives

to minimise it. However, using derivatives means no more than just making the asset immune from the fluctuation of the market. It can cover the underlying from unfavourable changes but it also blocks the firm from taking benefit when the asset lies under favourable situations. For instance, one has hedged EUR/USD at 1.10 with a European call option. If the EUR/USD rise to 1.2, by exercising the option he will save 0.1 USD per 1 purchased EUR. However, in case the rate remain at or get lower than 1.10, he can either exercise the option and pay for more expensive price than the market's or buy EUR at the market rate and lose the premium fee (the price to purchase an option contract) for nothing. As a result, even though derivative is very effective in risk eliminating, it does not always mean the most profitable strategy. For the optimal result the use of derivatives should always goes hand in hand with currency forecasting.

2.2 Measuring financial risk

In finance mathematic, risk, also referred as volatility, is measured by a statistic measurement called standard deviation. In foreign exchange content, standard deviation represents the annualised dispersion of exchange rates or derivatives prices around their arithmetic mean (mu μ). It is denoted by σ "sigma" and plays an important role in multiple financial theories and formulas (Jorion 1997, 64)

In the context of options, volatility represents the uncertainty of underlying asset's future price at the time of the option's expiration. It is categorised into three groups. Historical volatility describes the fluctuation of the asset in the past period. Realised volatility measures the level of volatility during the term of option which is from when the derivative is purchased to when it expires. And implied volatility measures the volatility of underlying price which is indirectly expressed in its option's price according to Black-Scholes model (Watsham 1998, 144).

Among three types of volatility, implied volatility outperforms the others on forecasting models in various derivative as well as equity indices market. Especially in predicting exchange rate, Pong, Shackleton, Taylor and Xu (2004) found that although for a week period, historical volatility showed better performance than implied volatility, for longer period of time, implied volatility delivers more effective forecast than the historical one. And in an

article of Jooyoung Jeon and James W.Taylor in 2013 on Oxford Journal of Forecast, implied volatility has been successfully applied directly into conditional autoregressive value at risk instead of traditionally using in volatility estimation. This is because implied volatility is better at representing the market's expectation of the future price rather than historical volatility, which describes the fluctuation of the price that already occurred. (Jeon and Taylor, 2013, 5)

2.3 Foreign exchange derivatives and options

Derivative is a type of financial instruments that derives its value from underlying entity or "underlying" in short. Underlying can be commodity (gold, oil), equity (stock, bond) or currency. Derivatives are traded on the market like the underlying is and they might or might not come with a fee called premium. There are three main types of foreign currency derivatives: options, futures and swaps (Taylor 1997, 168).

Foreign exchange option (FX option) includes call and put option. FX call option allows its owner to buy an amount of currency at a specific price on or before its expiration. On contrary, FX put option is contract providing its holder the right to sell a sum of currency at a specific exchange rate during its duration. Buyers of both call and put options are not obliged to exercise the contracts but they have to pay premium upfront even if the options are not used. The exchange rate at which an option owner can buy/sell currency is strike price (Taylor 1997, 172). Options can be exercised on or before expiration date or maturity date. The time between when the option is bought and its expiration date called maturity. (Shamah 2004, 49)

The two types of FX option that are most widely practiced are American option and European option. The American option gives the holders the opportunity to practise the option anytime they wish during the maturity. On to the European style, the options can only be taken into effect at the expiration date. (Taylor 1997, 173).

Option has three positions when its strike price is compared with spot rate. For call option, if the strike price is below the spot rate, it is in-the-money. If strike is higher than spot, the call option is out-of-the-money. On the other hand, a put option is in-the-money when its strike price is greater than spot rate and becomes out-of-the-money as its strike rate smaller

than spot rate. For both call and put option, the situation in which strike price is equal to spot rate is called at-the-money. (Shamah 2004, 49)

On calculating their profit or loss, option buyers and sellers use a position called break-even point. It is basically the point from where the option starts bringing profit. Break-even is the difference between strike and premium for put option while it is the sum of strike and option price in case of call option. (Shamah 2004, 52-60).

In the market, options can be in form of over-the-counter (OTC) or formal exchange. While OTC options are customised, private and highly negotiable contracts, formal exchange options are fixed in terms of contract size, expiration time, strike price, and are quoted publicly in big trading floors or exchanges such as Philadelphia Stock Exchange or Chicago Board Options Exchange. (Shamah 2004, 63).

Comparing with formal exchange, OTC provides customers more privacy and flexibility with longer maturity, less regulations, more choices of options exercise styles, commission and premium. It also offers better currency variety. However, because OTC is more like an agreement between customers and brokers or banks rather than a commodity in the financial market, it will has less transparency and greater credit risk. (Shamah 2004, 63-69). Additionally, better flexibility along with higher risk comes with higher price, OTC options normally have higher premiums and transaction fees than listed options do. (Downes & Goodman 2003, 53).

On contrary, standardised contract although has limited currency choices, more strictly regulations, shorter maturities and requires margin, it is more transparent, and apparently cheaper as well as safer. Because there is a third party (Options Clearing Corporation, OCC) involving in transactions, traders do not have to carry counterparty risk in situations where their partners fails to pay. (Shamah 2004, 63-69).

3 DISTRIBUTION OF OBSERVATIONS

This chapter introduces the basic definition of probability distribution, normal distribution and lognormal distribution. Subsequently, it will explain why lognormal distribution is an important assumption used in various financial formulas of currency exchange and options.

3.1 Probability distribution

Probability distribution or frequency distribution is mathematic model that describes the probability of events to happen. Probability can run from 0 (not occur at all) to 1 (100% happen). Probability distribution can be used in evaluate the future price of underlying assets and its risks. As a result, in foreign exchange market, it is very useful for investors and hedger to estimate the chances of exchange rate uncertainties to occur. (Watsham 1998, 58).

Variables in frequency distribution can be discrete or continuous. While discrete variables' values can be individually specified into concrete numbers, continuous variables can only be assessed in ranges of values. Due to the differences between them, their distributions are not similar and they are grouped into two corresponding categories: discrete distribution and continuous distribution. Continuous distribution is commonly used in the financial mathematic since the predication of loss and profit, price and rate cannot be written down in some finite value like 2, 5 or 30%, etc. Instead, the value of financial variables run in specified clusters or areas and continuous distribution finds the likelihood of variables having value that falls into the range. (Watsham 1998, 58).

3.2 Normal distribution

Normal distribution or Gaussian distribution describes many finance and economic variables and is the foundation for many other types of more complex distributions such as lognormal distribution. A variable is normal distributed when it takes values that are independently distributed. In other words, the likelihood of its value does not depend on each other. The normal distribution is formed by two moments: mean ( ) and standard deviation (

). Its curve has symmetrical bell shape and is divided into two equal halves by mean. In normal distribution, mean is equal to mode, which is the value that has the highest frequency, and median, which is the middle value. The standard deviation decides the dispersion level of the curve. Normal distribution can be transformed into a special form called standard normal distribution when mean is 0 and standard deviation takes value of 1 (Watsham 1998, 59-60).

Standard score (z) is a variable of standard normal distribution which has mean = 0 and standard deviation = 1. A random variable x can be calculated into z by the formula (Watsham 1998, 60):

$$z = \frac{(x - \mu)}{\sigma}$$

If x is normally distributed then standard variable or z-score is also normally distributed. z-score reflects the location of x to its mean because it indicates the number of standard deviations from mean to x. If z is positive, the value x lies on the right side of mean; on the other hand, if z is smaller than 0, x is on the left side of mean (see Figure 1). The area below the standard normal distribution curve is equal to 100%. (Watsham 1998, 60, 62).

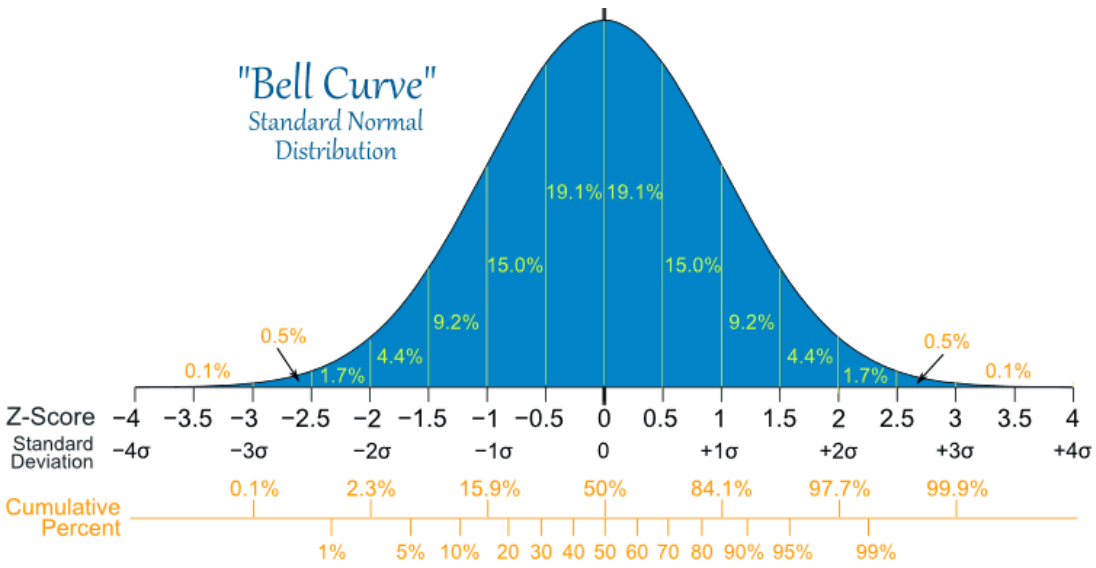

Figure 1: Standard Normal Distribution curve. Source Math is Fun n.d.

Cumulate distribution function (CDF) of standard normal distribution of x calculates the area under the curve of normal distribution from -∞ to the respective z-value of x. The area represent the probability of x taking value within the range satisfied this function. The function is commonly denoted by letter N or the Greek letter Φ and is calculated base on the frequency density function of normal distribution: (Watsham 1998, 59)

$$Y = \frac{e^{-(x-\mu)^2/2\sigma^2}}{\sigma\sqrt{2\pi}} \qquad (3.2.1)$$

with $-\infty < x < z$

But in standard normal distribution:

$$\mu = 0 \text{ and } \sigma = 1$$

Function 3.2.1 can be rewritten as (Watsham 1998, 60):

$$\Phi(x) = \int_{-\infty}^{z} \frac{e^{-x^2/2}}{\sqrt{2\pi}} \qquad (3.2.2)$$

where $e \approx 2.71828$ and $\pi \approx 3.14159$

In reality, it is not possible to calculate the 3.2.2 function since there unlimited number between -∞ and z. Normal table estimates the result of CDF at z. (Watsham 1998, 61). For instance, with z = 1,65 we have CDF of 0.9505 (Appendix 1/9). This means there are 95% of variable x will be smaller than the value of x that results in z = 1.65.

3.3 Log-normal distribution

Log-normal distribution, another type of continuous frequency distribution, is a very important mathematical model of options and currencies' price. Log-normal distribution describes the likelihood of variables if their natural logarithm is normal distributed. Log-normal distribution's curve is skewed to the right side of mean and does not contain negative value. (Watsham 1998, 64).

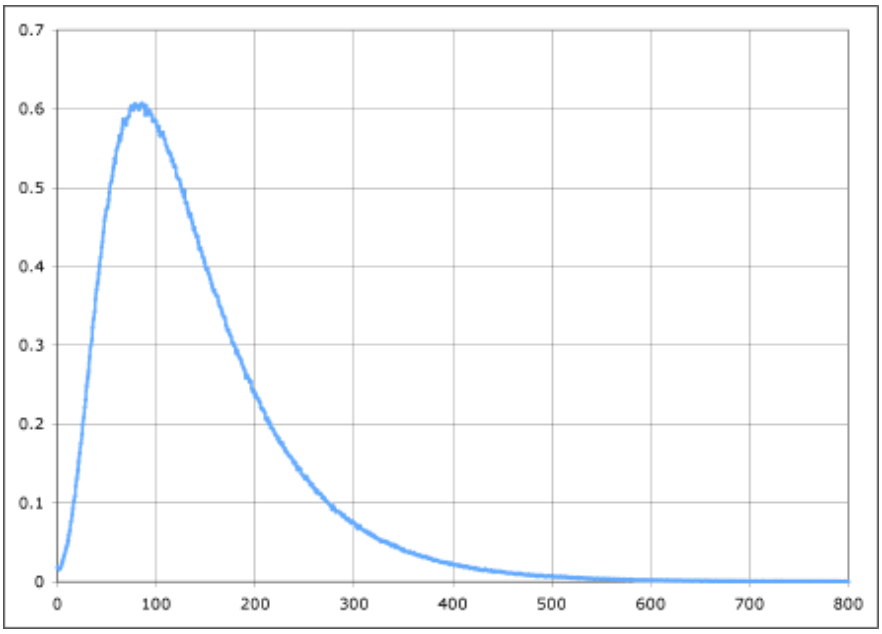

Figure 2: Log-normal distribution curve Source: Danvk, 2007

Log-normal distribution is the canvas for many option pricing as well as currency exchange models like Black-Scholes option pricing formula and Value at Risk because its attributions are similar to the characteristics of asset prices. Unlike normal distribution, log-normal distribution does not have negative numbers. As a result, lognormal distribution is suitable for explaining financial products like interest, exchange rate, stock prices, etc whose prices can never be negative. (Watsham 1998, 64).

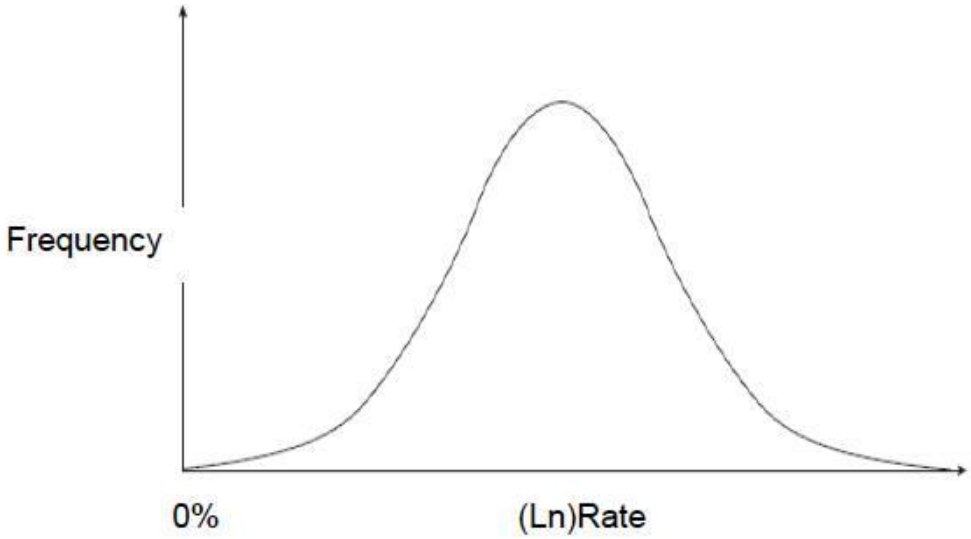

Figure 3: Nature logarithm of lognormal distribution. Source: Association of Corporate Treasurers, 2012

Moreover, financial data in reality hardly fall into the normal distribution curve but instead is skewed. In most of the cases, mean, mode and median are different, and the distribution curve loses its symmetry. Therefore, under the assumption of normal distribution, standard deviation cannot explain the distribution accurately. By using the natural logarithm, lognormal distribution approximately create the similar form to normal distribution (see Figure 3) while still preserving the skewness of the data's distribution. Thus, mean, z-score and standard deviation can correctly describe and predict the variables' frequency. (Association of Corporate Treasurers 2012, 13)

4 MODEL FOR FORECASTING CURRENCY OPTION'S VALUE

Garman Kohlhagen is one of the famous Black-Scholes model's extensions which is used for FX option. First, Black-Scholes option pricing model will be introduced. Subsequently, Garman Kohlhagen formula, assumptions and limitations will be explained in details.

4.1 Black-Scholes model

Black-Scholes is a Nobel prize winning economic model in 1997 created by Fischer Black, Myron Scholes and Robert C.Merton in the early 70s. It is mathematic model for evaluating stock's call options basing on volatility rate, risk-free interest rate of the stock, stock price, option's lifespan and strike price. The model is considered to be an evolution in economic evaluation world. It boosted the derivatives market and encouraged better risk management in the economy. (Nobel Prize 1997).

The Black-Scholes pricing model is based on the number of assumptions. First, the underlying asset in a future time is log-normal distributed. This happens when nature logarithms of the asset's price in the future divided by its current price, or return of the underlying, is normally distributed. (Hull 1997, 228). Second, the option is European style and has no tax or transaction cost. Third, the underlying stock is not prohibited to short selling and not pay dividend until the option's expiration. Its price is continuous with time and the stock itself can be traded regardless volume's fraction. Additionally, the interest rate as well as the volatility of the stock are constant. (Taylor 1997, 195).

