Risk Premia in Volatility Markets:
Exploiting Volatility Spillover and Clustering

- **We find that we can enhance the performance of volatility carry strategies. These carry strategies exploit the difference between implied and realized volatility via trading variance swaps, delta-hedged straddles or similar payoffs.**
- **We improve their performance by accounting for the fact that volatility is persistent (clustering) and that different volatility markets are interconnected (spillover).**
- **These results apply to international equity markets and across asset classes and are robust to different estimates of volatility risk premium based on past realized and implied volatilities.**

Opportunities in volatility markets

Many investors looking for yield believe that there are currently **opportunities in equity volatility carry**. These carry strategies exploit the spread between implied and realized volatility by trading variance swaps, volatility swaps or delta-hedged straddles for instance. Many investors are now attracted to these strategies as the spread between implied and realized volatility has been large over the past year. However, other investors believe both implied and realized volatility are too low now given the potential downside risks that the global economy still faces. These two views summarize the main characteristics of carry strategies in the volatility space: **potentially large premia in good times but a likelihood of large losses when volatility spikes,** as these spikes can be quite significant.

While spikes in equity volatility are not easily predictable, the effect of these spikes can be minimized if we consider clustering and spillover, two of the main features of market volatility. **Clustering** implies that whenever volatility is above (below) average it is more likely that volatility will remain higher (lower) than average. The **spillover effect** implies that after an increase in volatility in one particular market, it is more likely that volatility will remain higher than average in related markets. Additionally, we can take advantage of structural differences across volatility markets due to different supply and demand profiles.

Here we show the benefit of **implementing strategies that continuously monitor the level of volatility premium and account for contagion** from one volatility market to others. We consider different ways of estimating the volatility risk premium, i.e. the expected difference between implied and future realized volatility, using the recent values of both implied and realized volatility. We also use forecasting models or trading rules that account for the interconnection between the volatility premium in different markets. We assume the premium in a particular market is persistent and a function of the past realization of both implied and realized in that market and also in related markets.

Here we show **evidence of volatility clustering and spillover in equity markets and also in other asset classes**, which is consistent with previous studies. We also **discuss the reasons why there is a volatility risk premium and how it changes over time** and study the importance of local and common risks in short volatility strategies.

A strategy which selects in which market to go short volatility and whether to go short, based on an econometric model that forecasts the probability of a positive risk premium, **outperformed simply being short S&P 500 volatility** by nearly 5%

Investment Strategies: No. 75

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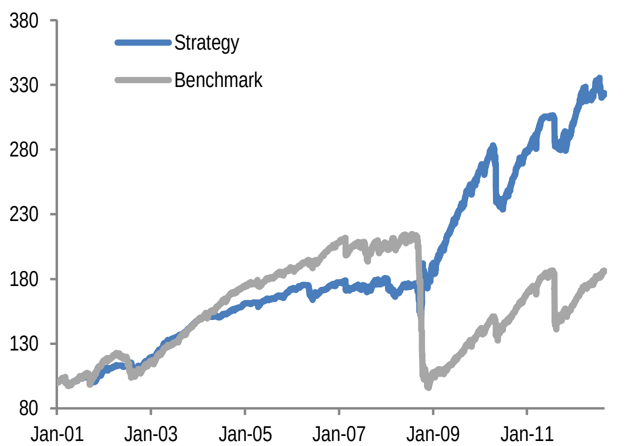
Chart 1: Exploiting Persistence and Spillover in Equities Markets
excess return index, (US, Europe and Japan)



Source: J.P. Morgan, Bloomberg. Calculations are net of transaction costs. These calculations are based on the model (described later on) where we trade US, Europe or Japan variance swaps based on the probabilities of a positive premium. Probabilities are based on a limited dependent variable model where probability of a positive premium depends on past values of realized and implied volatility in all the markets. Compared to a benchmark that is always short S&P 500 volatility with daily overlapping variance swaps.

annualized since 2001(Chart 1). This outperformance is due to both the ability to rotate between markets and to underweight the position if the volatility premium (estimated using past realized and implied volatility) is not clearly positive.

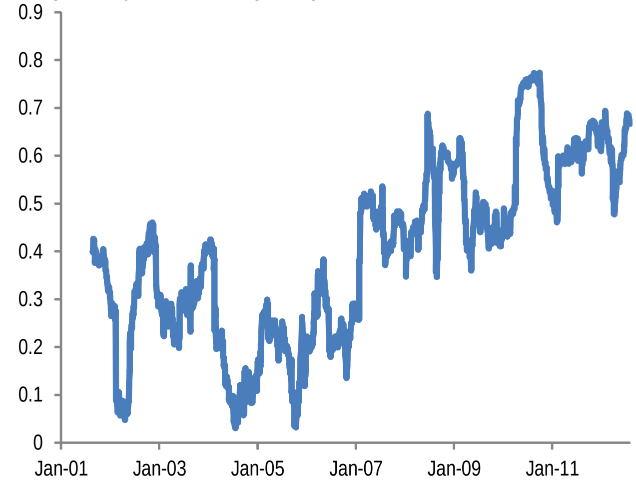
We take one step further and consider the **possible spillover between equities and other asset classes**. Here we focus on the interaction between equities and currency markets. But similar logic applies to other asset classes, particularly for markets that have a strong correlation (negative or positive) to equities (see Chart 2 for correlation between implied volatility in FX and Equity markets). Consistent with previous studies on volatility spillover between equities and FX, we find that it is possible to enhance a short FX volatility strategy if we use information on the past realized and implied volatilities of both FX and Equities.

The rest of the paper is organized as follows. First we review the reasons why there is a volatility/variance risk premium and why it varies over time. Second, we analyze the common and country-specific risks in short volatility positions. Third, we test volatility spillover in US, European and Japanese markets both in terms of realized volatility, implied volatility and their premium. Finally, we build strategies that exploit the spillover effect and time variation in the risk premium both with equities only and with equities and currencies.

Volatility Risk Premium: why and when?

