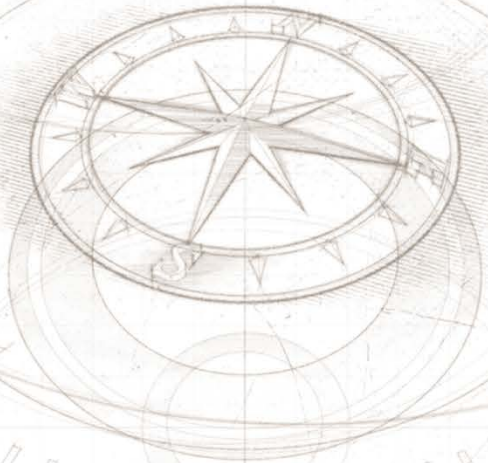
CORRELATIONS BETWEEN STOCKS AND BETWEEN SECTORS

CBOE Risk Management Conference Europe

September 29, 2015

Chris Rodarte, Portfolio Manager



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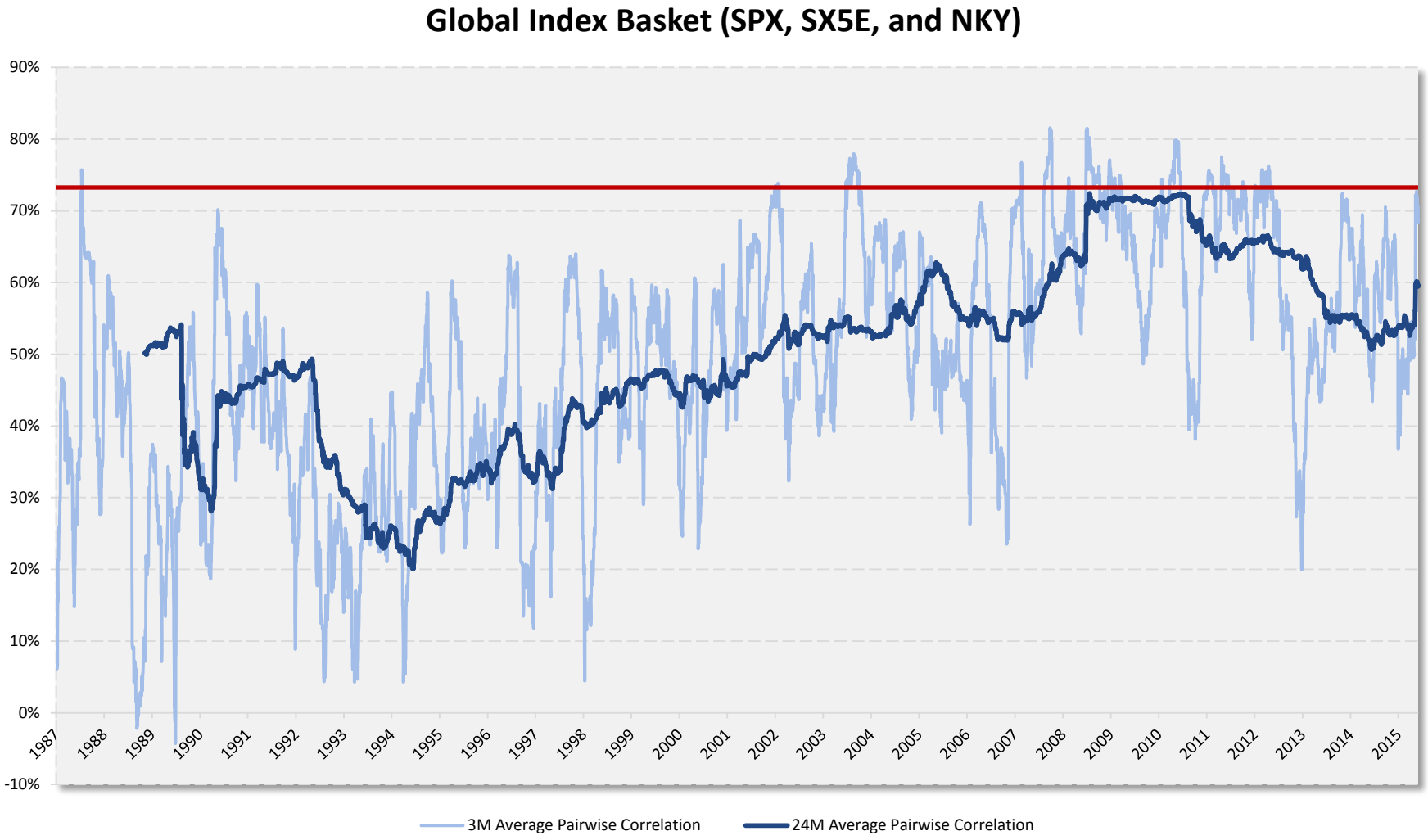
DATA IN THIS DOCUMENT IS AS OF SEPTEMBER 14, 2015 UNLESS OTHERWISE NOTED.

AGENDA

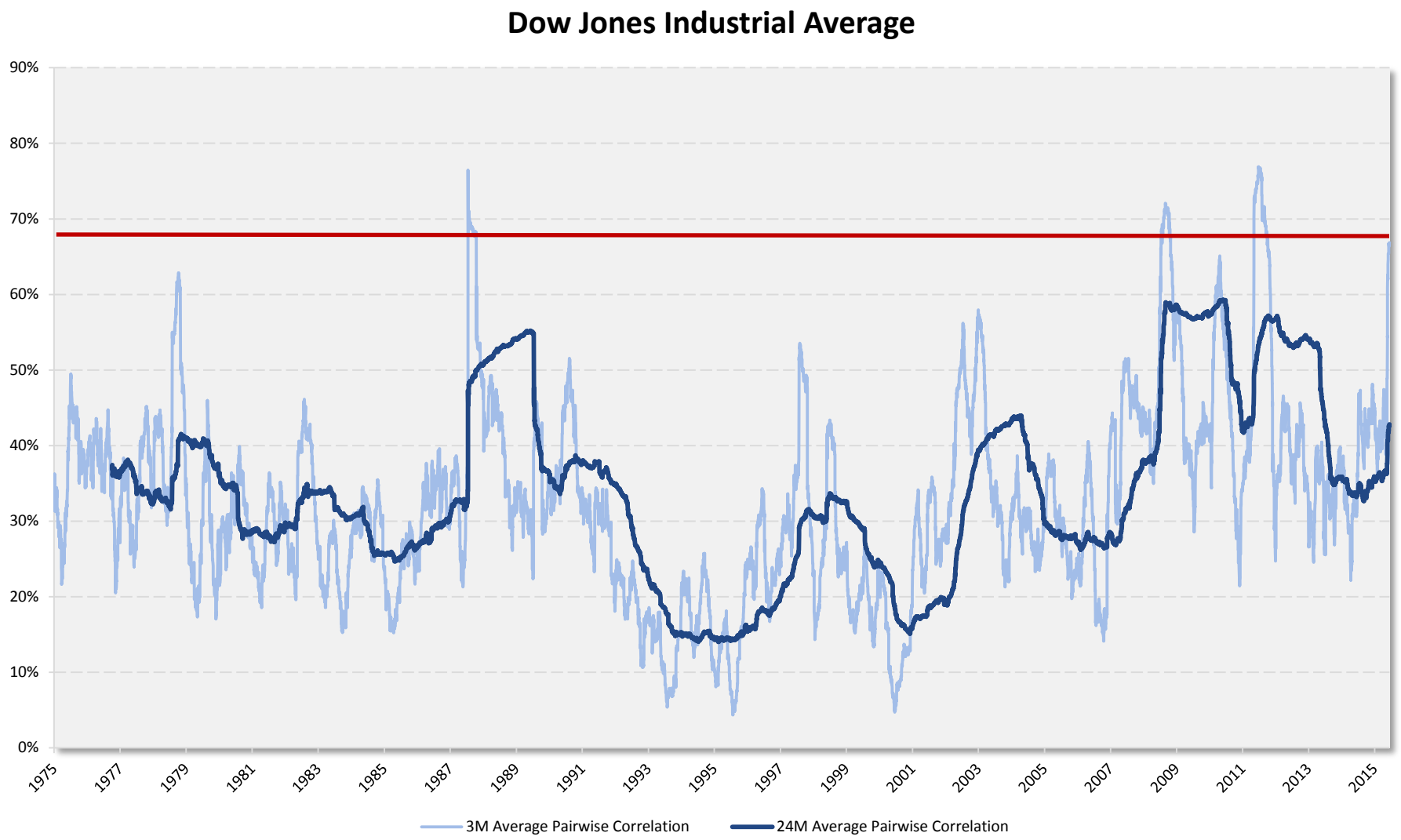
- A brief history of correlation and how we arrived where we are today
- Correlation as it's own asset class
- Typical trade constructs to gain exposure to correlation
- A detailed example of a **Listed Dispersion** trade
- Opportunity subset in the current market
- A detailed example of a **Volswap Dispersion** trade
- Historical/Analytical results illustrate how certain trades outperform in varying volatility and correlation paradigms