The formula of Black-Scholes is (Hull 1997, 240):

$$c = SN(d_1) - Xe^{-r(T-t)}N(d_2) \qquad (4.1.1)$$

where:

$$d_1 = \frac{ln(S/X) + (r+\sigma^2/2)(T-t)}{\sigma\sqrt{T-t}}$$

$$d_2 = \frac{ln(S/X) + (r-\sigma^2/2)(T-t)}{\sigma\sqrt{T-t}} = d_1 - \sigma\sqrt{T-t}$$

c: theoretical price of call option/call premium

X: strike price of the stock

S: Spot price of the option

r: Annual risk-free interest rate of the stock

σ: Annual implied volatility of the stock

$T - t$: annualised maturity of the option

e: Euler's number (approximately 2.71828)

ln: nature logarithms

N: cumulative probability distribution function of standard normal distribution (formula 3.2.2)

Put-call parity is a theory (not included in Black-Scholes) describing the relationship between European put and call option. It indicates that the value of call option can be derived from value of put option provided that the two options have the same strike price and excercise date. The formula of put-call parity is: (Hull 1997, 240).

$$\boldsymbol{c + Xe^{-r(T-t)} = p + S} \qquad \textit{(4.1.2)}$$

where:

c: price of European call option at strike price X and expiration date T

p: price of European put option at strike price X and expiration date T

S: spot price of the underlying at time t

r: interest rate of the underlying

e: Euler's number (approximately 2.71828)

Combining Black-Scholes formula for call option (4.1.1) and put-call parity formula (4.1.2) results in the equation to calculate European put option price (Hull 1997, 242):

$$p = Xe^{-r(T-t)}N(-d_2) - SN(-d_1)$$

This is a extension of Black-Scholes and is also used in Garman Kohlhagen model, which will be discussed later in this chapter.

Like many other economic mathematic model, Black-Scholes also has numerous of limitations which mainly derive from its assumptions. In fact, the more assumptions a formula is

based on, the more drawbacks it has, because assumptions are not always the same to the reality. First of all, stock dividend, fraction and commission, transaction fee are left out of the model's consideration although they all affect option prices. In addition, Black-Scholes model considers volatility to be constant throughout time. However, it actually changes as the market moves and it is one of financial quantities whose value can only be estimated rather than being known exactly. (Teneng 2014, 4).

The same concept is applied in interest rate in the formula. Interest rate is also altered as the volatility changes. Risk-free interest rate is defined as the rate of return from financial instrument without or very little credit risk (Thomson Reuter n.d.). Consequently, risk-free interest rate is almost unrealistic because the risk of loss is always existing in financial product investment. The closest form of risk-free interest is interest rate issued by major government financial institution like EURIBOR, LIBOR or the US Federal Treasury. (Teneng 2014, 4).

Additionally, the stock prices do not always fall into lognormal distribution. Although lognormal distribution is proofed to be a close imitation of the actual stock price, it still cannot describe precisely the stock's movement. In fact, the distribution of underlying's return tends to be slightly skewed like lognormal distribution rather than being normal distributed. (Teneng 2014, 4).

4.2 Garman Kohlhagen model

Garman Kohlhagen model is developed from the Black-Scholes model and is applied for currency option. It inherits most of Black-Scholes's concept, assumptions and formula's build.

Similar to Black-Scholes, the idea behind Garman Kohlhagen model is that the prices of currency and its option are comparable. In a risk-free portfolio, although they might not change by the same amount, their position, after constantly correcting options' price to recompense the changes of currency rate, is riskless. In other word, the fee of option will be compensated exactly by the investment's return. The model also indicates that the movement of currency is random and is not affected by market sentiment, trend or events. As a

result, no one can predict the movement of future exchange rate basing on historical data and its probability to increase and to decrease are even. (Shamah 2004, 73).

Garman Kohlhagen model's assumptions are also similar to Black-Scholes's. The movement of exchange rate follows lognormal distribution and the return of the currency is normally distributed. There are no transaction costs, commissions or limitation of exchange volume involved. Volatility and interest rate are known and unchanged during option's maturity. The model is also exclusive to European option style, in which options can only be exercised at the expiration date. (Shamah 2004, 76).

The model also introduce formula of put option price that derives from the calculation of call option premium. The Garman Kohlhagen calculation is (Shamah 2004, 75):

$$\boldsymbol{c = se^{-qt}\Phi(d_1) - xe^{-rt}\Phi(d_2)} \qquad \boldsymbol{(4.2)}$$

$$\boldsymbol{p = xe^{-rt}\Phi(-d_2) - se^{-qt}\Phi(-d_1)}$$

where:

$$\boldsymbol{d_1 = \frac{log(s/x) + (r - q + \sigma^2/2)t}{\sigma\sqrt{t}}}$$

$$\boldsymbol{d_2 = d_1 - \sigma\sqrt{t}}$$

c: theoretical price of call option/call premium

p: theoretical price of put option/ put premium

x: strike price of the stock

s: Spot price of the option

r: Annual, continuous compounded risk-free interest rate of domestic currency

q: Annual, continuous compounded risk-free interest rate of foreign currency

σ: Annual implied volatility of the exchange rate

t: annualised lifespan of the option

e: Euler's number (approximately 2.71828)

log: nature logarithms

Φ: cumulative probability distribution function of standard normal distribution (see formula 3.2.2)

From the formula, it is easy to notice the relationship between option prices and implied volatility. The higher implied volatility is, the higher d_1 is, the lower d_2 is and the more expensive c and p can get. Thus implied volatility is directly proportional to option prices.

Comparing formula 4.2 to 4.1.1, there is involvement of an additional interest rate in Garman Kohlhagen formula. And this is the biggest improvement of Garman Kohlhagen model to Black-Scholes. The model takes both foreign and domestic interest rate into consideration because they have major impacts on the option premium. When option price is paid up front, it naturally generates interest as it is considered as a deposit with domestic compound interest rate in the duration of the option's term. As a result, the higher domestic interest is, the more discounted option will be to compensate for the interest its premium makes. On the other hand, consider instead of buying a FX option, people can buy or sell the foreign currency at the time when the exchange rate reaches their idea value. This naturally creates interest as the money is held in form of deposit until the favourable FX rate happens. As a result, in order to bring the same profit as currency holding does, option must subtract the amount of interest created by depositing from its price. Therefore, the higher interest rate of foreign currency is, the less people pay for its option. (Shamah 2004, 82).

Another improvement Garman Kohlhagen has from Black-Scholes is that it also includes the formula of put option price. This derives from the put-call parity assumption discussed earlier. As a result, the put calculation is only reliable when the put-call parity relationship is true.

Garman Kohlhagen have similar drawbacks as Black-Scholes' as the two model based on the same assumptions. In practise, interest rate, volatility and currency are very sensitive to the effect of events, policies and market sentiment. Return from option investment does not exactly follow normal distribution and thus, FX rate is not always log-normally distributed. Option price changes as it runs short and all transaction come with fee in bid/offer spread. However, the model is an effective tool that commonly used in modern option market and its limitation can be forgiven in condition of not being ignored. (Shamah 2004, 74).

5 VALUE AT RISK

This section will gives a general view of the famous risk management tool: Value at Risk. The formulas, forms and limitations of Value at Risk will also be illustrated specifically.

5.1 Value at Risk and its basic form

Value at Risk is a popular tool in risk management that measures the maximum loss within a specific time period and a confidence interval (Jorion 1997, xiii). The model is popular because it is very versatile and user friendly. Value at Risk can be applied in multiple types of variables' distribution. It can target risks individually as well as assessing them in a portfolio and result in a concrete number which is easy to interpret and understand. It is a powerful tool for firms to control the risk from the market rate fluctuation damaging their financial performance. (Association of Corporate Treasurers 2012, 17).

Value at Risk is first used in banking industry and quickly it became a fundamental part in banks' regulation of risk controlling and reporting framework (Association of Corporate Treasurers 2012, 17). It is also qualified as a acceptable risk measuring methodology by the regulators of Us Federal Reserve bank, European Central bank and Basle Committee on Banking Supervision. Value at Risk is widely used in risk and performance reporting, resource allocation and in regulating financial institutions' minimum reserves. (Jorion 1997, xiv).

The basic formula of Value at Risk is applied for variables following normal distribution. It is: (Association of Corporate Treasurers 2012, 17)

$$VaR = z \times \sigma \times T \times Exposure$$

VaR is the expected change in value of the asset. $z \times \sigma \times T$ measures the probability of risk (σ) to occur in a period of time (T) under the confidence level that corresponds to standard variable (z). (Association of Corporate Treasurers 2012, 13)

The expected maximum value for normally distributed variables are then equal to the exposure plus VaR. In case of loss, the expected minimum return is what left from Exposure after subtracting VaR. (Association of Corporate Treasurers 2012, 25)

Confidence level or confidence interval indicates how close are the estimations on sample to what happen in the population or how true are the statistical results to reality. It normally takes value of 95% or 99%. In the content of Value at Risk, it means 95% or 99% of the time, loss will not exceed a particular level (VaR). Confidence intervals can be in distributions that have one or two tails. A two-tailed confidence level describe the area ranging between two ends of the distribution's curve while the one-tailed one only brackets the population lying either upper or lower part of the curve. For instance, confidence level of 95% means 5% excluded from an end of one-tailed distribution or 2.5% subtracted from each of two ends in two-tailed distribution (see Figure 4). Because Value at Risk only concentrates on the probability of loss, it only utilises the one-tailed distribution. (Association of Corporate Treasurers 2012, 13)

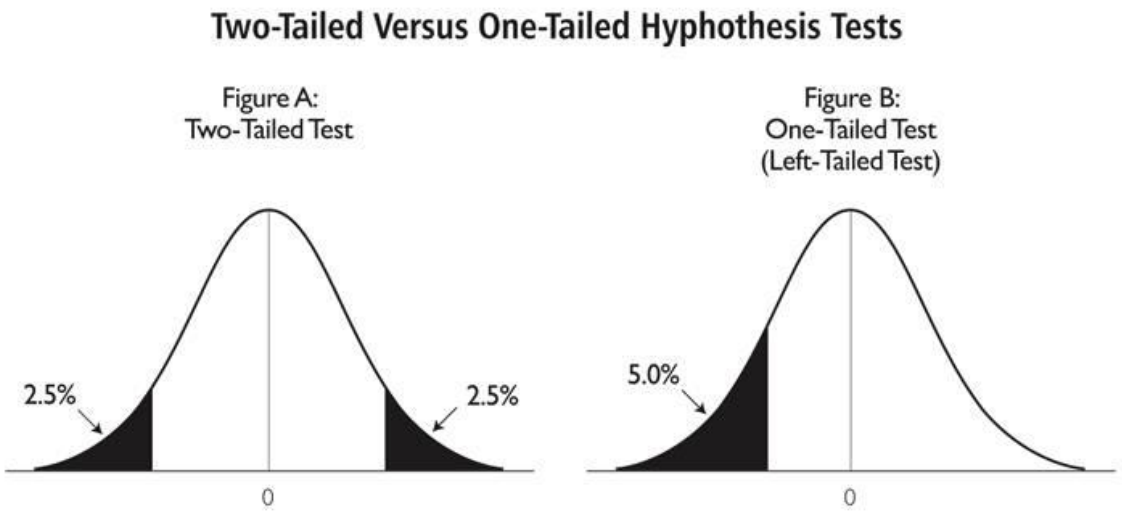

Figure 4: One- and Two-tailed distributions compared. Source: The Heritage Foundation 2007

5.2 Value at Risk in lognormal distribution

Time T is the holding period of the asset when it is exposed to market risks. Volatility (σ) represents the risks changes in market can cause to the exposure. It normally is referred as

implied volatility and is quoted on annual basis. As a result, it needs to adjust according to the time period T by multiplying with $\sqrt{T}$. (Association of Corporate Treasurers 2012, 13). The formula of transforming annual volatility is (Jorion 1997, 81):

$$\sigma = \sigma_{annual}\sqrt{T}$$

This formula bases on a assumption that expected return is normally distributed and along with variance, its value increase linearly with time (Jorion 1997, 81). When expected return follows normal distribution, we have asset price is log-normally distributed. This formula can be recognised as a part of Value at Risk's adaptation in log-normal distribution.

When applying into exchange rate, interest rate and equity indices, Value at Risk usually assumes variables following lognormal distribution rather than normal distribution because the prices of money never have negative value which is closer to being log-normally distributed. When the market prices (S_T) fall into lognormal distribution, natural logarithms of the price's fluctuation, which is calculated as $\ln(S_T/S_0)$, is normally distributed. Return on market rates is well described by normal distribution as the variables in normal distribution can have either negative or positive values in the similar way to how return can be loss or profit. (Association of Corporate Treasurers 2012, 24).

The expected maximum and minimum value of market prices on lognormal distribution are calculated respectively by these two equations (Association of Corporate Treasurers 2012, 25):

Expected maximum rate:

$$S_T = e^{z\sigma\sqrt{T}} \times S_0 \qquad (5.2.1)$$

Expected minimum rate:

$$S_T = e^{-z\sigma\sqrt{T}} \times S_0 \qquad (5.2.2)$$

where:

S_T: the expected future rate at time T

S_0: spot rate

$e \approx 2.71828$

σ: annualised implied volatility of the market

T: period of time between S_0 and S_T in number of year

z: standard variable of one-tailed distribution at a given level of confidence

5.3 Limitations of Value at Risk

Perhaps the biggest limitation of Value at Risk is that the actual market rate is not normally or log-normally distributed. There are more shocks happening in real life than what the model predicts as it did not take into consideration other factors that move the market like politics, regulations, events, etc. As a result, Value at Risk loses it reliability as the market is unstable (financial crisis, war, etc). (Association of Corporate Treasurers 2012, 18).

Another drawback of Value at Risk is that it heavily depends on existing statistic data. As a result, the accuracy of the model greatly relies on the liability of the data. If the inputs are outdated or samples are not close enough to population, the output taken from Value at Risk is not liable. Also, such data as market rates and prices can be accessed easily nowadays, however, corporate data like cash flow, budgets, sales is not always available. (Association of Corporate Treasurers 2012, 18).

In the background of foreign exchange, Value at Risk does not involve interest rate into calculation process. It assumes that the interest rate of the two currencies are similar, which is not true to the practise as interest rates normally vary among different currencies. (Association of Corporate Treasurers 2012, 15).

6 METHODOLOGY

Methodology describes how the research is conducted on the foundation of theoretical framework, how data is collected and with which statistical software is used to implement the calculation.

This thesis uses desk-based research method as data is already existed and available for collecting from the internet. All theories as well as formula in hypothesis background are also from earlier researches. The study is heavily based on mathematical and statistical techniques, as a result, it is considered to be a quantitative research.

For examining the model, an specific date is set as a starting day, which is 27 March 2015, and the testing period is decided to be exactly one month from there. There are two main steps in this forecasting model. Firstly, European options' prices, maturity and strike rates along with spot rate, risk-free interest rate of USA and EUR are collected and runs through the reversed Garman Kohlhagen formula to find out implied volatility. Secondly, the implied volatility is then with spot rate and a confidence level, which is set at 95%, are imputed into Value at Risk equation in lognormal distribution. The results are different price ranges of EUR price against USD limited by expected minimum and maximum rates of EUR/USD.

For testing the accuracy of the model, the actual exchange rate is compared against the result to see if it lies inside the predicted range. It is not necessary for the output to be 100% true to the actual FX rate, so the model is successful. As the confidence interval of Value at Risk is 95%, it is expected that there are 5% of the time, FX rate in real life will fall out of the forecasting range.

6.1 Data selection

Data selection starts with collecting options' quotes i.e. prices, time until expiration, exercise style and strike prices. There are two types of option contracts on the market: OTC and listed options. Although OTC options give are better reflection on the market's needs, as they are highly tailored according to customers' requirements, OTC contracts are only well-known among big corporations, whose large and stable equities allow them to be more risk

resistant and be able to afford pricier financial products. Listed options, on the other hand, are cheaper and more sensitive to volatility, thus, they are more popular among majority of hedgers and traders. Additionally, information of OTC contracts is private while standard options are published on major trading floors' websites. For those reasons, listed options are collected as the main samples of this study.

The option quotes are obtained from Philadelphia Stock Exchange (PHLX) website, on 27 March 2015. The data is extracted from the following columns in the quotes: last, calls, puts and strike. The calls and puts columns tell the type option as well as the expiration date of the contracts, the last column indicates the final price of the option and strike means price at which the option is exercised. Options are in European style, meaning they can only be exercised on the expiration date. The contract size of EUR option is fixed at 10.000 which is equal to contract point value of 100 USD. As a result, strike prices in option offers are quoted as the rate times 100. (NASDAQ n.d). The rate remains in the same form as quoted in the contracts when being used in the calculation process as it does not affect the result as long as spot rate is imputed in the same format.

