MSc MATHEMATICAL TRADING & FINANCE

"Implementation of Variance Swaps in Dispersion Trading Strategies"

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CONFIDENTIAL

Dedicated to my late father

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Abstract

The thesis discusses the calculation and implementation of implied correlation as a valuation method for the implied volatility of a basket or index option implied volatility. We suggested how a trader may find a practical application for this useful and relatively simple tool.

We believe that implied correlation for dispersion trading is an extremely useful and potentially profitable vehicle for tracing any disparity/inefficiency in the market.

More importantly, we have introduced the concept of using Variance swaps in the execution of correlation dispersion trades. This is in contrast the more traditional method of trading strangles on index and basket options. Variance swaps require no delta hedging and are therefore less operationally intensive than standard delta-hedged option strategies. This method of trading should not be underestimated and receive merits for its attractive qualities.

Furthermore, we were able to show how Bollinger bands can be used as an indicator to identify potential trading opportunities. One anticipates that the dispersion strategy outlined has been designed to generate a consistent return with a low correlation to the underlying market in a variety of market regimes.

This thesis indicates that using Variance swaps in correlation dispersion trading strategies can be profitable, but a backtest on a larger number of trades is recommended.

INTRODUCTION

Typically implied correlation is used in dispersion trading to identify opportunities in which distortion / mispricing of implied volatility has created an identifiable (tradable) gap between the implied volatility of a benchmark index and its constituent members. The thesis will explain how this gap can be identified and how to trade dispersion. Implied correlation also enables better timing for implied volatility investing, as the model provides an indication of relative value of the constituent members of a basket to its benchmark index.

Dispersion trading has a number of theoretical and practical appeals. While a strict arbitrage lower bound exists, minimal variance hedging can be used to construct tracking baskets of options to capitalise on the mispricing of the two different volatility markets that arises from time to time.

Dispersion trading typically consists of a strategy where one simultaneously sells index options and buys options on the index components or, conversely, buys index options and sells options on the underlying stocks. The fundamental theme associated with dispersion trading is correlation trading.

The value of an index option is determined by the implied volatility of the constituent single stocks and their cross correlation coefficient. Hence, it is possible to work backwards to derive how correlated the market estimates the basket of stocks to be. The value of a single stock option does not take correlation into account as the option is on a single security. If correlation is less than 100% there is a spread between the index option implied volatility and the basket implied volatility. In order to calculate index implied volatility from single stock implied volatility we need to ascertain what level of cross correlation exists between the market weighted single stocks.

A dispersion trader relies upon the fact that when implied correlation peaks, index implied volatility is considered to be too high, the trader therefore enters into a trade whereby he/she sells index implied volatility and simultaneously buys a basket of single stock implied volatility (market weighted) to hedge his/her short exposure.
In the event that implied correlation troughs the opposite trade is entered in to with a short position in a basket of market weighted single stock implied volatilities and a simultaneous long position in index implied volatility as it is considered to be too cheap.

A typical dispersion relative-value position consists of buying single stock volatility, while selling index volatility. Since the index is composed of single stocks, the two are closely correlated. The standard dispersion position consists of buying equity at-the-money strangles, and selling index at-the-money strangles. The total position should be delta-hedged continuously to achieve the returns expected from arbitrage. However, traditional dispersion (through calls, puts or strangles) has its failings. Firstly, daily delta hedging entails replication errors and transaction costs. Furthermore, the strategy is path-dependent; depending on the market's evolution, the position can become vega-biased (vega-positive/negative), and develop into a non-hedged volatility position, rather than a play on pure stock correlation which is the intention of the arbitrage.

A cleaner way to address these shortcomings is to build a position of variance swaps. These instruments allow traders to effectively build a long/short position that better matches the desired arbitrage. Unlike the option strategy, the instruments are delta-neutral at all times and continuous trading is therefore redundant. Variance swaps are a product that investors have, more recently, been taking advantage of to fine-tune their risk profile and reduce peripheral risks, such as path-dependency.

The Variance swap market has grown steadily in recent years. The development has primarily been driven by investor demand to take direct volatility exposure without the cost and complexity of managing and delta-hedging a vanilla options position. Measuring the size of an over-the-counter market is, at the best of times difficult, but the market turnover size has been estimated, measured in options notional equivalent, to be in the proximity of €20 billion a year. To put this into context, the turnover of listed Eurostoxx 50 options is about €200 billion a year.
Variance swap liquidity initially developed on equity index underlyings, and more recently the single-stock variance swap market has begun to open up.

"….as the market for variance swaps has matured, there have been more trades, at narrower spreads, and with the ability to execute very large transactions. Users are mainly hedge funds, with occasional insurance companies, endowments and sophisticated pension funds executing trades…." (Dean Curnutt, head of equity derivatives strategy at Bank of America Securities).

In the process of its development, the market has attracted dispersion traders who buy and sell index variance swaps against single-stock variance swaps to take correlation-like exposures.

This thesis will attempt to illustrate how the calculation and implementation of implied correlation can be used in volatility-dispersion trading strategies. More importantly, we introduce the concept of using Variance swaps in the execution of correlation dispersion trades.

CHAPTER 1

Introducing dispersion trading

1.1 Concept of dispersion trading

Volatility dispersion trading is a popular hedged strategy designed to take advantage of relative value differences in implied volatilities between an index and a basket of component stocks, looking for a high degree of dispersion. This strategy typically involves short option positions on an index, against which long option positions are taken on a set of components of the index. It is common to see a short straddle or near-ATM strangle on the index and long similar straddles or strangles on 40% to 50% of the stocks that make up the index. If maximum dispersion is realized, the strategy will make money on both the long options on the individual stocks and on the short option position on the index, since the latter would have moved very little, earning theta. The strategy is evidently a low-premium strategy, with very low initial Delta with typically positive Vega bias.

The success of the strategy lies in determining which component stocks to pick. At the simplest level they should account for a large part of the index to keep the net risk low, but at the same time it is critical to make sure you are buying "cheap" volatility as well as candidates that are likely to "disperse."

Let’s discuss the types of values that can be employed in the dispersion strategy. These values enable traders to determine whether current conditions are suitable for a dispersion trade. We will distinguish amongst these three kinds of values: realized, implied, and theoretical.

Realized values can be calculated on the basis of historical market data, e.g. prices observed on the market in the past. For example, values of historical volatility, correlations between stock prices are realized values.

Implied values are values implied by the option prices observed on the current day in the market. For example, implied volatility of stock or index is volatility implied by stock/index option prices, implied index correlation is an internal correlation implied by the market. We shall discuss this in further detail later on in the chapter.

Theoretical values are values calculated on the basis of some theory, so they depend on the theory you choose to calculate them. Index volatilities calculated on the basis of the portfolio risk formula are theoretical, and can differ from realized or implied volatilities.

A comparison of theoretical values with realized ones allows traders to determine what market behaviour are best applied to the actual trading environment. By studying and analyzing the historical relationship between these two types of values one can make an informed decision about related forecasts.

By comparing implied and historical volatilities, theoretical and realized, or theoretical and implied values of the index risk, one can attempt to ascertain the best time to employ the dispersion strategy or to choose to continue to monitor the markets.

The dispersion strategy typically consists of short selling options on a stock index while simultaneously buying options on the component stocks, the reverse dispersion strategy consist of buying options on a stock index and selling options on a the component stocks.
This is an example of a behavioural/stochastic arbitrage relationship and is the basis of the dissertation. In other words historical records show an *'a posteriori'* link between two derivatives. The relationship is based is principally based on correlation between different securities/derivatives or some form of dependence, but this association cannot be expected to resist all kinds of eventualities.

Later on we will discuss the behavioural/stochastic relationship between the two portfolios (i.e. between index options and the *n* individual options that are contained in the index). This arbitrage is called a non-linear index arbitrage, because options have a non-linear payoff structure.

Figure 1 illustrates the levels of implied and historic volatility on the Eurostoxx 50 Index. It can clearly be seen historic volatility was greater than implied volatility at times and reached a local maximum in the last week of September 2001. The explanation for this lies in the tragic events of September 11. A similar spike in volatility, which was driven by very different factors, can be observed in September 2002. This particular time was quite good for buying cheap index options, and thus to engage in the reverse dispersion strategy. Figure 2 displays the spread between the two measures over the same time horizon.

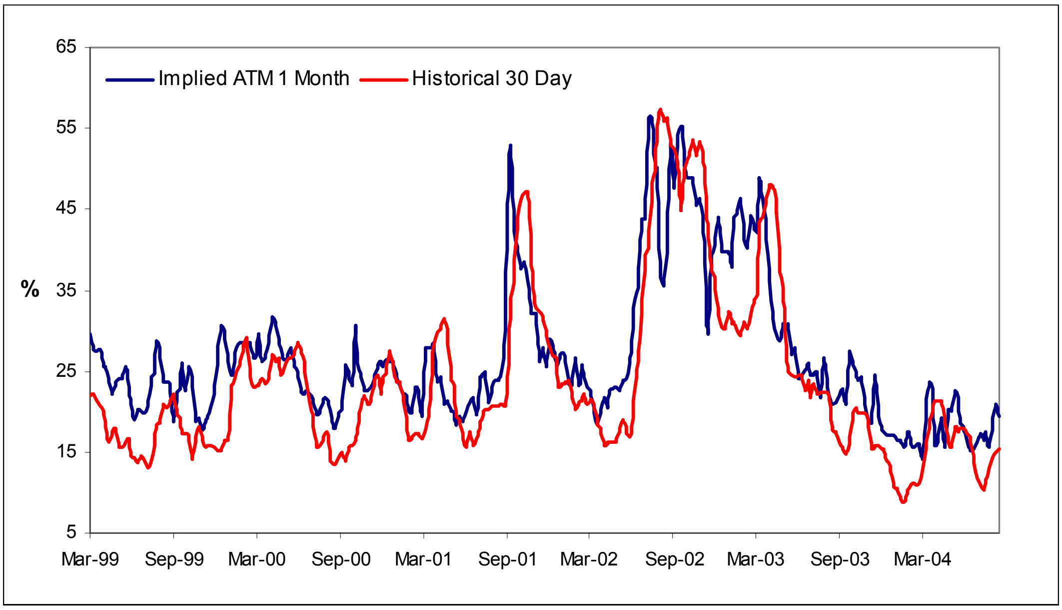

Figure 1. Levels of 1 month ATM Implied and 30 day historic volatilities on the Eurostoxx 50 Index

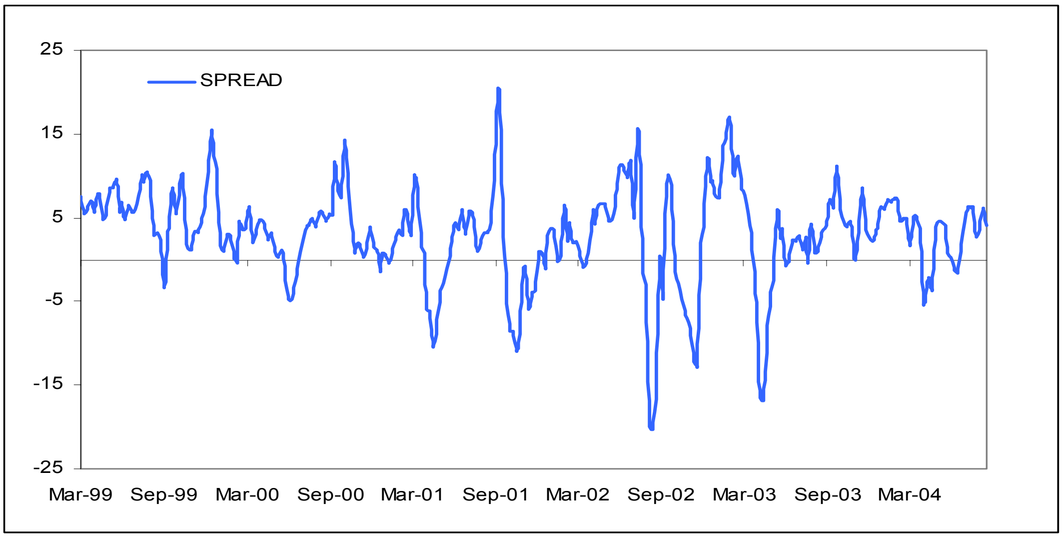

Figure 2. Volatility spread between Levels of 1 month ATM Implied and 30 day historic volatilities.

