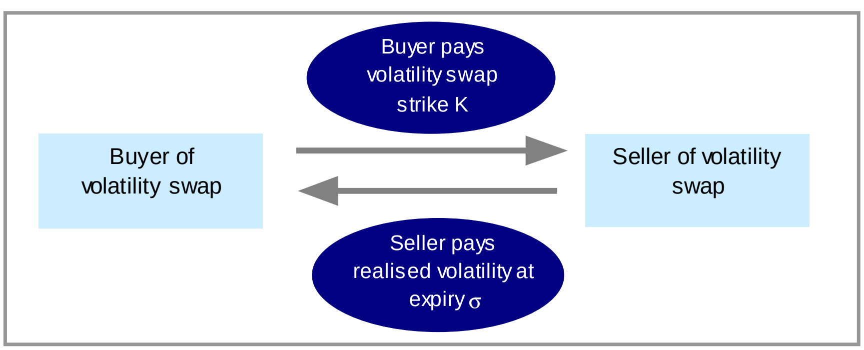
J.P.Morgan

Volatility Swaps

Product Note

- This note provides a guide to volatility swaps and discusses their mechanics, hedging, sensitivities, pricing and uses.
- Volatility swaps offer investors direct exposure to the realised volatility of an asset. Following the *de facto* shutdown of the single stock variance swap market in the aftermath of the 2008 credit crisis, volatility swaps are now preferred as an instrument for providing direct exposure to volatility for *single stock* underliers.
- We analyse the "Greeks" of volatility swaps and note that volatility swaps tend to be less "toxic" than variance swaps since their vega and gamma sensitivity both decline following a large move in the underlying asset price.
- Pricing of volatility swaps requires stochastic volatility models due to its dependency on volatility of volatility. Since no market standard exists for such models, pricing for volatility swaps will likely be wider than for other volatility products.
- We discuss the use of volatility swaps for relative value pair trades, credit-equity arbitrage and dispersion/correlation trading. We introduce a new measure, the "Mean volatility ratio", to illustrate the construction of a dispersion trade using volatility swaps.

Volatility swap cash-flows



Equity Derivatives and Delta One Strategy

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1. Introduction

Volatility swaps are instruments which offer investors direct exposure to the volatility of an asset. The instrument involves two parties which agree to exchange a pre-agreed volatility level for the amount of volatility realised over the life of the contract. Volatility swaps offer a clean way to invest in realised volatility without the operational complexity and path-dependency issues associated with delta-hedged options.

Unlike variance swaps, which provide exposure to the square of realised volatility, volatility swaps provide a linear exposure to volatility. The lack of convexity of volatility swaps make the contracts easier to manage from a risk perspective than variance swaps, especially for single stocks.

Historical context – the rise and fall of single stock variance swaps

Volatility trading has been present in some form since the '70s when the Black-Scholes model was introduced. The '90s saw the emergence of several volatility products, and the first documented variance swap trade on the FTSE index in 1993. A turning point for the evolution of volatility products was the publication of a key research piece by Peter Carr[1], which introduced a framework for pricing and hedging variance swaps. This new theoretical framework led to a consensus amongst the brokerage and investment community that variance swaps were the 'natural' instrument for gaining exposure to volatility.

One of the main attractions of variance swaps is the existence of a straightforward pricing theory and a static hedge. Static hedges remove the need to trade dynamically to manage the position, simplifying market making substantially. The existence of a theoretical static hedge for variance swaps is a direct consequence of the fact that delta-hedging options leads to a P/L linked to the variance of stock returns (rather than their volatility). An appropriately weighted portfolio of delta-hedged options can therefore theoretically be constructed to have a P/L linked to variance, irrespective of the spot level.

The market for both single stock and index variance swaps became fairly liquid, as investors used these instruments in correlation/dispersion trades, volatility pair trades and credit/equity volatility arbitrage trades, amongst others. Meanwhile, derivatives brokers were keen to make markets in variance swaps and hedge their exposure with options. The popularity of correlation trades where clients bought single stock and sold index volatility, led market makers to become net sellers of single stock variance swaps on average.

As the credit crisis intensified in 2008 and implied volatility surged while stock prices plunged, the practical limits of the theoretical static hedge for variance swaps started to show. The tail risks embedded in these instruments suddenly became apparent, and many market makers suffered large losses on their 'hedged' single stock variance swap positions. This situation led to a *de facto* shutdown of the single stock variance swap markets, which still persists. In section 4 of this report we describe in greater detail the mechanics of what went wrong with single stock variance swaps.

The continued client interest for trading single stock volatility products and brokers' reluctance to make markets in single stock variance swaps recently led to the re-surfacing of volatility swaps, a volatility instrument which was initially proposed in the '90s. Hedging volatility swaps requires dynamically trading options, but these instruments are less risky than variance swaps in case of extreme moves. In section 5 of this report we will explain in detail how these instruments are managed and how they differ from variance swaps. Volatility swaps can be used in the same trading strategies as variance swaps. In section 8 we touch on the potential applications of these instruments.

[1] 'Towards a Theory of Volatility Trading', Carr, Madan; 1998

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2. Volatility swap mechanics

The payoff function

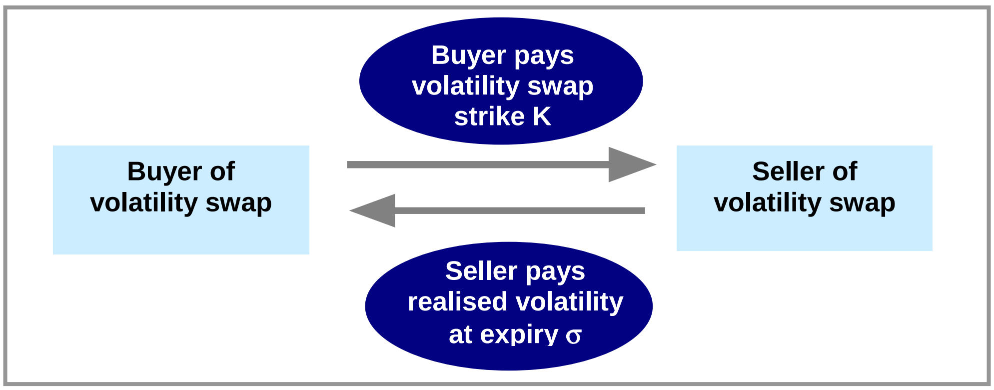
Volatility swaps offer direct exposure to the volatility (i.e. square root of the variance) of an underlying asset. Unlike a variance swap, the P/L of a volatility swap is linear with volatility. The P/L for a (long) volatility swap is given by:

Box 1: Volatility swap payoff function

$$P/L = N_{Vega} \times (\sigma - K)$$

where K is the volatility swap strike, σ is the realised volatility, and N_{Vega} is the vega notional

Figure 1: P/L of a volatility swap



Source: J.P. Morgan Equity Derivatives Strategy.

Volatility swap contract specifications

Volatility swap conditions are set out on term sheets such as the one shown in the following section. Standard terms and calculations surrounding realised volatility are broadly the same as for variance swaps, as detailed below. Strikes are typically expressed as 100 times the annualised volatility represented – for example 25 will represent a breakeven realised volatility of 25%. For this reason, the calculated value of the realised volatility (using an RMS calculation as described below) must also be multiplied by 100.

Realised volatility

Realised volatility in a volatility swap contract is calculated identically to a variance swap. The difference is in the treatment in the payoff function, where the realised volatility is squared in the variance swap payoff but is linear in the volatility swap payoff (as shown in Box 1 above). The volatility contract uses the RMS (root-mean-squared) measure, which is like a standard deviation assuming a zero mean. The calculation of this measure is as follows:

Box 2: Realised volatility (RMS measure)

$$\sigma = \sqrt{\frac{252}{T}\sum_{i=1}^{T}\left[\ln\left(\frac{S_i}{S_{i-1}}\right)\right]^2}$$

where S_i is the stock/index price on day i, and T is the contract maturity in days.

Margins and collateral

Volatility swaps are usually margined in a similar manner to options and variance swaps, with an initial amount to be posted as collateral (e.g. approximately 4 times the vega notional amount for the swap listed in section 3). The up-front margin is higher for a higher volatility swap strike, since volatility of volatility tends to be higher at higher volatility levels. The

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margin is also higher for sellers of the volatility swap than for buyers and for shorter maturities, since sellers are exposed to sudden spikes in volatility and spikes have less time to dissipate for shorter maturities. Further margin calls will be made during the course of the trade as necessary. Settlement is calculated at maturity and cash-flows are exchanged shortly afterwards (T+3 in the example below).

Disrupted days

The realised volatility used in a volatility swap payout is calculated from closing (or officially observed) prices on observation dates over a specified period. Observation dates are defined as all those scheduled trading days which are not disrupted. The occurrence of a disrupted day could potentially work for or against a long volatility position. Suppose a 5% loss is followed by a 6% gain over 2 consecutive trading days. If the first day is declared as disrupted, its closing price will not be used in the calculation of the realised volatility and only the single combined return of 0.7% will be counted. Conversely, if a 5% loss on a day declared disrupted is followed by a 6% loss the next day which is non-disrupted, this will count as a single, compounded 1-day loss of 10.7%. Such a move will act to increase realised volatility more than by the separate 5% and 6% moves, and will work in the favour of the long.

Index reconstitution risk

Volatility swaps on indices are defined to pay out on the returns of the index and *not* on the weighted returns of the basket of current constituents. This means that index volatility swaps (especially long-dated ones) will be exposed to the risk of index reconstitution, and the volatility swap may end with exposure to a substantially different set of stocks, potentially with different volatility characteristics than when it was originally traded.