Spot rate on 27 March 2015 and daily FX rate of EUR against USD are obtained from Bloomberg website. The closest form of risk-free interest rate is from short term investment of governmental financial products as they have highly limited credit and reinvestment risks. For EUR, risk-free interest rate is published in EURIBOR website under the form of 3-month interest rate. USD risk-free interest rate is the US 3-month treasury bills which is accessible from the US Federal Reserve webpage. (Thomson Reuters n.d)

There are 186 total option contracts collected from NASDAQ website on 27 March 2015. They include 81 call and 105 put options whose expirations vary among the months of April, May, June, September, December 2015 and March 2016. (Author's collected data).

The calculation and data procession of the study will be implemented by Microsoft Excel program with the uses of Visual Basic for Application (VBA). VBA is a Microsoft's programming language built in Excel which enables users to build their own customised functions (Microsoft 2008).

6.2 Finding Implied Volatility from Garman Kohlhagen formula

For complicated formulas like Garman Kohlhagen, it is impossible to solve the equation reversely from option price to have implied volatility. There have been many attempts to build a formula approximating the reverse form of Garman Kohlhagen as well as of Black Scholes like Newton-Raphson technique or Corrado and Miller solution in 1996. However, those approaches always have gaps especially when the options move away from at-the-money position as it is not possible to create a new formula without modifying in the original one. (Watsham 1998, 151).

The method used in this study will not have such kind of limitations because it does not change the original formula. First, the equation of Garman Kohlhagen is calculated normally in the spreadsheet from the collected spot and strike rates, risk-free USD and EUR interest rates, maturity and from an initial guess of implied volatility (0.1). Options' term is calculated by taking number of working days between 27 of March and the options' expiration date divided by 250, which is the total number of working days in a year time. The working day is counted by using Excel's function: "NETWORKDAY(27.03.15, expiration date)". Options' prices are quoted in USD. This means option buyers use USD to buy or sell EUR. Therefore, EUR is considered to be the foreign currency and USD is the domestic one. For the ease of calculating process, Garman Kohlhagen formula is written in VBA as a macro module. The module is named as GarmanKohlhagen and has two possibilities. If the input is "call", the module will implement the function 4.2 c and if the input is "put", it will run the 4.2 p (See Appendix 1/9).

The results after calculating the Garman Kohlhagen formula are certain number of call and put values. They are matched up to the call and put prices collected from PHLX using Excel's Goal Seek function. Goal Seek allows setting the result of a formula at a desired value by changing one of the equation's input. In the case of this step, Goal Seek will change the initial guess value of implied volatility so that the option premiums resulting from Garman Kohlhagen function are equal to the actual option prices quoted in the market. The final results are theoretical and actual option values are the same, and initial guessed implied volatility (0.1) is replaced by the implied volatility of EUR under the American market's perspective. However, the built-in Goal Seek function in Excel only allows implementing one row at a time. In order to employing Goal Seek on 186 samples (186 rows) with ease, an automatic

Goal Seek function is built in VBA as a spreadsheet's macro. The macro will automatically run Goal Seek on 186 samples with only one time of using. The VBA code of Goal Seek is enclosed in Appendix 1/9.

6.3 Value at Risk in log-normal distribution formula

Implied volatility resulted from reverse Garman Kohlhagen formula is then imputed into Value at Risk equations. The expected maximum rate (formula 5.2.1) can be calculated easily by Excel built-in functions: Spot rate * exp(z-score * implied volatility *sqrt(time of exposure)). For expected minimum rate (formula 5.2.2), the Excel simulating codes are: Spot rate * exp(- z-score * implied volatility *sqrt(time of exposure)).

Spot rates are quoted under its normal form, which is price of per EUR unit in USD. The cumulative distribution function of standard normal distribution calculating standard variable (z) from 95% confidence interval is simulated by the Excel's built-in standard normal distribution inverse function: NORMSINV(95%).

The time of exposure is the period of time in a year the FX rate is exposed under the market's movement. Here it is assumed to be from 27 March to 27 April 2015 as the first and last day of observation. As the FX trading floors are closed during weekend, only working days between the two time points are counted using Excel's NETWORKINGDAY function. The number of working day is then divided by 250 total working days in a year. The final results are expected maximum and minimum rate of EUR/USD in the time between 27 March and 27 April 2015 at the confidence level of 95%.

6.4 Testing the model's result

The results will be then tested against the actual price of EUR against USD. Daily EUR/USD rates during the assumed exposure period are collected and one by one compared against expected maximum and minimum rate separately. First, the market's rates are placed against the predicted maximum rate. Excel's Count If function is used to count if there are any predicted maximum rate having lower value than the actual rates: COUNTIF(range of expected maximum rate, "<" & market's rate day 1). On the contrary, to filter out if

there are market's rate falling lower than forecasted minimum results, the Count If function is written as: COUNTIF(range of expected minimum rate, ">" & market's rate day 1). The same calculation process applied in EUR/USD rate from the first day is copied down to other 21 rates in total of 22 observation days.

If the Count If results in value bigger than 0, there are real-life exchange rates lie outside the price range this study forecasted or, in different words, there are expected values that are not true to the reality. The percentage of inaccurate expected rates out of total maximum and maximum predicted rate indicates whether the forecasting model succeeds. If there are 5% or less of total results is incorrect to the actual FX rate, the model is concluded to be efficiency. Otherwise, if the error takes more than 5% of the total outcomes, this forecasting model is proofed to be unsuccessful.

7 EMPIRICAL RESULTS

The empirical results report outcomes from reverse Garman Kohlhagen model, Value at Risk formula and results testing against market's prices. Consequently, the calculation's results and errors will be deeper analysed. The thesis's limitations and reliability will also be discussed.

7.1 Implied Volatility

There are 163 implied volatilities resulted from total 186 collected option quotes. They range from 0.475 (max) to 0.041 (min) and distributed mostly around the value of 0.158 (mode). Mean of collected implied volatilities is 0.137. Comparing the implied volatility to the price of option, it is not difficult to notice the similarities between their movements (Figure 5). Implied volatilities rise in linear with option prices although their levels of increase or decrease are not the same. (Table 17, Appendix 2/7).

It is also noted from Figure 5 that the movement of option price is one step slower than the implied volatility's. This can be explained as after the changes of underlying asset happen, option premium immediately follows the changes as a mean to adjust accordingly to the underlying's movement. The fact 87% of total samples producing satisfied value of implied volatility proofs that most of the option prices conforms the relationship with volatility, underlying assets and time horizon which is described in Garman Kohlhagen formula (Table 17, Appendix 2/7).

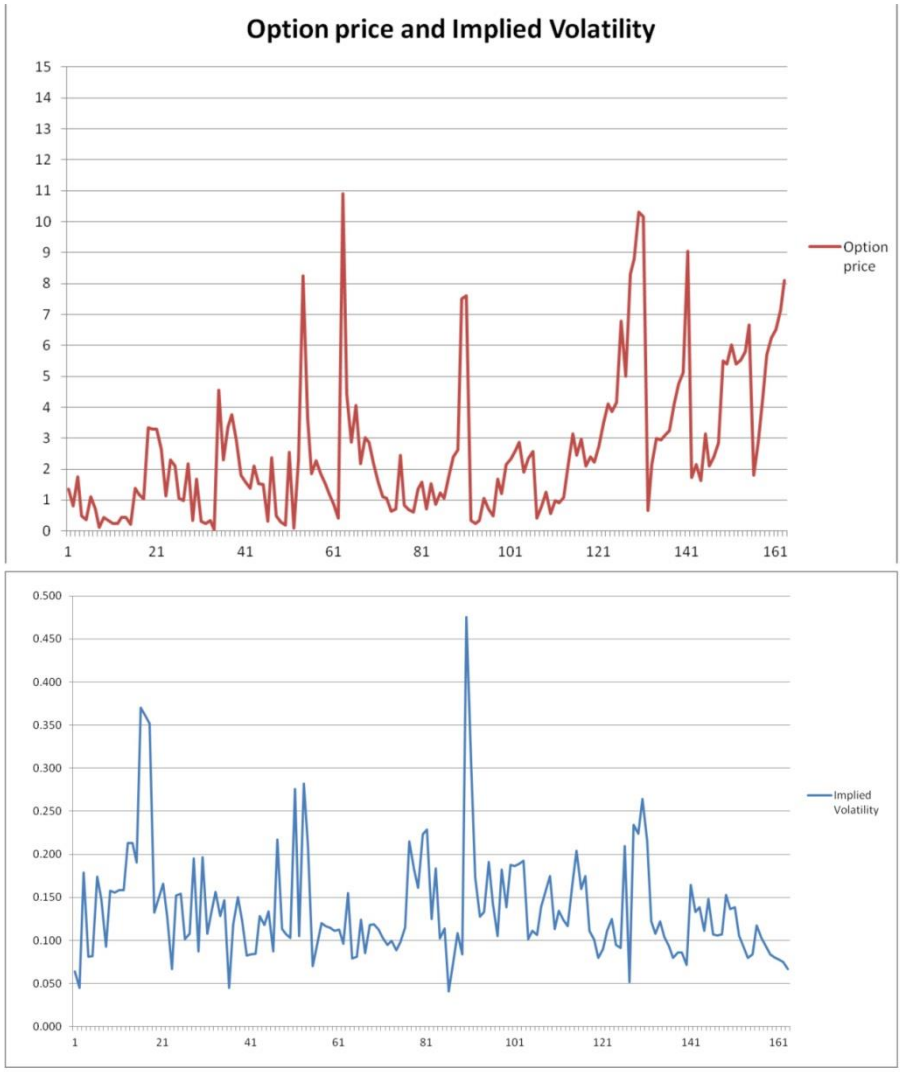

Figure 5: Implied Volatility and Option price comparison

However, there are 23 errors out of the 186 samples (Table 17, Appendix 2/7). Error assessment bases on if a sample's actual price has the same value as its price resulted from Garman Kohlhagen formula after Goal Seek function is implemented. They are option prices to which Goal Seek failed to satisfy. In other words, Goal Seek functions was unable to find a suitable value of implied volatility so that "Price calculated from GK formula" can be equal to "Market's option price". In fact, even though implied volatilities in these cases pushed down to almost nothing (0.001), the market prices are still way lower than calculation's results. Market's option showed in Table 1 have exceptionally low prices comparing with the hypothetical prices and with the fact that they are deeply in-the-money. These contracts have strike prices far from spot rate toward in-the-money position. In case of call op-

tion, their strike prices are considerably lower than market's current rate while with put options, their strikes are greatly higher than spot price.

It is possible that these cases do not follow the pricing model but instead market sentiment. In option selecting, option buyers usually choose strike prices that are reasonably close to current exchange rate. This is because options are extremely price-sensitive to the differences between spike and spot rate. The deeper the option is in-the-money, the more expensive it is. (Shamah 2004, 76). For hedgers, whose purpose is protecting their asset from risk exposure rather than speculation, slightly in-the-money options are significantly more cost-effective than deeply in-the-money ones as they provide the same protection while costing extensively less. As a result, the options at these strike prices are not that favourable by the market and thus generating noticeably less sales. With that being said, trading floors need to make some price adjustment on those options in order to keep their sales at reasonable levels. As a result, the premium of these options do not follow the Garman Kohlhagen pricing model.

Table 1: Implied Volatility Error Summary. Source: Author's calculation

	Expiration Date	Today Date	Strike rate	Spot rate	Implied volatility	Price calculated from GK formula	Market's option price
Call	4/17/2015	27/03/15	105.5	108.56	0.010	3.059315957	1.9
	4/17/2015	27/03/15	107	108.56	0.010	1.559344757	1.26
	6/19/2015	27/03/15	100	108.56	0.001	8.556989654	5.94
	6/19/2015	27/03/15	104	108.56	0.001	4.557282443	3.81
	9/18/2015	27/03/15	100	108.56	0.010	8.5537824	8.05
Put	4/17/2015	27/03/15	114.5	108.56	0.023	5.940511245	2.75
	4/17/2015	27/03/15	116	108.56	0.010	7.440482445	3.5
	6/19/2015	27/03/15	113	108.56	0.010	4.442058781	4.22
	6/19/2015	27/03/15	114.5	108.56	0.010	5.941948985	3.57
	6/19/2015	27/03/15	115.5	108.56	0.010	6.941875788	4.55
	6/19/2015	27/03/15	116.5	108.56	0.010	7.94180259	5.1
	6/19/2015	27/03/15	117.5	108.56	0.010	8.941729393	5.9
	6/19/2015	27/03/15	118	108.56	0.010	9.441692794	8.3
	6/19/2015	27/03/15	119	108.56	0.010	10.4416196	5.15
	9/18/2015	27/03/15	114	108.56	0.010	5.44410096	3.6
	9/18/2015	27/03/15	116	108.56	0.010	7.443798582	7.4
	9/18/2015	27/03/15	117	108.56	0.010	8.443647394	5.7
	9/18/2015	27/03/15	118	108.56	0.010	9.443496205	2.99
	9/18/2015	27/03/15	119	108.56	0.010	10.44334502	6.15
	12/18/2015	27/03/15	115	108.56	0.008	6.445986739	5.08
	12/18/2015	27/03/15	117	108.56	0.010	8.445528392	6.1
	12/18/2015	27/03/15	118	108.56	0.010	9.445299218	5.55
	12/18/2015	27/03/15	119	108.56	0.011	10.44507004	6.21

Also from Table 1, the number of error generated from put options are significantly higher than from call option. There is only 6% (5 out of 81) of call options does not follow Garman Kohlhagen model while that number of put options is 17% (18 out of 105). (Author's calculation result). This can explained by these put options do not fall into the put-call parity

relationship. The Black-Scholes model originally only built the formula for call option and Garman Kohlhagen formula for put contract only works when put-call parity is true for put options. However, in this case, the put options are deeply in-the-money because their strike prices are extremely high comparing to spot price. Call options at these positions are, in contrary, deeply out-of-the-money. Therefore, they are not feasible for option buyers and are not offered by the trading floor. As a result, put-call parity between put and call options at these strike price do not exist and these put options are not priced based on Garman Kohlhagen formula.

7.2 Expected maximum and minimum EUR/USD rate (Value at Risk result)

From 163 outtakes of implied volatility, Value at Risk model results in 163 values of expected maximum and 163 expected minimum rates. The maximum EUR/USD rate ranges from 1.3689 (max) to 1.1075 (min) and concentrates around the value of 1.1728 (mode). On the other hand, the minimum expected prices of EUR against USD include values varying from 1.0640 (max) to 0.8608 (min) and the most frequent values are around 1.0048 (mode). (Table 18, Appendix 2/7). The result is interpreted as for 95% of the chances, the EUR/USD rates in one month from 27 March 2015 will not exceed any of these 163 predicted maximum rates and will not drop lower than the 163 expected minimum rates. More specifically, for 95% of the time, the future FX rates of EUR and USD from 27 March to 27 April 2015 will fall in between 1.1075 (min of expected max) and 1.0640 (max of expected min).

Figure 6 shows the graphs of Value at Risk results comparing to spot rate. It is easy to see under the effects of Value at Risk formula, predicted maximum and minimum rates' lines are symmetrical around the axis of spot rate's. Videlicet, Value at Risk model forecasts how far the future rate will move away from spot rate. As a result, choosing the right time to collect spot rate is very important because the result of Value at Risk is heavily depended on the value of spot rate.