Characteristically, rising equity prices usually have the effect of cooling off the realised historical volatilities, and the implied volatilities tend to follow or anticipate that move, especially on the short end of the curve. Conventional wisdom has it that bear market moves tend to more volatile, with large spiky movements, whereas bull markets tend to be characterised by a steady appreciation in asset prices.

Empirical evidence has shown that in general implied volatilities on indices typically move synchronously. The implied volatility index of global equity indices such as the S&P 500, Dax, CAC40, FTSE100 and Nikkei are virtually coincident, since such indices reflect the state of economics as a whole, and so their performances are affected by analogous factors.
Another noteworthy point to make is that implied volatilities of global equity indices are lower than those of sector indices. This can be explained by the fact that changes in one stock within a sector can potentially have a considerable impact on the index of its sector, but the change may only have a slight influence on the overall market index. So, risk for an index that consists of equities from within the same industry is higher.

Major market indices have on the whole lower implied volatility in comparison with sector indices. But it should not be considered that some indices are better or worse for application of dispersion strategies. The important role in the strategy is not the absolute value of implied volatility, but the historical relationship between implied and realised index volatility.
The Eurostoxx 50 index is considered to be the most liquid of all European indices and hence the focus of our analysis will be primarily based on this.

1.2 Basket Options

Investors are typically interested in arbitrage possibilities between options on an index and options on the individual stocks. We will briefly discuss the pricing methodology that market practitioners use to price these options. Determining the price of a basket option is not a trivial task, because there is no explicit analytical expression available for the distribution of the weighted sum of the assets in the basket.

An option on such a basket is cheaper than buying options on each of the individual assets in the basket. The reason is that the volatility of the basket is less than the sum of the individual asset volatilities, unless the components' prices are perfectly correlated. Mathematically, this can be shown with a simple example: a basket that consists of two securities with volatilities σ_1 and σ_2, weights ω_1, ω_2 and correlated with coefficient ρ. Assuming that each of the assets exists in a Black Scholes economy and that their prices are distributed lognormally, the volatility of the basket, σ_B, is given by,

$$\sigma_B = \sqrt{\omega_1^2\sigma_1^2 + \omega_2^2\sigma_1^2 + 2\rho\omega_1\omega_2\sigma_1\sigma_2} \qquad (1)$$

When the two components are perfectly correlated, $\rho = 1$, and stocks weighted equally we obtain,

$$\sigma_B = \frac{1}{2}\sqrt{\sigma_1^2 + \sigma_1^2 + 2\sigma_1\sigma_2} = \frac{1}{2}\sqrt{(\sigma_1 + \sigma_2)^2} = \frac{\sigma_1 + \sigma_2}{2} \qquad (2)$$

which is the maximal possible value. (The correlation coefficient lies between minus one and one, by definition). From the financial perspective, the foregoing simple mathematical relations demonstrate the idea of diversification. The investor holds the basket to reduce the risk exposure compared with exposure to the individual assets. Hedging such a position with a set of options on the individual basket components works against the purpose. It overhedges the risk and costs too much.

However, to use an option on the basket as a whole, a pricing and hedging methodology is needed. The first step in using such a methodology consists of adopting a framework of underlying assumptions, and the most reasonable approach would be a straightforward extension of the familiar Black-Scholes framework onto the case of multiple assets.

What are possible approaches to pricing basket options in this setting? The simplest solution would be to treat the basket as a single asset—an index— and use familiar methods such as the Black-Scholes formula for European calls and puts to price the option.

The basket price at any given time t is a weighted sum of the prices $S_i(t)$ of *n* components,

$$B = \sum_{i=1}^{n} \omega_i S_i(t) \qquad (3)$$

where ω_i are the weights of each asset. We will assume that the world satisfies the conventional Black-Scholes assumptions, and each of the asset prices $S_i(t)$ follows a lognormal stochastic process,

$$dLnS_i(t) = S_i \exp\left[\left(\mu_i - \frac{\sigma_i^2}{2}\right)dt + \sigma_i dW_i(t)\right] \qquad (4)$$

where $dW_i(t)$ is a Wiener process. The solution of (1.1) is,

$$S_i(t) = S_i \exp\left[\left(\mu_i - \frac{\sigma_i^2}{2}\right)t + \sigma_i z_i \sqrt{t}\right] \qquad (5)$$

where $S_i = S_i(0)$ is the ith asset price at trade

σ_i is the ith annualised volatility

q_i is the corresponding continuously compounded, annualised dividend yield

$\mu_i = r - q_i$ is the mean rate of return on the ith asset in a risk-neutral world

r is the continuously compounded, annualised riskless interest rate and

x_i is a random variable, normally distributed with mean 0 and variance 1.

We shall also assume the logarithms of assets i and j are correlated with coefficient ρ_{ij} i.e. $E\lfloor z_i z_j \rfloor = \rho_{ij}$. Note that the mean α_i and the standard deviation β_i of $\ln S_i(t)$ are given by,

$$\alpha_i(t) = \ln S_i + \mu_i t_i \qquad \beta_i(t) = \sigma_i \sqrt{t} \qquad (6)$$

In this framework, the value of a European option on a basket is given by

$$V = e^{-rt} E\left\{\max\left(\phi\left[\sum_{i=1}^{n} \omega_i S_i(T) - K\right], 0\right)\right\} \qquad (7)$$

where T is the option expiry time, K is the strike price, $E[\bullet]$ denotes the risk-neutral expectation value, and ϕ is 1 for a call and –1 for a put.

While simplicity is an important advantage, this method has obvious drawbacks. If the basket components' prices are lognormally distributed, then assuming that the distribution of basket prices is also lognormal is inconsistent. An even bigger drawback of this approach is that it makes it impossible to hedge exposure to the individual volatilities and correlations.

Investors seek arbitrage possibilities between options on an index and options on individual stocks within the index. The trade based on this strategy is intended to exploit the discrepancy between the pricing of index options and the portfolio of individual stock options. This discrepancy can be found in the difference in correlation or volatility in almost equal portfolios and results in 'trading correlation' or 'trading volatility'. The discrepancy shows whether the index option or the portfolio of individual options is cheaper or more expensive than the other. The trading strategies should be insensitive to changes in other option parameters than the correlation and/or volatility sensitivity. i.e. the position should be hedged against these parameters. The next section attempts to explain implied correlation.

1.3 Implied Correlation

Implied correlation refers to the average correlation coefficient that adequately explains the difference between index implied volatility and the average implied volatility of the constituent stocks relative to their weight in the basket. A value for the expected average cross correlation coefficient can be extracted from single stock implied volatility and the index implied volatility.

Typically implied correlation is used in dispersion trading to identify opportunities in which distortion/mispricing of implied volatility has created an identifiable (tradeable) gap between the implied volatility of a benchmark index and its constituents members.

Implied correlation also enables better timing for implied volatility investing, as the model provides an indication of relative value of the constituent members of a basket to he benchmark index.

The fluctuations seen in the spread between the index volatility and the basket implied volatility are due to a change in either correlation expectations, a change of basket constituents or a change on volatility. It is a widespread observation that the spread between the two narrows in volatile markets as correlation rates tend to rise in volatile or declining markets.

Figure 3 below plots the implied correlation of the Eurostoxx 50 index components and the performance of the index itself. Three events have been highlighted. These events saw equity markets display directional shifts in volatility and simultaneous shifts in implied correlation rates.

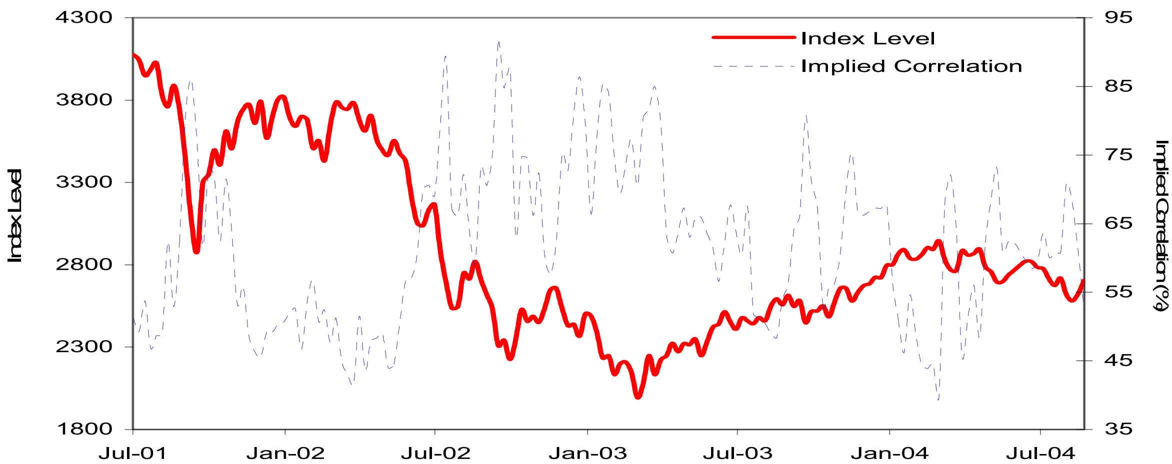

Figure 3. Implied Correlation and index performance of Eurostoxx 50 Index

The chart begins just prior to the tragic events of September 11. As one would expect the market experienced a sharp, prominent spike in implied correlation as the market declined sharply over this period. Subsequently, implied correlation remained relatively stable until global economic indicators began to weigh on the equity markets with concerns over rate cuts suggesting economic frailty.

By May 2002 equity markets had begun a pattern of decline that was met with a spike in implied correlation, that peaked when credit ratings were cut on some key financial stocks (heavily weighted within the index).
The start of 2003 saw markets concerned with the impact of the war in the gulf, this fear gradually eroded and as it did investors saw implied correlation decrease as the index gained back old ground.

Knowing at what point correlation and possibly implied volatility begin to decline after an initial spike in both implied volatility and correlation, are crucial in implementing recovery strategies.
The inverse of this rule is also true in stable or rising markets. Extremities of this rule were seen in the tech rally when single stock implied volatility rose and correlation remained at lower levels (mainly due to high diversification in heavily weighted stocks), causing index implied volatility to remain at subdued levels (relative to the basket).

Much has been written regarding the fact that correlation shares the same trait as implied volatility and its relationship with volatile stock markets; namely it has a tendency to increase in volatile markets.

Given this relationship investors have an interest in knowing if risk levels perceived by the options markets are suggesting an increase or decrease in correlation levels. As higher implied correlation often corresponds to fast markets where gains can be translated to losses in a rapid motion.