Dividend adjustments

Volatility swaps on single names are typically adjusted for dividends, both special and regular. This means that the return on the ex-dividend date is calculated after adjusting for the dividend. For example, if a stock is worth €100 on the day before the dividend, pays a dividend of €5 and closes at €94 on its ex-dividend day, the return used in calculating the realised volatility for the volatility swap payout will be 94/95-1 = -1.05% (*not* 94/100-1 = -6%). In other words, **changes to the stock price resulting from dividend payments do not count towards the realised volatility calculation for the volatility swap**. This can be important for stocks with high dividend yields which pay the entire annual dividend in a single payment. Additionally, for non-cash dividends (for example, rights issues), a cash value equivalent is determined to neutralise the price effect of the dividend.

By convention, index volatility swaps are not usually adjusted for dividends, since the payments are usually more spread out and the impact of a few index points worth of dividend is generally small in comparison to the average daily move. However, there are cases of indices containing high dividend paying stocks, some of which pay on the same day, where index moves as a result of dividend payments can be significant. In these cases, the extra volatility resulting from dividend payments will count in the calculation for the volatility swap payout, potentially giving an artificial boost to the realised volatility.

Volatility swap caps

Volatility swaps, especially on single-stocks (and sector indices), are usually sold with caps. These are often set at 2.5 times the strike of the swap, capping realised volatility above this level. Volatility swap caps are useful for short volatility positions, where investors are then able to quantify their maximum possible loss.

Box 3: Volatility swap caps

Suppose a volatility swap is traded with a cap set at 2.5 times the strike. Then the P/L (for the long) is given by:

$$P/L = N_{Vega} \times [Min(\sigma, 2.5K) - K]$$

Note that this sets the maximum loss for the short to $N_{Vega} \times 1.5K$

(by contrast, the maximum loss on a short variance swap is 75% higher at $N_{Vega} \times 2.625 K_{Var}$).

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In practice caps are rarely hit – especially on index underlyings and on longer-dated volatility swaps. When caps are hit, it is often due to a single large move – e.g. due to an M&A event or major earning surprise on an individual name, or from a dramatic sell-off on an index such as the one experienced in Q4-2008. Single-day moves needed to cause a volatility swap cap to be hit are large and increase with maturity. For example a 3-month volatility swap struck at 25 and realising 25% on all days except for one day which has a one-off 29% move, will hit its cap. A similar 1-month maturity swap would need only a 17% move to hit the cap, whereas the required 1-day move on a 1-year swap would be 62%. For lower strikes the required moves are also lower.

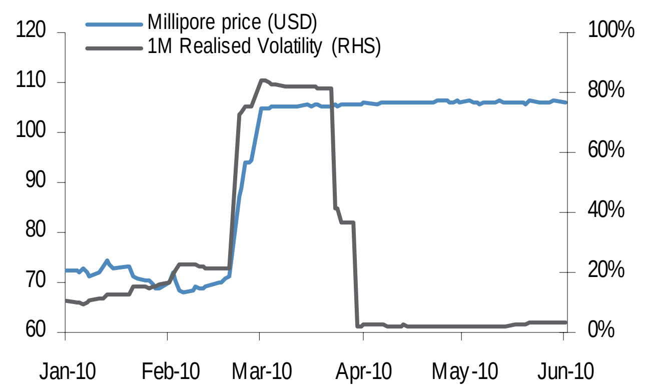
M&A events

M&A events present particular issues for volatility swaps, as an underlying being acquired can effectively cease to exist. The various options exchanges have rules for how such an event is dealt with, and volatility swap contracts generally follow these rules. Investors should be aware in which exchange the volatility swap is based since M&A rules are exchange specific. For share offers, or composed offers consisting of less than 67% cash, the options, and hence the volatility swap, will usually transfer into a volatility swap on the new underlying after the transaction date.

In the case of cash bids, options are unwound immediately after the offer has been declared unconditional. In Europe, some bourses unwind vanillas at intrinsic, but most use the theoretical fair value (generally taking the implied volatility to be the average over the 10 days before the bid). The Euronext and Eurex exchanges unwind at fair value, while the MEFF in Spain decides treatment on a case by case basis. In any case, documentation should either specify the exact rules in the case of an M&A event or should refer to the rules of the appropriate exchange.

One further issue with cash bids, is that the underlying will usually trade at close to the bid level after the offer has been accepted, often with close to zero volatility. However, the options are not unwound until the offer is declared unconditional. For example, unconfirmed reports of a bid for Millipore Corp (initially by Thermo Fisher) sent the stock soaring 32% over a week in late-February 2010; Merck finally announced a bid price of $107 on 28 February leading to a further return of 11% on the following day (Figure 2). These events led to a spike in volatility during the period of speculation and immediately following the bid announcement, and then a collapse in volatility thereafter. At the time of writing, the bid has yet to be made unconditional, while Millipore continues to trade nearly unchanged around the discounted bid price. In cases where the move on the bid is small, and the time until unconditional acceptance is long, the low realised volatility between the offer unconfirmed reports /announcement and the offer becoming unconditional could hurt long volatility swap positions.

Figure 2: Millipore volatility spiked on takeover reports and then collapsed following the cash bid announcement by Merck



Source: J.P. Morgan Equity Derivatives Strategy.

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3. Sample term sheet

Dec-10 volatility swap on Total SA

Volatility Buyer:	JPMorgan Chase Bank NA (London Branch)
Volatility Seller	******************
Share:	TOTAL SA (FP FP)
Trade Date:	30 April 2010
Valuation Date:	10 December 2010 (Cash Close price will be observed)
Termination Date:	3 Business Days following the Valuation Date
Volatility Amount:	EUR 50,000
Volatility Strike Price:	24.70
Cap Level:	61.75 (2.5x volatility strike price)
Expected N:	161
Initial Share Price:	Final Price of the Share on 30 April 2010
Equity Amount:	The Equity Amount payable on the Cash Settlement Payment Date will be determined by the Calculation Agent using the following formula:

$$VolatilityAmount \times \left[Min(FRV; CapLevel) - \text{Volatility Strike Price} \right]$$

$$FRV = \sqrt{\frac{252 \times \sum_{t=1}^{N} \left(\ln \frac{P_t}{P_{t-1}} \right)^2}{Expected\_N}} \times 100$$

If the Equity Amount is positive, then the Volatility Seller shall be the Equity Amount Payer.

If the Equity Amount is negative, then the Volatility Buyer shall be the Equity Amount Payer.

- ***"t"*** means the relevant Observation Day.
- ***"ln"*** means the natural logarithm.
- ***"P_t"*** means, in respect of any Observation Day, the Share Price on such Observation Day; provided that, except in respect of the Valuation Date, if an Observation Day is a Disrupted Day, P_t for such Observation Day shall be deemed to equal P_{t-1} (as defined below) for such Observation Day
- ***"P_{t-1}"*** means, (i) in respect of the first Observation Day, the Initial Equity Level; and (ii) in respect of any Observation Day subsequent to the first Observation Day, P_t for the Observation Day immediately preceding such Observation Day.

- **Share Price** means the Final Price for the relevant Observation Day, provided, however that, Section 5.9(b) of the Equity Definitions shall be amended whereby references to the Valuation Date shall be deemed to be references to the Observation Day. If an Ex-Date occurs after the date on which P_{t-1} is determined and on or before the date on which P_t is determined, the Share Price for P_{t-1}, shall be reduced by the Dividend Adjustment.

- "**Ex-Date**" means the date that the Shares commence trading ex-dividend or ex-right on the Exchange with respect to a dividend on the Shares.

- "**Dividend Adjustment**" means for an Ex-Date, (a) (i) the cash dividend; and (ii) the cash value of any non cash dividend, per Share (including Extraordinary Dividends) declared by the Issuer and to which the Ex-Date relates. If no cash value is declared by the Issuer in respect of any non cash

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dividend, the cash value shall be as determined by the Calculation Agent; and (b) in case of a rights issue, the cash value of such Rights issue as determined by the Calculation Agent. In this case the dividend amount is subtracted from **"P_{t-1}"**.

- *"N"* means the actual number of Observation Days.
- **Observation Day** means each Scheduled Trading Day during the Observation Period, whether or not such day is a Disrupted Day.
- **Observation End Date** means the Valuation Date.
- **Observation Period** means the period from, but excluding, the Trade Date (Observation Day t = 0) to, but excluding, the Observation End Date (Observation Day t = N) and the Valuation Date.

Market Disruption Event:	Section 6.3 of the ISDA Definitions should updated and subject to any statements applicable to variance swap transactions involving Japanese shares or indices, as published by ISDA from time to time.
Method of Adjustment:	Calculation Agent Adjustment
Extraordinary Events	
Consequences of Merger Events:	**Share-for-Share** – Alternative Obligations **Share-for-Other** – Cancellation and Payment **Share-for-Combined** – Calculation Agent Adjustment
Composition of Combined Consideration:	Not Applicable
Nationalization, Insolvency or Delisting:	Negotiated Close-out
Settlement:	Cash
Cash Settlement Payment Date:	The Termination Date
Settlement Currency:	EUR
Calculation Agent:	JP Morgan Securities Limited
Independent Amount :	0
Exchange:	Euronext Paris
Related Exchange:	Not Applicable
Business Days:	Paris
Documentation:	ISDA Master Agreement (together with any Credit Support Annex) and a Confirmation for this Transaction. 2006 ISDA Definitions and 2002 ISDA Equity Derivatives Definitions ("Equity Definitions") apply unless otherwise stated.
Non-Reliance:	Applicable
Agreements and Acknowledgments Regarding Hedging Activities:	Applicable
Additional Acknowledgments:	Applicable
Governing law:	English law

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4. Why the single stock variance swap market shut down

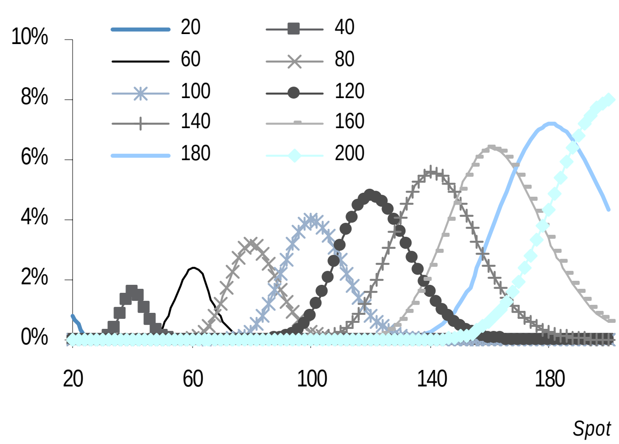
As discussed in section 1, market makers suffered heavy losses on their single stock variance swap positions during the 2008 volatility surge, as their hedges underperformed. Market makers' books were generally short single stock variance swaps, as the prevailing client flow prior to the crisis was skewed to buying variance swaps on single stocks and selling variance swaps on indices to capture the implied correlation premium (see the JPM primer on correlation trading). In order to hedge their variance swap books, market makers were holding portfolios of single stock options and delta-hedging daily.