INDEX REALIZED CORRELATIONS HAVE TRENDED HIGHER



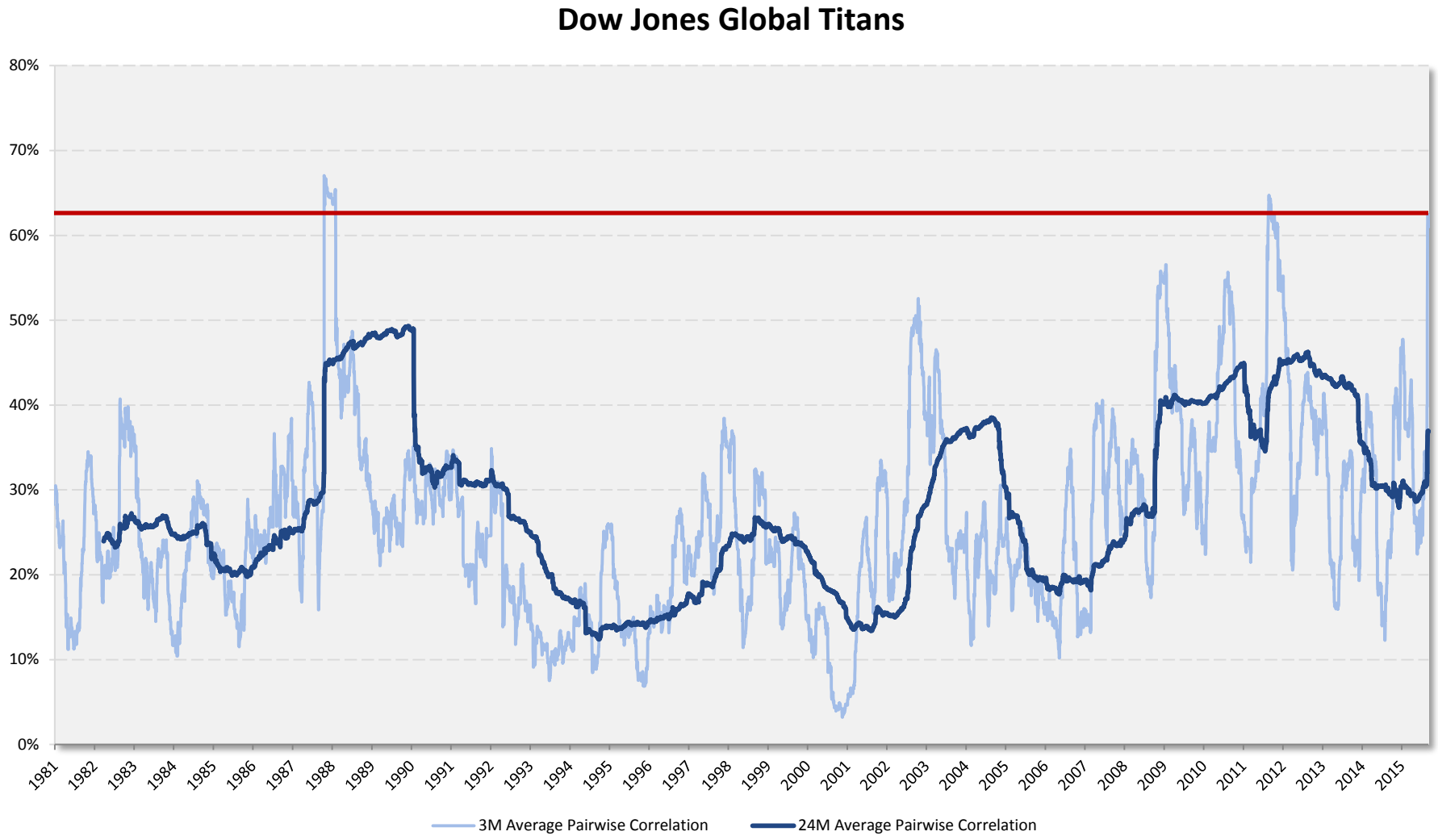
Source: Pine River, Bloomberg

RECENT REALIZED EQUITY CORRELATION IS ELEVATED



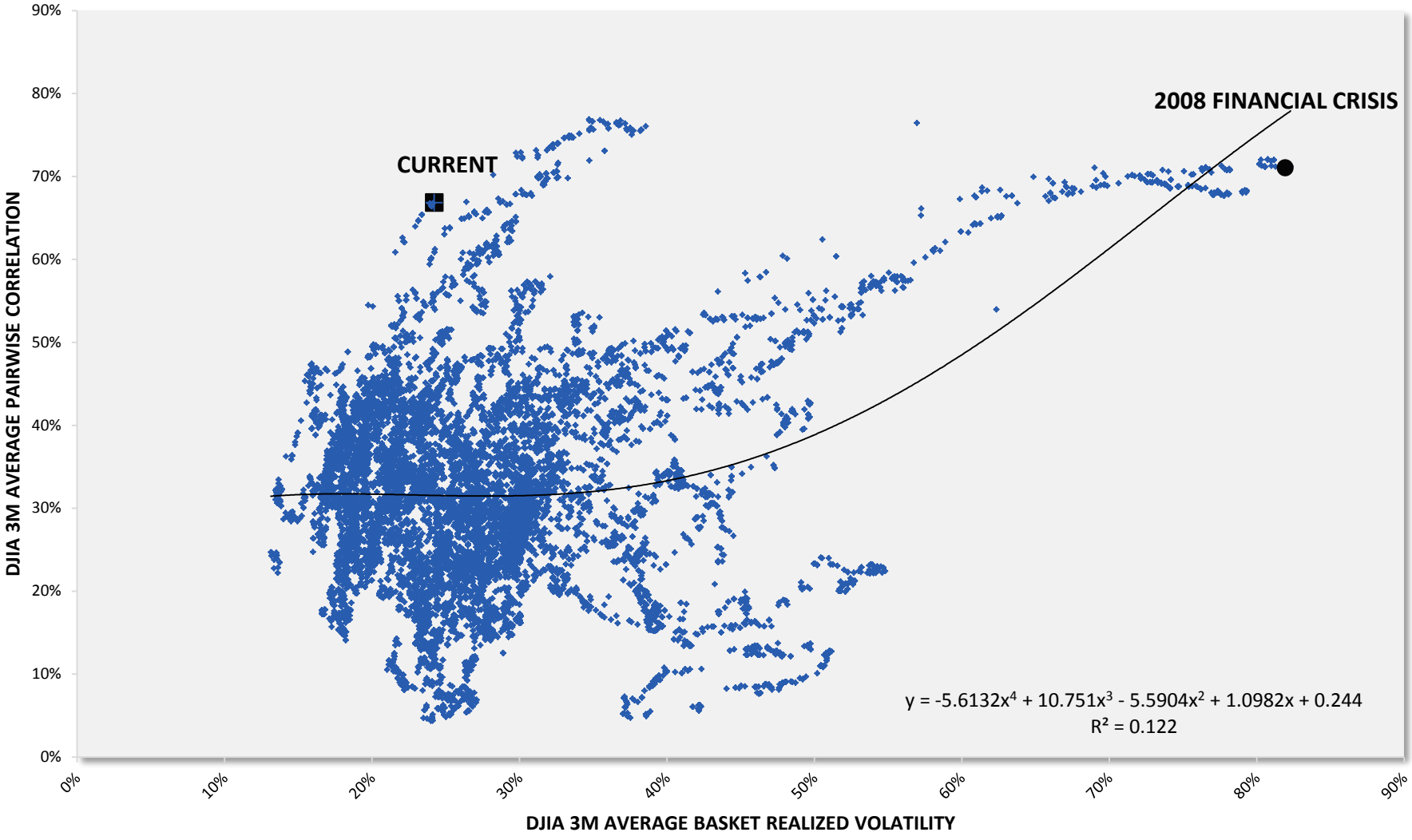
Source: Pine River, Bloomberg

CORRELATION IS ALSO ELEVATED ACROSS EQUITY MARKETS



Source: Pine River, Bloomberg

VOLATILITY AND CORRELATION ARE LINKED IN RISK-OFF EVENTS



Source: Pine River, Bloomberg

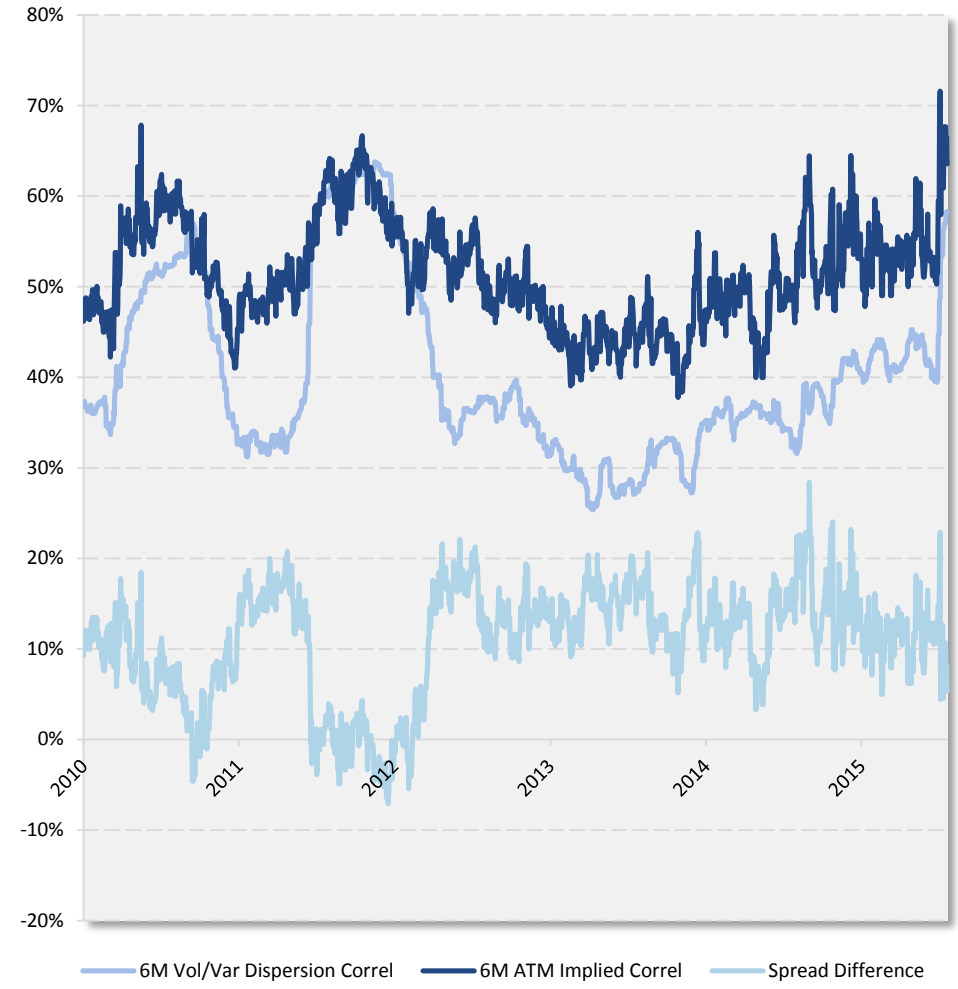
INDICES AND ETFS WITH LIQUID CORRELATION MARKETS