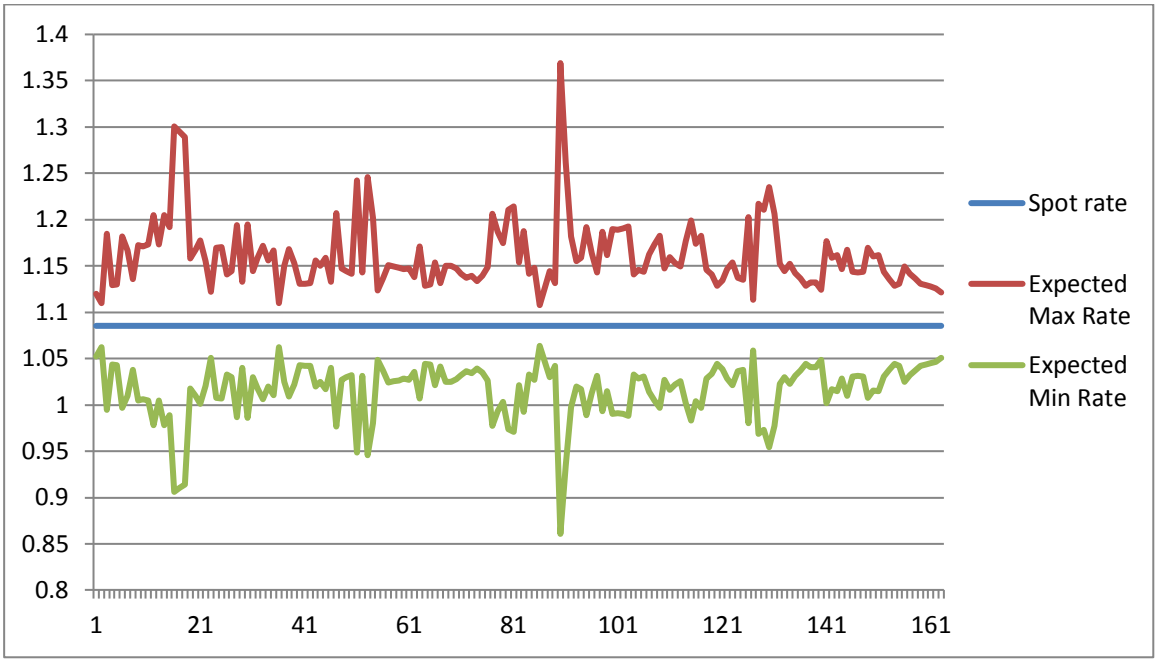

Figure 6: Spot rate, expected maximum and minimum EUR/USD rate. Source: Author's calculation.

7.3 Test result against actual EUR/USD rate

Comparing each of 163 expected maximum rate to the market's rates, there is no error occurring. All of 22 EUR/USD rates are below the result's upper limits. (Author's calculation). However, there are 4 errors coming from the expected minimum rates. Half of them is resulted from call options and the other half is from put options. Both of these call and put options have expiration dates on 17 of April and 19 of June 2015. EUR/USD rate on 10 April was 1.0604, which is smaller than 3 of the study's lower limits. The rate continued to decline to 1.0567 on 11 of April, which results in one more inaccurate expected minimum rate. (Table 20, Appendix 2/8)The errors are summarised in the table 2.

Table 2: Value at Risk Error Summary. Source: Author's calculation.

Expiration Date	Strike rate	Option price	Implied volatility	Spot rate	Expected Max Rate	Expected Min Rate
17/04/2015	108	0.82	0.045	1.0856	1.109674062	1.062048217
19/06/2015	106.5	2.31	0.045	1.0856	1.109589723	1.062128944
17/04/2015	109.5	1.07	0.041	1.0856	1.107564961	1.064070642
19/06/2015	113.5	4.99	0.052	1.0856	1.113489835	1.058408728

Function QUARTILE is applied on array of implied volatility. At quart of 0, the function gave the value of 0.041, which is the smallest value of implied volatility in table 2. At quart

of 1, the function results in value of 0.956. This indicates that 75% of implied volatilities is higher than 0.956. According to table 2, the errors derived from 4 values of implied volatility that approximate to each other around the rate of 0.0457 (mean of the errors). All of these value are very close to the minimum value and smaller the first quartile of calculated implied volatility's values. As a result, they are smaller than majority of 163 implied volatilities calculated from the reverse Garman Kohlhagen model. (Table 19, Appendix 2/7) Additionally, the errors are generated from four options that are in-the-money. (Table 16, Appendix 2/5).

Out of 326 results of EUR price range, there are 4 errors or 1.227%. The error percentage is significantly less than 5% of risk possibility in the Value at Risk 95% confidence level. Although resulting in accurate expected maximum rates, the 4 values of implied volatility in table 2 are still considered error as they produced incorrect expected minimum rate. They account for 2.45% of total 163 implied volatility rates. For conclusion, as the error rates of Value at Risk is less than 5%, the model of currency forecasting basing on market's perspective is successful.

7.4 Discussion

The results have answered the two research questions of this thesis. The price range of EUR against USD is expected to be between 1.1075 and 1.0640 during the time from 27 March to 27 April 2015 under the confidence interval of 95%. The forecast result is based on the American perspective toward the EUR which is represented by EUR option quotes. Although the forecast was for a short amount of time (1 month), it can benefit many financial entities especially speculators, who do short currency and option trading on exceedingly high frequency. It can also be useful for American non-financial firms who often have sudden foreign trade in Euro. By having the estimation of the Euro price, enterprises can decide their strategy on protecting their goods from FX risk exposure: is derivatives necessary, which types of derivatives are the most profitable, etc.

By finding the EUR/USD expected price range, the study has constructed a forecasting model from the viewpoint of the market which can be applied for different currency pairs on different time periods. This forecasting method uses option quotes and other existing data on Garman Kohlhagen model to translate what the current market thinks of the cur-

rency into implied volatility and consequently imputes the calculated volatility data into Value at Risk equations to ascertain expected maximum and minimum currency prices.

Even though involving complicate mathematic techniques, this model is still considered to be user friendly and can be employed by small to medium firms. It is not necessary for the users to understand the mathematics in the formulas because they can effortlessly be done by the computer. Users are only required to know what the inputs of the model are and what its outputs means. The outcomes of this forecasting method are concrete numbers which are easy to understand and interpret. The calculation is done completely by Excel, a standard and simple office application which is widely used. As a result, even small or non-financial companies, who do not have the fund for expensive financial and accounting programs, can utilise this model.

However, there are some issues need to consider when using this method. Firstly, there are possibilities of error to happen on the reverse Garman Kohlhagen. This is because not all options are priced basing on the model. Especially to put options, as they are not originally involved in the Black-Scholes formula, they can only be used in this model if there put-call parity relation between them and the respective call options. In fact, most put options in this study whose position is deeply in-the-money gave inaccurate results when being imputed into the model. Call options can also produce errors as deeply in-the-money call options' prices are adjusted to the market sentiment to gain a relative sale volume instead of completely following the pricing model. As a result, in order to minimise error, options collected for this model should have the position moderately around at-the-money toward out-of-the money.

Secondly, the results of Value at Risk heavily depend on the spot rate. Therefore, choosing the right time point to collect spot rate is crucial. As the Value at Risk model itself is most reliable when applying in stable period, spot rate should not be gathered in during the time when there are major political or economical events, new policies, financial crisis that might strongly affect the exchange rate. Market rates at historical rise or fall also do not give the most accurate results.

Thirdly, in order to improve the accuracy of Value at Risk, implied volatilities calculated from the earlier stage should be filtered out the irregular values. To assess which values should be eliminated, implied volatilities calculated should be compared to the historical im-

plied volatilities or the expected implied volatilities which can be obtained from reliable financial journal or websites such as Bloomberg and Yahoo Finance. The comparison gives a approximate range of which calculated implied volatilities should lie in and thus helps to remove the unusually small or high values before carrying on to Value at Risk.

The model also has a number of limitations. Most of them derive from each of the theories' assumptions the method based on. Currency prices do not always follow log-normal distribution and profit or loss from the currency might not normally distributed. Option and currency trades usually involve additional fees beside premium such as transaction fees and commissions for brokers. Interest rates are various among different currencies. The scenario of effective market with stable risk-free interest rate and constant implied volatility assumed in Garman Kohlhagen is not realistic. The trend of currency can absolutely predicted as it is influenced by political and economical events as well as monetary policies.

The model cannot be applied into every other exchange pair as FX options are not available for all currencies. In fact, this model only works on major currencies whose options are actively traded on relatively big markets. Only then, the option price can reflect accurately the views of the market. Additionally, as the model can only be used on European options, the view of the American option market on the currency is totally left out of consideration.

Like many other forecasting method, this model cannot be used alone due to its numerous drawbacks. It is best utilised as a complementary to other forecasting models. The model has proofed to be an effective tool of predicting EUR/USD rate deriving from market's view in a short time period (1 month). However, as it is only applied on this particular scenario, there is no guarantee that the model will work on other situations on other currencies and time frame. For that reason, it needs to be tested on more different currencies and OTC options on longer time periods to build a complete guideline for users.

7.5 Limitations and Reliability

Beside the limitations of the model, there are a number of drawbacks of this thesis deriving from its research methodology. The thesis use 100% secondary data and existing theories. Consequently, the accuracy of the model's outcome is highly depended on the quality of the data. If the inputs are unreliable or the sample is inaccurate to the population, the model will

not show valuable results. In addition, due to its heavily use of existing data, this research method is not useful in situations where data is not available or is not in public.

The quantitative research method used in this study also brings a number of limitations. The sample is relatively small (186 contracts) and the time frame for experimenting is short (1 month). The thoughts and trends of the market toward FX rate cannot be fully translated into numbers like implied volatility and the results of the model, as a result, does not truly reflect what it interprets. Although NASDAQ is the second biggest trading floor and is one of the biggest FX option providers in the US, data obtained from there does not completely represent the entire American currency option market.

The Goal Seek function used in this calculation requires general understanding of VBA which is not commonly known by basic Excel users. Because Goal Seek only process a limited number of values around the initial guess point to find out the result, the guess value need to be relatively close the real outcome.

Options collected for this study were standard fixed contracts which do not represent the market's perspectives as well as OTC options do. Another drawback derives from the model assessment. The model is considered to be effective if the actual rate fall in the expected range, which can happen due to luck. There is no way to conclude if the test's result is successful as the model actually works or because of coincidence, since the model is only tested once, in one period of time.

The thesis's theoretical background is sturdy because it encompasses the two popular financial theories: Black-Scholes and Value at Risk. Black-Scholes model is an Nobel prize winning economical work and Value at Risk is accepted widely in the risk management system nowadays. The hypothetical background is fully referenced from multiple academic books, articles and course materials. Each of theoretical section is reviewed and sourced from at least two different sources to avoid hypothesis bias.

The data is collected from reliable sources. Option quotes collected from Philadelphia Stock Exchange (NASDAQ), the second biggest trading floor in American. Although NASDAQ alone might not represent the entire American FX option market, it provides big enough option volume and active trading activities for the market's standpoints to show through FX options. Risk-free interest rates of USD and EUR are obtained from US Federal Reserve and EURIBOR, the most important governmental financial institutions of the USA and Eu-

ropean Union. Spot rate and daily EUR/USD rate is collected from Bloomberg, which is one of the biggest financial data and software company in the US.

8 CONCLUSION

This thesis attempts to build a currency forecasting model basing on the perspective of the market by combining multiple financial models and testing them against the actual market's rate. On the foundation of log-normal distribution, the theoretical framework includes Garman Kohlhagen and Value at Risk theories which are connected to each other by implied volatility. Garman Kohlhagen model is carefully analysed from its root in Black-Scholes model and Put-call parity as it explains the error occurring in the research's results.

The research method employed in this thesis is quantitative research and the data is collected completely from existing sources. The model is applied in three steps. The first step is to decide suitable data to be collected. The next step is finding the implied volatility of the EUR/USD by running the reverse Garman Kohlhagen model. After implied volatility is found, it is imputed into Value at Risk formula in order to find predicted price range of EUR on USD. The inputs of the model are option quotes, domestic and foreign risk-free interest rates, spot rate, an initial guess of implied volatility, confidence level, and the results are expected maximum and minimum price of foreign currency on the domestic one.

The result from the model was tested against the actual market rate and it shown positive performance with less than 5% of errors. This indicates that the model is effective on predicting EUR/USD rate on a short period of time. However, it also has a number of drawbacks from its hypothesis framework. As a result, it is recommended that the model should be used as a complementary for other traditional forecasting methods rather being used as it is. Additionally, the data selection is emphasised to be a crucial part to the model's accuracy. In the future, the model should be applied and tested more on different currencies, time frames and option types to be fully developed.

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LIST OF APPENDICES

APPENDIX 1: NORMAL TABLE, DATA COLLECTION AND VBA FUNCTION CODES

APPENDIX 2: FULL CALCULATION RESULTS

Table 1: Standard normal distribution table. Source: Free Image Collection n.d.

Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9031	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9924	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9958	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986

Table 2: USD Settled Euro Put 17 April 2015. Source: NASDAQ 2015

Puts	Root	Strike	Last	Net	Bid	Size	Ask	Size	Vol	Open Int
Apr 17, 2015	XDE	104.50	0.83		0.19	526	0.24	26	0	211
Apr 17, 2015	XDE	105.00	0.68		0.24	500	0.29	28	0	11
Apr 17, 2015	XDE	105.50	0.62		0.31	530	0.36	530	0	89
Apr 17, 2015	XDE	106.00	1.35		0.39	529	0.44	532	0	135
Apr 17, 2015	XDE	106.50	1.59		0.49	528	0.54	534	0	103
Apr 17, 2015	XDE	107.00	0.72		0.60	100	0.66	537	0	84
Apr 17, 2015	XDE	107.50	1.52		0.74	100	0.80	438	0	1
Apr 17, 2015	XDE	108.00	0.86		0.91	36	0.96	336	0	1
Apr 17, 2015	XDE	108.50	1.22		1.10	35	1.15	320	0	40
Apr 17, 2015	XDE	109.00			1.32	33	1.37	111	0	
Apr 17, 2015	XDE	109.50	1.70	0.02	1.57	30	1.63	130	9	10
Apr 17, 2015	XDE	110.00	1.75		1.85	26	1.92	126	0	150
Apr 17, 2015	XDE	110.50	2.41		2.17	23	2.24	23	0	1
Apr 17, 2015	XDE	111.00	2.62		2.50	19	2.59	19	0	8
Apr 17, 2015	XDE	111.50			2.89	18	2.97	18	0	
Apr 17, 2015	XDE	112.00	3.15		3.29	17	3.37	17	0	3
Apr 17, 2015	XDE	112.50	7.50		3.71	16	3.79	16	0	0
Apr 17, 2015	XDE	113.00	3.08		4.15	15	4.23	15	0	2
Apr 17, 2015	XDE	113.50			4.60	14	4.69	14	0	
Apr 17, 2015	XDE	114.00	4.80		4.95	100	5.25	100	0	0
Apr 17, 2015	XDE	114.50	2.75		5.40	100	5.70	100	0	4
Apr 17, 2015	XDE	115.00	7.60		5.90	100	6.20	100	0	26
Apr 17, 2015	XDE	115.50			6.40	100	6.70	100	0	
Apr 17, 2015	XDE	116.00	3.50		6.85	100	7.20	100	0	2

Table 3: USD Settled Euro Put 15 May 2015. Source: NASDAQ 2015

Puts	Root	Strike	Last	Net	Bid	Size	Ask	Size	Vol	Open Int
May 15, 2015	XDE	98.50			0.07	516	0.13	516	0	
May 15, 2015	XDE	99.00			0.08	500	0.14	17	0	
May 15, 2015	XDE	99.50			0.10	518	0.16	18	0	
May 15, 2015	XDE	100.00	0.35		0.13	500	0.18	18	0	10
May 15, 2015	XDE	100.50			0.15	519	0.21	519	0	
May 15, 2015	XDE	101.00			0.18	520	0.24	520	0	
May 15, 2015	XDE	101.50			0.22	500	0.27	22	0	
May 15, 2015	XDE	102.00	0.24		0.26	500	0.31	23	0	211
May 15, 2015	XDE	102.50	0.34		0.30	522	0.36	500	0	0
May 15, 2015	XDE	103.00	1.05		0.35	523	0.41	500	0	10
May 15, 2015	XDE	103.50			0.41	500	0.47	500	0	
May 15, 2015	XDE	104.00	0.70		0.48	522	0.53	500	0	13
May 15, 2015	XDE	104.50			0.56	522	0.61	500	0	
May 15, 2015	XDE	105.00	0.48		0.65	516	0.70	528	0	105
May 15, 2015	XDE	105.50	1.67		0.75	500	0.80	529	0	54
May 15, 2015	XDE	106.00	1.20		0.86	423	0.91	400	0	61
May 15, 2015	XDE	106.50	2.14		0.98	100	1.04	433	0	39
May 15, 2015	XDE	107.00	2.33		1.13	300	1.18	300	0	71
May 15, 2015	XDE	107.50	2.59		1.28	100	1.34	332	0	70
May 15, 2015	XDE	108.00	2.88		1.46	100	1.52	268	0	3
May 15, 2015	XDE	108.50			1.66	31	1.71	250	0	
May 15, 2015	XDE	109.00	1.91		1.87	112	1.93	110	0	67
May 15, 2015	XDE	109.50	2.34		2.11	128	2.18	128	0	1
May 15, 2015	XDE	110.00	2.58		2.37	26	2.44	126	0	45