The hedge held by market-makers consisted of a portfolio of options built in such a way to have constant dollar gamma both for movements in the stock prices and for the passage of time. This portfolio can be theoretically created by combining an infinite number of options with strikes spanning all possible values of the stock and the same maturity as the variance swap. Figure 3 shows the dollar gamma profile of individual options of different strikes. Weighting the options according to $1/\text{Strike}^2$ (see the JPM primer on variance swaps for an in-depth explanation of dollar gamma, gamma P/L and variance swap replication), creates a portfolio with the flat gamma profile needed to hedge a variance swap.

However, the static hedge has some practical limits. First, it is impossible to trade the infinite number of options of infinitesimally close strikes required by the theory, as only a limited set of strikes is available for trading. Second and most important, the liquidity for deep out-of-the-money options is limited, restricting the range of option strikes which can be actively traded. This means that market makers are unable to buy the complete theoretical hedge, and instead have to use a portfolio comprised of a limited number of options. The resulting portfolio hedges the variance swap well within a range of asset levels near the spot at inception, but not outside this range. Figure 4 shows the dollar gamma profile of holding portfolios of 1, 2 and 5 options, and illustrates the limited range of spot levels for which the dollar gamma profile is flat.

Figure 3: The dollar gamma of individual options depend on their moneyness

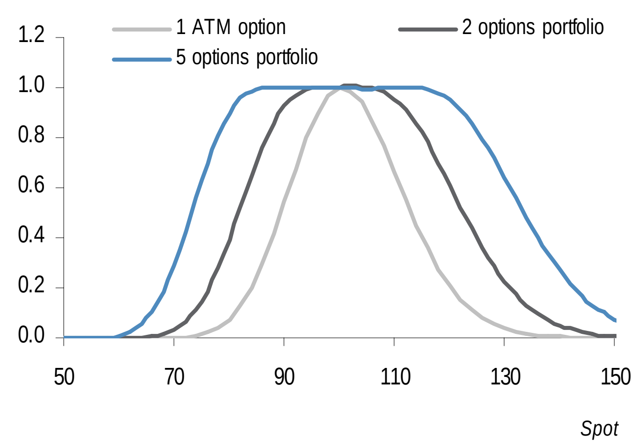
$ gamma (as a % of spot)



Source: J.P. Morgan Equity Derivatives Strategy.

Figure 4: A portfolio of options weighted by 1/strike2 has a flat dollar gamma profile, within a range of stock prices

$ gamma



Source: J.P. Morgan Equity Derivatives Strategy.

Most brokers thought that the restricted portfolio was a good hedging solution for replicating variance swaps, as it was cheap and easy to trade, and neutralised their risks for a wide range of stock prices, encompassing all but the most extreme scenarios. However, the 2008 crisis led to large drops in single stock prices, and many market makers found themselves un-hedged in the new trading range (Figure 5).

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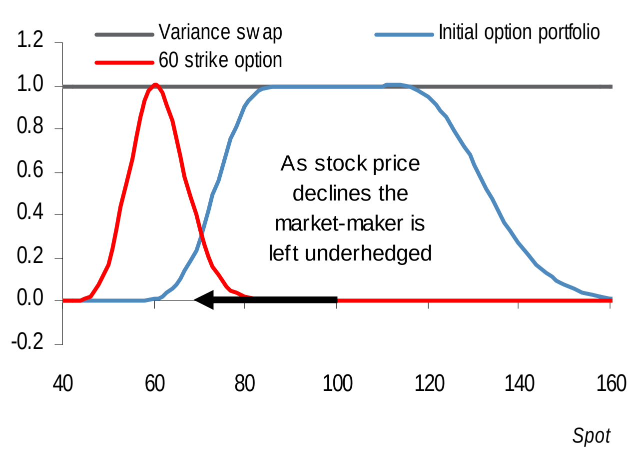
After the market declined, many single stock option desks became forced buyers of low strike options, in order to manage the gamma and vega risk of the variance swap positions in their books. In fact, by selling variance swaps, the traders had committed to deliver the P/L of a constant dollar gamma portfolio, irrespective of the spot level, but their replicating portfolio did not have sufficient dollar gamma at the new spot levels. Market makers were therefore forced to buy low strike options at the post-crash volatility level, which was much higher than the one prevailing when they sold the variance swap (Figure 6), and therefore incurred heavy losses.

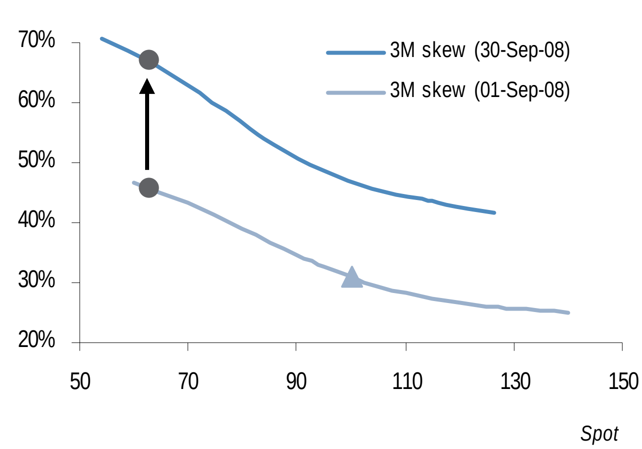
Not re-hedging the gamma risk was not a possibility, as this would have left the books exposed to potentially catastrophic losses if the stock prices declined further, and volatility continued to increase. The convexity of the variance swap payoff further exacerbated the downside risk. This situation led to large losses for many market-makers in the single stock variance swap markets. In turn this led banks to re-assess the risk of making markets in these instruments and to a substantial shutdown of the single stock variance swap market.

Figure 5: As the stock declines below the range where the hedge delivers a flat dollar gamma, the market maker needs to buy more options to manage the gamma risk



Source: J.P. Morgan Equity Derivatives Strategy.

Figure 6: This leads to a loss, as the volatility of options with low strikes have surged, while the fair variance swap was fixed based on the previous skew

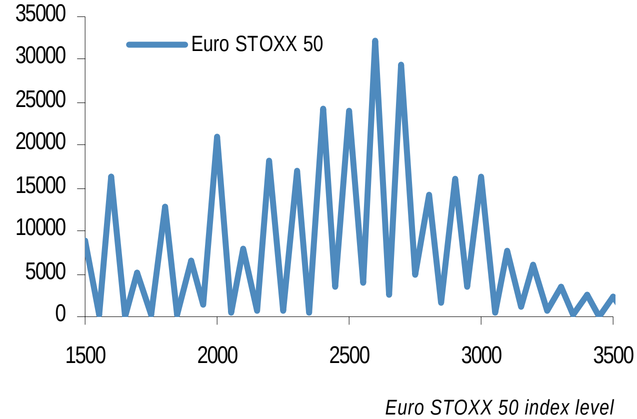


Source: J.P. Morgan Equity Derivatives Strategy.
Example based on Santander implied volatility data and stock price returns

While the single stock variance swap market essentially came to a halt following the 2008 market meltdown, index variance swap markets did not experience a similar disruption and were actively traded throughout the crisis, despite a widening of their bid-ask spreads. Index variance swaps continued to trade because of the high liquidity and depth of the index options markets. A wider range of OTM strikes are listed for index options compared to single stock options. For example, for the Euro STOXX 50 options are listed down to a strike of 250 (circa 10% of current spot!), although liquidity does not reach this far. Figure 7 shows the recent average daily volume for Euro STOXX 50 Dec-10 strike options, which is reasonable for a broad strike range. Another reason the index variance swap market continues to trade is that the 'gap risk' of a sudden large decline is significantly lower for indices than for single stocks. Figure 8 shows the largest daily decline for the Euro STOXX 50 index compared to its current constituents, on all available price history since Jan-90; the index had a smaller worst daily decline than any of its constituents.

Figure 7: The range of strike for which options are liquid on the Euro STOXX 50 index allows variance swaps to be hedged effectively

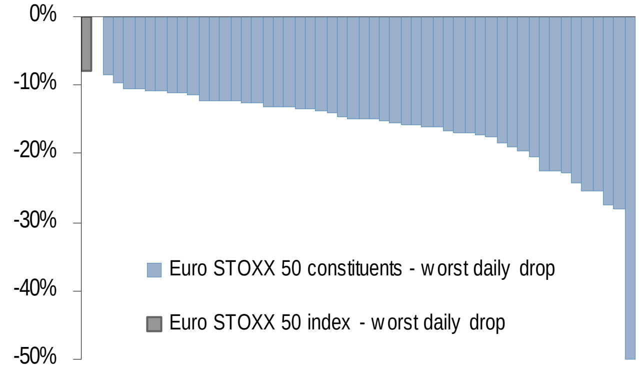
1M average Dec-10 daily option volume (number of contracts)



Source: J.P. Morgan Equity Derivatives Strategy. Data as of 1 June 2010.