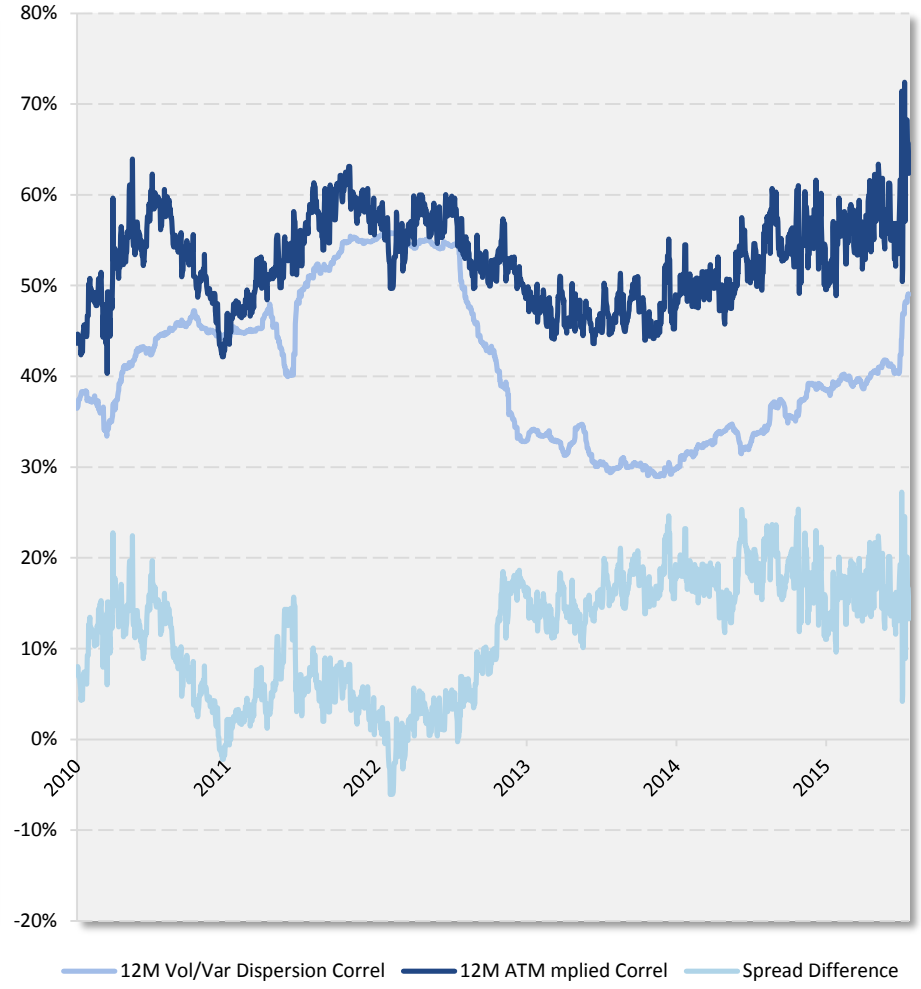
UNDERLYING INDEX OR ETF	LISTED/OTC OPTION MARKET	VARIANCE SWAP MARKET	VOLATILITY SWAP MARKET	CORRELATION SWAP MARKET	DISPERSION OPTION MARKET
S&P 500 Top (N)	Yes	Yes	Yes	Yes	Yes
S&P 500 Sectors	Yes	Yes	Yes	No*	No*
DJIA	Yes	Yes	Yes	Yes	No*
DJGT	Yes	No	Yes	Yes	No*
Euro Stoxx 50	Yes	No	Yes	Yes	Yes
Euro Stoxx Sectors	Yes	No	Yes	No*	No*
DAX	Yes	No	Yes	No*	Yes
CAC	Yes	No	Yes	No*	No*
FTSE 100 Top (N)	Yes	No	Yes	No*	No*
SMI Top (N)	Yes	No	Yes	No*	No*
TPX Core 30	Yes	No	Yes	No*	No*
HSI Top (N)	Yes	No	Yes	No*	No*
AS51 Top (N)	Yes	No	Yes	No*	No*
Bespoke Baskets	Yes	Yes	Yes	Yes	Yes

Note: Some Indices can be priced on request and thus indicated No*

IMPLIED CORRELATION RISK PREMIA CREATES OPPORTUNITY

Dow Jones Industrial Average





Source: Pine River, Bloomberg

S&P 500 SECTOR DISPERSION ATM SEPTEMBER 2015 SNAPSHOTS

Source: Pine River

LISTED TRADING OPPORTUNITY IN S&P 500 SECTOR DISPERSION

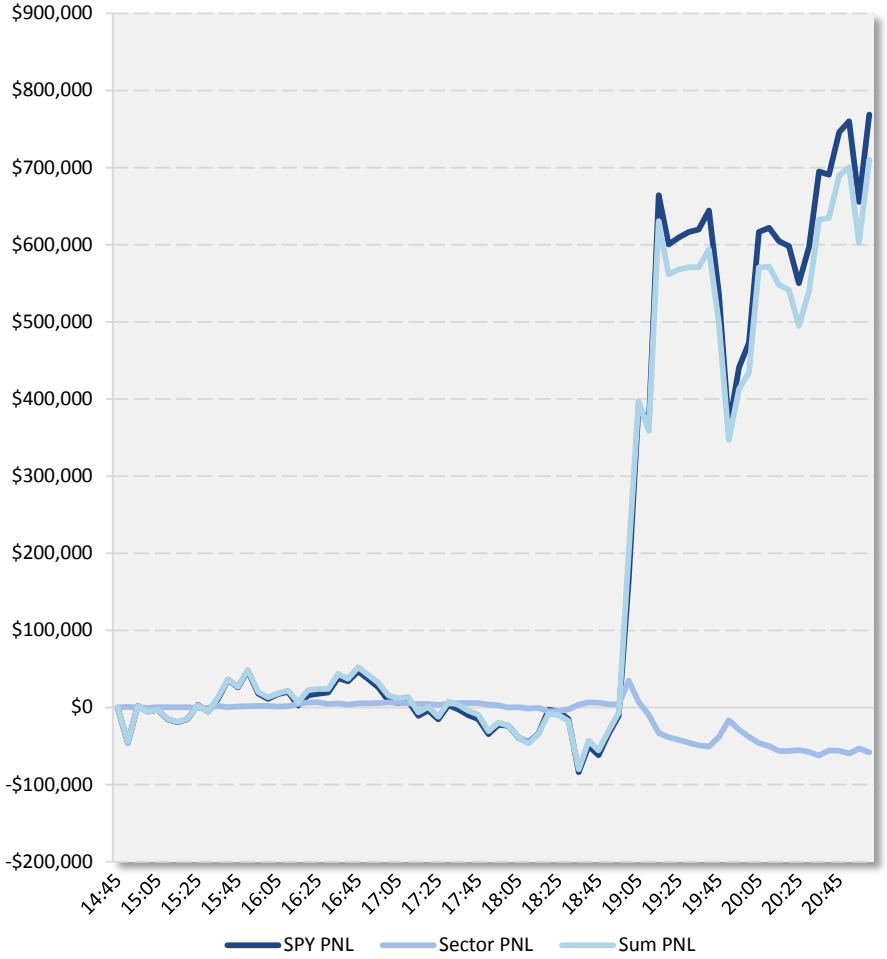
TICKER	SECURITY DESCRIPTION	OPTION TICKER	SHARE QUANTITY	BID	ASK	FILL	LIQUIDITY COST	PREMIUM	DELTA %	DELTA	GAMMA	VEGA
SPY US	SPDR S&P 500 ETF Trust	SPY US 09/18/15 C200.5	-1,162,600	1.46	1.48	1.46	-$23,252	-$1,697,396	43.20%	-$100,694,040	-$45,410,219	-$51,768
		SPY US 09/18/15 P200.5	-840,000	2.45	2.50	2.42	-$42,000	-$2,032,800	-59.07%	$99,470,387	-$28,063,195	-$37,543
XLY US	Consumer Discretionary Select Sector SPDR Fund	XLY US 09/18/15 C77	366,800	0.58	0.63	0.55	-$18,340	$201,740	46.79%	$13,228,478	$5,655,019	$6,348
		XLY US 09/18/15 P77	304,700	0.72	0.83	0.83	-$33,517	$252,901	-55.38%	-$13,005,896	$4,377,957	$5,397
XLP US	Consumer Staples Select Sector SPDR Fund	XLP US 09/18/15 C48	423,000	0.27	0.32	0.23	-$21,150	$99,405	48.39%	$9,841,595	$6,443,189	$4,145
		XLP US 09/18/15 P48	334,000	0.46	0.50	0.50	-$13,360	$167,000	-59.58%	-$9,569,047	$3,334,449	$3,613
XLE US	Energy Select Sector SPDR Fund	XLE US 09/18/15 C65.5	219,300	0.58	0.65	0.46	-$15,351	$99,782	49.45%	$7,124,925	$3,022,086	$3,003
		XLE US 09/18/15 P65.5	186,500	0.84	0.87	0.87	-$5,595	$162,255	-55.82%	-$6,839,427	$1,797,335	$2,705
XLF US	Financial Select Sector SPDR Fund	XLF US 09/18/15 C23.5	1,366,800	0.26	0.28	0.19	-$27,336	$258,325	52.17%	$16,822,807	$5,405,050	$7,098
		XLF US 09/18/15 P23.5	1,382,300	0.27	0.28	0.28	-$13,823	$387,044	-50.26%	-$16,388,613	$4,553,658	$7,657
XLV US	Health Care Select Sector SPDR Fund	XLV US 09/18/15 C72	524,500	0.44	0.47	0.47	-$15,735	$246,515	40.68%	$15,331,298	$7,101,050	$8,139
		XLV US 09/18/15 P72	352,200	0.84	0.88	0.73	-$14,088	$257,106	-60.52%	-$15,315,303	$4,494,241	$5,739
XLI US	Industrial Select Sector SPDR Fund	XLI US 09/18/15 C52.5	412,600	0.37	0.44	0.36	-$28,882	$148,495	48.59%	$10,541,208	$5,261,562	$4,675
		XLI US 09/18/15 P52.5	336,100	0.52	0.61	0.61	-$30,249	$205,021	-55.82%	-$9,864,838	$3,127,375	$4,084
XLK US	Technology Select Sector SPDR Fund	XLK US 09/18/15 C41	1,446,200	0.21	0.27	0.27	-$86,772	$390,474	38.28%	$22,634,800	$11,057,421	$12,938
		XLK US 09/18/15 P41	878,000	0.50	0.56	0.45	-$52,680	$395,100	-61.93%	-$22,231,979	$6,079,051	$7,785
XLB US	Materials Select Sector SPDR Fund	XLB US 09/18/15 C43.5	189,000	0.23	0.28	0.28	-$9,450	$52,920	37.15%	$3,043,104	$1,485,767	$1,656
		XLB US 09/18/15 P43.5	104,500	0.60	0.75	0.59	-$15,675	$61,655	-62.90%	-$2,848,625	$652,885	$974
XLU US	Utilities Select Sector SPDR Fund	XLU US 09/18/15 C42.5	130,700	0.33	0.39	0.28	-$7,842	$36,596	52.01%	$2,899,957	$1,451,379	$1,149
		XLU US 09/18/15 P42.5	117,900	0.50	0.70	0.59	-$23,580	$69,561	-57.43%	-$2,888,370	$711,026	$1,146
TOTALS			**11,077,700**				**-$498,677**	**-$238,302**		**$1,292,420**	**$2,537,085**	**-$1,060**