Academics believe that there is a relationship between index implied volatility and implied correlation, e.g. a high implied correlation results in high index implied volatility and vice versa. This is illustrated in Figure 4 that plots a scatter chart of the 60 day implied correlation against the 60 day implied volatility for the Eurostoxx Index weekly from Jan 1999 to Sep 2004.

The close relationship of implied volatility and correlation is one reason why the topic generates such a high degree of interest. The causation of high or low levels of implied correlation is a rather more speculative topic.

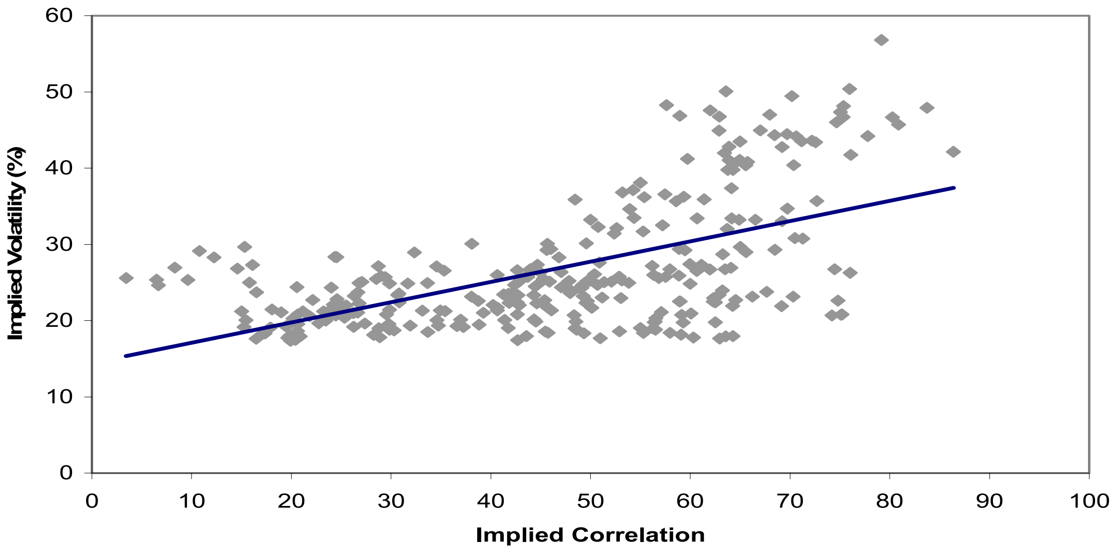

Figure 4. Scatter chart of 60 day implied correlation vs 60 implied volatility for the Eurostoxx 50 index.

The reason that dispersion traders employ implied correlation is that implied correlation and the disparity in implied volatility points between the underlying index and the basket of single stocks has a strong negatively correlated relationship, hence low implied correlation tends to equate to higher dispersion and visa versa.

However, the spread between the two sets of implied volatility data does not have a linear degree of negative correlation so apart from occasions when the two data sets are trading at parity the trader would have no way of knowing if the spread was at abnormal (i.e. tradeable) levels.

If for example index implied volatility is at 25% and the basket implied volatility is at 30% then implied correlation maybe 30%. However, if the same spread (5 vol points) is achieved at 60% index implied volatility and 65% basket implied volatility, implied correlation maybe 50%. Hence looking just at the spread does not provide enough information to suggest whether levels are extreme or not.

The dispersion strategy is designed to generate pure alpha by hedging stock market risk and exploit the mispricing and inefficiencies in the options market. In chapter 3 a strategy will be proposed whereby focus will be placed on periods when the implied average correlation deviates from its historical norm. This may offer the investor a potential to profit from using this strategy.

The general trading rules for the dispersion strategy are as follows:

$$\rho_{implied} > \rho_{average}$$

When the implied average correlation is greater than the average correlation, index options may be rich relative to the stock options. The dispersion trade would be to sell the index options and to buy the individual stock options, ‘sell correlation’.

$$\rho_{implied} < \rho_{average}$$

Conversely, when the implied average correlation is less than the average correlation, index options may be cheap relative to the stock options. The dispersion trade would be to buy the index options and to sell the individual stock options, ‘buy correlation’. The next section will discuss the difference between average and implied correlation.

Average Correlation

Historical correlation is the determination of the dependence between two stocks on the basis of their past movements. Before defining the correlation, let us first define the covariance. The covariance term emerges when calculating the variance of the sum of two variables say, Z=X+Y,

$$Var(Z) = Var(X) + Var(Y) + 2Cov(X,Y) \tag{8}$$

Application of statistical theory infers that the covariance between stock x and y can be estimated as follows,

$$Cov(x,y)_t = \sigma_{xy,t} = \frac{1}{m-1}\sum_{k=1}^{m}(R_{x,t-k} - \overline{R}_{x,t})(R_{y,t-k} - \overline{R}_{y,t}) \tag{9}$$

Using the above result we can now define the historical correlation between two random stocks x and *y.* It is defined as the ratio between the covariance and the individual deviations,

$$\rho_{xy,t} = \frac{\sigma_{xy,t}}{\sigma_{x,t}\sigma_{y,t}} \tag{10}$$

it can be estimated as follows,

$$\rho_{xy,t} = \frac{\sum_{k=1}^{m}(R_{x,t-k} - \overline{R}_{x,t})(R_{y,t-k} - \overline{R}_{y,t})}{\sqrt{\sum_{k=1}^{t}(R_{x,t-k} - \overline{R}_{x,t})^2 \sum_{k=1}^{m}(R_{y,t-k} - \overline{R}_{y,t})^2}} \tag{11}$$

Next consider a portfolio of *n* stocks. There will exist ½n(n-1) correlations. Using these pairwise correlations it is possible to define a single, historical ‘average’ correlation for the basket of constituents stocks. This is simply a question of calculating the weighted average of pairwise correlations between the individual components,

$$\rho_{avg} = \frac{\sum_{x=1}^{n}\sum_{y=x+1}^{n}\rho_{xy}\omega_x\omega_y\sigma_x\sigma_y}{\sum_{x=1}^{n}\sum_{y=x+1}^{n}\rho_{xy}\sigma_x\sigma_y} \quad (12)$$

<u>Implied Correlation</u>

Since there is only one basket price for a basket of *n* stocks means that it is impossible to calculate all the implied correlations from a basket option.

It is only possible to calculate the implied average correlation for a basket for which there exist traded index options and individual options on stocks in the index. Consider first the volatility of the basket (or index), this can be defined in terms of its component single stock volatilities as follows,

$$\sigma_I^2 = \sum_{x=1}^{n}\omega_x^2\sigma_x^2 + 2\sum_{x=1}^{n}\sum_{y=x+1}^{n}\omega_x\omega_y\sigma_x\sigma_y\rho_{xy} \quad (13)$$

where,

$$\sum_{x=1}^{n}\omega_x = 1$$

We now make an assumption that the correlation for each pairwise component is the same, so $\rho_{xy} = \overline{\rho}$ for every *x* and *y*.

If the component's implied volatilities are known then the average implied correlation, $\overline{\rho}$, is:

$$\overline{\rho} = \frac{\sigma_I^2 - \sum_{x=1}^{n}\omega_x^2\sigma_x^2}{2\sum_{x=1}^{n}\sum_{y=x+1}^{n}\omega_x\omega_y\sigma_x\sigma_y} \quad (14)$$

In extreme market conditions the implied correlation can exceed 100%.

The dispersion strategy above is based on the discrepancy between the implied and the realized average correlation.

Alternatively to monitoring the spread between implied and average correlation to identify trading opportunities, a trader could instead monitor the spread of single stock implied volatility (market weighted) to that of the traded index implied volatility.

If one compares the implied index volatility with the volatility calculated from the individual stock options volatilities and the historical correlation, one can see if the market is valuing the index volatility too high or too low. It is then possible to build a strategy on this comparison. The dispersion statistic can be introduced as, D.

$$D = \sigma_P - \sum_{i=1}^{n} \omega_i \sigma_i \qquad (15)$$

If one believes the index volatility to be high relative to the individual implied volatilities, one sells a straddle on the index and buy the straddles on the individual stock options.

One can think of the dispersion trade more intuitively by considering the following example.

- Go long at-the-money straddles (call + put) on constituent stocks.
- Go short an at-the-money straddle on the index.

This is easily illustrated using a hypothetical index containing two equally weighted stocks and examining the two general types of possible outcomes:

1. Should both stocks move in the same direction (high correlation), the total payoff of the calls or puts on both legs of the trade will be equal, resulting in no net profit or loss.
2. Should one stock move up while the other moves down (low/negative correlation), one call and one put on the single-stock options leg will end up in the money. By contrast, the index would move very little as the positive performance of one constituent is offset by the negative performance of the other. This would result in a net profit. The more volatile the single stocks, the greater the expected payoffs of the call and put.

Indeed for an index with more than two constituents, any level of dispersion, i.e. some constituents moving in opposite directions, will generate a positive payoff. We are therefore short correlation in this trade. Naturally, entering the trade would not be a zero-premium transaction. If we reverse the legs, such that we go short the stock straddles and long the index straddle, we become long correlation, i.e. any level of dispersion will cause a loss. Dispersion is therefore opposite to correlation.

long correlation $\Longleftrightarrow$ short dispersion

short correlation $\Longleftrightarrow$ long dispersion

1.4 Issues with the execution of dispersion trades

In practice the trade is harder to execute than this theoretical scheme might suggest, as hedging the single stock part of the trade is fraught with cost and difficulty. Furthermore, to actually trade entirely (or even partially) the correct market weighted constituents of the single stock basket exposes the dispersion trader to significant spread risk.

The spread risk is created by the liquidity and hence market makers; if an option is less popular the market maker widens the volatility spread that he/she is prepared to trade for. In constructing a market weighted single stock implied volatility basket the dispersion trader requires very tight spreads that actually reflect the degree of correlation that an underlying single stock may have with an index, as the spread deviates away from this range then the whole dispersion trade becomes less economically viable.

For example, stock options are available on all Eurostoxx 50 constituents as well as on the index itself, making it theoretically possible to implement a perfect directional hedge. However, stock options on Air Liquide, L'Oreal and several other stocks are considerably less liquid than most others, which serves to impede implementation. The bottom 6 stocks in terms of daily option notional turnover account for about 6.6% of the index by weight, which means they are not insignificant. It is still possible to place the complete trade, but "slippage" is to be expected, i.e. trading away from the initial price levels. When a trade is required in significant size, the level of slippage could become unacceptable.

One compromise to reducing spread risk is to limit the number of basket constituents as this does not materially effect the volatility profile of the basket as it maybe observed that in most market capitalization weighted indices that 70-80% of the index is represented by 50% of the index constituents.

	# of constituents	% weighting of top 50%
DAX	30	83.57
AEX	24	86.16
FTSE 100	102	87.21
Eurostoxx 50	50	71.63
CAC 40	39	81.55

A compromise to overcome spread risk could be:

• Go long at-the-money straddles (calls + puts) on the liquid subset of constituent stocks, with each straddle weighted in accordance with the constituent's weight in the index.
• Go short an at-the-money straddle on the index.

Implementing the trade by using only a subset of more liquid index constituents will still give correlation exposure. However, a directional risk has now opened up. Should the uncovered stocks rally or decline sharply, their impact will be reflected in the index leg of the trade but not in the stock leg. There is no limit to the potential downside of the payoff in such “incomplete” trades.

Another issue that adds to the trading complexity of dispersion trading is that the delta of all options has to be kept neutral at all times to maintain a pure volatility exposure rather than a directional one. This will involve constant rolling of positions and dynamically hedging the basket with futures or stocks, again exposing the dispersion trader to spread risk and cost.