Figure 8: The worst 1-day return on the Euro STOXX 50 index is smaller than that of each one of its current constituents

Worst 1-day returns (all available price history since Jan-90)



Source: J.P. Morgan Equity Derivatives Strategy.

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5. Hedging a volatility swap

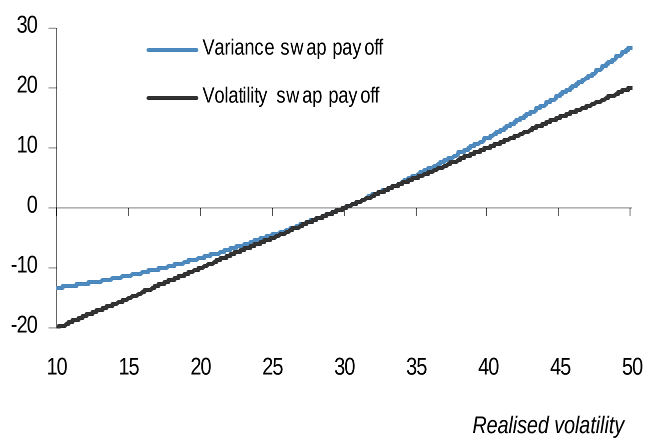
As we mentioned in the previous section, delta-hedging options leads to a P/L linked to the variance of returns rather than volatility. To achieve the linear exposure to volatility which volatility swaps provide it is therefore necessary to dynamically trade in portfolios of options, which would otherwise provide an exposure to the square of volatility. A volatility swap can be thought as a non-linear derivative of realised variance, the 'underlier' that can be traded through portfolios of delta-hedged options.

Some authors[2] initially suggested dynamically trading variance swaps to hedge volatility swaps, a solution which at least in theory would work. The idea is to trade in and out of variance swaps in order to replicate the square root of variance payoff of the volatility swap. As shown in Figure 9, the volatility swap payoff can be locally approximated by a variance swap, where the variance swap begins to outperform the further realised volatility moves from the initial strike.

As Derman *et al.* point out, this can be seen as analogous to replicating the non-linear payoff of an option with the underlying which is linear in the stock price[3]. Thus, the volatility swap could theoretically be replicated through "delta-hedging" by trading dynamically in the variance swap, where the "delta" is the sensitivity to the instruments' underlying, namely realised variance. Changes in this volatility "delta" will depend on the investor's estimate of volatility of volatility.

Figure 9: The linear payoff function of a volatility swap can be locally approximated by the convex variance swap payoff

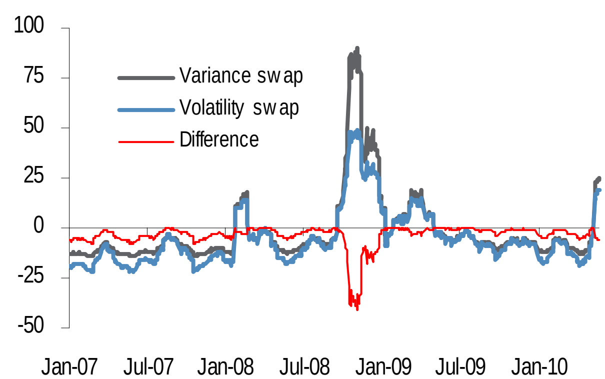
Payoff in vegas for K_{Var}=K_{Vol}=30%



Source: J.P. Morgan Equity Derivatives Strategy.

Figure 10: The convexity of a variance payoff leads to more extreme payoffs during a volatility spike

Historical payoff in vegas for 1M swap with K_{Var}=K_{Vol}=30%



Source: J.P. Morgan Equity Derivatives Strategy.

In practice it is not necessary (or practical) to trade variance swaps in order to hedge a volatility swap. A smaller portfolio of delta-hedged options can be used for the dynamic hedge. A volatility swap can be replicated using a delta-hedged portfolio of options, where the portfolio of options is dynamically rebalanced to replicate the vega and gamma profile of the volatility swap across the range of spot prices. One possible approach to hedging the volatility swap is to trade delta-hedged ratio strangles (e.g. short 1.5 80% strike puts and short one 120% call to hedge a long volatility swap), where the ratio and strikes are set in order to minimise the net exposure to volatility across the skew (i.e. to attempt to match the vega profile of the options to the volatility swap over a range of anticipated spot levels). Since the vega exposure of the strangle and volatility swap differ as the spot changes, the strangles will have to be re-striked when the net exposure to volatility exceeds the trader's tolerance.

[2] For example, see "More Than You Ever Wanted to Know About Volatility Swaps", E. Derman et al., March 1999

[3] To be more precise, it is the opposite of this action where an investor tries to replicate the linear stock value by trading dynamically in options.

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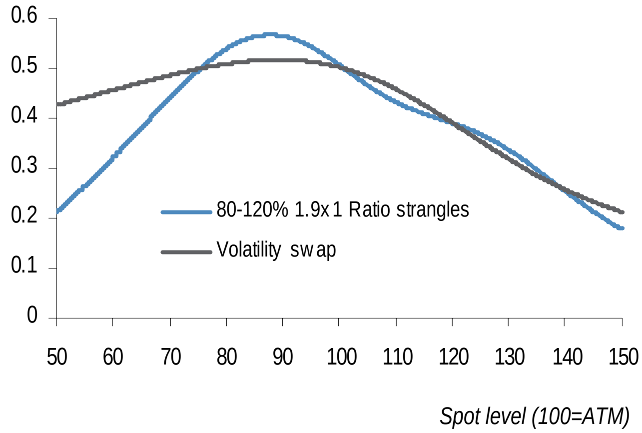
For example, we can see in Figure 11 and Figure 12 below how the vega and gamma sensitivity of the volatility swap compares to a sample ratio strangle chosen to minimise the error for near-the-money vega exposure for an assumed level of volatility and skew. Note that the preferred notional allocated to the strangle, strikes used and the ratio of puts to calls will depend on the shape of the implied volatility skew at the time the hedge is put in place. Additionally, it may not be possible to simultaneously replicate both vega and gamma well over a broad range of spot levels with this approach, as is the case in the example below where the chosen portfolio poorly replicates the gamma exposure of the volatility swap below the spot.

Figure 11: Vega sensitivity across spot levels

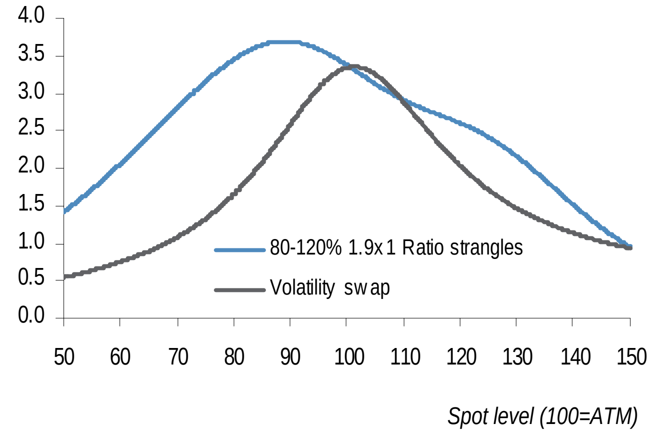
*Vega sensitivity**



Source: J.P. Morgan Equity Derivatives Strategy
* Based on 1-year volatility swap with 6-months remaining, 30% ATM implied volatility, 4% 90-100% convex shaped skew.

Figure 12: Dollar gamma sensitivity across spot levels

*Dollar gamma sensitivity**



Source: J.P. Morgan Equity Derivatives Strategy
* Based on 1-year volatility swap with 6-months remaining, 30% ATM implied volatility, 4% 90-100% convex shaped skew.

This requirement to re-strike the hedge adds risk to the replication process, as the new strangle may be initiated at significantly different volatility levels if the volatility surface has shifted. Additionally, re-striking causes the market maker to incur transaction costs multiple times on the hedge. The risk of gains/losses incurred when re-striking the hedging portfolio will depend on the volatility of volatility, as higher volatility of volatility environments will lead to larger shifts in the pricing of the options used to hedge the volatility swaps. This can cause market makers to have significant uncertainty on the costs of their hedge. As a result, we would expect the bid-ask spreads for volatility swaps to generally be wider than for other volatility products like options and variance swaps.

6. Sensitivities and mark-to-market

In this section we consider the Greeks for volatility swaps, giving information about the sensitivity of volatility swaps to various market variables. We work directly by differentiating a theoretical mark-to-market value of the volatility swap contract. At the end of this section we discuss complications in the mark-to-market value of the volatility swap to explain why the values shown in this section are theoretical. Note, for simplicity of exposition we assume a world with zero interest rates; alternatively in the presence of non-zero rates, the following parameters represent the *forward* Greeks and would have to be discounted by the appropriate discount factor. In analogy with the Greeks for vanilla options, we return to considering realised volatility and volatility swap strikes in percentage terms rather than the standard whole-number units.

The value of a volatility swap, per unit vega-notional, at time t is given by:

$$P_t = \sqrt{\sigma^2_{Expected,t}} - K$$

where K is the initial (fixed) volatility swap strike and $\sigma_{Expected,\,t}$ is the expected realised volatility at time t (where t is between trade inception and maturity). We retain the square root sign over the expected squared volatility in the price expression to emphasize that the sum of squared terms that comprise the expected realised volatility (see below) cannot be extracted individually. This expected volatility can be expressed as a combination of the accrued realised volatility to-date and future expected volatility. Note also that intra-day there is a term representing the square of the move which will act to give the volatility swap delta on an intra-day basis.