- Trade is selling **Implied Correlation** above 100% as we are collecting premium to buy the **Sector Component** options and sell the **SPY** options (e.g. getting paid 24bps for the basket)
- Basket criteria was constructed to have **Zero Delta** exposure at trade inception using the current **Sector ETF** weights to neutralize the **SPY Call/Put Delta**

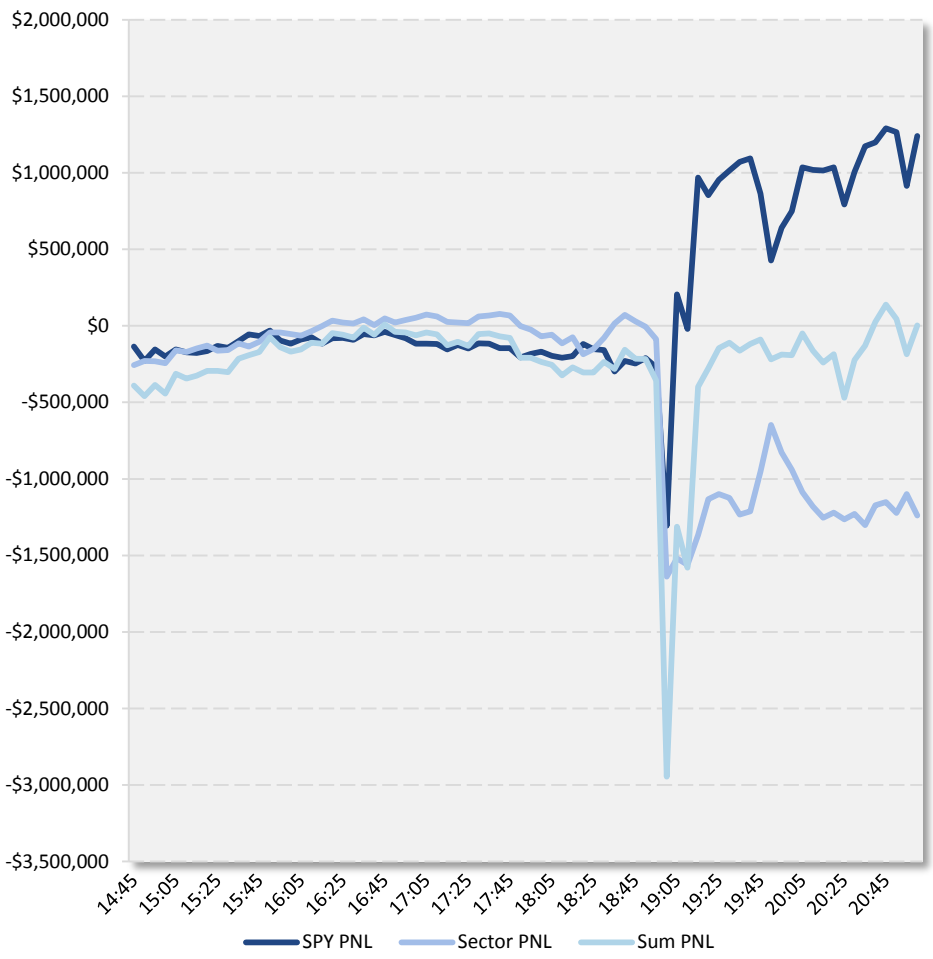
As of September 17, 2015. These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown.

WAS THE TRADE CLOSED AT A PROFIT?

Intraday Performance Using Option Mids



Intraday Performance Crossing Bid/Offer



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S&P 500 SECTOR DISPERSION PERFORMANCE AT EXPIRATION

TICKER	SECURITY DESCRIPTION	OPTION TICKER	SHARE QUANTITY	CLOSING PRICE	OPTION ITM?	% ITM	DELTA PROCEEDS	PREMIUM	GROSS TRADE PNL
SPY US	SPDR S&P 500 ETF Trust	SPY US 09/18/15 C200.5	-1,162,600	195.45	No	0.00%	$0	-$1,697,396	$1,697,396
		SPY US 09/18/15 P200.5	-840,000	195.45	Yes	2.52%	-$4,242,000	-$2,032,800	-$2,209,200
XLY US	Consumer Discretionary Select Sector SPDR Fund	XLY US 09/18/15 C77	366,800	75.46	No	0.00%	$0	$201,740	-$201,740
		XLY US 09/18/15 P77	304,700	75.46	Yes	2.00%	$469,238	$252,901	$216,337
XLP US	Consumer Staples Select Sector SPDR Fund	XLP US 09/18/15 C48	423,000	47.19	No	0.00%	$0	$99,405	-$99,405
		XLP US 09/18/15 P48	334,000	47.19	Yes	1.69%	$270,540	$167,000	$103,540
XLE US	Energy Select Sector SPDR Fund	XLE US 09/18/15 C65.5	219,300	63.10	No	0.00%	$0	$99,782	-$99,782
		XLE US 09/18/15 P65.5	186,500	63.10	Yes	3.66%	$447,600	$162,255	$285,345
XLF US	Financial Select Sector SPDR Fund	XLF US 09/18/15 C23.5	1,366,800	22.66	No	0.00%	$0	$258,325	-$258,325
		XLF US 09/18/15 P23.5	1,382,300	22.66	Yes	3.57%	$1,161,132	$387,044	$774,088
XLV US	Health Care Select Sector SPDR Fund	XLV US 09/18/15 C72	524,500	70.91	No	0.00%	$0	$246,515	-$246,515
		XLV US 09/18/15 P72	352,200	70.91	Yes	1.51%	$383,898	$257,106	$126,792
XLI US	Industrial Select Sector SPDR Fund	XLI US 09/18/15 C52.5	412,600	50.86	No	0.00%	$0	$148,495	-$148,495
		XLI US 09/18/15 P52.5	336,100	50.86	Yes	3.12%	$551,204	$205,021	$346,183
XLK US	Technology Select Sector SPDR Fund	XLK US 09/18/15 C41	1,446,200	40.06	No	0.00%	$0	$390,474	-$390,474
		XLK US 09/18/15 P41	878,000	40.06	Yes	2.29%	$825,320	$395,100	$430,220
XLB US	Materials Select Sector SPDR Fund	XLB US 09/18/15 C43.5	189,000	41.88	No	0.00%	$0	$52,920	-$52,920
		XLB US 09/18/15 P43.5	104,500	41.88	Yes	3.72%	$169,290	$61,655	$107,635
XLU US	Utilities Select Sector SPDR Fund	XLU US 09/18/15 C42.5	130,700	42.23	No	0.00%	$0	$36,596	-$36,596
		XLU US 09/18/15 P42.5	117,900	42.23	Yes	0.64%	$31,833	$69,561	-$37,728
TOTALS			**11,077,700**				**$68,055**	**-$238,302**	**$306,357**

- Assuming one had to cross full bid/offer to unwind the trade, it would have been a breakeven to marginally profitable proposition at best
- Even with adverse realized correlation when held to maturity, the trade would have made 31bps gross, assuming options were fully hedged on the close and not adjusted in the interim