As already pointed out, traders traditionally employ straddles to exploit the variations in implied volatility and correlation. The position has a delta of close to zero upon initiation, meaning that the positions pay-off is indifferent to market moves.

However, markets do move and hence the delta neutrality of a straddle position would be disrupted. As a result the position becomes dependant on the market direction. While the holder of the straddle has a long gamma position, which benefits them in times of big market moves, the short straddle investor can get hurt on a short gamma position.

The delta of the straddle position must be dynamically hedged in order for the position to retain its delta neutrality; a process which is highly cost intensive and often eats up a large proportion of the potential profit. Additionally, the option position would need to be rolled into higher or lower strikes depending on whether the market moves up or down to always be as close-to-the-money as possible, a process which adds up to the costs. Finally the positions should also be rolled into later expiries to avoid a high gamma exposure towards the end of the lifetime on an at-the-money option.

There is a third alternative, however, which can be implemented using dynamic hedging, and can be designed to take advantage of both a correlation and a volatility view. Furthermore, this trade can be put together without the directional risk highlighted above. The trade would be:

- Go long at-the-money straddles (calls + puts) on a liquid subset of constituent stocks,
- Go short a variance swap on the index

Variance swaps require no delta hedging and are therefore less operationally intensive than standard delta-hedged option strategies. Variance swaps trade much more than volatility swaps because they are easier for the dealer to hedge, and so have much narrower spreads.

For illustration, let us consider a simulation run on the Eurostoxx 50 between late September 2001 and early April 2002. Implied volatilities peaked on 23 September, following dramatic equity sell-offs. Between late September and the 1 April, equity markets saw a strong recovery with implied volatilities more than halving.

In the below example, a trader who wanted to take a short volatility position in September 2001 would have sold the closest at-the-money available straddles constructed with one short call and one short put on the Eurostoxx 50. To reduce gamma and increase liquidity we assumes that the trader sold options with around 90 days left to maturity and a minimum of 30 days.

The remaining delta position would be hedged with an according position in the future once a day. As investors are adopting different hedging strategies and face different fees for trading, we neglected the impact of commission. The chart below plots the theoretical profit and loss of a delta hedged short-straddle position and a position in a volatility swap with similar volatility exposure.

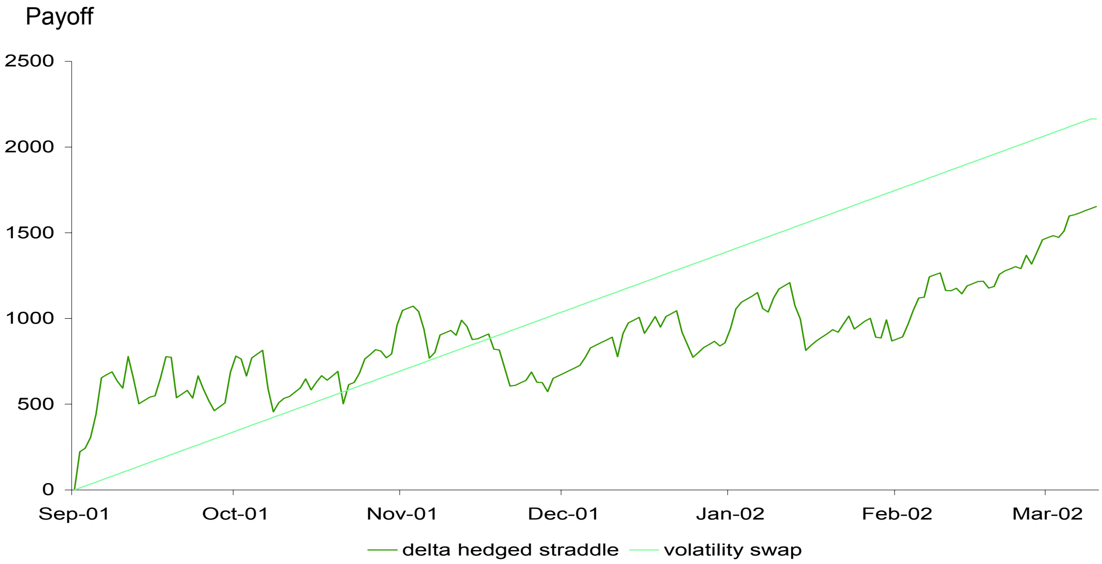

Figure 5. Deteriorating effect of a manually delta hedged short-straddle.

Note that the payoff of the variance swap is linearly split over the life of the option in order to compare the payoffs of both strategies. In practice, a volatility swap will usually be settled once at the end of its life.

Although both positions were yielding a profit, the payoff of the volatility swap clearly outperforms that of a delta hedged straddle. While the volatility swap contract gives straight exposure to realized volatility, the straddle has in practice some unavoidable exposure to the direction of the underlying, despite the delta hedge.

Another added advantage of the variance swap over the straddle is that the straddle would have been rolled from one expiry into another three times and from one strike to another over 50 times in order to always pick the ideal at-the-money strike, not to mention the continuous future hedge which adds additional costs.

Chapter 2 will now examine the concept and pricing methodology of a variance swap.

CHAPTER 2

Variance Swaps

2.1 How the variance swap works

Taking pure exposure to market volatility or variance is not a trivial task. Traditional instruments – such as straddles – fail to capture pure changes in volatility as soon as the underlying moves. Synthetic instruments such as variance and volatility swaps were developed to offer hedge-free and pure exposure to variance and volatility.

A variance swap gives a payoff at maturity, which is equal to the difference between the realized variance over the swap period and the contract variance, multiplied by the notional. Similarly a volatility swap pays out the difference between the realized volatility covered by the swap and the contract volatility. In contrast to a variance swap a volatility swap is linear in payout for the realized volatility.

In contrast to an option whose volatility exposure is contaminated by its dependence upon the underlying index level, volatility or variance swaps provide pure exposure to volatility.

Similar to the hedged option strategy, in the very short term, a position in a volatility or variance swap gives exposure to changes in implied volatility. By expiration of the swap, however, the strategy provides exposure to the difference between realized volatility over the life of the trade and implied volatility at the outset.

The reference level for a variance swap is determined from option prices.

The payoff from a long variance swap position at expiration is determined by comparing realized volatility over the lifetime of the swap with the reference level:

$$\text{Payoff} = (\text{Realized Volatility}^2 - \text{Reference Level}^2) \text{ x Notional} \qquad (16)$$

Furthermore,

$$\text{Realized volatility}^2 = Var = \frac{1}{n}\sum_{i=0}^{n-1}\left(\ln\left(\frac{S_{i+1}}{S_i}\right)\right)^2 \cong \frac{1}{n}\sum_{i=0}^{n-1}\left(\ln\left(\frac{S_{i+1}-S_i}{S_i}\right)\right)^2 \qquad (17)$$

where S_i is the closing price of the underlying at the ith business day and $(n+1)$ is the total number of trade days.

During the period between initiation and expiration of the swap, the investor's profit or loss is a function of (1) the accrued profit/loss from the difference between realized volatility and the variance swap reference level; and (2) the difference between the reference level for a newly-issued variance swap and the reference level of the original swap. The profit or loss becomes steadily more a function of realized volatility and how this compares to the reference level; it is steadily less a function of changes in the variance swap reference level.

Unlike options, variance swaps cost zero to enter into, since the variance swap rate represents the risk-neutral expected value of the realized return variance.

Variance swaps are offered on most benchmark indices, but variance swaps are neither offered on single stocks nor on sector indices. Typically a trader would need to trade a basket of options across the skew on the underlying instrument in order to be able to offer variance swaps. There are certain institutions, however, that are willing to package together an OTC Variance swap to allow employment of a dispersion trade. The most active players are Goldman Sachs, Credit Suisse First Boston and JP Morgan.

2.2 Methodology For Pricing Variance Swaps

The economic characteristics of the variance swap are similar to those of an option contract. Like an option, the value of a variance swap is influenced by both realized and implied volatility, as well as the passage of time. A portfolio consisting of an appropriately weighted combination of option contracts across different strikes can be constructed to hedge a variance swap. In general, such a hedge would be designed to render the vega exposure constant across different strikes. By weighting the number of options according to the inverse of the strike squared, a constant vega profile can be achieved and would effectively hedge the variance swap.

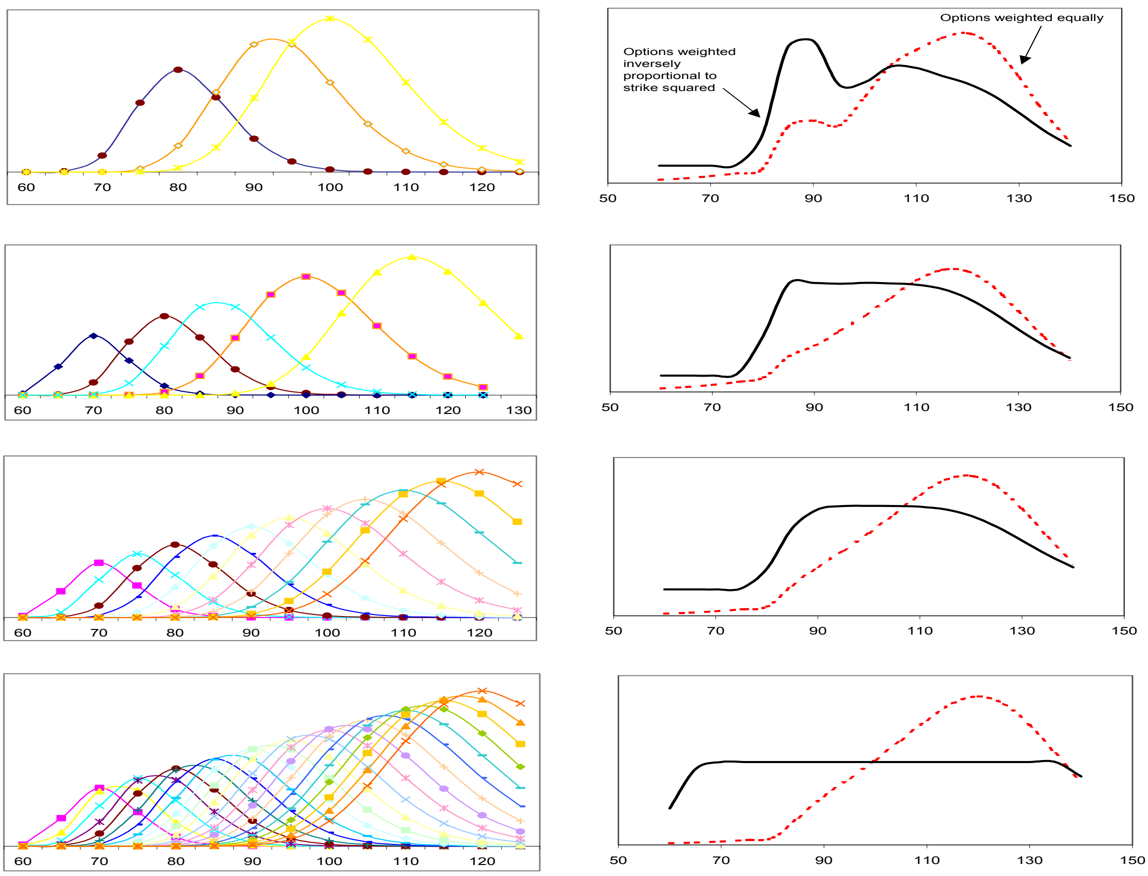

Figure 6.Variance exposure for a basket of options equally weighted vs sum of vega contributions for options weightings.