Table 4: USD Settled Euro Put 19 June 2015. Source: NASDAQ 2015

Puts	Root	Strike	Last	Net	Bid	Size	Ask	Size	Vol	Open Int
Jun 19, 2015	XDE	98.50			0.24	375	0.30	387	0	
Jun 19, 2015	XDE	99.00			0.28	386	0.33	375	0	
Jun 19, 2015	XDE	99.50			0.31	375	0.37	375	0	
Jun 19, 2015	XDE	100.00	0.41		0.35	375	0.41	375	0	18
Jun 19, 2015	XDE	100.50			0.40	375	0.46	375	0	
Jun 19, 2015	XDE	101.00	0.79		0.45	375	0.50	375	0	3
Jun 19, 2015	XDE	101.50			0.50	385	0.56	375	0	
Jun 19, 2015	XDE	102.00	1.25		0.56	386	0.62	397	0	8
Jun 19, 2015	XDE	102.50			0.62	75	0.68	390	0	
Jun 19, 2015	XDE	103.00	0.55		0.70	375	0.75	389	0	207
Jun 19, 2015	XDE	103.50	0.98		0.77	75	0.83	389	0	2
Jun 19, 2015	XDE	104.00	0.92	-0.17	0.86	75	0.92	390	4	43
Jun 19, 2015	XDE	104.50			0.96	393	1.02	375	0	
Jun 19, 2015	XDE	105.00	1.08		1.07	310	1.12	300	0	160
Jun 19, 2015	XDE	105.50	2.16		1.19	300	1.24	300	0	10
Jun 19, 2015	XDE	106.00	3.15		1.31	75	1.37	313	0	1
Jun 19, 2015	XDE	106.50	2.45		1.46	260	1.51	250	0	0
Jun 19, 2015	XDE	107.00	2.98		1.61	75	1.67	260	0	35
Jun 19, 2015	XDE	107.50			1.78	264	1.83	250	0	
Jun 19, 2015	XDE	108.00	2.10	-0.06	1.96	75	2.02	210	4	80
Jun 19, 2015	XDE	108.50			2.16	75	2.22	85	0	
Jun 19, 2015	XDE	109.00	2.40	0.07	2.37	75	2.43	75	2	3
Jun 19, 2015	XDE	109.50	2.23		2.60	75	2.67	100	0	257
Jun 19, 2015	XDE	110.00	2.75	-0.22	2.85	75	2.92	99	30	528
Jun 19, 2015	XDE	110.50	3.50		3.11	23	3.20	98	0	106
Jun 19, 2015	XDE	111.00	4.10		3.40	97	3.49	22	0	96
Jun 19, 2015	XDE	111.50	3.85		3.70	96	3.80	96	0	127
Jun 19, 2015	XDE	112.00	4.17		4.02	20	4.14	20	0	109
Jun 19, 2015	XDE	112.50	6.80		4.36	20	4.47	20	0	87
Jun 19, 2015	XDE	113.00	4.22		4.72	19	4.85	94	0	495
Jun 19, 2015	XDE	113.50	4.99		5.10	93	5.22	18	0	5
Jun 19, 2015	XDE	114.00	8.30		5.45	75	5.61	17	0	115
Jun 19, 2015	XDE	114.50	3.57		5.90	85	6.01	17	0	25
Jun 19, 2015	XDE	115.00	8.80		6.30	85	6.43	16	0	8
Jun 19, 2015	XDE	115.50	4.55		6.70	75	6.86	15	0	0
Jun 19, 2015	XDE	116.00	10.30		7.17	14	7.30	14	0	36
Jun 19, 2015	XDE	116.50	5.10		7.61	13	7.76	13	0	5
Jun 19, 2015	XDE	117.00	10.15		8.05	86	8.25	86	0	457
Jun 19, 2015	XDE	117.50	5.90		8.50	75	8.75	75	0	8
Jun 19, 2015	XDE	118.00	8.30		8.95	75	9.20	75	0	238
Jun 19, 2015	XDE	118.50			9.45	75	9.70	75	0	
Jun 19, 2015	XDE	119.00	5.15		9.90	75	10.15	75	0	57
Jun 19, 2015	XDE	119.50			10.40	75	10.65	75	0	

Table 5: USD Settled Euro Put 18 September 2015. Source: NASDAQ 2015

Puts	Root	Strike	Last	Net	Bid	Size	Ask	Size	Vol	Open Int
Sep 18, 2015	XDE	98.50			0.67	388	0.77	385	0	
Sep 18, 2015	XDE	99.00	0.66		0.73	389	0.83	385	0	4
Sep 18, 2015	XDE	99.50			0.79	389	0.89	385	0	
Sep 18, 2015	XDE	100.00	0.89	0.01	0.86	390	0.95	375	22	2429
Sep 18, 2015	XDE	101.00	0.84		1.01	388	1.10	375	0	783
Sep 18, 2015	XDE	102.00	1.40		1.18	389	1.27	389	0	18
Sep 18, 2015	XDE	103.00	1.48	0.20	1.37	389	1.46	389	15	876
Sep 18, 2015	XDE	104.00	1.58		1.59	17	1.67	375	0	1686
Sep 18, 2015	XDE	104.50	1.83		1.71	18	1.79	375	0	173
Sep 18, 2015	XDE	105.00	1.90		1.84	14	1.92	300	0	429
Sep 18, 2015	XDE	105.50	2.00		1.98	13	2.06	310	0	105
Sep 18, 2015	XDE	106.00	2.15	0.14	2.12	313	2.21	300	6	732
Sep 18, 2015	XDE	106.50			2.28	14	2.36	300	0	
Sep 18, 2015	XDE	107.00	3.80		2.45	14	2.53	300	0	234
Sep 18, 2015	XDE	107.50			2.62	12	2.71	313	0	
Sep 18, 2015	XDE	108.00	2.94		2.81	14	2.90	312	0	16
Sep 18, 2015	XDE	108.50			3.00	10	3.10	85	0	
Sep 18, 2015	XDE	109.00	3.11		3.20	85	3.30	75	0	61
Sep 18, 2015	XDE	109.50			3.42	18	3.54	18	0	
Sep 18, 2015	XDE	110.00	3.25		3.65	93	3.79	18	0	32
Sep 18, 2015	XDE	111.00	4.08		4.15	93	4.27	2	0	628
Sep 18, 2015	XDE	112.00	4.75	0.05	4.73	17	4.84	18	6	808
Sep 18, 2015	XDE	113.00	5.13		5.35	10	5.50	92	0	28
Sep 18, 2015	XDE	114.00	3.60		6.00	85	6.18	16	0	129
Sep 18, 2015	XDE	115.00	9.05		6.74	15	6.91	15	0	10
Sep 18, 2015	XDE	116.00	7.40		7.50	85	7.69	13	0	5
Sep 18, 2015	XDE	117.00	5.70		8.30	85	8.50	12	0	4
Sep 18, 2015	XDE	118.00	2.99		9.15	85	9.35	12	0	1
Sep 18, 2015	XDE	119.00	6.15		10.00	85	10.25	11	0	22

Table 6: USD Settled Euro Put 18 December 2015. Source: NASDAQ 2015

Option Chain for PHLX U.S. Dollar-Settled Euro Currency										
Puts	Root	Strike	Last	Net	Bid	Size	Ask	Size	Vol	Open Int
Dec 18, 2015	XDE	98.50			1.07	11	1.21	11	0	
Dec 18, 2015	XDE	99.00			1.14	11	1.28	11	0	
Dec 18, 2015	XDE	99.50			1.21	11	1.35	11	0	
Dec 18, 2015	XDE	100.00	1.72		1.29	11	1.43	11	0	28
Dec 18, 2015	XDE	101.00	2.15		1.47	12	1.61	12	0	3
Dec 18, 2015	XDE	102.00	1.62	-0.41	1.67	12	1.81	12	1	27
Dec 18, 2015	XDE	103.00	3.13		1.89	13	2.03	13	0	11
Dec 18, 2015	XDE	104.00	2.09	-0.84	2.13	14	2.24	250	30	80
Dec 18, 2015	XDE	105.00	2.41	0.88	2.40	14	2.51	250	20	10
Dec 18, 2015	XDE	106.00	2.85		2.71	14	2.81	260	0	106
Dec 18, 2015	XDE	107.00	4.96		3.04	14	3.15	210	0	10
Dec 18, 2015	XDE	108.00	5.49		3.40	14	3.55	200	0	0
Dec 18, 2015	XDE	109.00	5.40		3.79	14	3.95	60	0	5
Dec 18, 2015	XDE	110.00	6.03		4.23	14	4.40	60	0	34
Dec 18, 2015	XDE	110.50			4.47	14	4.60	60	0	
Dec 18, 2015	XDE	111.00	5.40		4.72	14	4.85	60	0	3
Dec 18, 2015	XDE	111.50			4.98	14	5.16	14	0	
Dec 18, 2015	XDE	112.00	5.53		5.26	14	5.47	14	0	54
Dec 18, 2015	XDE	112.50			5.53	14	5.72	14	0	
Dec 18, 2015	XDE	113.00	5.80		5.83	14	6.05	14	0	2
Dec 18, 2015	XDE	113.50			6.13	14	6.33	14	0	
Dec 18, 2015	XDE	114.00	6.67		6.44	14	6.68	14	0	105
Dec 18, 2015	XDE	114.50			6.78	14	6.99	14	0	
Dec 18, 2015	XDE	115.00	5.08		7.11	14	7.36	14	0	1
Dec 18, 2015	XDE	116.00			7.79	13	8.05	13	0	
Dec 18, 2015	XDE	117.00	6.10		8.55	12	8.80	12	0	1
Dec 18, 2015	XDE	118.00	5.55		9.30	11	9.60	11	0	2
Dec 18, 2015	XDE	119.00	6.21		10.15	10	10.45	10	0	0

Table 7: USD Settled Euro Put 18 March 2016. Source: NASDAQ 2015

Option Chain for PHLX U.S. Dollar-Settled Euro Currency

Puts	Root	Strike	Last	Net	Bid	Size	Ask	Size	Vol	Open Int
Mar 18, 2016	XDE	98.50			1.41	10	1.57	10	0	
Mar 18, 2016	XDE	99.00			1.49	10	1.65	10	0	
Mar 18, 2016	XDE	99.50			1.58	10	1.74	10	0	
Mar 18, 2016	XDE	100.00	1.80		1.67	11	1.83	11	0	10
Mar 18, 2016	XDE	100.50			1.76	11	1.91	11	0	
Mar 18, 2016	XDE	101.00			1.86	11	2.02	11	0	
Mar 18, 2016	XDE	101.50			1.96	12	2.12	12	0	
Mar 18, 2016	XDE	102.00			2.07	12	2.23	12	0	
Mar 18, 2016	XDE	102.50			2.18	12	2.34	12	0	
Mar 18, 2016	XDE	103.00			2.29	12	2.46	12	0	
Mar 18, 2016	XDE	103.50			2.43	13	2.59	13	0	
Mar 18, 2016	XDE	104.00			2.56	13	2.72	13	0	
Mar 18, 2016	XDE	104.50			2.69	13	2.85	13	0	
Mar 18, 2016	XDE	105.00	2.90		2.83	13	3.00	13	0	50
Mar 18, 2016	XDE	105.50			2.98	13	3.15	13	0	
Mar 18, 2016	XDE	106.00			3.14	13	3.31	13	0	
Mar 18, 2016	XDE	106.50			3.30	13	3.47	13	0	
Mar 18, 2016	XDE	107.00			3.47	13	3.65	13	0	
Mar 18, 2016	XDE	107.50			3.64	13	3.82	13	0	
Mar 18, 2016	XDE	108.00			3.83	13	4.01	13	0	
Mar 18, 2016	XDE	108.50			4.03	13	4.20	30	0	
Mar 18, 2016	XDE	109.00	4.35		4.22	13	4.40	30	0	50
Mar 18, 2016	XDE	109.50			4.42	13	4.65	38	0	
Mar 18, 2016	XDE	110.00			4.65	60	4.85	38	0	
Mar 18, 2016	XDE	110.50			4.87	13	5.10	43	0	
Mar 18, 2016	XDE	111.00			5.10	30	5.35	43	0	
Mar 18, 2016	XDE	111.50			5.35	30	5.60	38	0	
Mar 18, 2016	XDE	112.00	5.70		5.62	13	5.84	13	0	1
Mar 18, 2016	XDE	112.50			5.88	13	6.11	13	0	
Mar 18, 2016	XDE	113.00	6.25		6.16	13	6.40	13	0	7
Mar 18, 2016	XDE	113.50	6.51		6.45	13	6.69	13	0	13
Mar 18, 2016	XDE	114.00			6.75	13	7.00	13	0	
Mar 18, 2016	XDE	114.50	7.14		7.06	13	7.35	13	0	13
Mar 18, 2016	XDE	115.00			7.38	13	7.67	13	0	
Mar 18, 2016	XDE	115.50			7.71	13	8.00	13	0	
Mar 18, 2016	XDE	116.00	8.10		8.05	13	8.35	13	0	2

Table 8: USD Settled Euro Call 17 April 2015. Source: NASDAQ 2015

Calls	Last	Chg	Bid	Ask	Vol	Open Int	Root	Strike
Apr 17, 2015	2.52				0	43	XDE	104.50
Apr 17, 2015					0		XDE	105.00
Apr 17, 2015	1.90				0	58	XDE	105.50
Apr 17, 2015	1.70				0	6	XDE	106.00
Apr 17, 2015					0		XDE	106.50
Apr 17, 2015	1.26				0	100	XDE	107.00
Apr 17, 2015	1.35				0	1	XDE	107.50
Apr 17, 2015	0.82				0	273	XDE	108.00
Apr 17, 2015					0		XDE	108.50
Apr 17, 2015	1.75				0	10	XDE	109.00
Apr 17, 2015	0.50				0	10	XDE	109.50
Apr 17, 2015	0.36				0	11	XDE	110.00
Apr 17, 2015	1.11				0	13	XDE	110.50
Apr 17, 2015	0.70				0	13	XDE	111.00
Apr 17, 2015					0		XDE	111.50
Apr 17, 2015	0.11				0	56	XDE	112.00
Apr 17, 2015	0.45				0	5	XDE	112.50
Apr 17, 2015	0.35				0	6	XDE	113.00
Apr 17, 2015					0		XDE	113.50
Apr 17, 2015	0.24				0	15	XDE	114.00
Apr 17, 2015					0		XDE	114.50
Apr 17, 2015	0.44				0	50	XDE	115.00
Apr 17, 2015	0.24				0	15	XDE	114.00
Apr 17, 2015					0		XDE	114.50
Apr 17, 2015	0.44				0	50	XDE	115.00
Apr 17, 2015					0		XDE	115.50
Apr 17, 2015	0.21				0	23	XDE	116.00
Apr 17, 2015	1.37				0	54	XDE	116.50
Apr 17, 2015	1.19				0	99	XDE	117.00
Apr 17, 2015	1.03				0	50	XDE	117.50

Table 9: USD Settled Euro Call 15 May 2015. Source: NASDAQ 2015

Calls	Last	Chg	Bid	Ask	Vol	Open Int	Root	Strike
May 15, 2015	3.34				0	2	XDE	106.50
May 15, 2015	3.28				0	5	XDE	107.00
May 15, 2015	2.65				0	2	XDE	107.50
May 15, 2015					0		XDE	108.00
May 15, 2015	1.13				0	32	XDE	108.50
May 15, 2015	2.29				0	19	XDE	109.00
May 15, 2015	2.10				0	2	XDE	109.50
May 15, 2015	1.06				0	185	XDE	110.00
May 15, 2015	0.98				0	5	XDE	110.50
May 15, 2015	2.17				0	2	XDE	111.00
May 15, 2015					0		XDE	111.50
May 15, 2015	0.34				0	5	XDE	112.00
May 15, 2015	1.69				0	15	XDE	112.50
May 15, 2015					0		XDE	113.00
May 15, 2015	0.32				0	2	XDE	113.50
May 15, 2015					0		XDE	114.00
May 15, 2015					0		XDE	114.50
May 15, 2015					0		XDE	115.00
May 15, 2015					0		XDE	115.50
May 15, 2015	0.25				0	13	XDE	116.00
May 15, 2015					0		XDE	116.50
May 15, 2015	0.33				0	0	XDE	117.00
May 15, 2015					0		XDE	117.50
May 15, 2015					0		XDE	118.00
May 15, 2015					0		XDE	118.50
May 15, 2015					0		XDE	119.00
May 15, 2015	0.05				0	10	XDE	119.50