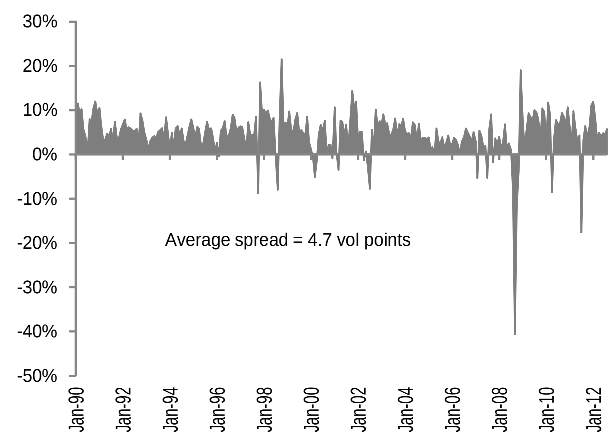
Equity index implied volatility tends to trade at a premium to subsequent realized volatility. Chart 3 shows the spread of 30-day S&P 500 implied volatility, as measured by the VIX index, to the subsequent 1M realised volatility of the index,

Chart 2: Correlation between Equity and FX Implied Volatilties
Rolling 126-day correlation, log changes



Source:J.P. Morgan, Bloomberg. Currency pairs: EURUSD, USDJPY and EURGBP. Equities: Eurostoxx, S&P 500 and Nikkei. Currency is equally-weighted average of the implied volatility of the currency pairs, and Equity is equally-weighted average of the implied volatility of the equity indices.

Chart 3: S&P 500 1M Implied vs 1M Realized Volatility Premium



Source: J.P. Morgan, Bloomberg.

which has averaged 4.7 volatility points since Jan-1990.

The volatility risk premium exists to compensate option traders for the risk they take in making a market in volatility. In fact, market makers typically delta-hedge their option positions and have profit/losses linked to the difference between the implied volatility of the option they traded and the subsequent realised volatility of the index, rather than to the return of the index.

When volatility levels are low, the volatility premium is typically elevated. This fact is only apparently unintuitive once we consider the general dynamic behavior of volatility, which is to spike to the upside and revert to lower levels. The risk for an option market maker is therefore strongly skewed in one direction when volatility is low, as a surge in volatility is much more likely than a large fall. The volatility risk premium reflects the asymmetric nature of the risk that option market makers are taking. In other words, short implied volatility positions can lead to infrequent but large losses, and risk averse traders require compensation for this risk (which is non-diversifiable and concentrated among few market players), therefore making the average volatility risk premium positive.

When volatility is elevated (e.g. following a market crash) implied volatility often trades below short-dated realised volatility. This low or even negative risk premium reflects the fact that the possible outcomes are more balanced, as sharp declines in realised volatility are substantially more likely when the volatility levels are high.

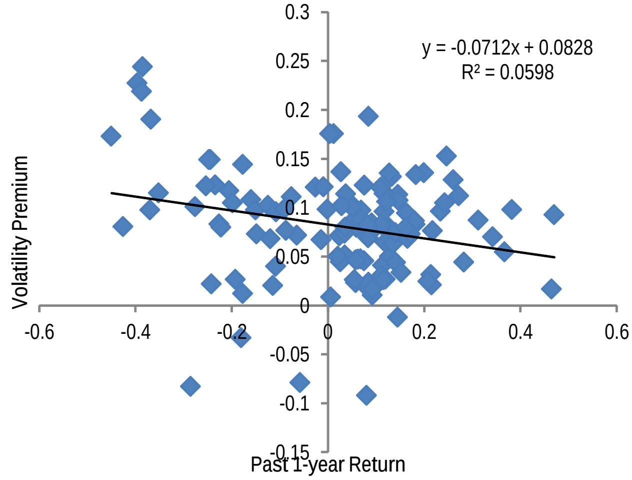
Option supply and demand dynamics also affect the size of the volatility risk premium. For example, in a market where investors are on aggregate net buyers of index options, market makers will on average be net short volatility. Having all a similar position, market makers will have reduced their ability to cover their volatility shorts, should markets correct, thus making the trade riskier and leading to a widening of the volatility premium.

In addition, the overall net short or long position of option market makers will also have another impact on realised volatility, as the market maker's **dynamic delta hedging activity will impact the realized volatility of the index**. This is referred to as 'gamma effect' ('gamma' describes how much the option delta changes with the index level) and has been discussed in detail in Kolanovic. M., *Market Impact of Derivatives Hedging*, *J. P. Morgan*, 2008.

The **implied volatility risk premium is a measure of the perceived risk that realized volatility will turn out to be higher than currently estimated**. It reflects the behaviour of volatility (mean reversion and propensity to spike), but also the perceived risk linked to an event. As the supply/demand dynamics and perception of idiosyncratic or event risk typically differ from market to market and across time, **different markets can display very different volatility risk premia** (different levels, but markets can be interconnected as we will discuss later). See Box 1 for a discussion on the Japanese market that illustrates how different market characteristics may affect volatility markets in general.

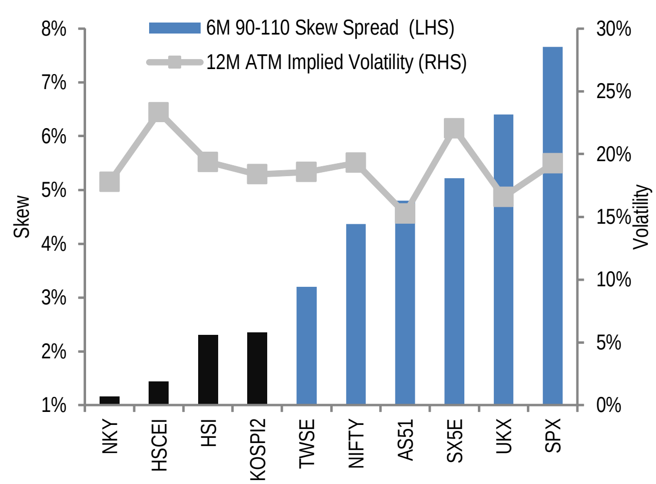
The implied volatility risk premium provides a potentially attractive source of returns for investors, but the risk of a sharp and unexpected loss is all very real, making risk management in short volatility positions an absolute necessity. But these risks are the reason that this risk premium can be attractive and why it varies over time. As we