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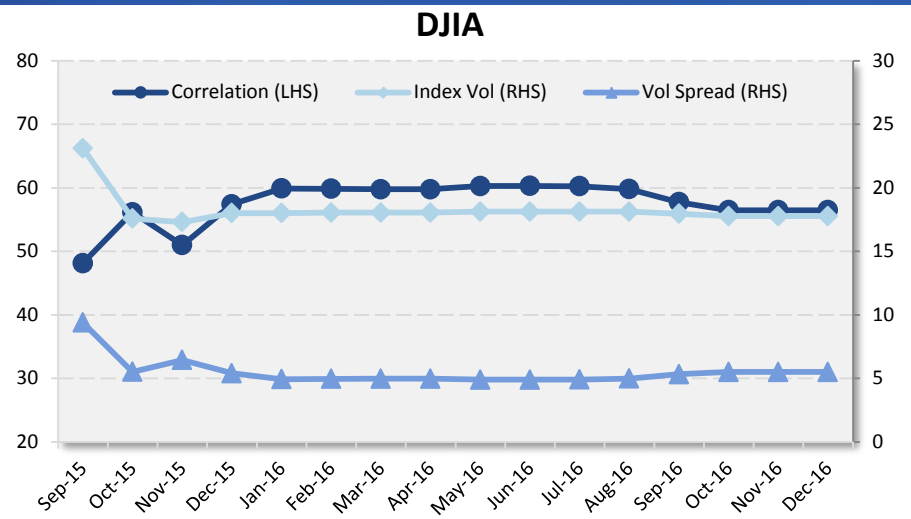
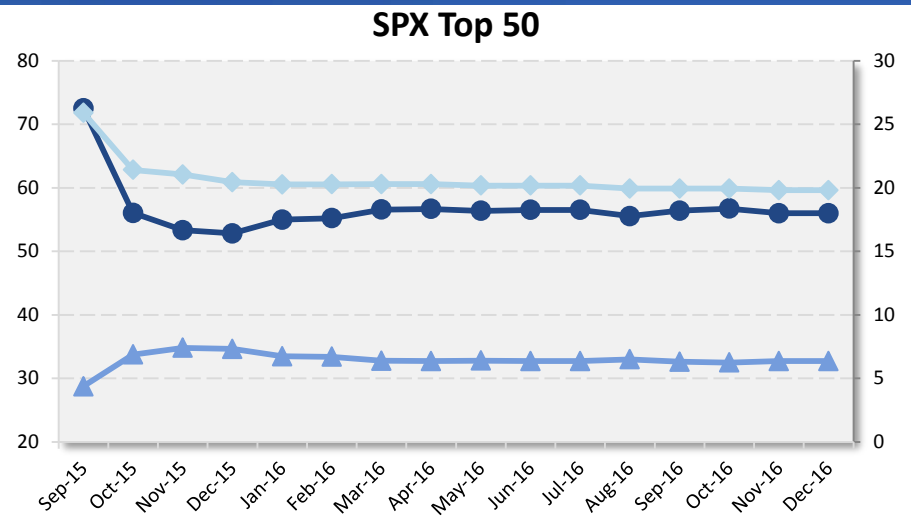
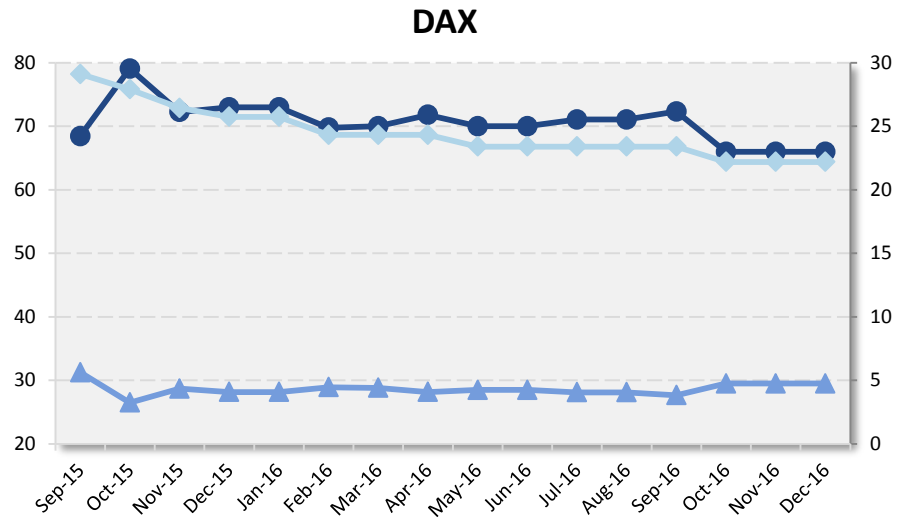
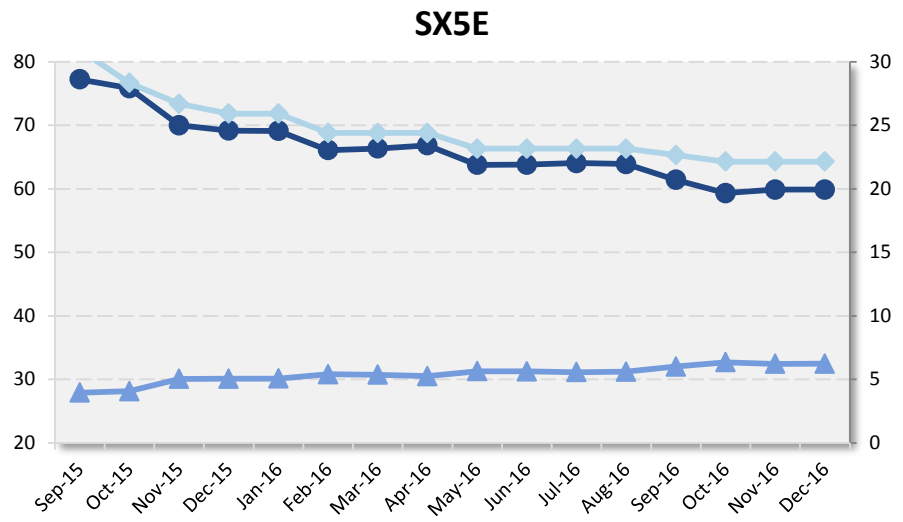
ATM CORRELATION TERM STRUCTURE ACROSS VARIOUS INDICES



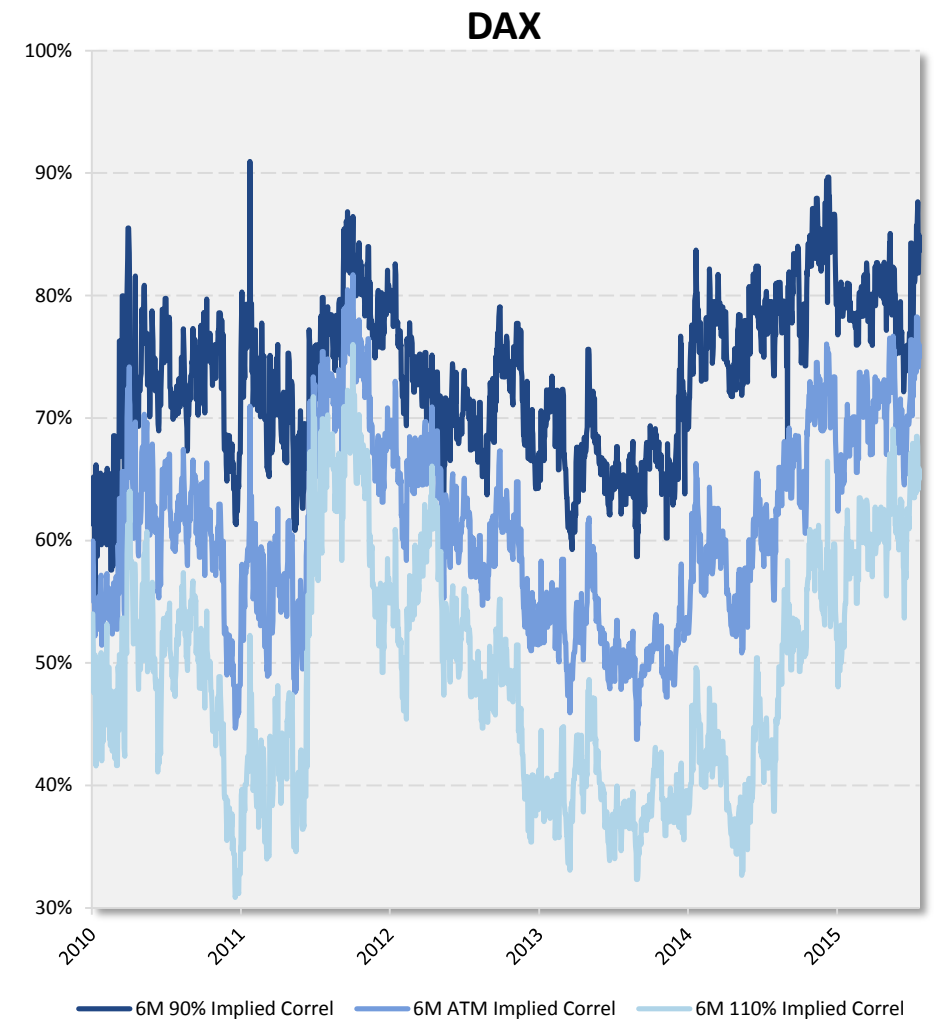


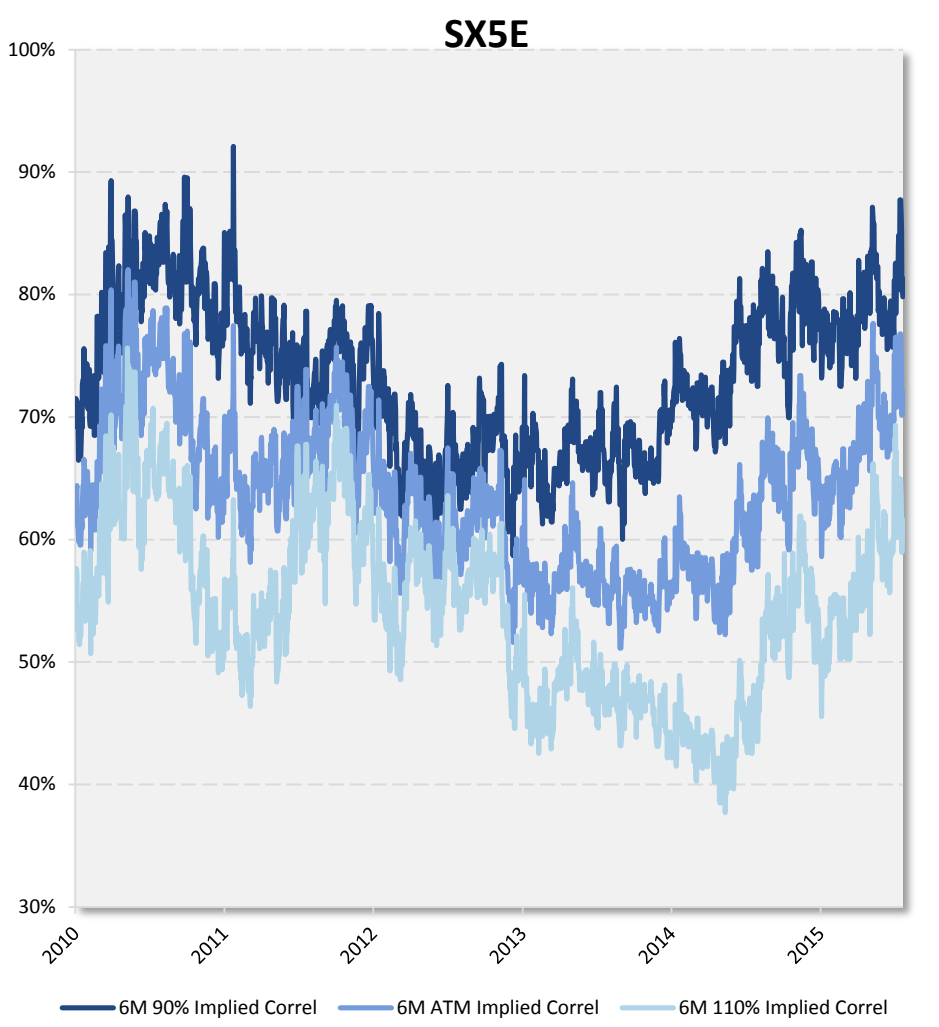




Source: Pine River

CORRELATION SKEW IS AT MULTI-YEAR HIGHS IN EUROPE





As of September 11, 2015. Source: Pine River, Bloomberg.