To demonstrate this we computed and plotted the variance exposure of a portfolio of options of various strikes as a function of the underlying price. Each of the figures on the left hand side shows the individual variance exposure contributions for each option of different strike. The corresponding figures on the right show the computed combined sensitivity for the equally weighted and strike weighted portfolios. We note that in the portfolio with weights inversely proportional to the strike of the option squared produces a variance exposure that is virtually independent of stock price S, provided the price of the underlying remains inside the range of available strikes and far from the edge of the range, and provided the strikes are distributed evenly and closely. The intuition behind the inverse strike property is as straightforward. As the stock price moves higher, each additional option of higher strike in the portfolio will provide and additional contribution to Vega proportional to that strike. Also, an option with higher strike will produce a Vega contribution that increases with the strike. In order to offset this accumulation of stock price dependence, one needs diminishing amounts of higher-strike options, with weights inversely proportional to the strike squared.

Pricing a variance swap is an exercise in computing the weighted average of the implied volatilities of the options required to hedge the swap. That is, the strike price is set so as to reflect the aggregate cost (in implied volatility terms) of the hedge portfolio. To see this more clearly, suppose the strike price on the variance swap were set to zero. Since standard deviation (and thus variance) is always non-negative, the payoff of this contract would always be positive and the contract would necessarily carry a cost. This differs from market convention in which variance swaps are entered into without any initial cash flow. The cost of the zero-strike variance swap, then, is simply the sum of the option premium expended in purchasing the correct hedge portfolio.

Consider a positive price process S_t for $t \in [0, T]$, where

$$dS_t = \sigma_t S_t dW_t \qquad (18)$$

Here W is a Brownian motion under a risk-neutral probability measure.

In particular, S is continuous, but σ need not be.

Let $X_t := \log(S_t / S_0)$. We want to create payoff

$$\langle X \rangle_T \equiv \int_0^T \sigma_t^2 dt \qquad (19)$$

By Itô's rule,

$$dX_t = \frac{1}{S_t} dS_t + \frac{1}{2}\left(\frac{-1}{S_t^2}\right)\sigma_t^2 S_t^2 dt. \qquad (20)$$

$$X_T = \int_0^T \frac{1}{S_t} dS_t - \frac{1}{2}\int_0^T \sigma_t^2 dt \qquad (21)$$

Rearranging,

$$\langle X \rangle_T = -2X_T + \int_0^T \frac{2}{S_t} dS_t \qquad (22)$$

This is the sum of $-2\log(S_T / S_0)$ and gains from a dynamic trading strategy.

So a static options position with initial value

$$\int_0^{S_0} \frac{2}{K^2} P_0(K)dK + \int_{S_0}^{\infty} \frac{2}{K^2} C_0(K)dK \qquad (23)$$

together with dynamic trading strategy that holds at each time t

$2 / S_t$ shares

replicates the variance payoff. Thus, the payout to a variance swap is well approximated by summing the payouts from a dynamic position in futures and a static position in options. The static component comprises of positions in $2/K^2$ puts at all strikes below S_0, and $2/K^2$ calls at all strikes above S_0.

This dissertation proposes that traders use Variance Swaps to execute the dispersion strategy. Variance swaps on the index can be bought/sold against short/long Variance swaps on the single stocks. The overall position takes advantage of relative moves in volatility. Trading a variance swap as a proxy to trading implied index volatility is an efficient way of gaining exposure to index volatility while removing directional risk from the trade.

For instance, if a trader considers that the single stock basket is ‘rich’ with respect to the index, they could sell a variance swap on the basket of stocks and buy a variance swap on the index as a long hedge against it.

CHAPTER 3

Implementing the dispersion trading strategy

3.1 Bollinger Bands

One of the core principles of market trading is the idea of mean reversions, that prices abhor extremes and always return to average levels over time. This mean-reversion concept can be applied similarly to stock correlations.

As speculators, looking for an entry point, probabilities for a lucrative trade begin increasing at two standard deviations from the mean and grow very high at three standard deviations. If a price happens to stretch two standard deviations above or below its average, then odds are that a significant to major move in the opposite direction is probably imminent.

Speculators can look for these rare two-standard-deviation readings as a secondary confirmation of a major interim high or low in a particular market. Used in conjunction with other technical indicators, the standard deviations are very effective in helping speculators decide when to launch a bet on a mean reversion of a particular market that they happen to be trading.

Bollinger Bands are a widely-used formed of standard-deviation technical analysis. Mr. Bollinger popularized their use and continues to push the envelope in the practical deployment of standard-deviation Bollinger Bands for real-world speculations. While Bollinger Bands are not necessarily rigidly defined, they have evolved into a primary definitive form in real-world usage.

Today Bollinger Bands are most often considered to be +/-2 SD bands above and below a 30-day moving average. In the past academics have recommended 10-day moving averages for short-term trading, 30dmas for intermediate-term trading, and 50dmas for long-term trading. Sometimes on the longer-term 50dma Bollinger Bands, technical analysts expand the bands to +/-2.5 standard deviations.

Figure 7 below illustrates the history of implied correlation and that of its standard deviation buffers. As detailed below we can observe that on occasions when the implied correlation on the Eurostoxx 50 touched levels of 2 standard deviations or above we suggest that values are extreme and *likely* to mean-revert. At the opposite end of the scale, when the implied correlation reached –2 standard deviations it also tended to revert back to its moving average. Standard-deviation bands show us relatively overbought and oversold levels, but just as the implied correlation hugged +2 standard deviations for sometime between June and October 2001, an SD extreme does not necessarily warn of a certain turn happening immediately although, it can reveal to us the general tenor of a market and how anomalous it happens to appear at the moment in statistical probability terms.

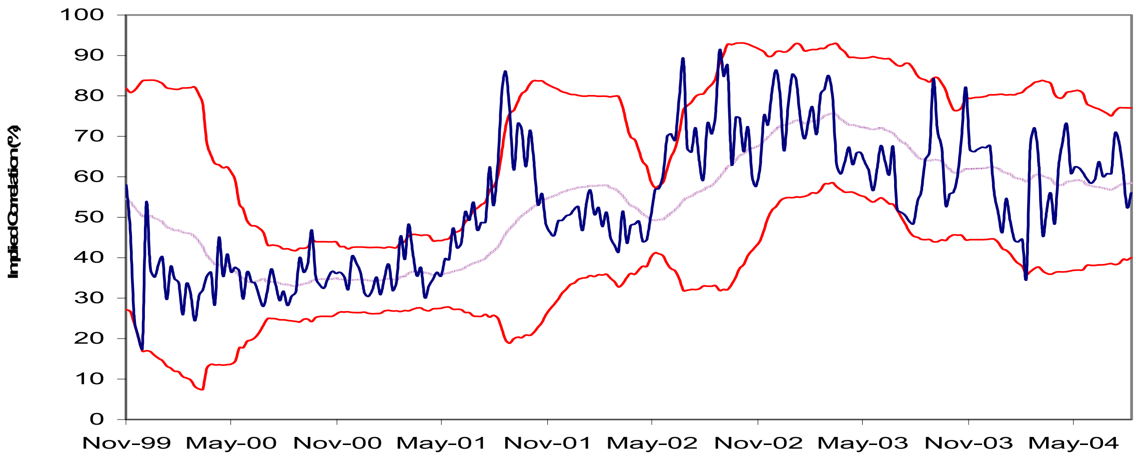

Figure 7.2 standard deviation Bollinger bands for the implied correlation on the Eurostoxx 50 Index.

The farther out that a price happens to be in standard-deviation terms from its average, the rarer that such an event truly is, and the higher the probability that such an anomaly will not last long. If an SD extreme exists while other more well-defined technical indicators are calling for a trend change, speculators would do well to heed their combined message. SD bands nicely compliment and augment other forms of technical analysis.

The common theme that the dispersion trader relies upon is that when implied correlation peaks, index implied volatility is felt to be too high and hence sells index volatility via selling index variance swaps whilst simultaneously buying a basket of market weighted single stock variance swaps to hedge their short exposure.

In the event that implied correlation troughs the opposite trade is entered into with a short position in a basket of market weighted single stock variance swaps and a simultaneous long position in index implied volatility as it is considered relatively cheap.

Dispersion trade decision matrix

Implied Correlation	Index Implied Vol	Single Stock implied Vol
High	Short	Long
Low	Long	Short

We will attempt to exploit this logic in order to test whether we can in fact use the strategy explained above to identify opportunities that have arisen from a distortion in the spread of single stock implied volatility to that of the traded index implied volatility.

3.2 Trading methodology

We shall backtest this strategy over the period spanning from April 2003 to August 2004[1]. To set the scene briefly, this was a period just after a time when markets had experienced severe declines. The markets had bottomed in March 2003 as relief was experienced when credit rating downgrades finally occurred after rising speculation that they would be cut for many blue chip firms.

At the beginning of April 2003 crude oil prices began to decline after the US reported the biggest inventory increase thus spurring equity markets to resume their rally.
It was 4 months into the rally, at which point the implied correlation staged a rally of its own and peaked at 2 standard deviations above its normalized level. The index had surged more than 40% since falling to their lowest in more than 6 years in March 2003 on optimism that economic and profit growth were accelerating.
The telecom and insurance industries led the rebound, bouncing back from oversold conditions at the end of the third quarter. Earnings and economic reports were better than expected, while the US and ECB both lowered rates by 50 basis points.

However, the rally faltered temporarily towards the end of September 2003 when a government report showed that French consumer spending declined the most in almost seven years. Investors used this as an excuse to take some profit and the index sold off.

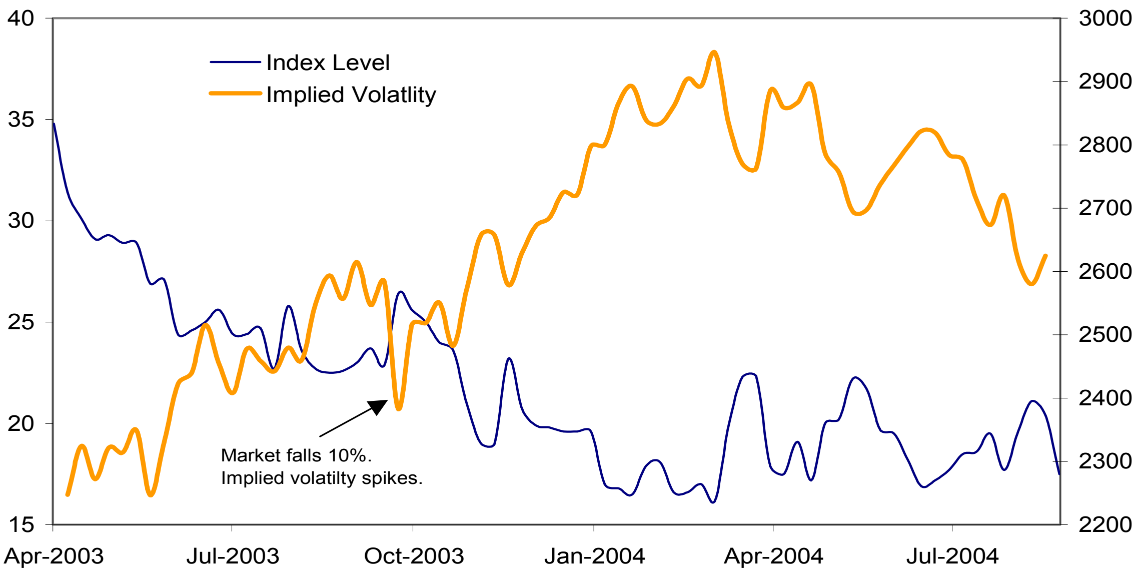

Figure 8.Performance and implied volatility of the Eurostoxx 50 Index.