Chart 4: S&P 500 Volatility Premium conditional on previous market moves (S&P 500 past 1-year return)



Source: J.P. Morgan, Bloomberg. Volatility premium based on Implied Volatility and 2-day Range Volatility. Only end of month data to make chart clearer, but results are similar for daily. Note that short lookbacks such as 1 month would lead to positive slopes. This is due to the short-term relationship between volatility and returns as discussed in Ribeiro and di Pietro, *Volatility Signals for Asset Allocation*, J.P. Morgan, 2008.

Chart 5: Skew across International Equity Markets



Source: J.P. Morgan, Bloomberg.

mentioned before, one of the empirical facts is that the premium tends to be higher after market losses (Chart 4) as market players look more actively for protection after they suffer losses, which changes the supply and demand balance.

Volatility Risk Premium: Common and Country-Specific Risk

Most of the movements in volatility and/or risk premium are common to multiple markets. In an analysis of the three main markets (US, Europe and Japan), we find that the average correlation of the monthly changes in implied volatility is around 0.75. The same analysis for daily changes delivers a lower level of commonality implying that (i) most of the changes in volatility are of a global nature, but (ii) there are short-term deviations that do not persist (alterna-

Box 1: Volatility markets in Japan

The peculiarities of the structured products market in Japan have been a major factor influencing Japanese equity volatility. Driven by the hunger for yield under a prolonged low interest rate environment, domestic retail investors flock to equity-linked structured notes for income generation, which offer considerably higher yield than fixed deposits but with a higher possibility of capital being at risk.

Structured products, notably those sold in the uridashi market, tend to be very homogenous, with a limited range of structures and underlyings representing the vast majority of the volume. The most common product being sold is the "auto-callable", also known as equity gain knock-outs (EGKs), linked to Nikkei, with maturities typically ranging from 3 to 5 years. The product is suitable for investors with a range bound view. Investor is essentially long a bond with a coupon that is funded by selling of an ATM put option with a down-and-in (DI) barrier of 50% to 70% of initial spot and / or an up-and-out (UO) barrier of 100% to 110% from initial spot, or a combination of both.

Due to the embedded put selling features for yield enhancement, investment banks supplying the EGKs are effectively buying options from the retail investors. The heavy issuance activities have resulted in EGKs becoming the most significant source of volatility supply in Japan. As the banks look to manage these positions, their collective hedging tends to suppress market volatility and skew. Without a consistent stream of demand from institutional investors buying options for hedging or directional purposes, the volatility supply and demand imbalance caused by the EGK issuance can persist for an extended period of time. Hence, it is not surprising to find that in Japan and other Asian equity markets with active structured product issuance, skews tend to be among the lowest in the world (see Chart 5, previous page).

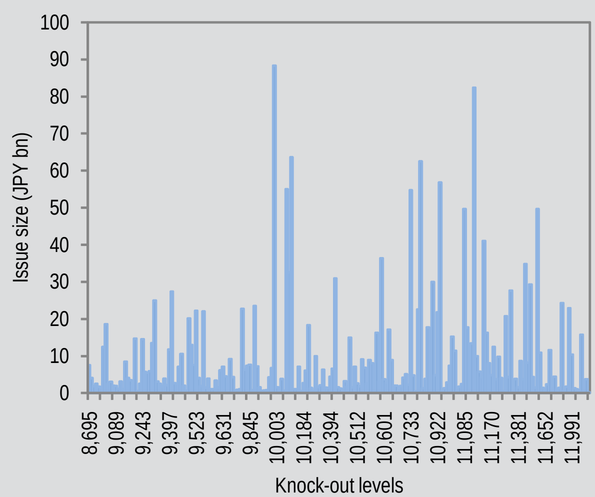
Although heavy EGK issuance and related hedging initially suppress volatility and skew, the product vega concentration and discontinuity from the DI and UO barriers can provide volatility catalysts to the equity market. During sharp market sell-offs, if a put option is knocked-in, it is already deep in-the-money, hence there would be large discontinuity on the downside. Though discontinuity on the upside is generally smaller, the value of the put option lost in the case of the knock-out event can be large if the product is still far from maturity and volatility is high.

The delta of the knock-in put becomes more negative as it approaches the barrier and hence the Nikkei-linked EGK issuers would have to buy more index futures to hedge as the barrier approaches. However, as the barrier is breached the knock-in put becomes a vanilla option that is very much in the money. With less negative delta exposure, the product issuers have to reduce their delta hedge quickly by selling index futures.

To hedge the long vega exposure from EGK issuance, the issuers have generally shorted volatility and skew. When the structure becomes knocked-in on the downside, the knock-in put becomes a vanilla option that is very much in the money with very little vega exposure. As a result, the issuers are forced to buy back their short volatility positions to re-hedge.

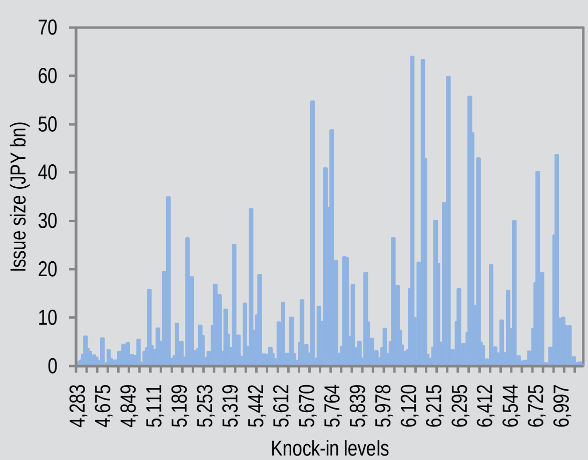
Charts 6 and 7 illustrate the concentration of the UO and DI barriers of the currently outstanding Nikkei-linked EGKs (data available in Nov 08 2012). We see that the current Nikkei level (around 9000) is far from those DI barrier levels (i.e. below Nikkei level of 7000), although the peak vega exposures from the EGKs are estimated to be slightly above 7000. On the upside, the risk of the UO barriers does not appear very significant until Nikkei reaches near the level of 10000.