VARSWAP/VOLSWAP DISPERSION CAN BENEFIT FROM CORRELATION SKEW

- Recall that **Varswap** and **Volswap** contracts maintain volatility exposure regardless of spot price evolution and their pricing has greater sensitivity to lower strike options
- Given the demand for downside protection on **Index** options, the **Implied Correlation** for lower strike options is often higher than that for upside strike options
- Systematically selling this expensive **Correlation Skew** can be a profitable strategy as we will see in the **SX5E Volswap Dispersion** example below
- The payoff of a **Volswap Dispersion** trade can be simplified by the following formula:

$$PNL_{VolswapDisp} = \sum_{i}^{N} PNL_{VolswapShare_i} - PNL_{VolswapIndex}$$

- To isolate correlation as the primary risk factor in the trade construct, the **Index Vega** should be a factor of the **Single-Stock Vega** times the inverse of the square root of **Implied Correlation**:

$$Vega_{Index} = \frac{1}{\sqrt{\rho_{impliedcorrelation}}} \sum_{i}^{N} Vega_{VolswapShare_i}$$

- **SX5E Volswap Dispersion** trade with 9 month tenor traded at 77.80% IC mids, thus for $100K **Vega of Singles**, the **Index Vega** to sell is $113K to be "**Theta Flat**"
- **Index Volswap Strike** of 27.10 vs. **Weighted Stock Volswap Strike** of 30.65

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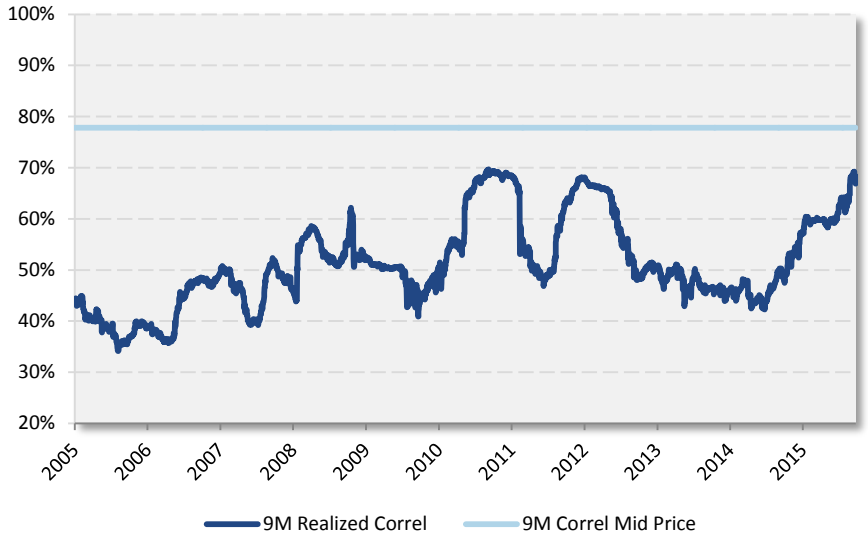
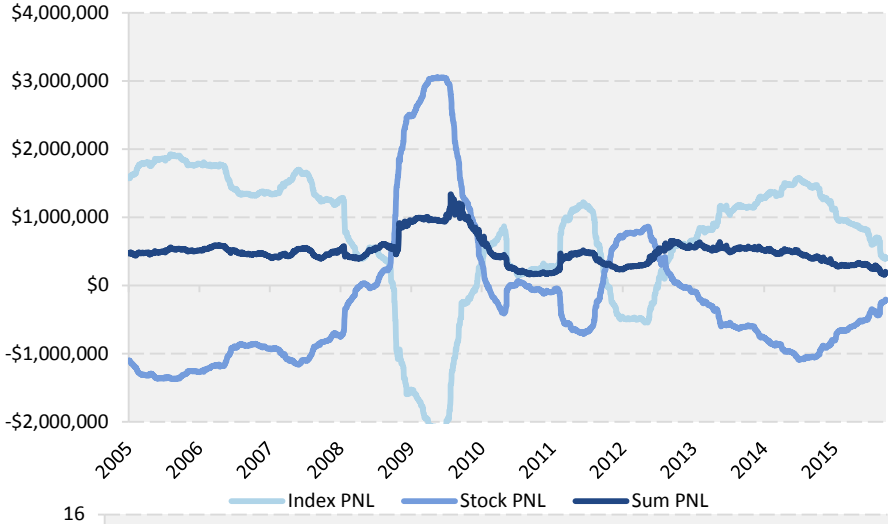
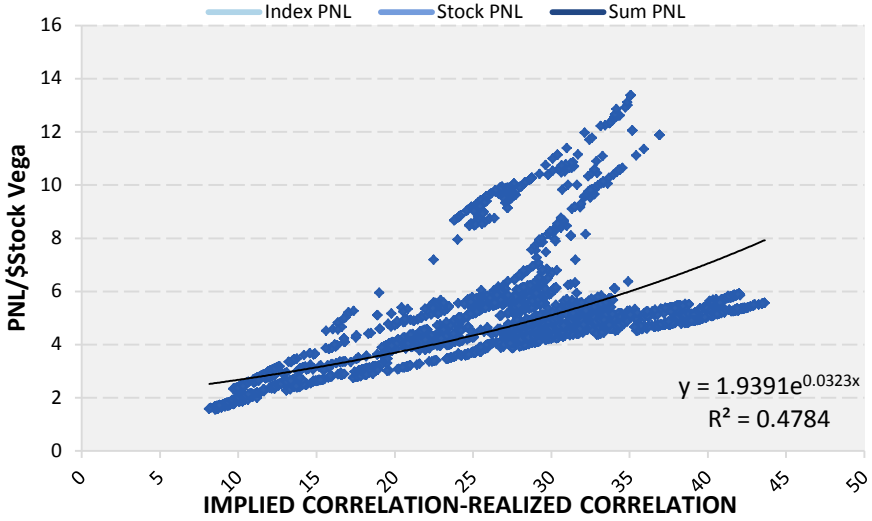
SX5E VOLSWAP DISPERSION HISTORICAL ANALYSIS





- Although the ratio of **Index Vega** to **Stock Vega** was selected to isolate correlation as a risk factor, there are other dynamics at work
- General rule of thumb is that the **Cega** sensitivity is a multiple of .15 to .25 of **Stock Vega** (historically in this trade example it is .186 or $18.6K)



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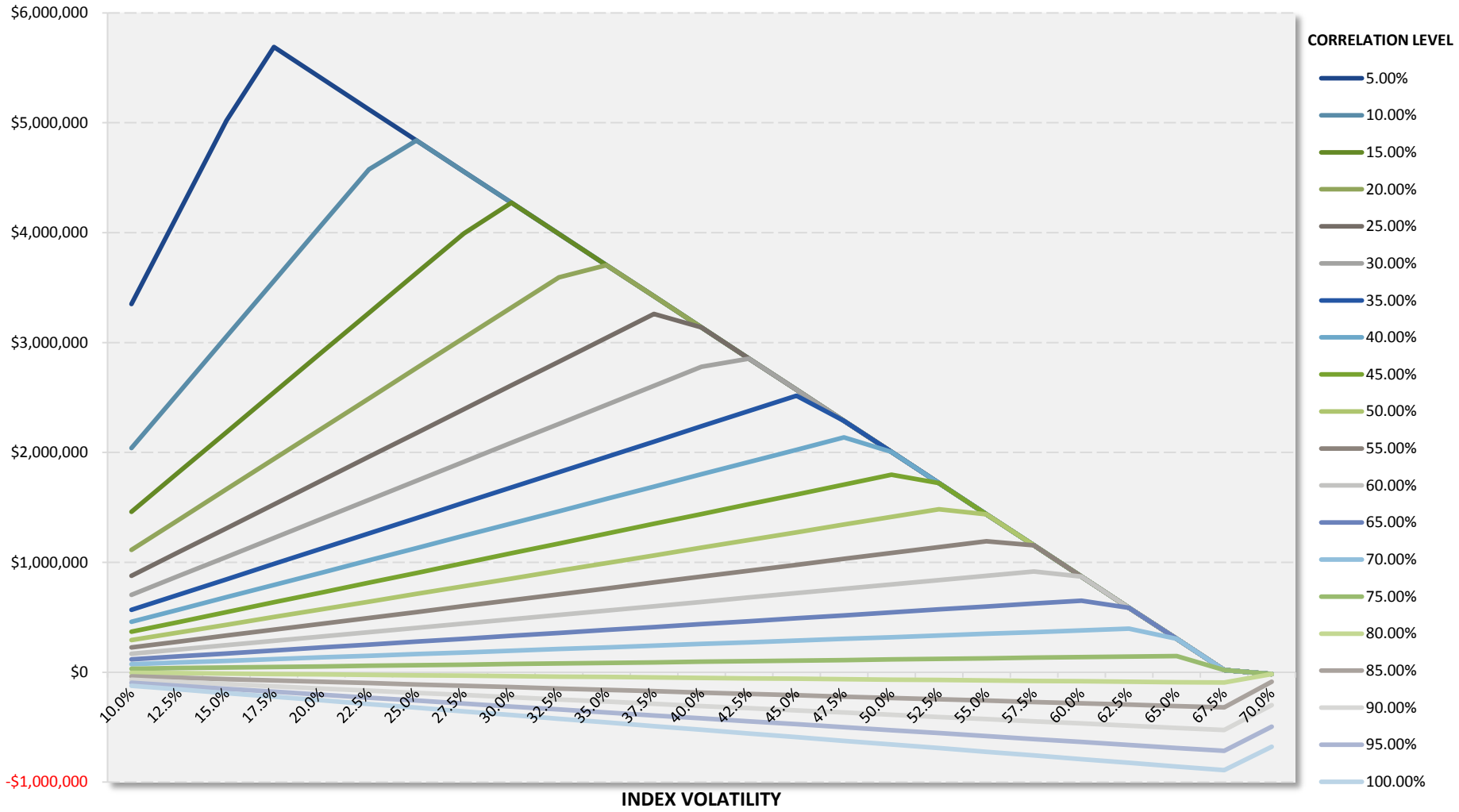
SX5E VOLSWAP DISPERSION RISK PROFILE