[1] Ideally we would wish to backtest this strategy over a longer timespan, say several years. However, this was one of the restraints that we had to work with. The data retrieval system from DrKW (from where we extracted historical information) had the limitation of only being able to 'lookback' as far as 1½ years. Hence, due to the lack of available historical data we were unable to backtest beyond this time horizon.

The Eurostoxx sold off almost 10% of the index value in just under 2 weeks. This was the cause of the spike in implied correlation during the end of September 2003. More specifically on 30th September was when the implied correlation peaked and touched through its 2 standard deviation 'overbought' level.

The greater the implied index correlation, the greater the components and index volatilities are moving in the same direction. Therefore, the higher the average correlation between index volatility and volatilities of constituent stocks, the better the timing of a dispersion strategy. Note in Figure 9 how index implied volatility has a tendency to spike with spikes in implied volatility.

As detailed above in this situation the correct stance to adopt is to immediately short the index implied volatility (or in our case take a short position in a Variance swap on the Eurostoxx 50 Index) in anticipation of a return to a less correlated and less volatile index level and to simultaneously go long the basket implied volatility (i.e. take a long position in a Variance swap with the weighted Eurostoxx constituents as its underlying). The arbitrage objective would be to profit from the spread moving back to its normal relationship.

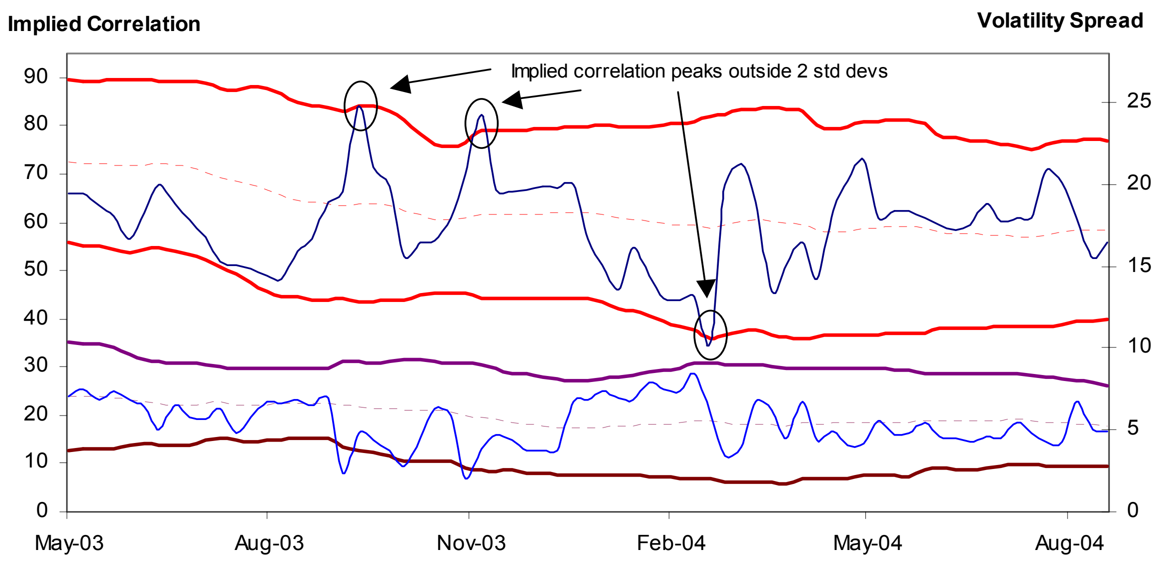

Figure 9.Bollinger bands for both implied correlation and volatility for the Eurostoxx 50 Index.

The above trade would essentially consist of two components; the first is the Variance swap on the Eurostoxx index and the second is the weighted basket of Variance swaps on the Eurostoxx constituents. For all intents and purposes, this is in fact, one complete packaged OTC trade; which remember, costs zero to enter into.

Recreating the payoff from deploying the recommended strategy can assess the profitability of this trade. As previously shown the payoff from a variance swap is given by:

$$\text{Payoff} = (\text{Realized volatility}^2 - \text{Reference level}^2) \times \text{Notional}$$

where,

$$\text{Realized volatility}^2 = Var = \frac{1}{n}\sum_{i=0}^{n-1}\left(\ln\left(\frac{S_{i+1}}{S_i}\right)\right)^2 \qquad (24)$$

Note that as the variance swap approaches maturity, exposure to implied volatility declines and exposure to realized volatility increases, until at maturity the payout depends purely on realized volatility.

The reference level of the variance swap can be inferred by setting the value of the variance swap to zero at inception. The variance swap rate represents the risk-neutral expected value of the realized return variance and reflects not just at-the-money implied volatility but also the price of other strikes, as described by the volatility skew.

It is worth noting that in the equity options market equity variance swaps trade at a premium to the at-the-money implied volatility. This is as a result of the put skew inherent in the market.

The Exotic Options trading desk at Dresdner Kleinwort Wasserstein were kind enough to allow me to use their proprietary variance swap pricing model to infer the strike levels in both the Eurostoxx Index and its constituent members for the times the trades were entered into. The limitation of their pricing system meant that we had to make a dividend assumption. The assumption being that current dividend levels are assumed to be the same as dividend levels in the past. The impact of this assumption is not deemed a major shortcoming in the implementation since dividend levels have not changed drastically over the period being tested. It is anticipated that this will not have insignificant impact on any findings.

Additional inputs into the model include the volatility surface, at the time of inception of the trade for Eurostoxx index and all its constituent members, since the replicating portfolio consists of a portfolio of options across all different strikes. More specifically we are interested in the volatility smile across all strikes for a 3-month term to maturity as we are utilizing a corresponding 3 month implied correlation measure for our strategy. We perceive that using an implied correlation measure of less than 3-months would prove too sensitive a measure to use as a trading indicator and would potentially lead to too many false trading entry points and may contain too much 'noise'. A 3 month indicator is generally perceived as being fairly stable. The 3 month volatility smile for the Eurostoxx and corresponding members were retrieved from DRKW's 'SPOTS' database. Similarly, we were able to extract the Euribor interest rates (3 month interest rate Euribor) from the same source.

The historic index constituents and their corresponding market capitalized weights were found to be directly available from the official 'Stoxx' website (www.stoxx.com).

The realized variance was calculated using daily closing price data obtained from Bloomberg.

Another issue that we needed to consider was the size of the long volatility position to the size of the short volatility position. Academic research has shown that there is no ideal or perfect ratio. It is at the discretion of the investor as to whether they wish to introduce a vega bias to the trade. For our purposes, however, we will initiate the trade with zero vega bias.

To implement a zero vega bias we require the sensitivity of the index variance swap to change in volatility of stock i. The sensitivity to stock i is given by

$$\frac{\partial V}{\partial \sigma_i} = \frac{\partial V}{\partial \sigma_B}\frac{\partial \sigma_B}{\partial \sigma_i} \qquad (25)$$

but from before we know that,

$$\sigma_B = \sqrt{\sum_{i=1}^{n}\omega_i^2\sigma_i^2 + 2\rho_{avg}\sum_{i=1}^{n}\sum_{j=i+1}^{n}\omega_i\omega_j\sigma_i\sigma_j} \qquad (26)$$

thus,

$$\frac{\partial \sigma_B}{\partial \sigma_i} = \frac{1}{2}\frac{2\omega_i^2\sigma_i + 2\rho_{avg}\sum_{j=1}^{n}\omega_i\omega_j\sigma_j}{\sigma_B} = \frac{\omega_i^2\sigma_i + \rho_{avg}\sum_{\substack{j=1\\ j\neq i}}^{n}\omega_i\omega_j\sigma_j}{\sigma_B} \qquad (27)$$

For every unit of the Index Variance swap entered into, we must trade in the opposite direction, the corresponding ratio of the Single stock basket variance swap to initiate a vega-neutral portfolio. These have been calculated and tabulated below for each of the three instances when implied correlation breached its two standard deviation Bollinger band during our period of empirical analysis.

Breach Case	Breach Date	Vega Ratio
Case A	30 Sep 2003	0.76
Case B	25 Nov 2003	0.75
Case C	09 Mar 2004	0.70

3.4 Presentation of results

Based on the trading strategy presented we were able to compute the profitability of the dispersion trades using the methodology and assumptions illustrated above. The Variance swap was assumed to be entered into and held for the full 3-month term to maturity at which time any profit and loss was realized.

Case	Implied Correlation	Strategy	Profit/Loss
A	Peak	Short Index Vol/Long Basket Vol	1.19
B	Peak	Short Index Vol/Long Basket Vol	1.51
C	Trough	Long Index Vol/Short Basket Vol	0.08

The profit and loss indicates the return from the trade in volatility points. Note that the above analysis assumes a 1.5% bid-offer spread for each transaction. Other transaction costs are assumed negligible.

The results generated seem to indicate modest profitability in each case. All trades spawned a humble profit. The cases where Implied correlation peaked appear to be more profitable than the case where implied correlation troughed. Intuitively this is what an investor would expect, since an upspike in implied correlation typically occurs when the market experiences a significant sell-off due to a market event/uncertainty, this is rationally when the implied volatilities move together. The mean reversion tendencies of the implied correlation tend to be stronger in these instances than in the case when correlation is low as a result of market conditions in which asset prices are growing gradually and progressively.

Given the fact that the trading strategy was successful for the trades considered, it would have been interesting to explore a larger number of trades to investigate whether they would also have been consistent with the above findings. The prime focus of this thesis was to illustrate the how to employ variance swaps in dispersion trading arbitrage. A backtest of a larger number of trades can therefore be left as an area for further analysis.

CONCLUSIONS

The thesis discussed the calculation and implementation of implied correlation as a valuation method for the implied volatility of a basket or index option implied volatility. We have suggested how a trader may find a practical application for this useful and relatively simple tool.

We suggest that implied correlation for dispersion trading is an extremely useful and potentially profitable vehicle for tracing any disparity/inefficiency in the market.

More importantly, we have introduced the concept of using Variance swaps in the execution of correlation dispersion trades. This is in contrast the more traditional method of trading strangles on index and basket options. Variance swaps require no delta hedging and are therefore less operationally intensive than standard delta-hedged option strategies. This method of trading should not be underestimated and receive merits for its attractive qualities.

Furthermore, we were able to show how Bollinger bands can be used as an indicator to identify potential trading opportunities. However, due to the limitations on historical data availability, the trading rule could not be tested thoroughly enough for the level of significance of the trading profits. However, one anticipates that the dispersion strategy outlined has been designed to generate a consistent return with a low correlation to the underlying market in a variety of market regimes.

This thesis indicates that using Variance swaps in correlation dispersion trading strategies can be profitable, but a backtest on a larger number of trades is recommended.

Dispersion trading continues to evolve and be refined. One potential future development that investors expect to see is the OTC commoditization of implied correlation, so that the investor could simply take a position on the degree of implied correlation in the form of a swap. Much in the same way as the variance swap.

This would allow the end user to gain the benefit of trading implied correlation without the computational or trading difficulties, the investment bank or swap counterparty would then have to hedge this correlation risk, much as they would that of a conventional OTC basket trade or even as they would a variance swap as the payoff would be similar.