Chart 6: Concentration of the UO barriers



Source: J.P. Morgan, Bloomberg.

Chart 7: Concentration of the DI barriers



Source: J.P. Morgan, Bloomberg.

tively, there are spillover effects, as we will discuss later on). A similar pattern applies to realized volatility independently of the measure. Above we looked at the correlation of the changes, but the correlation of the level of the implied (or realized) volatility is much higher in the 0.80-0.90 range.

But there is **important idiosyncratic variation in volatility**. In the case of the Japanese market, we find that 49% of the variation in implied volatility is due to idiosyncratic variation. This calculation is based on a contemporaneous regression of the log changes in Japanese implied volatility on the equivalent variables for the European and US markets. To be clear, that does not imply that 49% of the changes are Japan-specific, as they can be common to other Asian countries. Thus, there may be information that is common to other markets in those residuals. They are just not common to the US and Europe. (We will test that idea later on). Also, note that residuals are negatively serially correlated (-0.17). We tend to see large negative residuals after large positive ones, as in the case of events such as the 2011Tohoku earthquake. This is consistent with the view that most of the deviations are short-term and that there may be spillover effects.

Volatility Spillover and Clustering: can we forecast drawdowns in variance swaps?

In this section, we analyze the autocorrelation/persistence/clustering of different volatility measures, but we also introduce the possibility that there is cross autocorrelation (spillover) between markets. We focus on the US, Europe and Japan using data since 2001.

In economic terms, we **test whether there are spillover effects between markets** in the sense that a change in any of the measures of volatility/variance (realized volatility, implied volatility, ex-ante and realized premium) in a particular market today implies a move in the same direction later in all other related markets[1].

At the same time, we **test the persistence of these volatility measures, i.e. their serial correlation or clustering**. In the specific case of the volatility premium, we test if changes in the volatility premium in a certain market have any effect in the same direction on the future level of volatility in another market or the same market.

These linkages in volatility markets have been analyzed exhaustively in the academic literature and we do not aim to review the literature here[2]. We test spillover and clustering using three different measures: implied volatility, realized volatility and the volatility premium[3].

Box 2: Measuring Volatility

We considered the following measures:

- **Measures of Realized Volatility**:

  1) Average Daily Squared Returns: Standard measure. We considered both 30-calendar day or 21-business day daily squared returns. We use the square root of that calculation.

  2) Range Volatility: There are many types of range-based volatility that we considered from the traditional Parkinson (based on high and lows only) and Garman-Klass (also account for open and close levels) to other methods that try to address downward biases of the above measures in the presence of drift and jumps. We leave these variations for the reader and focus on one particular model. We use the Yang-Zhang estimator (Yang and Zhang (2000)) which is a price range estimator that is unbiased, independent of any drift, and consistent in the presence of opening price jumps. We use a 10-day window.

- **Measures of Implied Volatility**:

  1) Average Implied Volatility: to minimize the effect of outliers/noise, we also compute monthly rolling averages (Average 30-calendar day or 21-business day). This measure matches the same range of days used to estimate the relevant measure of realized volatility (Average 30-calendar day or 21-business day Daily Squared Returns).

  2) Lagged Implied Volatility: we use the 30-calendar day or 21-business day lagged value.

1 In econometric terms: In the cross-country case, if a particular volatility measure in country i Granger-causes the same volatility measure in country j, but with a positive direction and not any direction.

2 The main differences in approach are that: a) we do not use GARCH-like models or multivariate versions; b) we focus on the implications for the trading of variance swaps and related instruments. Therefore, we want to forecast squared daily returns even if they are not the best measures of realized volatility (in terms of efficiency, relative to range volatility measures for instance). However, we consider both past daily squared returns and past range-based volatility measures when forecasting future volatility (we ignore models based on intraday pricing here).

3 Note that finding that both implied and realized volatilities are persistent and that they present spillover effects does not necessarily imply that the premium (difference between implied and realized) will also have the same properties. It is possible that implied and realized share a common persistent component, while the difference is not persistent at all. Empirically, we do find that the difference (premium) is persistent as well.

Table 1: Implied Volatility - Vector Autoregression
regression coefficients and t-stats, constants are not reported

	VIX(t)	VSTOXX(t)	VNKY(t)
		Daily	
VIX(t-1)	0.81	0.26	0.55
(t-stat)	5.27	1.70	2.31
VSTOXX(t-1)	0.01	0.70	-0.15
(t-stat)	0.17	7.12	-1.44
VNKY(t-1)	0.01	-0.13	0.43
(t-stat)	0.13	-1.74	3.99
R-sqr	0.67	0.67	0.60
		Monthly	
VIX(t-1)	0.66	0.13	0.56
(t-stat)	4.99	0.88	3.10
VSTOXX(t-1)	0.11	0.82	-0.17
(t-stat)	1.26	8.03	-1.36
VNKY(t-1)	0.00	-0.16	0.41
(t-stat)	0.03	-1.57	3.28
R-sqr	0.73	0.73	0.59

Source: J.P. Morgan, Bloomberg. We use 21-day lagged info on both cases. We also tested the monthly case using end-of-month data only. We also tested Granger causalility in that case and found that VIX Granger-causes all three indices at a 10% level.

We first consider a VAR approach[4] using both implied volatility and measures of realized volatility, so we estimate a vector autoregressive model with our three selected countries. We present the results of monthly and daily VAR's. By using monthly regressions, we minimize the effect of different time zones in our analysis.