Box 4: Expected realised volatility on a volatility swap contract

$$\sigma^2_{Expected,t} = \frac{t-1}{T}\sigma^2_{0,t-1} + \frac{252}{T}\left[\ln\left(\frac{S_t}{S_{t-1}}\right)\right]^2 + \frac{T-t}{T}y^2$$

where $\sigma_{0,t-1}$ is the annualised realised volatility accrued to day $t-1$, and y is the expected future volatility (which we refer to hereafter as the volatility swap "implied volatility") at day t for the expiry at T, S_{t-1} is the value of the underlying at the close on day $t-1$, and S_t is the value of the underlying at the valuation time on day t

Note this "implied volatility" y is a theoretical construct for the purposes of illustrating the Greeks. Unlike for a variance swap, y is not necessarily equal to the strike for a new volatility swap initiated at t and expiring at T, since volatility is not additive like variance.

The Greeks of the volatility swap can then be calculated by differentiating P_t.

Vega

A somewhat unintuitive result is that the vega exposure of the volatility swap decreases for higher levels of realised volatility, but increases (asymptotically) for increasing levels of implied volatility (while vega exposure remains constant for variance swaps with respect to both realised volatility and the strike). We illustrate the sensitivity of the price function given above with respect to the theoretical implied volatility (y) to derive the volatility swap's vega sensitivity:

Box 5: Volatility swap vega sensitivity

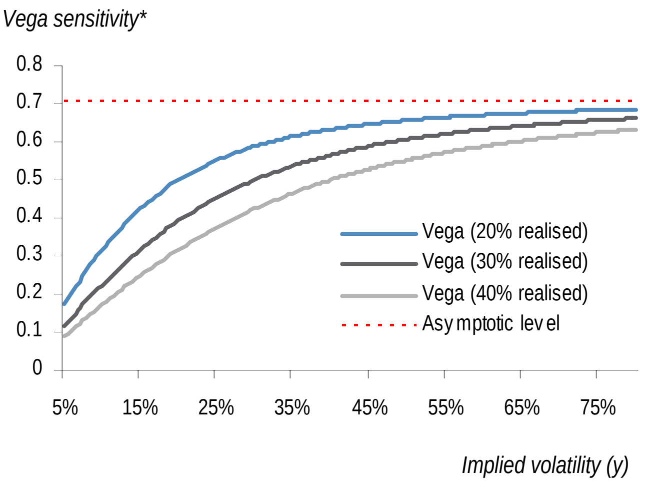
$$Vega = \frac{\partial P}{\partial y} = \frac{\frac{T-t}{T}y}{\sqrt{\sigma^2_{Expected,t}}}$$, where $\sigma^2_{Expected,t}$ is defined in Box 4 above

The first observation we can make from this formula, is that as $t \rightarrow T$ the expression for vega sensitivity approaches zero. This matches our expectation that, as the contract approaches maturity, the volatility swap price becomes insensitive to the level of implied volatility, as the accrued realised volatility is locked into the P/L.

Another interesting observation from the above is that if $\sigma = y$ (i.e. the past realised volatility is equal to the current implied volatility) once the current day's return has been accumulated into realised volatility, then vega becomes locally insensitive to the level of realised and implied volatility, and is simply a function of the remaining time to maturity (i.e. the expression in Box 5 reduces to $Vega = \frac{T-t}{T}$). Note also that the vega exposure has no relationship to the initial volatility swap strike in this case. This means, for example, that for a volatility swap with a strike of 30, the vega sensitivity is the same whether $\sigma = y = 10$, $\sigma = y = 30$, *or* $\sigma = y = 100$.

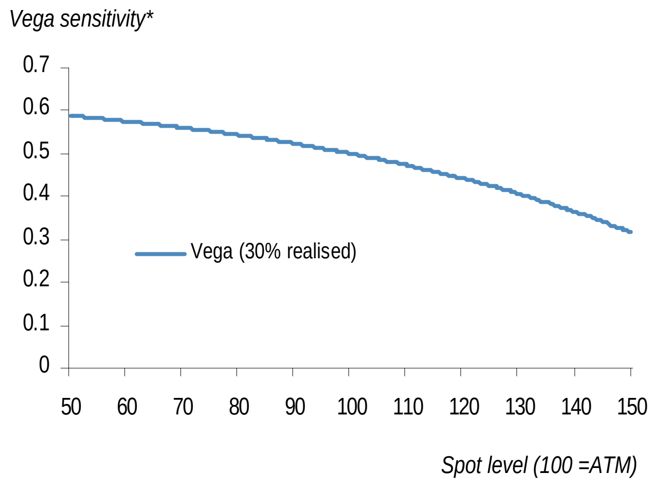
If we hold σ constant, the vega sensitivity of the volatility swap increases for higher levels of implied volatility (y). Conversely, for a given level of y, the volatility swap vega sensitivity declines for increases in realised volatility (σ). In Figure 13 below we illustrate a numerical example of the impact of a change in implied volatility (y) if realised volatility is held constant (at 20%, 30% and 40%) on the vega exposure of the volatility swap. In all cases, we assume a 1-year volatility swap struck 6 months ago.

Figure 13: Volatility swap vega sensitivity for varying levels of implied and realised volatility



Source: J.P. Morgan Equity Derivatives Strategy.
* Curves illustrate a 1-year volatility swap with 6-months remaining, assuming varying levels of realised volatility to-date

Figure 14: The presence of skew causes the vega sensitivity to increase as the spot falls, all else remaining equal



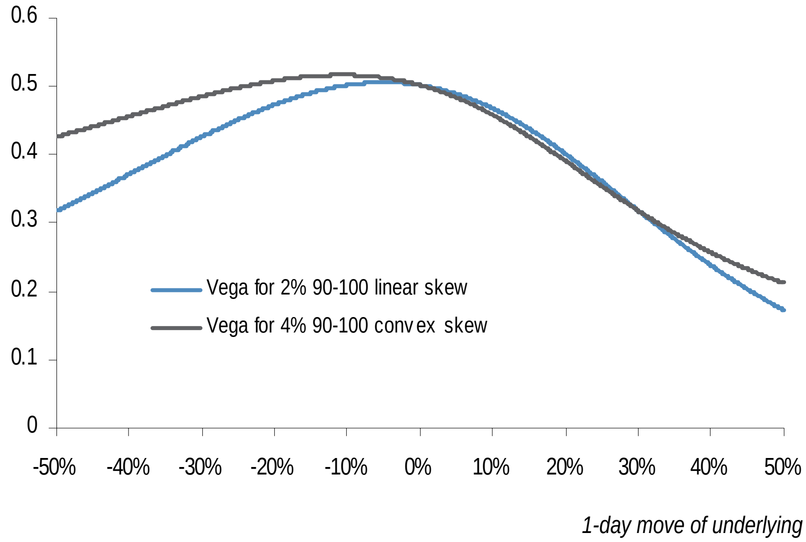
Source: J.P. Morgan Equity Derivatives Strategy
* Based on 1-yr volatility swap with 6-months remaining, 30% ATM implied volatility, 3% 90-100% linear skew. Assumes implied volatility slides along the skew, but realised volatility remains fixed.

Moreover, from Box 5 we can gain insights on the impact of skew on the vega exposure of the volatility swap. If we assume the implied volatility (y) of the volatility swap slides along a downward sloping skew as the spot moves, and hold constant the realised volatility level, the vega sensitivity of the volatility swap increases with a decline in the spot (Figure 14).

Thus, we can see that **increases in realised and implied volatility have opposing effects on the vega sensitivity of a volatility swap**. Combining the effects of realised volatility (which is inversely related to vega sensitivity) and implied volatility (which is positively related to vega sensitivity), in Figure 15 below we look at vega exposure of a volatility swap following a large one-day move in the underlying asset. In this graph we assume that the implied volatility level slides along the skew, while the one-day move adds to the accumulated realised volatility.

Figure 15: Vega sensitivity can decline for large moves in the underlying, making volatility swaps less "toxic" than variance swaps

*Vega sensitivity**



Source: J.P. Morgan Equity Derivatives Strategy.

* Based on 1-year volatility swap with 6-months remaining, 30% ATM implied volatility, 30% annual realised volatility to-date.

In this example, we note that the **vega exposure tends to decrease for a large move in the underlying asset – whether the move is up or down – but not symmetrically**. The decline in vega sensitivity occurs because the effect of increased realised volatility dominates the effect of an increase in implied volatility from a slide along the skew. However, the extent to which the effects of changes in realised volatility will dominate those of implied volatility in general for a large move in the underlying, will be lessened in environments with steeper skew (for downside moves in the underlying only) and higher skew convexity (for both upside and downside moves).

By contrast, the vega exposure of a variance swap (with respect to the strike) depends only on the time to maturity, but not on the level of realised volatility or implied volatility. This property ensures that volatility swaps have less "tail risk" than variance swaps, since the size of further potential mark-to-market losses is lessened after a large move in the underlying.

Delta

As for variance swaps, volatility swaps take on delta only intra-day if we assume the implied volatility (y) has no sensitivity to the level of the underlying. The expression for delta is given in Box 6, and we can make a couple of interesting observations from this formula:

Box 6: Volatility swap delta and dollar delta

$$\Delta = \frac{\partial P}{\partial S_t} = \frac{\frac{252}{T}\ln\left(\frac{S_t}{S_{t-1}}\right)}{S_t\sqrt{\sigma^2_{Expected,t}}}$$, or by multiplying by S_t, we obtain the dollar delta: $$\Delta_\$ = \Delta S_t = \frac{\frac{252}{T}\ln\left(\frac{S_t}{S_{t-1}}\right)}{\sqrt{\sigma^2_{Expected,t}}}$$

First, once we accrue the current day's move into the past realised volatility after the close, we have $S_t=S_{t-1}$ which means the *ln* of the ratio of the two is zero. This makes the entire expression for delta reduce to zero. In other words, as mentioned above, volatility swaps only take on delta intra-day. It also means that delta is zero when the underlying is trading intra-day at the previous day's closing level.