References

Alexander, C. (2001) *"Market Models: A Guide to Financial Data Analysis."* John Wiley & Sons

Avellaneda M. (2002) *"Empirical Aspects of Dispersion Trading in U.S. Equity Markets."* Petit Dejeuner De la Finance

Bernhard G and Daiss M. (2003) *"Nonlinear Index Arbitrage."* Quantitative Strategies Research Notes, Equity Derivatives Research, Dresdner Kleinwort Wasserstein Presentation January 2003

Canina, L. and S. Figlewski (1993) *"The Informational Content of Implied Volatility."* Review of Financial Studies, Volume 6, No 3, 659-81

Chriss, N. and W Morokoff (1999) *"Market risk for volatility and variance swaps."* Risk October, 55-59

Derman, E., M. Kamal, I. Kani and J. Zou (1996) *"Valuing Contracts with Payoffs Based on Realized Volatility."* Global Derivatives (July) Quarterly Review, Equity Derivatives Research, Goldman Sachs & Co.

Demeretfi K, E. Derman, M. Kamal, and J. Zou (1999) *"More than you ever wanted to know about volatility swaps"* Quantitative Strategies Research Notes, Equity Derivatives Research, Goldman Sachs & Co.

Hull, J. (2000) *"Options, Futures, & Other Derivatives"* Prentice Hall International , Fourth edition

Neuberger, A. (1994) *"The Log Contact: A new instrument to hedge volatility"* Journal of Portfolio Management, Winter, 74-80

Petsas, K. and N. Porfiris (2002) *"Volatility Analysis and Trading Opportunities in the FTSE/ASE-20 index options of ADEX"* Quantitative Research, Athens Derivatives Exchange (ADEX)

Reghai A. (2001) *"Pricing & Hedging Variance Swaps"*

Roelfsema M.R. (2000) *"Non-linear Index Arbitrage: Exploiting the Dependencies between Index and Stock Options."* Delft University Press

Walter, C. and J. Lopez (1997) *"Is implied correlation worth calculating? Evidence from foreign exchange options and historical data."* Research Paper #9730, Federal Reserve Bank of New York

Appendix I : Eurostoxx 50 Index and Index Constiutent weights, Spot Prices & 3-month Volatility smile as of 30 Sep 2003

Ric	Weight	Ticker	Date	Close	Volatility Smile (% of ATM strike)							
				Price	70%	80%	90%	100%	110%	120%	130%	140%
TOTF.PA	7.39	FP FP Equity	30/09/2003	129.6	29.38	29.38	28.09	26.12	24.60	23.76	23.49	23.48
RD.AS	6.66	RDA NA Equity	30/09/2003	37.71	27.57	27.57	26.71	24.72	22.58	21.15	20.58	20.57
NOK1V.HE	5.33	NOK1V FH Equity	30/09/2003	13.22	45.94	45.31	43.30	40.90	39.13	37.84	36.86	36.37
TEF.MC	4.00	TEF SM Equity	30/09/2003	10.052	31.99	31.87	30.73	27.92	25.48	23.73	22.85	22.78
SIEGn.DE	3.58	SIE GY Equity	30/09/2003	51.14	43.69	42.46	39.59	36.96	34.82	33.11	32.15	31.93
BNPP.PA	3.01	BNP FP Equity	30/09/2003	42.1	38.23	38.23	37.65	35.38	32.98	31.26	30.16	29.68
SAN.MC	2.92	SAN SM Equity	30/09/2003	7.28	37.09	36.76	35.27	32.60	30.33	28.50	27.20	26.97
ENI.MI	2.83	ENI IM Equity	30/09/2003	13.119	24.99	24.95	23.70	21.62	20.02	19.28	19.15	19.14
AVEP.PA	2.59	AVE FP Equity	30/09/2003	44.55	37.55	36.98	35.21	32.75	30.80	29.33	28.36	27.96
DBKGn.DE	2.56	DBK GY Equity	30/09/2003	52.25	42.46	41.42	38.50	35.37	32.71	30.53	29.32	28.99
DTEGn.DE	2.52	DTE GY Equity	30/09/2003	12.44	32.57	32.41	30.84	28.86	27.12	25.78	25.27	25.19
UNc.AS	2.43	UNC NA Equity	30/09/2003	50.5	26.54	26.46	24.67	22.07	19.85	18.95	18.82	18.82
ING.AS	2.39	INGA NA Equity	30/09/2003	15.73	46.40	45.96	43.94	40.66	37.86	35.64	34.57	34.31
BBVA.MC	2.38	BBVA SM Equity	30/09/2003	8.86	34.91	34.87	34.46	32.10	29.82	27.80	26.21	25.40
EONG.DE	2.30	EOA GY Equity	30/09/2003	41.9	32.41	32.32	30.99	27.97	24.93	22.56	21.35	21.26
SOGN.PA	2.11	GLE FP Equity	30/09/2003	57.2	38.68	38.17	35.95	33.19	31.04	29.49	28.61	28.37
PHG.AS	2.09	PHIA NA Equity	30/09/2003	19.46	53.19	51.18	48.10	45.34	43.15	41.48	40.32	39.80
DCXGn.DE	2.08	DCX GY Equity	30/09/2003	30.14	46.28	44.81	41.84	38.92	36.48	34.57	33.36	32.95
ALVG.DE	2.08	ALV GY Equity	30/09/2003	75.8	51.66	49.28	46.09	43.41	41.28	39.59	38.32	37.75
CARR.PA	2.08	CA FP Equity	30/09/2003	43.2	33.64	33.53	32.19	29.70	27.54	25.96	25.07	24.95
AAH.AS	2.01	AABA NA Equity	30/09/2003	15.85	35.04	34.72	33.13	30.24	27.48	25.25	23.87	23.60
BASF.DE	1.81	BAS GY Equity	30/09/2003	37.7	35.42	35.17	33.50	30.74	28.20	26.07	24.71	24.50
GASI.MI	1.80	G IM Equity	30/09/2003	19.38	29.98	29.89	28.43	26.30	24.43	23.20	22.78	22.74
AXAF.PA	1.70	CS FP Equity	30/09/2003	14.47	44.89	43.89	41.33	38.29	35.93	34.11	32.73	31.97
CRDI.MI	1.64	UC IM Equity	30/09/2003	4.061	24.82	24.60	22.97	20.41	18.68	18.44	18.44	18.44
TLIT.MI	1.62	TIT IM Equity	30/09/2003	2.118	29.64	29.58	28.48	26.75	25.17	24.02	23.53	23.47
SASY.PA	1.61	SAN FP Equity	30/09/2003	52.2	36.58	36.22	34.23	31.47	29.27	27.62	26.66	26.44
OREP.PA	1.55	OR FP Equity	30/09/2003	58.65	31.30	31.20	29.51	27.47	25.72	24.38	23.91	23.86
FTE.PA	1.52	FTE FP Equity	30/09/2003	19.75	45.39	43.94	40.84	37.70	35.51	34.03	33.11	32.66
FOR.AS	1.48	FORA NA Equity	30/09/2003	14.59	39.76	39.22	37.25	34.43	32.05	30.32	29.42	29.34
DANO.PA	1.40	BN FP Equity	30/09/2003	65.5	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30
EAUG.PA	1.37	EX FP Equity	30/09/2003	15.2	51.89	50.05	45.96	42.85	40.64	39.05	37.94	37.19
TIM.MI	1.25	TIM IM Equity	30/09/2003	3.993	27.74	27.69	26.73	25.07	23.66	23.05	22.97	22.97
AEGN.AS	1.11	AGN NA Equity	30/09/2003	9.99	52.00	51.17	48.62	45.70	43.20	41.21	39.74	38.96
REP.MC	1.11	REP SM Equity	30/09/2003	14.11	26.52	26.50	26.15	24.62	22.24	20.38	19.59	19.44
LYOE.PA	1.07	SZE FP Equity	30/09/2003	13.63	46.23	44.53	41.41	38.72	36.67	35.10	33.87	32.91
BAYG.DE	1.07	BAY GY Equity	30/09/2003	18.55	44.31	43.45	41.07	37.92	35.44	33.39	31.63	30.75
ELE.MC	1.06	ELE SM Equity	30/09/2003	13.27	28.55	27.60	25.56	23.32	21.40	19.78	18.44	17.52
LVMH.PA	1.06	MC FP Equity	30/09/2003	53.35	35.62	35.26	33.10	30.66	28.75	27.47	26.95	26.86
AIRP.PA	1.02	AI FP Equity	30/09/2003	110.27	36.42	36.35	35.16	32.33	29.89	27.89	26.27	25.22
CGEP.PA	0.98	CGE FP Equity	30/09/2003	10.17	53.73	52.88	49.83	47.11	45.04	43.45	42.29	41.77
IBE.MC	0.94	IBE SM Equity	30/09/2003	14.45	21.70	21.69	21.25	19.87	18.36	17.56	17.38	17.38
SGOB.PA	0.92	SGO FP Equity	30/09/2003	31.57	37.74	37.46	36.15	33.76	31.68	29.95	28.61	27.88
MUVGn.DE	0.92	MUV2 GY Equity	30/09/2003	81.139	51.00	49.91	47.51	44.99	43.01	41.40	40.07	39.03
ENEI.MI	0.87	ENEL IM Equity	30/09/2003	5.34	24.77	24.75	24.11	22.55	20.89	19.80	19.33	19.30
SPI.MI	0.86	SPI IM Equity	30/09/2003	8.559	39.16	38.24	35.19	32.80	31.03	29.85	29.66	29.64
LAFP.PA	0.78	LG FP Equity	30/09/2003	55.65	39.35	38.62	36.06	33.55	31.50	29.78	28.86	28.66
RWEG.DE	0.78	RWE GY Equity	30/09/2003	22.84	31.98	31.88	30.77	28.94	27.20	25.75	24.90	24.76
VOWG.DE	0.72	VOW GY Equity	30/09/2003	38.59	49.78	47.01	43.24	40.25	37.86	35.81	34.43	34.09
AHLN.AS	0.64	AHLN NA Equity	30/09/2003	6.927	72.80	69.61	64.66	59.43	55.28	52.10	49.51	47.43

				50%	60%	70%	80%	90%	100%	110%	120%
.STOXX50E	SX5E Index	30/09/2003	2395.87	51.20	46.69	42.03	37.37	32.78	28.30	24.16	21.40
				130%	140%	150%	160%	170%	180%	190%	200%
				19.89	19.34	19.58	20.53	21.93	23.60	25.20	26.60