Table 10: USD Settled Euro Call 18 September 2015. Source: NASDAQ 2015

Calls	Last	Chg	Bid	Ask	Vol	Open Int	Root	Strike
Sep 18, 2015	8.05				0	9	XDE	100.00
Sep 18, 2015					0		XDE	101.00
Sep 18, 2015					0		XDE	102.00
Sep 18, 2015					0		XDE	103.00
Sep 18, 2015					0		XDE	104.00
Sep 18, 2015					0		XDE	104.50
Sep 18, 2015	8.25				0	2	XDE	105.00
Sep 18, 2015					0		XDE	105.50
Sep 18, 2015	3.65				0	205	XDE	106.00
Sep 18, 2015					0		XDE	106.50
Sep 18, 2015					0		XDE	107.00
Sep 18, 2015					0		XDE	107.50
Sep 18, 2015					0		XDE	108.00
Sep 18, 2015					0		XDE	108.50
Sep 18, 2015					0		XDE	109.00
Sep 18, 2015					0		XDE	109.50
Sep 18, 2015					0		XDE	110.00
Sep 18, 2015	1.85				0	47	XDE	111.00
Sep 18, 2015	2.27				0	359	XDE	112.00
Sep 18, 2015	1.85				0	603	XDE	113.00
Sep 18, 2015	1.52				0	141	XDE	114.00
Sep 18, 2015	1.20				0	102	XDE	115.00
Sep 18, 2015					0		XDE	116.00
Sep 18, 2015	0.85				0	90	XDE	117.00
Sep 18, 2015	0.42				0	47	XDE	118.00

Table 11: USD Settled Euro Call 18 December 2015. Source: NASDAQ 2015

Calls	Last	Chg	Bid	Ask	Vol	Open Int	Root	Strike
Dec 18, 2015	10.90				0	1	XDE	100.00
Dec 18, 2015					0		XDE	101.00
Dec 18, 2015					0		XDE	102.00
Dec 18, 2015					0		XDE	103.00
Dec 18, 2015					0		XDE	104.00
Dec 18, 2015					0		XDE	105.00
Dec 18, 2015	4.42				0	1	XDE	106.00
Dec 18, 2015					0		XDE	107.00
Dec 18, 2015					0		XDE	108.00
Dec 18, 2015	2.87				0	4	XDE	109.00
Dec 18, 2015	4.05				0	6	XDE	110.00
Dec 18, 2015					0		XDE	110.50
Dec 18, 2015	2.18				0	20	XDE	111.00
Dec 18, 2015					0		XDE	111.50
Dec 18, 2015	3.02				0	70	XDE	112.00
Dec 18, 2015	2.86				0	13	XDE	112.50
Dec 18, 2015					0		XDE	113.00
Dec 18, 2015					0		XDE	113.50
Dec 18, 2015	2.17				0	7	XDE	114.00
Dec 18, 2015					0		XDE	114.50
Dec 18, 2015	1.59				0	23	XDE	115.00
Dec 18, 2015	1.11				0	0	XDE	116.00
Dec 18, 2015	1.05				0	47	XDE	117.00
Dec 18, 2015	0.63				0	63	XDE	118.00
Dec 18, 2015	0.71				0	10	XDE	119.00
Mar 18, 2016	2.45				0	13	XDE	115.50

```
Function GarmanKohlhagen(CallOrPut As String, SpotRate As Double, Strike As Double, TimeToMaturity As Double, DomesticInterestRate As Double, ForeignInterestRate As Double, Volatility As Double) As Double

Dim d1 As Double, d2 As Double

d1 = (Log(SpotRate / Strike) + (DomesticInterestRate - ForeignInterestRate + Volatility ^ 2 / 2) * TimeToMaturity) / (Volatility * Sqr(TimeToMaturity))

d2 = d1 - Volatility * Sqr(TimeToMaturity)

If CallOrPut = "Call" Then

   GarmanKohlhagen = SpotRate * Exp(-ForeignInterestRate * TimeToMaturity) * Application.NormSDist(d1) - Strike * Exp(-DomesticInterestRate * TimeToMaturity) * Application.NormSDist(d2)

ElseIf CallOrPut = "Put" Then

   GarmanKohlhagen = Strike * Exp(-DomesticInterestRate * TimeToMaturity) * Application.NormSDist(-d2) - SpotRate * Exp(-ForeignInterestRate * TimeToMaturity) * Application.NormSDist(-d1)

End If

End Function

Option Explicit

 Private Sub CheckGoalSeek()

   Dim i As Long

   For i = 5 To 190

      Range("D" & i).GoalSeek Goal:=Range("C" & i), ChangingCell:=Range("B" & i)

   Next

 End Sub
```

Table 12: Garman Kohlhagen full calculation of call options

Expiration Date	Implied volatility	Option price	Price from formula	Today Date	Networkdays	Annualised time until expiration	Strike rate	Spot rate	Annualised EUR Risk-free rate	Annualised USD Risk-free rate
17/04/2015	0.010	1.9	3.059315957	27/03/15	16.00	0.064	105.5	108.56	0.039%	0.03%
17/04/2015	0.010	1.26	1.559344757	27/03/15	16.00	0.064	107	108.56	0.039%	0.03%
17/04/2015	0.064	1.35	1.350528872	27/03/15	16.00	0.064	107.5	108.56	0.039%	0.03%
17/04/2015	0.045	0.82	0.82073446	27/03/15	16.00	0.064	108	108.56	0.039%	0.03%
17/04/2015	0.179	1.75	1.750443467	27/03/15	16.00	0.064	109	108.56	0.039%	0.03%
17/04/2015	0.081	0.5	0.500242603	27/03/15	16.00	0.064	109.5	108.56	0.039%	0.03%
17/04/2015	0.082	0.36	0.360214439	27/03/15	16.00	0.064	110	108.56	0.039%	0.03%
17/04/2015	0.174	1.11	1.110586481	27/03/15	16.00	0.064	110.5	108.56	0.039%	0.03%
17/04/2015	0.148	0.7	0.700202784	27/03/15	16.00	0.064	111	108.56	0.039%	0.03%
17/04/2015	0.093	0.11	0.110159148	27/03/15	16.00	0.064	112	108.56	0.039%	0.03%
17/04/2015	0.158	0.45	0.450111517	27/03/15	16.00	0.064	112.5	108.56	0.039%	0.03%
17/04/2015	0.156	0.35	0.350639685	27/03/15	16.00	0.064	113	108.56	0.039%	0.03%
17/04/2015	0.158	0.24	0.240021019	27/03/15	16.00	0.064	114	108.56	0.039%	0.03%
17/04/2015	0.158	0.24	0.240021019	27/03/15	16.00	0.064	114	108.56	0.039%	0.03%
17/04/2015	0.213	0.44	0.440006771	27/03/15	16.00	0.064	115	108.56	0.039%	0.03%
17/04/2015	0.213	0.44	0.440592056	27/03/15	16.00	0.064	115	108.56	0.039%	0.03%
17/04/2015	0.191	0.21	0.210105644	27/03/15	16.00	0.064	116	108.56	0.039%	0.03%
17/04/2015	0.370	1.37	1.370125669	27/03/15	16.00	0.064	116.5	108.56	0.039%	0.03%
17/04/2015	0.361	1.19	1.190740269	27/03/15	16.00	0.064	117	108.56	0.039%	0.03%
17/04/2015	0.352	1.03	1.030105928	27/03/15	16.00	0.064	117.5	108.56	0.039%	0.03%
15/05/2015	0.133	3.34	3.340984319	27/03/15	36.00	0.144	106.5	108.56	0.039%	0.03%
15/05/2015	0.148	3.28	3.279999641	27/03/15	36.00	0.144	107	108.56	0.039%	0.03%
15/05/2015	0.166	3.28	3.279999869	27/03/15	36.00	0.144	107.5	108.56	0.039%	0.03%
15/05/2015	0.127	2.65	2.649999663	27/03/15	36.00	0.144	107.5	108.56	0.039%	0.03%
15/05/2015	0.067	1.13	1.130787408	27/03/15	36.00	0.144	108.5	108.56	0.039%	0.03%
15/05/2015	0.152	2.29	2.289999979	27/03/15	36.00	0.144	109	108.56	0.039%	0.03%
15/05/2015	0.154	2.1	2.100674524	27/03/15	36.00	0.144	109.5	108.56	0.039%	0.03%
15/05/2015	0.102	1.06	1.060582367	27/03/15	36.00	0.144	110	108.56	0.039%	0.03%
15/05/2015	0.108	0.98	0.979998863	27/03/15	36.00	0.144	110.5	108.56	0.039%	0.03%
15/05/2015	0.195	2.17	2.170526331	27/03/15	36.00	0.144	111	108.56	0.039%	0.03%
15/05/2015	0.087	0.34	0.339995521	27/03/15	36.00	0.144	112	108.56	0.039%	0.03%
15/05/2015	0.197	1.69	1.690046236	27/03/15	36.00	0.144	112.5	108.56	0.039%	0.03%
15/05/2015	0.108	0.32	0.3200824	27/03/15	36.00	0.144	113.5	108.56	0.039%	0.03%
15/05/2015	0.133	0.25	0.250711656	27/03/15	36.00	0.144	116	108.56	0.039%	0.03%
15/05/2015	0.156	0.33	0.330195576	27/03/15	36.00	0.144	117	108.56	0.039%	0.03%
15/05/2015	0.128	0.05	0.0503895	27/03/15	36.00	0.144	119.5	108.56	0.039%	0.03%
19/06/2015	0.001	5.94	8.556989654	27/03/15	61.00	0.244	100	108.56	0.039%	0.03%
19/06/2015	0.001	3.81	4.557282443	27/03/15	61.00	0.244	104	108.56	0.039%	0.03%
18/09/2015	0.209	8.25	8.249999361	27/03/15	126.00	0.504	105	108.56	0.039%	0.03%
19/06/2015	0.147	4.55	4.54999916	27/03/15	61.00	0.244	106	108.56	0.039%	0.03%
19/06/2015	0.045	2.31	2.309994499	27/03/15	61.00	0.244	106.5	108.56	0.039%	0.03%
19/06/2015	0.118	3.37	3.369999345	27/03/15	61.00	0.244	107	108.56	0.039%	0.03%
19/06/2015	0.150	3.75	3.749999891	27/03/15	61.00	0.244	107.5	108.56	0.039%	0.03%
19/06/2015	0.124	2.93	2.929999953	27/03/15	61.00	0.244	108	108.56	0.039%	0.03%
19/06/2015	0.083	1.8	1.800000002	27/03/15	61.00	0.244	108.5	108.56	0.039%	0.03%
19/06/2015	0.084	1.58	1.579999944	27/03/15	61.00	0.244	109	108.56	0.039%	0.03%
19/06/2015	0.084	1.38	1.379999726	27/03/15	61.00	0.244	109.5	108.56	0.039%	0.03%
19/06/2015	0.128	2.1	2.099999778	27/03/15	61.00	0.244	110	108.56	0.039%	0.03%
19/06/2015	0.118	1.52	1.519999298	27/03/15	61.00	0.244	111	108.56	0.039%	0.03%
19/06/2015	0.134	1.5	1.500845623	27/03/15	61.00	0.244	112	108.56	0.039%	0.03%
19/06/2015	0.088	0.31	0.310361327	27/03/15	61.00	0.244	114	108.56	0.039%	0.03%
19/06/2015	0.217	2.38	2.380781583	27/03/15	61.00	0.244	114.5	108.56	0.039%	0.03%
19/06/2015	0.113	0.49	0.490474737	27/03/15	61.00	0.244	115	108.56	0.039%	0.03%
19/06/2015	0.107	0.3	0.300724933	27/03/15	61.00	0.244	116	108.56	0.039%	0.03%
19/06/2015	0.103	0.18	0.180225083	27/03/15	61.00	0.244	117	108.56	0.039%	0.03%
19/06/2015	0.276	2.55	2.550783114	27/03/15	61.00	0.244	118	108.56	0.039%	0.03%
19/06/2015	0.105	0.09	0.090233404	27/03/15	61.00	0.244	119	108.56	0.039%	0.03%
19/06/2015	0.282	2.31	2.310187787	27/03/15	61.00	0.244	119.5	108.56	0.039%	0.03%
18/09/2015	0.010	8.05	8.5537824	27/03/15	126.00	0.504	100	108.56	0.039%	0.03%
18/09/2015	0.070	3.65	3.649996653	27/03/15	126.00	0.504	106	108.56	0.039%	0.03%
18/09/2015	0.094	1.85	1.849998964	27/03/15	126.00	0.504	111	108.56	0.039%	0.03%
18/09/2015	0.120	2.27	2.269998781	27/03/15	126.00	0.504	112	108.56	0.039%	0.03%
18/09/2015	0.116	1.85	1.849998082	27/03/15	126.00	0.504	113	108.56	0.039%	0.03%
18/09/2015	0.115	1.52	1.519997325	27/03/15	126.00	0.504	114	108.56	0.039%	0.03%
18/09/2015	0.111	1.2	1.199996382	27/03/15	126.00	0.504	115	108.56	0.039%	0.03%
18/09/2015	0.113	0.85	0.849994529	27/03/15	126.00	0.504	117	108.56	0.039%	0.03%
18/09/2015	0.097	0.42	0.419992983	27/03/15	126.00	0.504	118	108.56	0.039%	0.03%
18/12/2015	0.155	10.9	10.89999127	27/03/15	191.00	0.764	100	108.56	0.039%	0.03%
18/12/2015	0.079	4.42	4.419997576	27/03/15	191.00	0.764	106	108.56	0.039%	0.03%
18/12/2015	0.081	2.87	2.869999964	27/03/15	191.00	0.764	109	108.56	0.039%	0.03%
18/12/2015	0.124	4.05	4.049999756	27/03/15	191.00	0.764	110	108.56	0.039%	0.03%
18/12/2015	0.085	2.18	2.17999847	27/03/15	191.00	0.764	111	108.56	0.039%	0.03%
18/12/2015	0.118	3.02	3.01999871	27/03/15	191.00	0.764	112	108.56	0.039%	0.03%
18/12/2015	0.119	2.86	2.859998383	27/03/15	191.00	0.764	112.5	108.56	0.039%	0.03%
18/12/2015	0.113	2.17	2.169996221	27/03/15	191.00	0.764	114	108.56	0.039%	0.03%
18/12/2015	0.103	1.59	1.589995006	27/03/15	191.00	0.764	115	108.56	0.039%	0.03%
18/12/2015	0.095	1.11	1.109994566	27/03/15	191.00	0.764	116	108.56	0.039%	0.03%
18/12/2015	0.099	1.05	1.049994329	27/03/15	191.00	0.764	117	108.56	0.039%	0.03%
18/12/2015	0.089	0.63	0.62998979	27/03/15	191.00	0.764	118	108.56	0.039%	0.03%
18/12/2015	0.098	0.71	0.709992651	27/03/15	191.00	0.764	119	108.56	0.039%	0.03%
18/03/2016	0.115	2.45	2.449995719	27/03/15	256.00	1.024	115.5	108.56	0.039%	0.03%