Table 1 presents the results for implied volatiltity. Overall, we find coefficients that are **consistent with positive autocorrelation (persistence) in the changes in implied volatility and also positive cross autocorrelation (spillover)**, even though the interaction between Europe and Japan is not consistent.

Table 2 presents the results when using realized volatility instead, showing that we do find some spillover effects. In the case of realized volatility, we present the results using measures based on Yang-Zhang range volatility using 10-day windows[5]. We find similar results when using other volatility measures, but these are not reported here. We do not find a strong effect coming from Japanese volatility in the full sample.

4 VAR (Vector Autoregression) is is a statistical model used to capture the linear interdependencies among multiple time series, where the evolution of each series depends on the past realizations of the same variable and other variables in the system. We use VAR(1) here implying that only one lag is used.

5 There is no overlap in the data used to compute lagged and forward volatility in the monthly regressions. There are no biases in our monthly tests, but standard errors can still be biased in daily regressions. In order to address these concerns, we use Newey-West adjusted standard errors.

Table 2: Range Volatility - Vector Autoregression
regression coefficients and t-stats, constants are not reported

	US(t)	Europe(t)	Japan(t)
		Daily	
US(t-1)	0.22	0.21	0.11
(t-stat)	1.60	1.30	0.74
Europe(t-1)	0.44	0.59	0.26
(t-stat)	5.38	5.83	4.29
Japan(t-1)	0.12	-0.13	0.19
(t-stat)	1.37	-1.04	1.69
R-sqr	0.61	0.45	0.39
		Monthly	
US(t-1)	0.39	0.36	0.26
(t-stat)	3.38	2.26	2.19
Europe(t-1)	0.32	0.58	0.17
(t-stat)	4.64	6.01	2.44
Japan(t-1)	-0.01	-0.28	0.12
(t-stat)	-0.11	-1.58	0.96
R-sqr	0.56	0.48	0.39

Source: J.P. Morgan, Bloomberg. Based on Yang-Zhang range volatility estimates using 10 business days.

Table 3: Forecasting Volatility Premium - Selected Model
regression coefficients and t-stats, constants are not reported

	US(t)	Europe(t)	Japan(t)
		Daily	
US(t-1)	0.42	0.51	0.44
(t-stat)	2.57	5.45	1.52
Europe(t-1)	0.18	0.08	0.11
(t-stat)	1.80	0.97	0.88
Japan(t-1)	0.04	-0.09	0.25
(t-stat)	0.33	-1.56	1.31
R-sqr	0.12	0.14	0.14
		Monthly	
US(t-1)	0.59	0.93	0.40
(t-stat)	3.26	6.04	1.83
Europe(t-1)	0.19	-0.04	0.01
(t-stat)	1.30	-0.36	0.07
Japan(t-1)	-0.06	-0.26	0.36
(t-stat)	-0.41	-2.11	2.06
R-sqr	0.13	0.23	0.13

Source: J.P. Morgan, Bloomberg. Premium is measured as the difference between implied volatility at the beginning of the period and the average squared daily returns over the next month. Regressors are based on the monthly average of the implied volatility and range volatility computed using 10 business days.

Table 4: Correlation between Realized and Forecast Vol Premium
Daily models

	Average Implied	Lagged Implied
Range Volatility	0.37	0.32
Squared Returns	0.29	0.28

Source: J.P. Morgan, Bloomberg.

Interestingly, **we also find similar, but weaker, pattern for the volatility premium**. In the case of the volatility premium, we change the set of explanatory variables and depart from the VAR framework. While the left-hand side of the equation should represent the payoff of an actual strategy (payoffs are usually based on realized squared daily returns or similar), it may still be best to measure the ex-ante premium using range-based measures or measures that include more granular intraday price information.

Table 3 shows the results for our selected model, indicating that, also for the volatility premium, **there may be useful information in the past volatility premium in other countries** (particularly from the US).

Overall, all the models are useful in forecasting future volatility premia. Table 4 shows the range of correlation between fitted and actual realized premia (the square roots of the regression's R-squares, the average of the three regressions) obtained with different forecasting models for daily observations. We look at all the combinations of measures as described in Box 2.

We should note that the models above are trying to forecast the precise level of the volatility premium. This is challenging as coefficients may become distorted due to extreme events. From a trading point of view, it is more important to forecast the sign of the premium than the level itself. Below we will focus on estimating the probability of a positive premium and not on its level.

Exploiting Volatility Spillover and Clustering

Given the empirical evidence of spillover and persistence/clustering, we can now design strategies that exploit these features. Therefore, we introduce the following modifications to a traditional short volatility strategy:

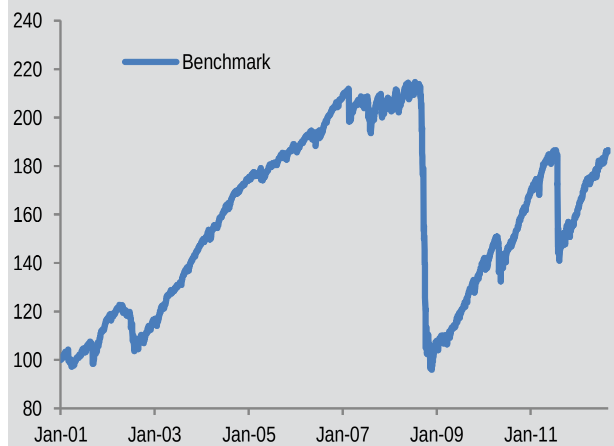
- **Frequent monitoring and trading**: instead of trading once a month and praying for nothing to happen over the next 30 days as in the case of a single variance swap, we will use overlapping positions[6], trading a fraction of the notional invested every day (rebalancing fully over the course of the month).

- **Conditional on the expected premium**: we only go short volatility at any day if the probability of a positive realized premium over the next 30 days is larger than a pre-determined level (for example, 85%), doing nothing otherwise. An example of long-short version is to go short if the probability of a positive premium is larger than 85%, go long volatility if the probability is less than 65% and do nothing otherwise. In this case, there is a neutral region between 65% and 85% where we do not trade that day. We want to make sure the probability of a positive premia is high, as losses can be quite high in magnitude.