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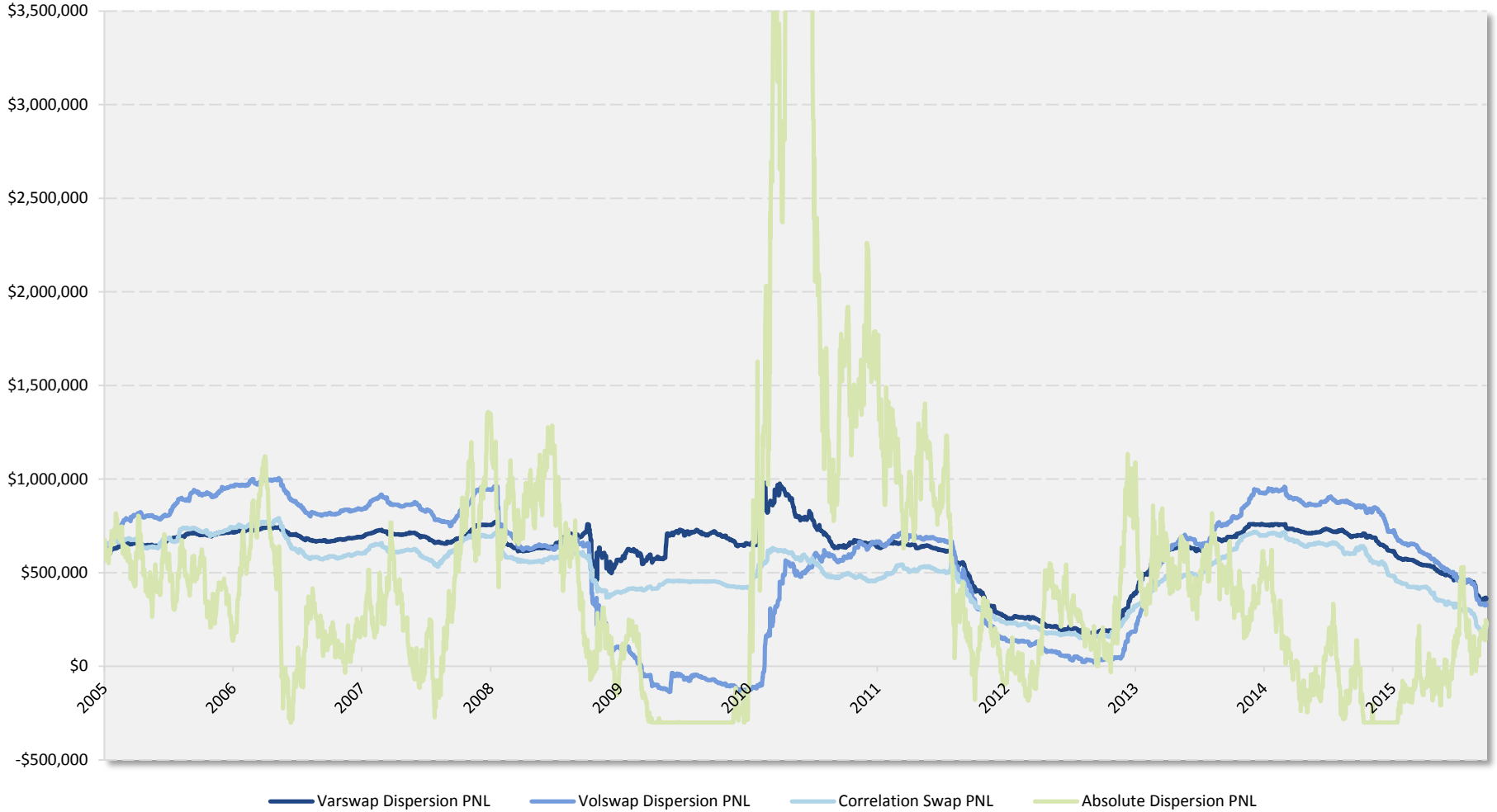
COMPARING HYPOTHETICAL TRADES ON THE DAX



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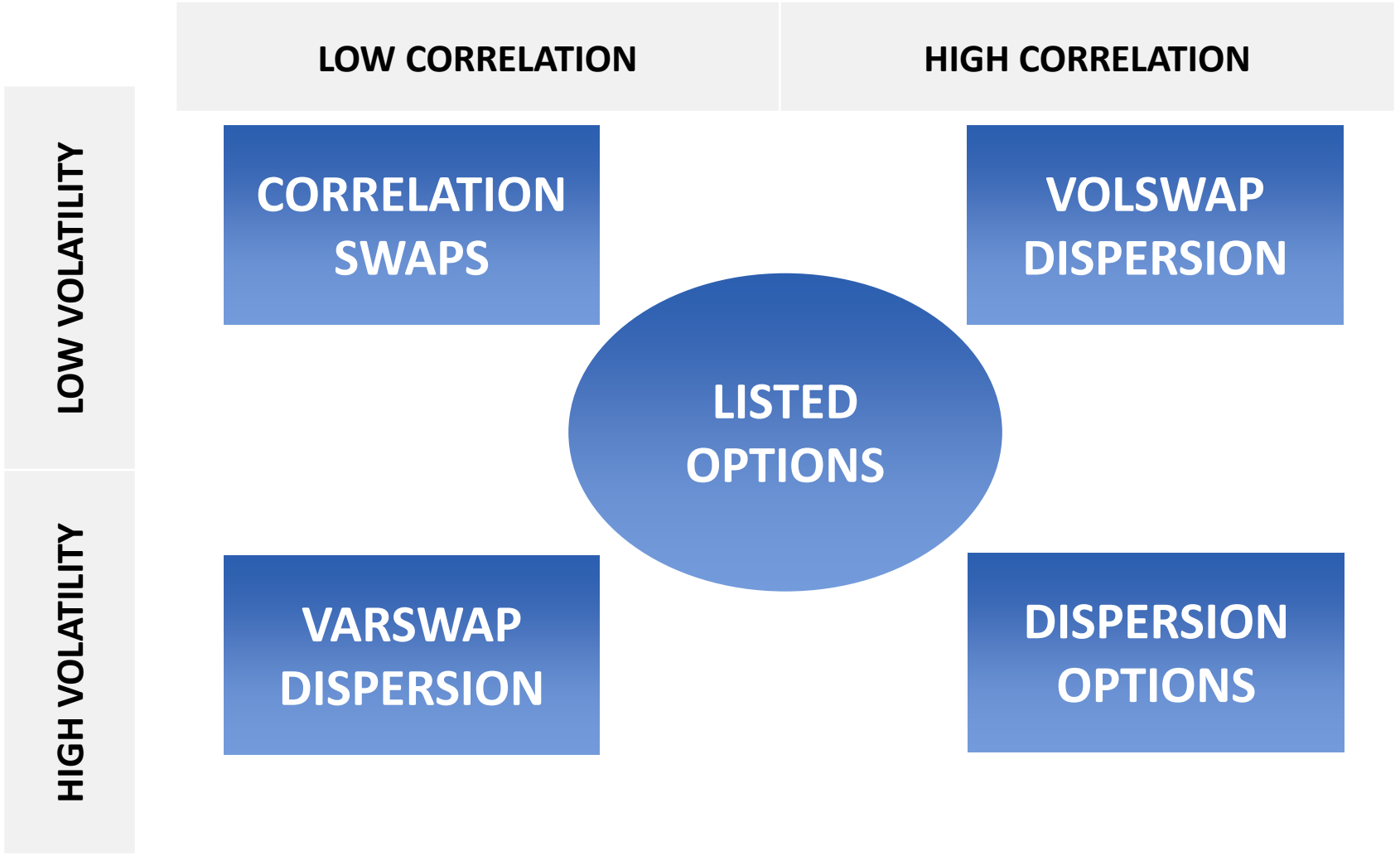
TRADE CONSTRUCTS FOR DIFFERENT MARKET REGIMES



APPENDIX

PINE RIVER
CAPITAL MANAGEMENT L.P.