Secondly, we can see that the delta is positive for positive current day returns and negative for negative returns, since the numerator will reflect the sign of the current day return while the denominator is always positive. This also makes intuitive

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sense as we would expect the value of the volatility swap to increase for a larger magnitude of returns whether the returns are positive or negative. When the current day return becomes more negative, it adds more to realised volatility, which results in a higher profit for the long volatility swap; hence the volatility swap has negative delta once the return is negative.

Gamma

The expression for gamma is somewhat menacing and appears in the footnote[4]. If we differentiate the dollar delta formula to get the dollar gamma, we note the volatility swap retains gamma linked to the expected realised volatility, even outside of its intraday exposure (see the 2nd equation in Box 7).

Box 7: Volatility swap dollar gamma

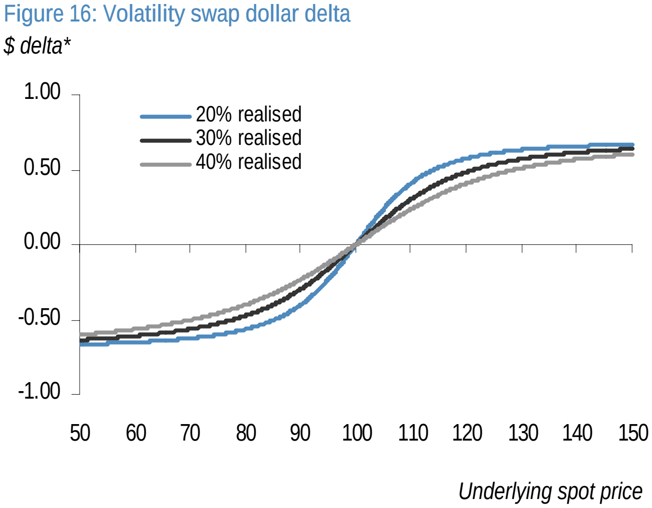
$$\Gamma_{\$} = S_t \frac{\partial \Delta_{\$}}{\partial S_t} = \frac{\frac{252}{T}}{\sqrt{\sigma^2_{Expected,t}}} - \frac{\left[\frac{252}{T}\ln\left(\frac{S_t}{S_{t-1}}\right)\right]^2}{\left(\sigma^2_{Expected,t}\right)^{3/2}}$$

, where $\sigma^2_{Expected,t}$ is as defined in Box 4.

Or, at the end of day where $S_t=S_{t-1}$, this expression reduces to $\Gamma_{\$} = \frac{252}{T\sqrt{\sigma^2_{Expected,t}}}$

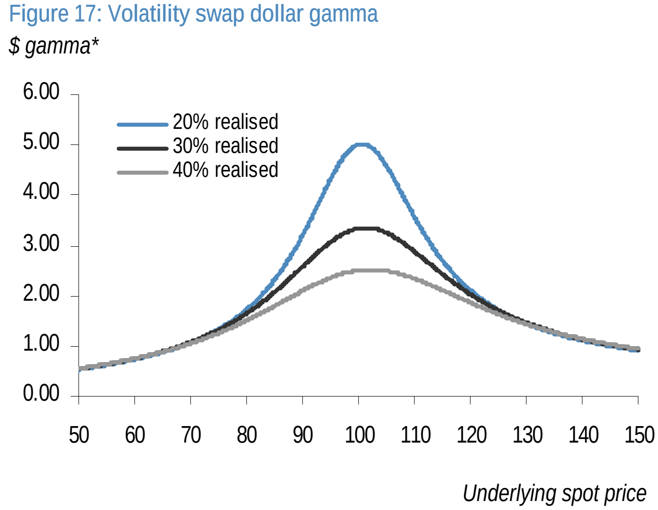
From the expression in Box 7 above we note that, unlike variance swaps, **not only is the dollar gamma exposure of the volatility swap non-constant, but it is dependent on the levels of both the past realised and future implied volatility**. Moreover, as we noted in the analysis of vega sensitivity, the volatility swap appears to be less "toxic" than variance swaps as **the dollar gamma decreases following large moves in the spot, reducing the risk of further mark-to-market losses**. In Figure 16 and Figure 17 below, we illustrate the dollar delta and dollar gamma for sample levels of realised volatility.

Figure 16: Volatility swap dollar delta



Source: J.P. Morgan Equity Derivatives Strategy.
* Based on 1-year volatility swap with 6-months remaining, prior day's closing spot level of 100. Assumes convex 3% 90-100 skew for the 20% realised case, 4% 90-100 for 30% realised, and 5% 90-100 for 40% realised.

Figure 17: Volatility swap dollar gamma



Source: J.P. Morgan Equity Derivatives Strategy.
* Based on 1-year volatility swap with 6-months remaining, prior day's closing spot level of 100. Assumes convex 3% 90-100 skew for the 20% realised case, 4% 90-100 for 30% realised, and 5% 90-100 for 40% realised.

[4] $$\Gamma = \frac{\partial^2 P}{\partial S_t^2} = \frac{\frac{252}{T}\left[1-\ln\left(\frac{S_t}{S_{t-1}}\right)\right]}{S_t^2\sqrt{\sigma^2_{Expected,t}}} - \frac{\left[\frac{252}{T}\ln\left(\frac{S_t}{S_{t-1}}\right)\right]^2}{S_t^2\left(\sigma^2_{Expected,t}\right)^{3/2}}$$

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Theta

Calculating the theta of the volatility swap gives:

Box 8: Volatility swap theta

$$\theta = \frac{\partial P}{\partial t} = \frac{\sigma_{0,t-1}^2 - y^2}{T\sqrt{\sigma_{Expected,t}^2}}$$

We note from this expression that theta can be positive or negative, depending on whether the past realised or future implied term is larger. If the past realised volatility exceeds the future implied volatility, theta is positive (i.e. negative 'theta bleed'), so the long volatility swap position is paid for time decay.

Mark-to-market

As discussed in section 7 below, the pricing of a volatility swap requires an estimate of volatility of volatility, leading to model dependency. This complication will also lead to uncertainty on the mark-to-market levels of the volatility swap over its lifetime. However, greater certainty will be gained as the swap approaches maturity, since the mark-to-market price should converge to the P/L based on past realised volatility. Variance swaps do not have this ambiguity, due to the additivity of variance, and can be priced as the sum of realised and implied (i.e. expected future realised) variance less the strike.

To determine the mark-to-market level of a volatility swap, traders can effectively price a variance swap (which will reflect the realised volatility to-date) and apply a convexity adjustment for the difference in the payoff function. This convexity adjustment will be dependent on the trader's volatility of volatility model, and thus will lead to some uncertainty on the value of a volatility swap prior to expiry.

Novation

The lack of standardised models has practical implications for end investors that go beyond simple pricing considerations. In fact, the lack of a consensus on the implied volatility of volatility makes the mark-to-market of these instruments extremely model-dependant, making novation essentially impossible. The process of novation replaces one party to a contract with a new party, transferring both rights and duties, and requiring the consent of both the original and the new party.

A client looking to close a volatility swap trade and be left with no exposure will therefore have to close his position with the initial counterparty. The client would not be able to novate the exposure after trading with someone else, and would therefore keep economic exposure to both counterparties, and be subject to the risk of potentially different mark-to-market on the two positions.

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7. Pricing of volatility swaps

As discussed in section 5, the hedging of volatility swaps requires dynamically trading options, and the amount of re-hedging needed is a function of the expected volatility of volatility. Because of this, models describing the behavior and evolution of volatility are needed in order to determine the fair value of a volatility swap. Such models are known as stochastic volatility models, and a vast collection of technical and academic literature deals with their specification, calibration and characteristics.

Several stochastic volatility models have been proposed in the last 20 years, the simplest being the Heston and GARCH(1,1) models. However, as of today there is no general consensus on which model best reflects the behaviour of volatility. Market participants use their in-house stochastic volatility model specification and constantly modify their models to improve their reliability and performance. The lack of standardisation leads to potential differences in the pricing of volatility swaps which are wider than that for more standard products such as vanilla options.

Another consequence of this situation is that implied volatility of volatility, the market estimation of the future variability of volatility and one of the most important parameters for pricing volatility swaps, is not as easily observable as implied volatility for vanilla options. There are two main reasons why implied volatility of volatility is difficult to observe while there is a good consensus for the level of implied volatility. First, vanilla option prices can be observed in the listed (i.e. exchange traded) market for a large universe of stocks, and second there is a widely accepted market standard model that can be used to extract the implied volatilities – the Black-Scholes model. The absence of an easily observable market for volatility of volatility products on single stocks and the lack of a 'market standard' model, make implied volatility of volatility essentially non-observable. This leads to potentially wide ranges in the assessment of implied volatility of volatility and related products between different brokers.

Nevertheless, it is possible to draw some general considerations on volatility swap prices which are model-independent. In particular, it is possible to define a range within which the volatility swap fair strike must trade (Box 9).

Box 9: Boundaries for volatility swap fair prices

$$ATMF_0 \leq VOL_0 \equiv \sqrt{E_0(v)} \leq VAR_0 \equiv E_0\left(\sqrt{v}\right)$$

where $ATMF_0$ is the at-the-money forward implied volatility at trade inception, VOL_0 is the volatility swap fair strike, VAR_0 is the realised variance swap fair strike, v is the variance of the stock and E_0 indicates the expectation at trade inception.

The reason why the fair value of a variance swap cannot exceed the variance swap fair strike can be grasped by considering the payoff of the spread of a volatility swap and a variance swap (Figure 9 on page 12). A variance swap's payoff is always higher than that of a volatility swap with the same strike, except when the realised volatility over the contract is equal to the strike, when both contracts deliver a payoff of zero. If the fair strike of a volatility swap was higher that that of a variance swap it would be possible to create a riskless arbitrage by buying the variance swap and selling the volatility swap. The absence of such arbitrage opportunities is one of the founding assumptions in derivatives pricing theory. Therefore under the no-arbitrage assumption the right side of the inequality in Box 9 must hold.