Box 3: Short Volatility Benchmark

In our analysis, we compare returns of our strategies to the ones of a benchmark short volatility strategy. In our strategies, we exploit two features: a) time variation in risk premium; and b) spillover effects. So our benchmark will ignore both features by being systematically (always) short volatility and by focusing only on one market (US market). Chart 8 shows the payoff of our benchmark based on a transparent calculation methodology (using VIX Index to determine the strike). Every day, we go short this synthetic 30-day S&P 500 variance swap. The sizing of the position is such that we fully rebalance our allocation over the course of a month (1/20 of the allocation is implemented everyday, with same vega). The performance chart has some features to note: large losses after the Lehmann debacle and in 2011; decreasing return from 2001 to 2007 as the curve looks concave (lower return near 2007 than earlier); and steep premium after large losses (steeper after large losses in 2008).

Chart 8: Synthetic Short S&P 500 Variance



Source: J.P. Morgan, Bloomberg. Calculations are net of transaction costs. Excess Returns

How do we estimate these probabilities? In the previous section, we considered a model where we estimate the future realized premia for each country based on forecasting variables from all three countries analyzed here. We do not change the right-hand side of the equation but replace the left-hand side with 0's or 1's where the dependent variable becomes 1 if the realized premium is positive and 0

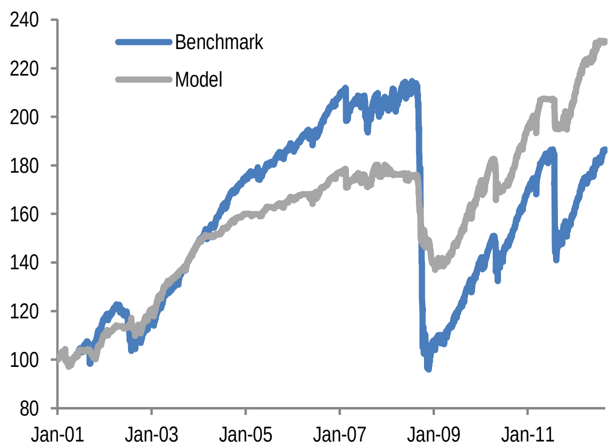
6 Note that using overlapping positions on a daily basis per se does not add value as our benchmark already has that feature (Box 3), but the combination of these two features does add value as we respond to changes in the expected premium more effectively.

Table 5: S&P 500 Short Volatility vs Predictive Model
Summary Statistics

	S&P Short Vol	S&P Vol (Predictive model)
Avg Excess Return	5.3%	7.2%
Standard Deviation	13.7%	6.6%
Sharpe Ratio	0.39	1.09
T-stats	1.34	3.78
Correlation (S&P 500)	0.59	0.40
Max Drawdown	-55.3%	-24.0%

Source: J.P. Morgan, Bloomberg. Calculations are net of transaction costs. Sharpe ratio is not necessarily a good performance measure due to the convexity of the payoff, but it is useful for comparison across models.

Chart 9: Performance of S&P 500 Short Volatility vs Model
Excess Return Index



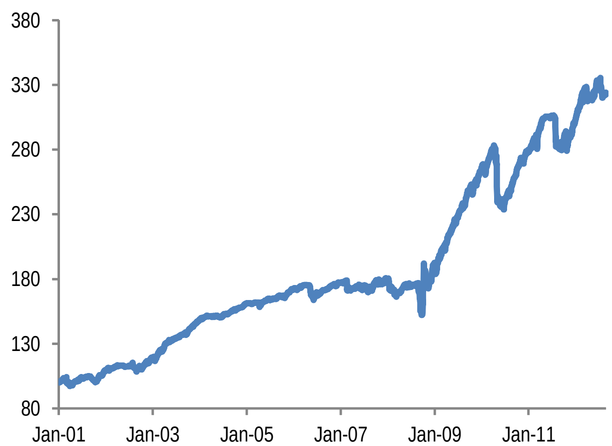
Source: J.P. Morgan, Bloomberg. Calculations are net of transaction costs.

Table 6: International vs US Model
Summary Statistics

	US Only	US, Europe and Japan
Avg Excess Return	7.2%	10.2%
Standard Deviation	6.6%	8.6%
Sharpe Ratio	1.09	1.19
T-stats	3.78	4.14
Correl (MSCI World)	0.35	0.23
Max Drawdown	-24.0%	-17.4%

Source: J.P. Morgan, Bloomberg. Calculations are net of transaction costs.Sharpe ratio is not necessarily a good performance measure due to the convexity of the payoff, but it is useful for comparison across models.

Chart 10: Trading US, Europe and Japan
Excess Return Index



Source: J.P. Morgan, Bloomberg. Calculations are net of transaction costs.

otherwise. This is what is called a limited dependent variable model, where the dependent variable is 1 if the realized premium is positive and 0 otherwise. We do not present results with Probit or Logit models here, but they are also alternatives.

To make sure the strategy is feasible, we re-estimate the model everyday using only information prior to each day. Therefore, we never use future information to estimate regressions. We use the estimated parameters (with the appropriate lag) and the actual past realizations of the independent variables to compute the predicted probability for the coming month at each point in time.

Given this forecasting model, everyday we have an estimated probability of a positive premia for each country for the coming 30 calendar days. Hence, we can use these estimates to build trading strategies.

In order to test this strategy, we will **trade on publicly available data** using implied volatilities as an indication of the actual variance swap quotes as these are bank-specific OTC quotes. We ignore the differences between these two measures (ignoring skew, for example), but our analysis based on JPM internal variance swap quotes lead to similar qualitative results. In order to evaluate performance, we also use transparent and publically available implied volatility levels and compare those to the realized volatility over the next 30 calendar days according to swap conventions.