Table 13: Garman Kohlhagen full calculation of put options

Expiration Date	Implied volatility	Option price	Price from formula	Today Date	Networkdays	Annualised time until expiratio	Strike rate	Spot rate	Annualised EUR Risk-free rate	Annualised USD Risk-free rat
17/04/2015	0.215	0.83	0.829948067	27/03/15	16.00	0.064	104.5	108.56	0.039%	0.03%
17/04/2015	0.183	0.68	0.679803193	27/03/15	16.00	0.064	105	108.56	0.039%	0.03%
17/04/2015	0.161	0.62	0.619986779	27/03/15	16.00	0.064	105.5	108.56	0.039%	0.03%
17/04/2015	0.223	1.35	1.349997953	27/03/15	16.00	0.064	106	108.56	0.039%	0.03%
17/04/2015	0.229	1.59	1.589390198	27/03/15	16.00	0.064	106.5	108.56	0.039%	0.03%
17/04/2015	0.125	0.72	0.719948476	27/03/15	16.00	0.064	107	108.56	0.039%	0.03%
17/04/2015	0.184	1.52	1.519951721	27/03/15	16.00	0.064	107.5	108.56	0.039%	0.03%
17/04/2015	0.102	0.86	0.859711363	27/03/15	16.00	0.064	108	108.56	0.039%	0.03%
17/04/2015	0.114	1.22	1.219654258	27/03/15	16.00	0.064	108.5	108.56	0.039%	0.03%
17/04/2015	0.041	1.07	1.069502185	27/03/15	16.00	0.064	109.5	108.56	0.039%	0.03%
17/04/2015	0.076	1.75	1.749634965	27/03/15	16.00	0.064	110	108.56	0.039%	0.03%
17/04/2015	0.108	2.41	2.409453725	27/03/15	16.00	0.064	110.5	108.56	0.039%	0.03%
17/04/2015	0.084	2.62	2.619460773	27/03/15	16.00	0.064	111	108.56	0.039%	0.03%
17/04/2015	0.475	7.5	7.499958332	27/03/15	16.00	0.064	112.5	108.56	0.039%	0.03%
17/04/2015	0.023	2.75	5.940511245	27/03/15	16.00	0.064	114.5	108.56	0.039%	0.03%
17/04/2015	0.308	7.6	7.599303192	27/03/15	16.00	0.064	115	108.56	0.039%	0.03%
17/04/2015	0.010	3.5	7.440482445	27/03/15	16.00	0.064	116	108.56	0.039%	0.03%
15/05/2015	0.174	0.35	0.349935783	27/03/15	36.00	0.144	100	108.56	0.039%	0.03%
15/05/2015	0.128	0.24	0.239944723	27/03/15	36.00	0.144	102	108.56	0.039%	0.03%
15/05/2015	0.133	0.34	0.339973829	27/03/15	36.00	0.144	102.5	108.56	0.039%	0.03%
15/05/2015	0.191	1.05	1.049995874	27/03/15	36.00	0.144	103	108.56	0.039%	0.03%
15/05/2015	0.143	0.7	0.699615271	27/03/15	36.00	0.144	104	108.56	0.039%	0.03%
15/05/2015	0.105	0.48	0.480863532	27/03/15	36.00	0.144	105	108.56	0.039%	0.03%
15/05/2015	0.182	1.67	1.669967108	27/03/15	36.00	0.144	105.5	108.56	0.039%	0.03%
15/05/2015	0.139	1.2	1.199981536	27/03/15	36.00	0.144	106	108.56	0.039%	0.03%
15/05/2015	0.188	2.14	2.139314441	27/03/15	36.00	0.144	106.5	108.56	0.039%	0.03%
15/05/2015	0.187	2.33	2.329280122	27/03/15	36.00	0.144	107	108.56	0.039%	0.03%
15/05/2015	0.189	2.59	2.589285141	27/03/15	36.00	0.144	107.5	108.56	0.039%	0.03%
15/05/2015	0.192	2.88	2.879366477	27/03/15	36.00	0.144	108	108.56	0.039%	0.03%
15/05/2015	0.102	1.91	1.909334094	27/03/15	36.00	0.144	109	108.56	0.039%	0.03%
15/05/2015	0.111	2.34	2.339539265	27/03/15	36.00	0.144	109.5	108.56	0.039%	0.03%
15/05/2015	0.107	2.58	2.579074025	27/03/15	36.00	0.144	110	108.56	0.039%	0.03%
19/06/2015	0.140	0.41	0.409992717	27/03/15	61.00	0.244	100	108.56	0.039%	0.03%
19/06/2015	0.158	0.79	0.789400886	27/03/15	61.00	0.244	101	108.56	0.039%	0.03%
19/06/2015	0.175	1.25	1.249350199	27/03/15	61.00	0.244	102	108.56	0.039%	0.03%
19/06/2015	0.113	0.55	0.549533517	27/03/15	61.00	0.244	103	108.56	0.039%	0.03%
19/06/2015	0.135	0.98	0.979349888	27/03/15	61.00	0.244	103.5	108.56	0.039%	0.03%
19/06/2015	0.123	0.92	0.919013069	27/03/15	61.00	0.244	104	108.56	0.039%	0.03%
19/06/2015	0.117	1.08	1.079225844	27/03/15	61.00	0.244	105	108.56	0.039%	0.03%
19/06/2015	0.165	2.16	2.159999209	27/03/15	61.00	0.244	105.5	108.56	0.039%	0.03%
19/06/2015	0.204	3.15	3.1499997	27/03/15	61.00	0.244	106	108.56	0.039%	0.03%
19/06/2015	0.160	2.45	2.449999685	27/03/15	61.00	0.244	106.5	108.56	0.039%	0.03%
19/06/2015	0.175	2.98	2.97915995	27/03/15	61.00	0.244	107	108.56	0.039%	0.03%
19/06/2015	0.111	2.1	2.099999957	27/03/15	61.00	0.244	108	108.56	0.039%	0.03%
19/06/2015	0.101	2.4	2.39999996	27/03/15	61.00	0.244	109	108.56	0.039%	0.03%
19/06/2015	0.080	2.23	2.229197803	27/03/15	61.00	0.244	109.5	108.56	0.039%	0.03%
19/06/2015	0.090	2.75	2.749024159	27/03/15	61.00	0.244	110	108.56	0.039%	0.03%
19/06/2015	0.111	3.5	3.499999207	27/03/15	61.00	0.244	110.5	108.56	0.039%	0.03%
19/06/2015	0.125	4.1	4.09999893	27/03/15	61.00	0.244	111	108.56	0.039%	0.03%
19/06/2015	0.095	3.85	3.849998084	27/03/15	61.00	0.244	111.5	108.56	0.039%	0.03%
19/06/2015	0.092	4.17	4.169995828	27/03/15	61.00	0.244	112	108.56	0.039%	0.03%
19/06/2015	0.210	6.8	6.799999242	27/03/15	61.00	0.244	112.5	108.56	0.039%	0.03%
19/06/2015	0.010	4.22	4.442058781	27/03/15	61.00	0.244	113	108.56	0.039%	0.03%
19/06/2015	0.052	4.99	4.990004638	27/03/15	61.00	0.244	113.5	108.56	0.039%	0.03%
19/06/2015	0.234	8.3	8.299998404	27/03/15	61.00	0.244	114	108.56	0.039%	0.03%
19/06/2015	0.010	3.57	5.941948985	27/03/15	61.00	0.244	114.5	108.56	0.039%	0.03%
19/06/2015	0.224	8.8	8.799997982	27/03/15	61.00	0.244	115	108.56	0.039%	0.03%
19/06/2015	0.010	4.55	6.941875788	27/03/15	61.00	0.244	115.5	108.56	0.039%	0.03%
19/06/2015	0.264	10.3	10.29999754	27/03/15	61.00	0.244	116	108.56	0.039%	0.03%
19/06/2015	0.010	5.1	7.94180259	27/03/15	61.00	0.244	116.5	108.56	0.039%	0.03%
19/06/2015	0.216	10.15	10.149995	27/03/15	61.00	0.244	117	108.56	0.039%	0.03%
19/06/2015	0.010	5.9	8.941729393	27/03/15	61.00	0.244	117.5	108.56	0.039%	0.03%
19/06/2015	0.010	8.3	9.441692794	27/03/15	61.00	0.244	118	108.56	0.039%	0.03%
19/06/2015	0.010	5.15	10.4416196	27/03/15	61.00	0.244	119	108.56	0.039%	0.03%
18/09/2015	0.122	0.66	0.659223996	27/03/15	126.00	0.504	99	108.56	0.039%	0.03%
18/09/2015	0.108	2.15	2.149999385	27/03/15	126.00	0.504	106	108.56	0.039%	0.03%
18/09/2015	0.122	3	2.999999824	27/03/15	126.00	0.504	107	108.56	0.039%	0.03%
18/09/2015	0.105	2.94	2.93999996	27/03/15	126.00	0.504	108	108.56	0.039%	0.03%
18/09/2015	0.094	3.11	3.109999965	27/03/15	126.00	0.504	109	108.56	0.039%	0.03%
18/09/2015	0.080	3.25	3.249999229	27/03/15	126.00	0.504	110	108.56	0.039%	0.03%
18/09/2015	0.086	4.08	4.079998292	27/03/15	126.00	0.504	111	108.56	0.039%	0.03%
18/09/2015	0.086	4.75	4.749995716	27/03/15	126.00	0.504	112	108.56	0.039%	0.03%
18/09/2015	0.071	5.13	5.129989862	27/03/15	126.00	0.504	113	108.56	0.039%	0.03%
18/09/2015	0.010	3.6	5.44410096	27/03/15	126.00	0.504	114	108.56	0.039%	0.03%
18/09/2015	0.165	9.05	9.049995539	27/03/15	126.00	0.504	115	108.56	0.039%	0.03%
18/09/2015	0.010	7.4	7.443798582	27/03/15	126.00	0.504	116	108.56	0.039%	0.03%
18/09/2015	0.010	5.7	8.443647394	27/03/15	126.00	0.504	117	108.56	0.039%	0.03%
18/09/2015	0.010	2.99	9.443496205	27/03/15	126.00	0.504	118	108.56	0.039%	0.03%
18/09/2015	0.010	6.15	10.44334502	27/03/15	126.00	0.504	119	108.56	0.039%	0.03%
18/12/2015	0.133	1.72	1.719995396	27/03/15	191.00	0.764	100	108.56	0.039%	0.03%
18/12/2015	0.138	2.15	2.149996077	27/03/15	191.00	0.764	101	108.56	0.039%	0.03%
18/12/2015	0.111	1.62	1.619996348	27/03/15	191.00	0.764	102	108.56	0.039%	0.03%
18/12/2015	0.148	3.13	3.129997713	27/03/15	191.00	0.764	103	108.56	0.039%	0.03%
18/12/2015	0.107	2.09	2.089997416	27/03/15	191.00	0.764	104	108.56	0.039%	0.03%
18/12/2015	0.106	2.41	2.409998573	27/03/15	191.00	0.764	105	108.56	0.039%	0.03%
18/12/2015	0.107	2.85	2.849999166	27/03/15	191.00	0.764	106	108.56	0.039%	0.03%
18/12/2015	0.153	5.49	5.490000061	27/03/15	191.00	0.764	108	108.56	0.039%	0.03%
18/12/2015	0.136	5.4	5.400000049	27/03/15	191.00	0.764	109	108.56	0.039%	0.03%
18/12/2015	0.139	6.03	6.029999834	27/03/15	191.00	0.764	110	108.56	0.039%	0.03%
18/12/2015	0.106	5.4	5.399998823	27/03/15	191.00	0.764	111	108.56	0.039%	0.03%
18/12/2015	0.092	5.53	5.529996526	27/03/15	191.00	0.764	112	108.56	0.039%	0.03%
18/12/2015	0.080	5.8	5.799992301	27/03/15	191.00	0.764	113	108.56	0.039%	0.03%
18/12/2015	0.084	6.67	6.66998916	27/03/15	191.00	0.764	114	108.56	0.039%	0.03%
18/12/2015	0.008	5.08	6.445986739	27/03/15	191.00	0.764	115	108.56	0.039%	0.03%
18/12/2015	0.010	6.1	8.445528392	27/03/15	191.00	0.764	117	108.56	0.039%	0.03%
18/12/2015	0.010	5.55	9.445299218	27/03/15	191.00	0.764	118	108.56	0.039%	0.03%
18/12/2015	0.011	6.21	10.44507004	27/03/15	191.00	0.764	119	108.56	0.039%	0.03%
18/03/2016	0.118	1.8	1.799993868	27/03/15	256.00	1.024	100	108.56	0.039%	0.03%
18/03/2016	0.103	2.9	2.899998196	27/03/15	256.00	1.024	105	108.56	0.039%	0.03%
18/03/2016	0.094	4.35	4.35000001	27/03/15	256.00	1.024	109	108.56	0.039%	0.03%
18/03/2016	0.084	5.7	5.69999605	27/03/15	256.00	1.024	112	108.56	0.039%	0.03%
18/03/2016	0.080	6.25	6.249992784	27/03/15	256.00	1.024	113	108.56	0.039%	0.03%
18/03/2016	0.078	6.51	6.509990631	27/03/15	256.00	1.024	113.5	108.56	0.039%	0.03%
18/03/2016	0.075	7.14	7.139985408	27/03/15	256.00	1.024	114.5	108.56	0.039%	0.03%
18/03/2016	0.067	8.1	8.099977858	27/03/15	256.00	1.024	116	108.56	0.039%	0.03%

Table 14: Value at Risk full calculation of call options

Implied volatility	Spot rate	The first day of observation	The last day of observation	Exposure time /year	Confidence level	z-score	Expected Maximumn Rate	Expected Minimum Rate
0.064	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.119968738	1.052285943
0.045	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.109674062	1.062048217
0.179	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.18457269	0.994896616
0.081	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.129443671	1.043458289
0.082	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.129884074	1.043051573
0.174	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.182017191	0.997047563
0.148	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.166898614	1.009965515
0.093	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.135814896	1.037605128
0.158	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.172607458	1.005048494
0.156	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.171235513	1.006225773
0.158	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.172855919	1.004835582
0.213	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.20464038	0.978322975
0.158	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.172855919	1.004835582
0.213	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.204694374	0.978279127
0.191	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.19147156	0.989135955
0.370	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.300416415	0.906269212
0.361	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.294469543	0.910432668
0.352	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.288998591	0.914296856
0.133	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.158131203	1.017611267
0.149	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.167181983	1.009720316
0.166	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.177364799	1.000987426
0.127	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.155108482	1.02027418
0.067	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.121694069	1.050667372
0.152	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.169277924	1.007910383
0.154	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.170397829	1.006945955
0.102	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.14088943	1.03298999
0.108	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.144213143	1.029989358
0.195	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.194192358	0.986882349
0.087	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.132933276	1.04024428
0.197	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.19503086	0.986189896
0.108	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.144301973	1.029909401
0.133	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.158413101	1.017363632
0.156	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.171701842	1.005825303
0.128	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.155668747	1.019779555
0.147	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.166335711	1.01045295
0.045	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.109589723	1.062128944
0.119	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.15024961	1.024584012
0.150	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.168104675	1.008922732
0.124	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.153264071	1.021905901
0.083	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.130403626	1.042572169
0.084	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.130850138	1.042160513
0.084	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.131256694	1.041785977
0.128	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.155742152	1.019714785
0.118	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.150115512	1.024703473
0.134	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.158743905	1.01707319
0.088	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.132986736	1.040195196
0.217	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.207112437	0.976319458
0.113	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.147255743	1.027257756
0.107	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.143985626	1.030194203
0.103	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.141644409	1.032306864
0.276	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.24213183	0.948794107
0.105	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.142634547	1.031412329
0.282	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.245941584	0.94589295
0.209	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.202229734	0.980284655
0.070	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.123530111	1.0489504
0.094	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.136392105	1.037078096
0.120	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.15104256	1.023878178
0.116	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.149074446	1.025631858
0.115	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.148027932	1.0265668
0.111	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.146266011	1.028144731
0.113	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.147107387	1.027390612
0.097	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.138006886	1.035606528
0.155	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.170879034	1.006532123
0.080	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.128600672	1.044237691
0.082	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.129676722	1.043243024
0.125	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.153628461	1.021583118
0.085	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.131720757	1.041358792
0.118	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.150022758	1.02478612
0.119	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.150279356	1.024557516
0.113	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.146932864	1.027546945
0.103	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.141681154	1.032273639
0.095	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.136927017	1.036590161
0.099	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.139545282	1.03420845
0.089	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.133656883	1.039580298
0.098	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.138948906	1.034749982
0.115	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.148403083	1.026231449

Table 15: Value at Risk full calculation of put options

Implied volatilit	Spot rate	The first day of observation	The last day of observation	Exposure time /year	Confidence level	z-score	Expected Maximumn Rate	Expected Minimum Rate
0.215	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.205909806	0.977293123
0.183	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.186816417	0.993015721
0.161	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.174269847	1.003625668
0.223	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.210564994	0.973534974
0.229	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.213924226	0.970840959
0.125	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.153882145	1.02135852
0.184	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.187541676	0.992409263
0.102	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.141128154	1.032773888
0.114	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.147723501	1.026839094
0.041	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.107564961	1.064070642
0.076	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.12670849	1.045991373
0.108	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.144516858	1.029716034
0.084	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.131110973	1.04192019
0.475	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.368956025	0.860894973
0.308	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.261424281	0.934283078
0.174	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.181594192	0.997404497
0.128	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.155464024	1.019960237
0.133	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.158472784	1.017311219
0.191	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.191702289	0.988944446
0.143	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.163816257	1.0126404
0.105	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.142749958	1.031308163
0.182	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.186503954	0.993277229
0.139	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.16160149	1.01457115
0.188	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.18987756	0.990461035
0.187	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.189135279	0.9910793
0.189	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.19046249	0.989974376
0.192	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.19237402	0.988387318
0.102	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.140993315	1.032895938
0.111	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.145970354	1.02840999
0.107	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.14363784	1.03050749
0.140	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.162090449	1.014144262
0.158	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.172834856	1.004853628
0.175	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.182213323	0.99688215
0.113	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.147166313	1.027337838
0.135	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.159376508	1.016518234
0.123	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.152960916	1.022174597
0.117	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.149332938	1.025401188
0.165	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.17657039	1.001663284
0.204	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.19916995	0.982785934
0.160	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.17348976	1.004292837
0.175	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.182115953	0.996964263
0.111	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.146028066	1.028358201
0.101	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.140622272	1.033231938
0.080	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.12877521	1.044076225
0.090	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.134478094	1.038827781
0.111	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.146274381	1.028137224
0.125	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.153924179	1.021321315
0.095	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.136920389	1.036596204
0.092	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.135317481	1.038059732
0.210	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.202448658	0.980106179
0.052	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.113489835	1.058408728
0.234	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.216875504	0.968486386
0.224	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.210799035	0.973346795
0.264	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.235007456	0.954267405
0.216	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.206171433	0.977081141
0.122	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.152126802	1.022914629
0.108	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.144156176	1.03004064
0.122	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.152254494	1.02280127
0.105	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.142507517	1.031527007
0.094	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.136320516	1.037143432
0.080	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.128551584	1.044283112
0.086	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.132292294	1.040833154
0.086	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.132097419	1.041012319
0.071	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.124116191	1.04840351
0.165	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.17639084	1.001816166
0.133	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.158562491	1.017232449
0.138	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.161491766	1.014666995
0.111	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.146268303	1.028142676
0.148	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.167054402	1.009830697
0.107	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.143692162	1.030458544
0.106	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.143066517	1.031022554
0.107	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.143739258	1.030416112
0.153	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.169609823	1.007624369
0.136	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.160367177	1.015650376
0.139	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.161527928	1.014635406
0.106	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.143295012	1.030816498
0.092	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.135551265	1.037846019
0.080	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.128687091	1.044157739
0.084	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.13085421	1.04215676
0.118	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.149695959	1.025077414
0.103	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.14175006	1.03221134
0.094	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.13650434	1.036975679
0.084	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.130861967	1.042149612
0.080	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.12907885	1.043795444
0.078	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.127697308	1.045074199
0.075	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.125909812	1.046733359
0.067	1.0856	27/03/15	27/04/15	0.09	95%	1.644853627	1.121543226	1.050808683