DEFINING AVERAGE PAIRWISE CORRELATION

Average **Pairwise Correlation** is defined as:

$$\bar{\rho}_{Basket\ of\ N\ Shares} = \frac{2}{N \times (N-1)} \sum_{\substack{i=2,j=1 \\ i>j}}^{N} \rho_{ij}$$

Where **Correlation** for a pair of given shares is defined as:

$$\rho_{S1,S2} = \frac{\sum_{t=1}^{n}[(x_t - \bar{x})(y_t - \bar{y})]}{\sqrt{\sum_{t=1}^{n}(x_t - \bar{x})^2 \sum_{t=1}^{n}(y_t - \bar{y})^2}}$$

And the relevant terms are per the following:

$$x_t = Ln\left(\frac{P_t^{S1}}{P_{t-1}^{S1}}\right) \qquad y_t = Ln\left(\frac{P_t^{S2}}{P_{t-1}^{S2}}\right)$$

$$\bar{x} = \frac{1}{n}\sum_{t=1}^{n} x_t \qquad \bar{y} = \frac{1}{n}\sum_{t=1}^{n} y_t$$

NOTES:

- Although this calculation is easy to apply to any basket of shares (or other asset), it is computationally intensive as the number of shares increases
- For example, the data on the first chart of this presentation took ~5 seconds to produce with three distinct pairs and if the same calculation were done for the S&P 500 with 124,750 distinct pairs it would take ~58 hours

DEFINING VARSWAP/VOLSWAP CORRELATION

Implied Correlation and **Realized Correlation** for an index are defined as:

$$\rho = \frac{\sigma^2_{Index} - \sum_i^N w^2_{Share_i} \sigma^2_{Share_i}}{\left(\sum_i^N w_{Share_i} \sigma_{Share_i}\right)^2 - \sum_i^N w^2_{Share_i} \sigma^2_{Share_i}}$$

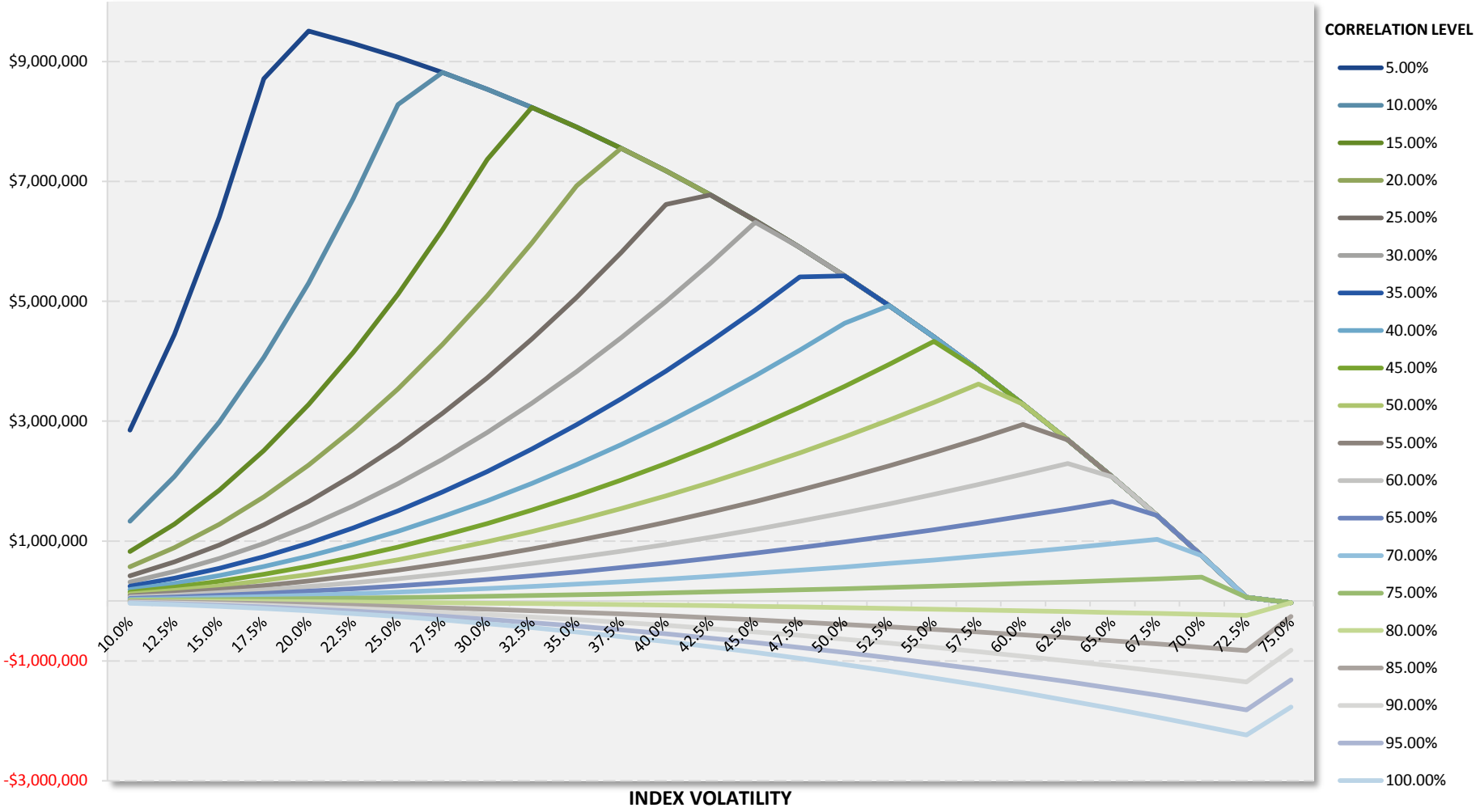
Where **Volatility** is defined as:

$$\sigma = \sqrt{\frac{252 \times \sum_{t=1}^{n} \left(Ln \frac{P_t}{P_{t-1}} \right)}{n}}$$

NOTES:

- For indices with a large number of constituents the market convention is to trade a subset of the names (e.g. SPX Top 50 where N = 50), otherwise all components are typically included
- **σ** is defined as the implied volatility of the **Varswap** or **Volswap** contract for the relevant **Index/Shares** for computing **Implied Correlation** or, alternatively, the realized volatility when computing the **Realized Correlation** as defined above
- ***w*** is fixed at trade inception and, for the purposes of backtest results, is held constant for a simplified approach unless otherwise noted
- ***Pt*** is the price return of the underlying index/share and adjusted for dividends on ex-date for the share price returns only

SX5E VARSWAP DISPERSION RISK PROFILE



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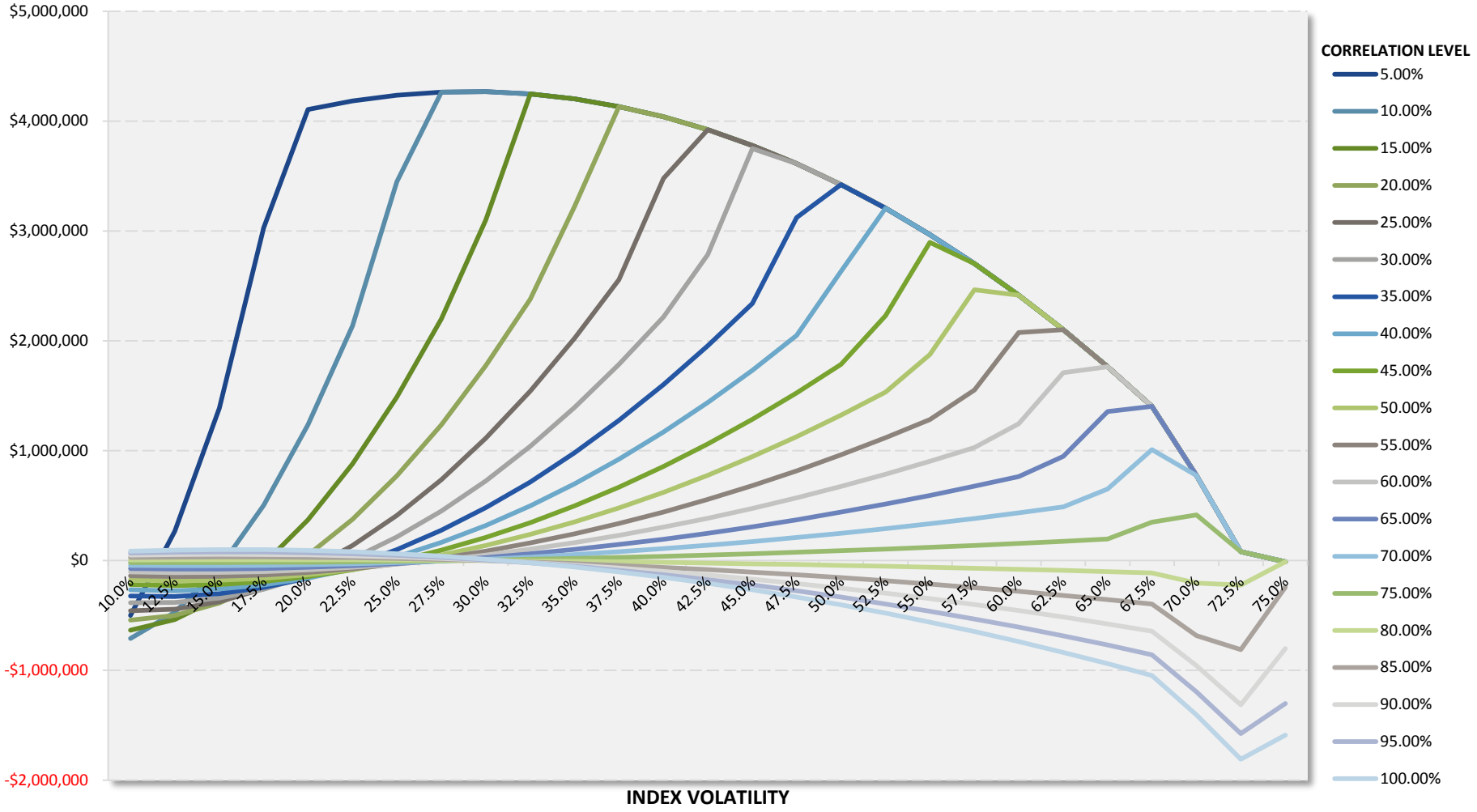
SX5E VARSWAP/VOLSWAP DIFFERENTIAL



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DEFINING OPTION ON ABSOLUTE DISPERSION

Payoff for a call option on **Absolute Dispersion** with strike K:

$$PNL = NA \times MAX\left[0\,, Dispersion(T_{Final}) - K\right]$$

And the relevant terms are per the following:

$$Dispersion(t) = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{{S_t}^i}{{S_{t_0}}^i} - BasketPerf(t)\right|$$

$$BasketPerf(t) = \frac{1}{N}\sum_{i=1}^{N}\frac{{S_t}^i}{{S_{t_0}}^i}$$

NOTES:

- ***T0*** is the option **Strike Date** and the relevant share prices are fixed at that time
- ***K*** is often set to the **ATM Forward** level of the resultant calculation of ***Dispersion(t)*** where ***St*** is set to the **Forward Price** of each given equity in the basket at the time of fixing
- Using volatility and correlation assumptions for the basket, one can use a closed form model to solve for option premium similar to Black-Scholes or, alternatively, Monte-Carlo analysis

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