Trading S&P500 volatility on spillover

First, we test the spillover idea trading only one market (S&P 500) but we use all countries to estimate the probability of a positive premium. We compare this new model to the benchmark version that is always short US volatility (Box 3). Chart 9 shows that our S&P 500 volatility premium model outperforms the benchmark case. Table 5 shows the performance statistics of both strategies.

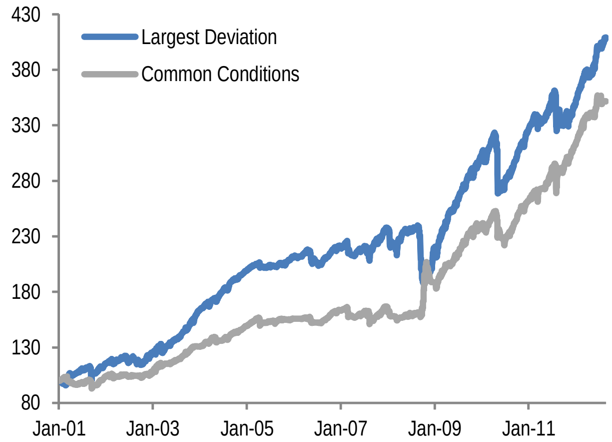
We manage to improve average returns while reducing the volatility and the drawdowns of the strategy. This strategy will be more conservative than a pure strategy that is always

Table 7: Simpler Rules
Summary Statistics

	Rule 1 (largest deviation)	Rule 2 (common conditions)
Avg Excess Return	12.4%	10.2%
Standard Deviation	9.9%	8.5%
Sharpe Ratio	1.25	1.21
T-stats	4.34	4.19
Correlation (MSCI World)	0.22	0.15
Max Drawdown	-21.7%	-12.2%

Source: J.P. Morgan, Bloomberg. Sharpe ratio is not necessarily a good performance measure due to the convexity of the payoff, but it is useful for comparison across models.

Chart 11: Performance of Simple Short Volatility Strategies
Excess Return Index



Source: J.P. Morgan, Bloomberg. Calculations are net of transaction costs.

short volatility, so it will tend to underperform in ex-post "bullish" periods.

In these calculations, we apply a rule that is short volatility if the probability of a positive premium is above 85%, but goes long volatility if it is lower than 65%. If we are between those two levels, we do nothing that day. Note that results are robust to changes in both cut-off points. Note that the choice of 85% was not arbitrary as it is roughly the average probability of a positive premium.

Trading US, European and Japanese volatility

Second, we look at a **version of the strategy that can trade all markets**. This generalized version goes short the market (US, Europe or Japan) with the highest probability of a positive premium (or goes long the one with lowest probability of a positive premium). We choose the position that is the most extreme.

For example, let us assume that our benchmark probability is 75%, which was the mid-point of the S&P 500 volatility strategy analyzed before. Let us also assume that the US market has a probability of a positive premium of 90%, Europe has a probability of a positive premium of 30% and Japan is 60%. Hence, we choose to trade Europe as the 30% probability is the most extreme relative to 75%. Obviously we will be long volatility in Europe as the probability of a positive premium is very low. The larger difference relative to the benchmark probability may imply that the information in this particular market is more significant in some sense.

We manage to **improve performance even further by adding additional markets** (Chart 10 and Table 6). All performance statistics improve with the exception of the volatility of the strategy. The main reason we manage to improve the performance is that we increase the dispersion in the range of premia (in part due to structural differences).

Two Simple Rules

Third, we look at **simpler versions of this idea that do not depend on any parameter estimation**, avoiding regression models. We estimate the volatility premium for each market independently using the measures decribed in Box 2, so that the volatility premium is a function of the recent spread between implied and realized volatilities. However, we use a rule that considers the interaction between markets. The main advantage is that we reduce the potentially large impact of estimation error, but not without a cost as we ignore the actual relationship between each market.

We considered two simple (not simplistic) rules:

Rule 1

- To estimate the premium, we use the difference between Average Monthly Implied Volatility and Range Volatility.
- We select a benchmark premium. We use 2% in our example.
- Identify the market with largest deviation from the benchmark premium and trade that market accordingly (if above the benchmark premium, go short volatility and if below, go long volatility).
- If the premium is within a band, do not trade that day. In our example, we use a range between 1% and 3%.
- Sizing of each position is based on a fixed vega (2.5bps per day).
- Note that each daily position in never unwound or offset.

Rule 2

- To estimate the premium, use the difference between Average Monthly Implied Volatility and Average Monthly

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Table 8: Simpler Rules (No Long positions)

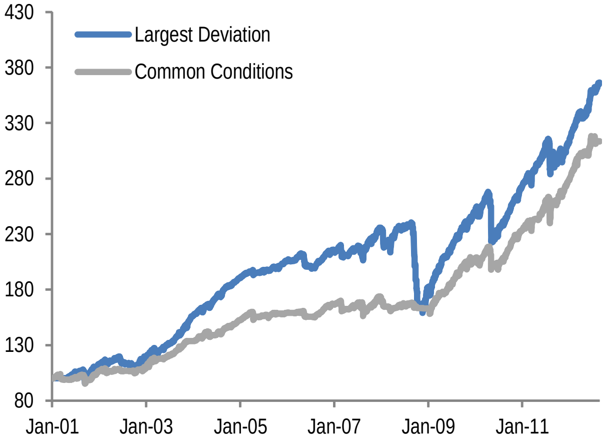
Summary Statistics

	Rule 1 (largest deviation)	Rule 2 (common conditions)
Avg Excess Return	11.4%	9.9%
Standard Deviation	9.3%	7.1%
Sharpe Ratio	1.22	1.39
T-stats	4.24	4.83
Correlation (MSCI World)	0.40	0.32
Max Drawdown	-33.8%	-9.5%

Source: J.P. Morgan, Bloomberg. Sharpe ratio is not necessarily a good performance measure due to the convexity of the payoff, but it is useful for comparison across models.