The comparison of volatility swaps and variance swaps also leads to another interesting consideration, namely the existence of a direct link between volatility of volatility and the payoff of the spread of variance swaps to volatility swaps. If volatility of volatility is low then the spread is likely to have a relatively small payoff at expiry, as the volatility level will likely be close to the strike and the gain from the convexity of the variance swap compared to the linear volatility swap will be modest. In the (unrealistic) limit case where the volatility of volatility is zero, the spread between the payoffs will be zero. On the other hand, if volatility of volatility is elevated it is more likely that the spread will deliver a large payoff at expiry. Given that the fair value of volatility swaps and variance swaps will reflect these dynamics, **an increase in the implied volatility of volatility will increase the discount of volatility swaps relative to variance swaps.**

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Brockhaus and Long[5] worked out an approximate formula for quantifying the relationship between the fair strike of variance and volatility swaps (Box 10).

Box 10: Convexity adjustment for volatility swaps

$$E\left(\sqrt{v}\right) \approx \sqrt{E(v)} - \frac{Var(v)}{8E(v)^{3/2}}$$

where E(v) is the fair variance swap strike and Var(v) is the expected variance of the realised variance of the stock

The difference in price between the two instruments, is often referred to as a 'convexity adjustment' in the academic literature. The magnitude of the convexity adjustment is directly proportional to the variance of the stock variance, which is linked to the volatility of volatility. The term in the denominator of the convexity adjustment is the 3/2 power of the variance swap strike. For a fixed numerator (i.e. no change in volatility of volatility), the convexity adjustment will decline as the variance fair strike increases.

The convexity adjustment in Box 10 can be explicitly calculated once a stochastic volatility model is chosen and calibrated. The crucial parameter in the equation is Var(v), due to its high model dependency. Javaheri and Wilmott[6] provide detail for the calculation of this convexity correction under two simple stochastic volatility models, Heston and GARCH(1,1).

A key driver of the volatility swap pricing is the convexity of implied volatility skew. This skew convexity is linked to volatility of volatility, and an increase in skew convexity typically leads to a higher volatility of volatility. This implies that, based on the formula for the convexity adjustment in Box 10, a higher skew convexity translates into a larger discount for volatility swaps relative to variance swaps. However, an increase in skew convexity also causes the variance swap premium to at-the-money forward implied volatility to increase, as described in the JPM primer on variance swaps. Therefore, while an increase in skew convexity will lead to a larger convexity adjustment to variance swaps, it is more difficult to draw general conclusions about how it will affect the volatility swap premium to at-the-money forward volatility.

Rules of thumb

A couple of rules of thumb exist for the pricing of volatility swaps. The first rule of thumb puts the size of the convexity adjustment at roughly half the difference between at-the-money-forward volatility and the theoretical variance swap strike. Thus, for underlying assets with available variance swap levels one could approximate the fair volatility swap strike as the midpoint between the variance swap strike and ATMF implied volatility. Another rule of thumb prices the volatility swap strike at 1.07 times the at-the-money forward implied volatility level.

[5] 'Volatility swaps made simple'; O. Brockhaus, D. Long; 2000
[6] 'GARCH and volatility swaps'; A. Javaheri, P. Wilmott; 2002

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8. Applications

Single stock volatility swaps can be used in the implementation of pretty much any volatility trading strategy where single stock variance swaps were used (see the JPM primer on variance swaps for more details on these strategies). In this piece we focus on three applications in particular: single stock pair-trades, volatility dispersion trades and individual company credit-equity trades.

Single stock volatility pairs

Volatility swaps can be used to trade spreads between single stock volatilities, in order to monetise relative value. Trading volatility pairs using volatility swaps rather than delta-hedged options removes the hurdle of managing the delta hedges and allows investors to isolate exposure to realised volatility. Additionally, volatility swaps eliminate any path dependence of the P/L and ensure that the exposure to realised volatility is maintained irrespective of the spot level of the two stocks.

Investors can identify pairs based on their fundamental views on the relative riskiness of the two companies and of the expected future realised volatility. Upcoming events and catalysts should be taken into consideration when trading volatility pairs. An alternative approach is to use quantitative models to identify volatility pairs, such as the JPM Volatility Pairs Model. We produce a daily Volatility Pairs Report[7] covering all possible pairs within 11 broad-based sectors. The report ranks the pairs according to the difference between the implied and realised z-scores. See Volatility pairs for details on the model specifications.

Single company equity volatility versus credit (CDS)

Investors can consider trading volatility against credit default swaps (CDS) to exploit potential discrepancies between the equity and credit markets. In fact, while credit and equity have a very strong relationship over the long run, there can be instances when in the short term the two asset classes price risk in a substantially different way, giving rise to relative value opportunities. For example, credit spreads started rising well before equity volatility in 2008, as credit reflected the risk of a major crisis ahead of equity.

When considering individual companies, both volatility swaps and CDSs should reflect company specific risk and the two instruments should therefore be correlated. This relationship can be formalised by modeling the relationship of a company's share price to the price of its credit and equity options, for example by using reduced form or capital structure models.

JPM developed a propriety reduced form model - the CEV model (see A framework for credit-equity investing for more details) - which allows investors to identify companies where credit and equity market pricing has diverged. We publish a daily report[8] which provides the model output for a vast universe of stocks and provides detailed company by company analysis.

[7] Volatility Pairs Report 3M and Volatility Pairs Report 1Y
[8] Global CEV credit-equity relative value

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Trading correlation using volatility swaps

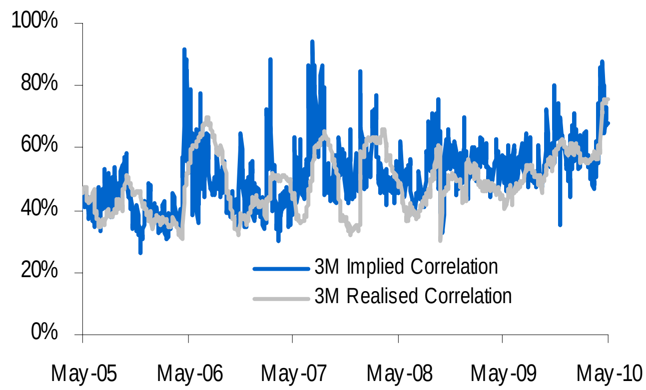
Equity correlation measures how much stock prices tend to move together. It provides the link between the volatility of an index and the volatilities of component stocks; described approximately by the formula:

$$\text{Index Volatility} \approx \sqrt{\text{Correlation}} \times \text{Average Single Stock Volatility}$$

By examining the relative levels of *implied* index and *implied* single-stock volatilities, it is possible to back out the level of forward-looking correlation being priced in by the market. Both implied and realised correlation are currently high relative to their average historical levels. This could be because correlation is biased to fall or perhaps because the underlying environment has changed and we should expect correlation to remain higher. As with implied index volatility, this ***implied correlation*** tends to trade at a premium to that actually delivered (Figure 18).

Figure 18: Euro Stoxx 50 implied correlation generally trades at a premium to realised correlation.

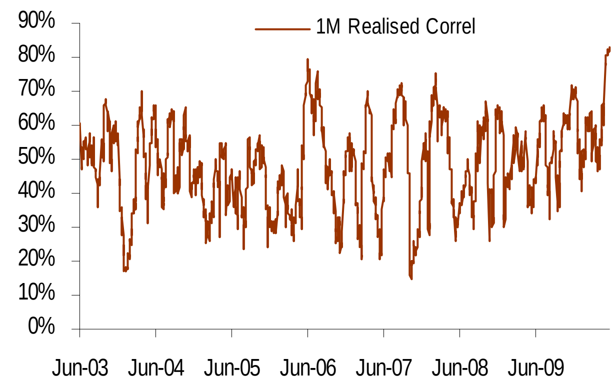
Correlation



Source: J.P. Morgan Equity Derivatives Strategy.

Figure 19: Recent short-dated realised correlation has been particularly high for the Euro Stoxx 50.

Euro Stoxx realised correlation



Source: J.P. Morgan Equity Derivatives Strategy.

The realised correlation of an *index* is simply an average across all possible pairs of constituent stocks. There are two ways of computing this average, the results of which drive the payoffs of the two principal vehicles for trading correlation.

- ***Average pairwise correlation:*** This is a simple equally weighted average of the correlations between all pairs of distinct stocks in an index. It is the payoff of a ***correlation swap***.

- ***Index correlation***: This is a measure of correlation derived from the volatility of an index and its constituent single stocks. Realised index correlation turns out to be equal to the weighted sum of constituent pairwise stock correlations, where the correlations are weighted by the product of the stock weights and their respective volatilities. This measure of correlation is the principal driver for the p/l of ***volatility dispersion trades***.

In practice these two correlation measures are very similar. The difference between the two represents the spread of volatilities and correlations across the index. If either all volatilities are the same, or if all pairwise correlations are the same, the difference will be zero.

Like volatility, correlation can itself be treated as an asset and traded in its own right. Selling correlation has historically been profitable, capitalising on the relative richness of index volatility. The spread between index implied and realised volatility has generally been positive and has consistently exceeded the spread between average implied and realised single-stock volatility. To take advantage of this we can sell index volatility and buy single-stock volatility in order to capture the implied correlation premium whilst hedging out some or all of the short volatility exposure. Alternatively, an investment that is long correlation (implied or realised) can be a good hedge against market risk. In this section, we investigate the use of volatility swaps in for trading correlation.

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We review two potential weighting schemes for correlation trades using volatility swaps

Box 11: Mean Volatility Ratio

Suppose a volatility dispersion trade is initiated with unit index vega notional and β of single-stock vega notional.

Let K_{Index} and K_i be index and single-stock volatility swap strikes, with σ_{Index} and σ_i the subsequent realised volatility and ω_i the weight of the ith stock in the index.