Ric	Weight	Ticker	Date	Close Price	Volatiliy Smile (% of ATM Strike) 70%	80%	90%	100%	110%	120%	130%	140%
TOTF.PA	6.97	FP FP Equity		134.5	25.27	25.27	24.29	22.39	21.04	20.60	20.55	20.54
RD.AS	6.01	RDA NA Equity	25/11/2003	37.85	23.36	23.36	22.82	21.14	19.04	17.82	17.52	17.51
NOK1V.HE	5.49	NOK1V FH Equity	25/11/2003	15.08	39.41	37.98	35.65	33.78	32.43	31.62	31.32	31.27
TEF.MC	3.86	TEF SM Equity	25/11/2003	10.72	25.54	25.54	24.29	22.04	20.24	19.42	19.28	19.28
SIEGn.DE	3.86	SIE GY Equity	25/11/2003	60.87	36.95	34.82	31.94	29.50	27.71	27.05	26.99	26.99
SAN.MC	3.16	SAN SM Equity	25/11/2003	8.63	31.42	29.60	26.76	24.39	23.29	23.16	23.16	23.16
BNPP.PA	3.05	BNP FP Equity	25/11/2003	46.31	32.06	31.44	29.41	26.91	25.29	24.67	24.50	24.50
ENI.MI	2.78	ENI IM Equity	25/11/2003	14.097	21.57	21.09	19.42	17.56	16.64	16.47	16.47	16.47
DBKGn.DE	2.58	DBK GY Equity	25/11/2003	56.71	36.80	35.36	32.03	28.98	26.77	25.66	25.44	25.44
AVEP.PA	2.54	AVE FP Equity	25/11/2003	48.24	31.01	30.63	28.75	26.31	24.68	24.10	23.97	23.97
DTEGn.DE	2.54	DTE GY Equity	25/11/2003	13.65	28.83	27.72	25.72	23.88	22.52	22.03	21.99	21.99
ING.AS	2.46	INGA NA Equity	25/11/2003	17.73	42.19	39.45	35.37	32.10	29.58	27.86	27.19	27.10
BBVA.MC	2.44	BBVA SM Equity	25/11/2003	9.99	30.10	29.29	27.04	24.65	22.79	21.88	21.74	21.74
EONG.DE	2.36	EOA GY Equity	25/11/2003	46.45	27.72	27.57	25.60	23.18	21.41	20.57	20.56	20.56
ALVG.DE	2.33	ALV GY Equity	25/11/2003	91	42.55	41.04	37.96	35.60	33.82	32.54	31.93	31.90
PHG.AS	2.31	PHIA NA Equity	25/11/2003	23.75	42.96	40.62	37.71	35.38	33.56	32.48	32.07	32.00
SOGN.PA	2.23	GLE FP Equity	25/11/2003	66.6	35.91	32.95	29.95	27.95	26.94	26.65	26.61	26.61
UNc.AS	2.18	UNC NA Equity	25/11/2003	51	22.92	22.92	21.93	19.35	17.05	16.18	16.06	16.06
AAH.AS	2.11	AABA NA Equity	25/11/2003	18.14	32.94	30.95	27.26	23.86	22.03	21.57	21.54	21.54
DCXGn.DE	1.99	DCX GY Equity	25/11/2003	32.03	37.28	36.53	33.81	30.97	28.78	27.47	26.98	26.91
CARR.PA	1.96	CA FP Equity	25/11/2003	45.2	31.40	30.58	28.57	26.33	24.84	24.24	24.07	24.05
BASF.DE	1.80	BAS GY Equity	25/11/2003	41.46	32.26	31.04	28.45	25.95	23.93	22.79	22.52	22.52
GASI.MI	1.75	G IM Equity	25/11/2003	20.74	23.51	23.38	21.91	19.73	18.29	17.80	17.79	17.79
AXAF.PA	1.70	CS FP Equity	25/11/2003	15.95	40.03	37.89	34.86	31.97	29.80	28.49	27.82	27.62
TLIT.MI	1.68	TIT IM Equity	25/11/2003	2.388	28.66	27.51	25.42	23.71	22.86	22.70	22.70	22.70
SASY.PA	1.58	SAN FP Equity	25/11/2003	56.85	32.53	30.61	27.69	25.34	24.15	23.82	23.82	23.82
EAUG.PA	1.57	EX FP Equity	25/11/2003	19.29	38.83	35.44	32.81	31.04	30.07	29.74	29.68	29.68
CRDI.MI	1.53	UC IM Equity	25/11/2003	4.203	24.98	24.18	21.98	19.69	18.23	17.79	17.77	17.77
FTE.PA	1.51	FTE FP Equity	25/11/2003	21.4	37.18	35.71	32.77	29.94	28.14	27.37	27.13	27.11
OREP.PA	1.48	OR FP Equity	25/11/2003	62.45	29.63	28.41	26.08	23.86	22.58	22.17	22.10	22.10
FOR.AS	1.44	FORA NA Equity	25/11/2003	15.6	31.08	30.58	28.51	25.63	23.48	22.61	22.41	22.41
DANO.PA	1.26	BN FP Equity	25/11/2003	64.75	20.36	20.36	20.36	20.36	20.36	20.36	20.36	20.36
TIM.MI	1.22	TIM IM Equity	25/11/2003	4.301	23.26	23.06	21.79	20.11	19.25	19.03	19.02	19.02
MUVGn.DE	1.19	MUV2 GY Equity	25/11/2003	94.91	43.91	42.67	40.09	37.57	35.58	34.06	33.09	32.69
BAYG.DE	1.18	BAY GY Equity	25/11/2003	22.46	37.29	36.43	34.03	31.16	29.05	28.06	27.64	27.63
AEGN.AS	1.12	AGN NA Equity	25/11/2003	11.14	47.42	44.48	40.39	37.08	34.50	32.55	31.54	31.17
REP.MC	1.04	REP SM Equity	25/11/2003	14.64	24.68	24.67	23.60	21.70	20.11	19.40	19.26	19.26
LVMH.PA	1.03	MC FP Equity	25/11/2003	57.6	34.57	32.67	29.84	27.24	25.70	25.15	25.04	25.04
LYOE.PA	1.03	SZE FP Equity	25/11/2003	14.14	31.75	30.29	27.88	25.55	24.01	23.26	22.96	22.94
AIRP.PA	1.02	AI FP Equity	25/11/2003	121.82	36.09	34.20	31.53	29.19	27.30	25.78	24.75	24.31
ELE.MC	1.00	ELE SM Equity	25/11/2003	13.65	24.66	24.62	23.07	20.64	18.65	17.94	17.89	17.89
SGOB.PA	0.99	SGO FP Equity	25/11/2003	36.36	37.24	35.45	32.82	30.69	29.24	28.47	28.19	28.14
SPI.MI	0.98	SPI IM Equity	25/11/2003	10.644	33.29	30.91	28.27	26.45	25.49	25.13	25.11	25.11
CGEP.PA	0.95	CGE FP Equity	25/11/2003	10.87	49.76	47.79	44.89	42.34	40.43	39.07	38.36	37.96
IBE.MC	0.85	IBE SM Equity	25/11/2003	14.4	19.68	19.68	18.92	17.26	15.92	15.56	15.54	15.54
LAFP.PA	0.85	LG FP Equity	25/11/2003	65.15	35.81	32.75	30.21	28.19	26.90	26.55	26.52	26.52
RWEG.DE	0.83	RWE GY Equity	25/11/2003	26.41	29.38	29.13	27.21	25.09	23.47	22.58	22.55	22.55
ENEI.MI	0.78	ENEL IM Equity	25/11/2003	5.264	20.83	20.76	19.85	18.08	16.99	16.70	16.70	16.70
AHLN.AS	0.71	AHLN NA Equity	25/11/2003	6.995	53.87	53.35	51.69	48.92	45.71	43.11	40.96	39.16
VOWG.DE	0.70	VOW GY Equity	25/11/2003	43.08	37.06	36.44	34.47	31.67	29.08	27.32	26.44	26.15
SAPG.DE		SAP GY Equity	25/11/2003	129.45	43.82	41.85	38.87	36.44	34.59	33.34	32.79	32.67

					50%	60%	70%	80%	90%	100%	110%	120%
.STOXX50E		SX5E Index	25/11/2003	2625.31	40.65	40.64	38.32	32.19	26.58	21.61	18.23	16.83
					130%	140%	150%	160%	170%	180%	190%	200%
					16.62	16.62	16.62	16.62	16.62	16.62	16.62	16.62
TEF.MC	4.13	TEF SM Equity	09/03/2004	13.11	25.00	23.82	22.00	20.65	20.08	20.07	20.07	20.07
SIEGn.DE	3.60	SIE GY Equity	09/03/2004	62.87	33.51	33.16	30.63	28.07	26.00	24.43	23.94	23.88
SAN.MC	3.10	SAN SM Equity	09/03/2004	9.17	28.20	28.02	25.87	23.28	21.22	20.06	19.81	19.81
BNPP.PA	3.03	BNP FP Equity	09/03/2004	49.78	28.64	28.08	25.62	22.96	21.07	20.36	20.32	20.32
ENI.MI	3.02	ENI IM Equity	09/03/2004	16.3	20.10	19.83	18.41	16.31	15.29	15.12	15.12	15.12
DBKGn.DE	3.01	DBK GY Equity	09/03/2004	72.47	35.03	33.86	31.27	28.70	27.51	27.30	27.30	27.30
AVEP.PA	2.82	AVE FP Equity	09/03/2004	62.8	24.07	24.07	22.67	20.55	19.16	18.77	18.76	18.76
DTEGn.DE	2.62	DTE GY Equity	09/03/2004	15.92	29.58	29.54	28.26	26.24	24.32	22.89	22.30	22.25
ING.AS	2.52	INGA NA Equity	09/03/2004	19.61	31.83	31.48	29.35	26.50	24.35	23.04	22.57	22.56
BBVA.MC	2.52	BBVA SM Equity	09/03/2004	11.12	29.55	28.95	26.39	23.99	22.30	21.46	21.40	21.40

Appendix IV : Eurostoxxx 50 Index and Index constituent variance swap strike levels

Case A	30-Sep-03	
RIC	Security	Implied Strike Vol %
TEF.MC	TELEFONICA	28.27
RD.AS	ROYAL DUTCH PETROLEUM	24.28
ING.AS	ING GROEP	40.51
VOWG.DE	VOLKSWAGEN	41.00
MUVGn.DE	MUENCHENER RUECKVER R	44.96
AIRP.PA	AIR LIQUIDE	31.97
AHLN.AS	AHOLD	61.14
REP.MC	REPSOL YPF	23.84
RWEG.DE	RWE	28.51
SGOB.PA	SAINT GOBAIN	33.37
BBVA.MC	BCO BILBAO VIZCAYA ARGENT	31.65
BNPP.PA	BNP	34.62
BAYG.DE	BAYER	37.97
ENEI.MI	ENEL	22.13

Case B	25-Nov-03	
RIC	Security	Implied Strike Vol %
TEF.MC	TELEFONICA	22.47
RD.AS	ROYAL DUTCH PETROLEUM	20.65
ING.AS	ING GROEP	33.00
VOWG.DE	VOLKSWAGEN	31.55
MUVGn.DE	MUENCHENER RUECKVER R	37.72
AIRP.PA	AIR LIQUIDE	29.35
AHLN.AS	AHOLD	47.91
REP.MC	REPSOL YPF	21.52
RWEG.DE	RWE	25.08
SGOB.PA	SAINT GOBAIN	31.01
BBVA.MC	BCO BILBAO VIZCAYA ARGENT	24.98
BNPP.PA	BNP	27.12
BAYG.DE	BAYER	31.45
ENEI.MI	ENEL	18.02

Case C	09-Mar-04	
RIC	Security	Implied Strike Vol %
TEF.MC	TELEFONICA	21.03
RD.AS	ROYAL DUTCH PETROLEUM	16.77
ING.AS	ING GROEP	26.63
VOWG.DE	VOLKSWAGEN	28.54
MUVGn.DE	MUENCHENER RUECKVER R	29.67
AIRP.PA	AIR LIQUIDE	24.28
AHLN.AS	AHOLD	38.69
REP.MC	REPSOL YPF	17.95
RWEG.DE	RWE	26.51
SGOB.PA	SAINT GOBAIN	26.04
BBVA.MC	BCO BILBAO VIZCAYA ARGENT	24.39
BNPP.PA	BNP	23.20
BAYG.DE	BAYER	28.43
ENEI.MI	ENEL	15.00