Table 16: Result summary

Expiration Date	Strike rate	Option price	Implied volatility	Spot rate	Expected Max Rate	Expected Min Ra
17/04/2015	107.5	1.35	0.064	1.0856	1.119968738	1.052285943
17/04/2015	108	0.82	0.045	1.0856	1.109674062	1.062048217
17/04/2015	109	1.75	0.179	1.0856	1.18457269	0.994896616
17/04/2015	109.5	0.5	0.081	1.0856	1.129443671	1.043458289
17/04/2015	110	0.36	0.082	1.0856	1.129884074	1.043051573
17/04/2015	110.5	1.11	0.174	1.0856	1.182017191	0.997047563
17/04/2015	111	0.7	0.148	1.0856	1.166898614	1.009965515
17/04/2015	112	0.11	0.093	1.0856	1.135814896	1.037605128
17/04/2015	112.5	0.45	0.158	1.0856	1.172607458	1.005048494
17/04/2015	113	0.35	0.156	1.0856	1.171235513	1.006225773
17/04/2015	114	0.24	0.158	1.0856	1.172855919	1.004835582
17/04/2015	114	0.24	0.213	1.0856	1.20464038	0.978322975
17/04/2015	115	0.44	0.158	1.0856	1.172855919	1.004835582
17/04/2015	115	0.44	0.213	1.0856	1.204694374	0.978279127
17/04/2015	116	0.21	0.191	1.0856	1.19147156	0.989135955
17/04/2015	116.5	1.37	0.370	1.0856	1.300416415	0.906269212
17/04/2015	117	1.19	0.361	1.0856	1.294469543	0.910432668
17/04/2015	117.5	1.03	0.352	1.0856	1.288998591	0.914296856
15/05/2015	106.5	3.34	0.133	1.0856	1.158131203	1.017611267
15/05/2015	107	3.28	0.149	1.0856	1.167181983	1.009720316
15/05/2015	107.5	3.28	0.166	1.0856	1.177364799	1.000987426
15/05/2015	107.5	2.65	0.127	1.0856	1.155108482	1.02027418
15/05/2015	108.5	1.13	0.067	1.0856	1.121694069	1.050667372
15/05/2015	109	2.29	0.152	1.0856	1.169277924	1.007910383
15/05/2015	109.5	2.1	0.154	1.0856	1.170397829	1.006945955
15/05/2015	110	1.06	0.102	1.0856	1.14088943	1.03298999
15/05/2015	110.5	0.98	0.108	1.0856	1.144213143	1.029989358
15/05/2015	111	2.17	0.195	1.0856	1.194192358	0.986882349
15/05/2015	112	0.34	0.087	1.0856	1.132933276	1.04024428
15/05/2015	112.5	1.69	0.197	1.0856	1.19503086	0.986189896
15/05/2015	113.5	0.32	0.108	1.0856	1.144301973	1.029909401
15/05/2015	116	0.25	0.133	1.0856	1.158413101	1.017363632
15/05/2015	117	0.33	0.156	1.0856	1.171701842	1.005825303
15/05/2015	119.5	0.05	0.128	1.0856	1.155668747	1.019779555
19/06/2015	106	4.55	0.147	1.0856	1.166335711	1.01045295
19/06/2015	106.5	2.31	0.045	1.0856	1.109589723	1.062128944
19/06/2015	107	3.37	0.119	1.0856	1.15024961	1.024584012
19/06/2015	107.5	3.75	0.150	1.0856	1.168104675	1.008922732
19/06/2015	108	2.93	0.124	1.0856	1.153264071	1.021905901
19/06/2015	108.5	1.8	0.083	1.0856	1.130403626	1.042572169
19/06/2015	109	1.58	0.084	1.0856	1.130850138	1.042160513
19/06/2015	109.5	1.38	0.084	1.0856	1.131256694	1.041785977
19/06/2015	110	2.1	0.128	1.0856	1.155742152	1.019714785
19/06/2015	111	1.52	0.118	1.0856	1.150115512	1.024703473
19/06/2015	112	1.5	0.134	1.0856	1.158743905	1.01707319
19/06/2015	114	0.31	0.088	1.0856	1.132986736	1.040195196
19/06/2015	114.5	2.38	0.217	1.0856	1.207112437	0.976319458
19/06/2015	115	0.49	0.113	1.0856	1.147255743	1.027257756
19/06/2015	116	0.3	0.107	1.0856	1.143985626	1.030194203
19/06/2015	117	0.18	0.103	1.0856	1.141644409	1.032306864
19/06/2015	118	2.55	0.276	1.0856	1.24213183	0.948794107
19/06/2015	119	0.09	0.105	1.0856	1.142634547	1.031412329
19/06/2015	119.5	2.31	0.282	1.0856	1.245941584	0.94589295
18/09/2015	105	8.25	0.209	1.0856	1.202229734	0.980284655
18/09/2015	106	3.65	0.070	1.0856	1.123530111	1.0489504
18/09/2015	111	1.85	0.094	1.0856	1.136392105	1.037078096
18/09/2015	112	2.27	0.120	1.0856	1.15104256	1.023878178
18/09/2015	113	1.85	0.116	1.0856	1.149074446	1.025631858
18/09/2015	114	1.52	0.115	1.0856	1.148027932	1.0265668
18/09/2015	115	1.2	0.111	1.0856	1.146266011	1.028144731
18/09/2015	117	0.85	0.113	1.0856	1.147107387	1.027390612
18/09/2015	118	0.42	0.097	1.0856	1.138006886	1.035606528
18/12/2015	100	10.9	0.155	1.0856	1.170879034	1.006532123
18/12/2015	106	4.42	0.080	1.0856	1.128600672	1.044237691
18/12/2015	109	2.87	0.082	1.0856	1.129676722	1.043243024
18/12/2015	110	4.05	0.125	1.0856	1.153628461	1.021583118
18/12/2015	111	2.18	0.085	1.0856	1.131720757	1.041358792
18/12/2015	112	3.02	0.118	1.0856	1.150022758	1.02478612
18/12/2015	112.5	2.86	0.119	1.0856	1.150279356	1.024557516
18/12/2015	114	2.17	0.113	1.0856	1.146932864	1.027546945
18/12/2015	115	1.59	0.103	1.0856	1.141681154	1.032273639
18/12/2015	116	1.11	0.095	1.0856	1.136927017	1.036590161
18/12/2015	117	1.05	0.099	1.0856	1.139545282	1.03420845
18/12/2015	118	0.63	0.089	1.0856	1.133656883	1.039580298
18/12/2015	119	0.71	0.098	1.0856	1.138948906	1.034749982
18/03/2016	115.5	2.45	0.115	1.0856	1.148403083	1.026231449

17/04/2015	104.5	0.83	0.215	1.0856	1.205909806	0.977293123
17/04/2015	105	0.68	0.183	1.0856	1.186816417	0.993015721
17/04/2015	105.5	0.62	0.161	1.0856	1.174269847	1.003625668
17/04/2015	106	1.35	0.223	1.0856	1.210564994	0.973534974
17/04/2015	106.5	1.59	0.229	1.0856	1.213924226	0.970840959
17/04/2015	107	0.72	0.125	1.0856	1.153882145	1.02135852
17/04/2015	107.5	1.52	0.184	1.0856	1.187541676	0.992409263
17/04/2015	108	0.86	0.102	1.0856	1.141128154	1.032773888
17/04/2015	108.5	1.22	0.114	1.0856	1.147723501	1.026839094
17/04/2015	109.5	1.07	0.041	1.0856	1.107564961	1.064070642
17/04/2015	110	1.75	0.076	1.0856	1.12670849	1.045991373
17/04/2015	110.5	2.41	0.108	1.0856	1.144516858	1.029716034
17/04/2015	111	2.62	0.084	1.0856	1.131110973	1.04192019
17/04/2015	112.5	7.5	0.475	1.0856	1.368956025	0.860894973
17/04/2015	115	7.6	0.308	1.0856	1.261424281	0.934283078
15/05/2015	100	0.35	0.174	1.0856	1.181594192	0.997404497
15/05/2015	102	0.24	0.128	1.0856	1.155464024	1.019960237
15/05/2015	102.5	0.34	0.133	1.0856	1.158472784	1.017311219
15/05/2015	103	1.05	0.191	1.0856	1.191702289	0.988944446
15/05/2015	104	0.7	0.143	1.0856	1.163816257	1.0126404
15/05/2015	105	0.48	0.105	1.0856	1.142749958	1.031308163
15/05/2015	105.5	1.67	0.182	1.0856	1.186503954	0.993277229
15/05/2015	106	1.2	0.139	1.0856	1.16160149	1.01457115
15/05/2015	106.5	2.14	0.188	1.0856	1.18987756	0.990461035
15/05/2015	107	2.33	0.187	1.0856	1.189135279	0.9910793
15/05/2015	107.5	2.59	0.189	1.0856	1.19046249	0.989974376
15/05/2015	108	2.88	0.192	1.0856	1.19237402	0.988387318
15/05/2015	109	1.91	0.102	1.0856	1.140993315	1.032895938
15/05/2015	109.5	2.34	0.111	1.0856	1.145970354	1.02840999
15/05/2015	110	2.58	0.107	1.0856	1.14363784	1.03050749
19/06/2015	100	0.41	0.140	1.0856	1.162090449	1.014144262
19/06/2015	101	0.79	0.158	1.0856	1.172834856	1.004853628
19/06/2015	102	1.25	0.175	1.0856	1.182213323	0.99688215
19/06/2015	103	0.55	0.113	1.0856	1.147166313	1.027337838
19/06/2015	103.5	0.98	0.135	1.0856	1.159376508	1.016518234
19/06/2015	104	0.92	0.123	1.0856	1.152960916	1.022174597
19/06/2015	105	1.08	0.117	1.0856	1.149332938	1.025401188
19/06/2015	105.5	2.16	0.165	1.0856	1.17657039	1.001663284
19/06/2015	106	3.15	0.204	1.0856	1.19916995	0.982785934
19/06/2015	106.5	2.45	0.160	1.0856	1.17348976	1.004292837
19/06/2015	107	2.98	0.175	1.0856	1.182115953	0.996964263
19/06/2015	108	2.1	0.111	1.0856	1.146028066	1.028358201
19/06/2015	109	2.4	0.101	1.0856	1.140622272	1.033231938
19/06/2015	109.5	2.23	0.080	1.0856	1.12877521	1.044076225
19/06/2015	110	2.75	0.090	1.0856	1.134478094	1.038827781
19/06/2015	110.5	3.5	0.111	1.0856	1.146274381	1.028137224
19/06/2015	111	4.1	0.125	1.0856	1.153924179	1.021321315
19/06/2015	111.5	3.85	0.095	1.0856	1.136920389	1.036596204
19/06/2015	112	4.17	0.092	1.0856	1.135317481	1.038059732
19/06/2015	112.5	6.8	0.210	1.0856	1.202448658	0.980106179
19/06/2015	113.5	4.99	0.052	1.0856	1.113489835	1.058408728
19/06/2015	114	8.3	0.234	1.0856	1.216875504	0.968486386
19/06/2015	115	8.8	0.224	1.0856	1.210799035	0.973346795
19/06/2015	116	10.3	0.264	1.0856	1.235007456	0.954267405
19/06/2015	117	10.15	0.216	1.0856	1.206171433	0.977081141
18/09/2015	99	0.66	0.122	1.0856	1.152126802	1.022914629
18/09/2015	106	2.15	0.108	1.0856	1.144156176	1.03004064
18/09/2015	107	3	0.122	1.0856	1.152254494	1.02280127
18/09/2015	108	2.94	0.105	1.0856	1.142507517	1.031527007
18/09/2015	109	3.11	0.094	1.0856	1.136320516	1.037143432
18/09/2015	110	3.25	0.080	1.0856	1.128551584	1.044283112
18/09/2015	111	4.08	0.086	1.0856	1.132292294	1.040833154
18/09/2015	112	4.75	0.086	1.0856	1.132097419	1.041012319
18/09/2015	113	5.13	0.071	1.0856	1.124116191	1.04840351
18/09/2015	115	9.05	0.165	1.0856	1.17639084	1.001816166
18/12/2015	100	1.72	0.133	1.0856	1.158562491	1.017232449
18/12/2015	101	2.15	0.138	1.0856	1.161491766	1.014666995
18/12/2015	102	1.62	0.111	1.0856	1.146268303	1.028142676
18/12/2015	103	3.13	0.148	1.0856	1.167054402	1.009830697
18/12/2015	104	2.09	0.107	1.0856	1.143692162	1.030458544
18/12/2015	105	2.41	0.106	1.0856	1.143066517	1.031022554
18/12/2015	106	2.85	0.107	1.0856	1.143739258	1.030416112
18/12/2015	108	5.49	0.153	1.0856	1.169609823	1.007624369
18/12/2015	109	5.4	0.136	1.0856	1.160367177	1.015650376
18/12/2015	110	6.03	0.139	1.0856	1.161527928	1.014635406
18/12/2015	111	5.4	0.106	1.0856	1.143295012	1.030816498
18/12/2015	112	5.53	0.092	1.0856	1.135551265	1.037846019
18/12/2015	113	5.8	0.080	1.0856	1.128687091	1.044157739
18/12/2015	114	6.67	0.084	1.0856	1.13085421	1.04215676
18/03/2016	100	1.8	0.118	1.0856	1.149695959	1.025077414
18/03/2016	105	2.9	0.103	1.0856	1.14175006	1.03221134
18/03/2016	109	4.35	0.094	1.0856	1.13650434	1.036975679
18/03/2016	112	5.7	0.084	1.0856	1.130861967	1.042149612
18/03/2016	113	6.25	0.080	1.0856	1.12907885	1.043795444
18/03/2016	113.5	6.51	0.078	1.0856	1.127697308	1.045074199
18/03/2016	114.5	7.14	0.075	1.0856	1.125909812	1.046733359
18/03/2016	116	8.1	0.067	1.0856	1.121543226	1.050808683

Table 17: Garman Kohlhagen Result Summary

Total number of option	186	
Total call	81	
Total put	105	
Total error	23	
Error in Call	5	6%
Error in Put	18	17%
Total implied volatility outtake	163	
Outtakes from call	76	
Outtakes from put	86	
IV Mean	0.126	
IV Max	0.475	
IV Min	0.001	
IV Mode	0.01	

Table 18: Value at Risk Result Summary

	Expected Maximumn Rate	**Expected Minimum Rate**
Max	1.368956025	1.064070642
Min	1.107564961	0.860894973
Mode	1.172855919	1.004835582

Table 19: Implied Volatility Quartile

Implied volatility quartile	
Quart = 0	0.095648
Quart = 1	0.041052

Table 20: Result testing

Date	Actual EUR/USD rate	Number of max rate error	Number of min rate error
27/03/2015	1.08962	0	0
30/03/2015	1.0833	0	0
31/03/2015	1.0731	0	0
01/04/2015	1.0763	0	0
02/04/2015	1.088	0	0
03/04/2015	1.0969	0	0
06/04/2015	1.0922	0	0
07/04/2015	1.0814	0	0
08/04/2015	1.0781	0	0
09/04/2015	1.0659	0	0
10/04/2015	1.0604	0	3
13/04/2015	1.0567	0	4
14/04/2015	1.0655	0	0
15/04/2015	1.0684	0	0
16/04/2015	1.0761	0	0
17/04/2015	1.0806	0	0
20/04/2015	1.0738	0	0
21/04/2015	1.0736	0	0
22/04/2015	1.0725	0	0
27/03/2015	1.0828	0	0
Total		**0**	**4**