The p/l of a dispersion trade (combined short index volatility swap with long single stock volatility swaps) will be given by:

$$p/l = \left(K_{Index} - \sigma_{Index}\right) - \beta \sum_i \omega_i \left(K_i - \sigma_i\right) \quad = \left(K_{Index} - \beta \sum_i \omega_i K_i\right) - \left(\sigma_{Index} - \beta \sum_i \omega_i \sigma_i\right)$$

If we set the single-stock weighting factor $\beta_{MeanVolRatio} = \dfrac{K_{Index}}{\sum_i \omega_i K_i}$, then the first term of the p/l will be zero, leaving:

$$p/l \qquad = -\left(\sigma_{Index} - \frac{K_{Index}}{\sum_i \omega_i K_i} \sum_i \omega_i \sigma_i\right) = \sum_i \omega_i \sigma_i \left(\frac{K_{Index}}{\sum_i \omega_i K_i} - \frac{\sigma_{Index}}{\sum_i \omega_i \sigma_i}\right)$$

$$= \sum_i \omega_i \sigma_i \left(MVolR_I - MVolR_H\right) \quad \text{where } MVolR_I = \frac{K_{Index}}{\sum_i \omega_i K_i} \text{ and } MVolR_H = \frac{\sigma_{Index}}{\sum_i \omega_i \sigma_i}.$$

The ratios $MVolR_I$ and $MVolR_H$ can be seen as proxies for implied and realised correlation, respectively, however, as is clear from the correlation proxy $\rho_H \approx \dfrac{\sigma_I^2}{\left(\sum_i \omega_i \sigma_i\right)^2}$, these ratios actually represent the *square root of implied correlation* and the *square root of realised correlation*, respectively.

In deference to *"A New Framework for Correlation", 3 January 2007*, which introduced the mean variance ratio framework for variance swap dispersion trades, we will refer to the ratio of index implied volatility to weighted average single stock implied volatility as the **mean volatility ratio**.

The "mean volatility ratio" provides a simple characterisation of the profit or loss from a volatility swap dispersion trade. A short correlation trade, if weighted according to the mean volatility ratio, will generate a profit whenever realised correlation turns out to be lower than the level of implied correlation that was sold (Figure 20). While the mean volatility ratio-weighted dispersion trade does provide a payoff that is linked to correlation, it is equal to the square root of correlation as opposed to correlation itself (as discussed in Box 11 above). A further disadvantage of the mean volatility ratio framework is that the profit or loss will be sensitive to changes in volatility - more specifically, the initial vega exposure of the dispersion position will be equal to one minus the correlation.

It is possible to make the volatility swap dispersion trade vega neutral at inception by choosing the proper hedge ratio (the amount of index volatility that needs to be sold for every unit of long single stock volatility so that an increase in average single stock volatility is offset by the vega-weighted increase in index volatility resulting from this change).

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Vega Neutral at Inception

In order to make the trade vega neutral at inception one must choose the ratio of total single stock vega to index vega to be equal to the square root of correlation. i.e. $\text{Index Vega} = \sqrt{\text{Correlation}} \times \text{Average Single Stock Vega}$.

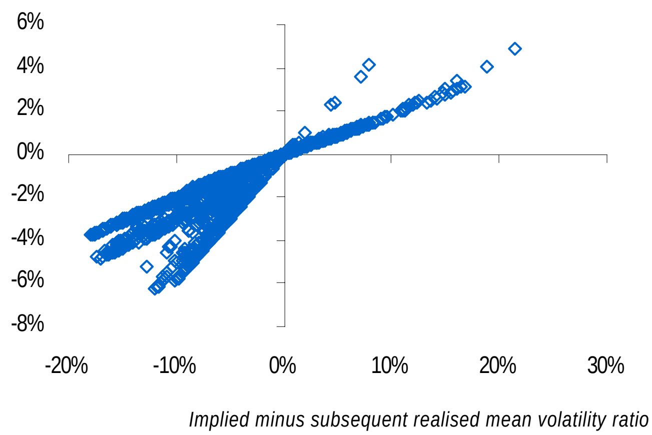
In other words, we need to set the single-stock weighting factor $\beta_{VegaNeutral} = \dfrac{1}{\sqrt{\rho_{Expected}}}$,

If expected correlation is best represented by the implied correlation proxy then

$\beta_{VegaNeutral} \approx \dfrac{1}{MVolR_I} = \dfrac{\sum_i \omega_i K_i}{K_{Index}}$ (the inverse of the original factor $\beta_{MeanVolRatio}$ introduced previously).

Figure 20: "Mean Volatility Ratio" provides a simple characterisation of the profit or loss from a volatility dispersion trade, with the same sign as the difference between implied and realised correlation

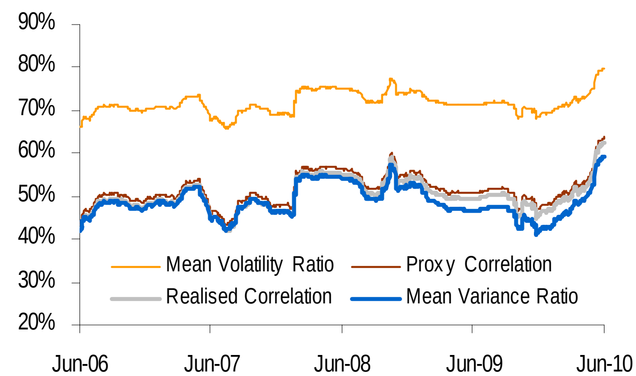
Profit / Loss assuming hypothetical implied vol swap levels (vegas)



Source: J.P. Morgan Equity Derivatives Strategy.

Figure 21: The relationship between different measures of correlation, including the "Mean Volatility Ratio" which is effectively the square root of the proxy correlation measure

Euro Stoxx 1-year realised correlation



Source: J.P. Morgan Equity Derivatives Strategy.

For a daily update of implied and realised correlation levels for global indices, please refer to our Daily Correlation Report.

For further details on trading correlation, please see previous publications from J.P.Morgan Equity Derivatives Strategy:

"A New Framework for Trading Index Correlation – Sector Impact on Index Volatility and Correlation", 17 February 2010

"S&P 500 Correlation Trade – A Trade to Profit from the Recent Recovery of Stock Fundamentals and Inefficiencies in the Index Options Market", 21 October 2009.

"Dispersion Trading and Volatility Gamma Risk – Analysis of Tail Risk in Dispersion Trades", 17 November 2008.

"A New Framework for Correlation – the Mean Variance Ratio", 3 January 2007.

"Correlation Vehicles – Techniques for trading equity correlation", 24 May 2005.

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Risks of common option strategies

Risks to Strategies:
Not all option strategies are suitable for investors; certain strategies may expose investors to significant potential losses. We have summarized the risks of selected derivative strategies. For additional risk information, please call your sales representative for a copy of "Characteristics and Risks of Standardized Options". We advise investors to consult their tax advisors and legal counsel about the tax implications of these strategies. Please also refer to option risk disclosure documents

Put Sale. Investors who sell put options will own the underlying stock if the stock price falls below the strike price of the put option. Investors, therefore, will be exposed to any decline in the stock price below the strike potentially to zero, and they will not participate in any stock appreciation if the option expires unexercised.

Call Sale. Investors who sell uncovered call options have exposure on the upside that is theoretically unlimited.

Call Overwrite or Buywrite. Investors who sell call options against a long position in the underlying stock give up any appreciation in the stock price above the strike price of the call option, and they remain exposed to the downside of the underlying stock in the return for the receipt of the option premium.

Booster. In a sell-off, the maximum realised downside potential of a double-up booster is the net premium paid. In a rally, option losses are potentially unlimited as the investor is net short a call. When overlaid onto a long stock position, upside losses are capped (as for a covered call), but downside losses are not.

Collar. Locks in the amount that can be realized at maturity to a range defined by the put and call strike. If the collar is not costless, investors risk losing 100% of the premium paid. Since investors are selling a call option, they give up any stock appreciation above the strike price of the call option.

Call Purchase. Options are a decaying asset, and investors risk losing 100% of the premium paid if the stock is below the strike price of the call option.

Put Purchase. Options are a decaying asset, and investors risk losing 100% of the premium paid if the stock is above the strike price of the put option.

Straddle or Strangle. The seller of a straddle or strangle is exposed to stock increases above the call strike and stock price declines below the put strike. Since exposure on the upside is theoretically unlimited, investors who also own the stock would have limited losses should the stock rally. Covered writers are exposed to declines in the long stock position as well as any additional shares put to them should the stock decline below the strike price of the put option. Having sold a covered call option, the investor gives up all appreciation in the stock above the strike price of the call option.

Put Spread. The buyer of a put spread risks losing 100% of the premium paid. The buyer of higher ratio put spread has unlimited downside below the lower strike (down to zero), dependent on the number of lower struck puts sold. The maximum gain is limited to the spread between the two put strikes, when the underlying is at the lower strike. Investors who own the underlying stock will have downside protection between the higher strike put and the lower strike put. However, should the stock price fall below the strike price of the lower strike put, investors regain exposure to the underlying stock, and this exposure is multiplied by the number of puts sold.

Call Spread. The buyer risks losing 100% of the premium paid. The gain is limited to the spread between the two strike prices. The seller of a call spread risks losing an amount equal to the spread between the two call strikes less the net premium received. By selling a covered call spread, the investor remains exposed to the downside of the stock and gives up the spread between the two call strikes should the stock rally.

Butterfly Spread. A butterfly spread consists of two spreads established simultaneously. One a bull spread and the other a bear spread. The resulting position is neutral, that is, the investor will profit if the underlying is stable. Butterfly spreads are established at a net debit. The maximum profit will occur at the middle strike price, the maximum loss is the net debit.

Pricing Is Illustrative Only: Prices quoted in the above trade ideas are our estimate of current market levels, and are not indicative trading levels.

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