Chart 12: Performance of Simple Short Volatility Strategies (no long positions)

Excess Return Index



Source: J.P. Morgan, Bloomberg. Calculations are net of transaction costs.

Realized Volatility based on squared daily returns .

- If the volatility premium is positive in all three markets, go short the one with the most positive premium that day.
- If the volatility premium is negative in all three markets, go long the one with the most negative premium that day.
- If the volatility premium is not consistent (two negatives/ one positive or two positives/one negative), do nothing that day.
- The sizing of each position is based on a fixed vega (2.5bps per day).
- Note that each daily position in never unwound or offset.

Even these simpler versions deliver strong performance. Chart 11 and Table 7 show the performance statistics of these two strategies. Rule 1 focus on the market with the largest deviation while Rule 2 tries to identify market conditions when the sign of premia is common across markets as this makes us more confident that the volatility premia is positive or negative. In both cases, we are using information on all markets but we only trade a single market per day.

Table 9: Asian Markets (Japan, HK and Australia)

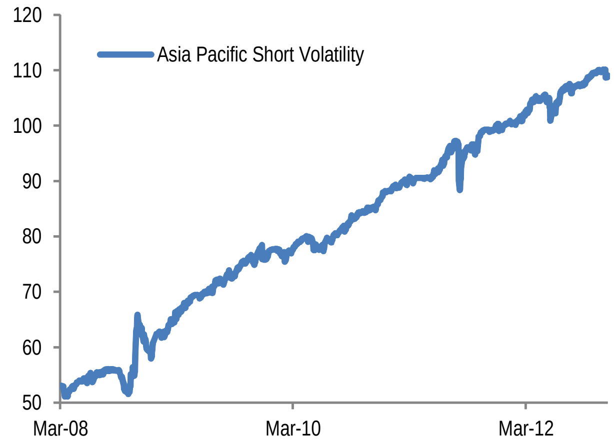
Summary Statistics

	Asia-only Strategy
Avg Excess Return	17.2%
Standard Deviation	10.6%
Sharpe Ratio	1.62
T-stats	3.28
Correlation (MSCI Asia Pac)	0.12
Max Drawdown	-12.0%

Source: J.P. Morgan, Bloomberg. Calculations are net of transaction costs. Since March 2008. Sharpe ratio is not necessarily a good performance measure due to the convexity of the payoff, but it is useful for comparison across models.

Chart 13: Performance of Asian Short Volatility Strategy

Excess Return Index



Source: J.P. Morgan, Bloomberg. Calculations are net of transaction costs.

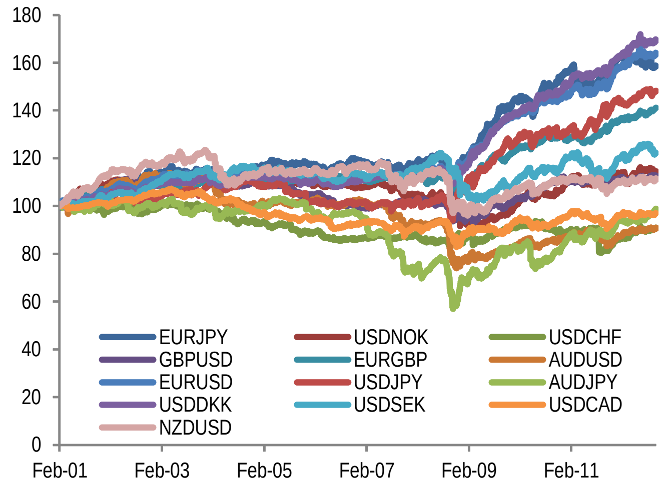
Chart 12 and Table 8 show the performance of short-only versions of the same strategies. Therefore, we never take long volatility positions. We see that that return-risk profile remains interesting.

Other International Markets

We also find that this **approach has paid off even if we restrict ourselves to particular regions such as Asia**. One point that we made earlier is that some of the Japan-specific shocks in a regression of Japanese volatility on US and European volatility were not necessarily Japan-specific and potentially broad Asia shocks. If this is the case, there could be Asian spillover effects.

A lot of academic papers have analyzed spillover in Asian equity markets, so here we focus only on the strategy side. We test a model where we trade Japan, HK and Australia. Chart 13 and Table 9 shows the performance of a version of the simple model (no regression, Rule 2) using those markets. Sample is shorter due to data limitations.

Chart 14: Performance of Systematic FX Short Volatility Strategies
Excess Return Index



Source: J.P. Morgan, Bloomberg. Gross of transaction costs.

Table 10: FX and Equities Spillover
Regression statistics

	FX(t)	Equities(t)
	Implied Volatility	
FX(t-1)	0.80	0.21
(t-stat)	11.90	0.82
Equities(t-1)	0.00	0.68
(t-stat)	0.18	8.74
R-sqr	0.75	0.65
	Realized Volatility	
FX(t-1)	0.61	0.79
(t-stat)	9.63	4.44
Equities(t-1)	0.09	0.62
(t-stat)	4.35	10.07
R-sqr	0.57	0.59

Source: J.P. Morgan, Bloomberg. Monthly regressions.

Cross-asset Volatility Spillover

A natural extension of this idea is to **exploit spillover to similar volatility carry strategies in other asset classes or the persisitence in their premium**. Other asset classes such as FX may be subject to similar spillover effects in the sense that large moves in equity markets could anticipate similarly large moves in currencies and vice versa. It is well known that there are common risks across asset classes and that the common risks become more pronounced in high-volatility periods. Then, it is not suprising that different volatility processes in different asset classes would also be correlated both contemporaneously or with lags.

In this note, we test this hypothesis using FX, which has been the most common subject of the academic studies of volatility spillover including multiple asset classes. First, we test spillover effects and analyze the contemporaneous correlation in implied and realized volatility. Then, we test spillover-based ideas using a FX volatility carry strategy constructed by going short at-the-money straddles or synthetic variance swaps based on at-the-money implied volatility (note that this will underestimate the actual performance as the premium will be biased downwards).

Relation between FX and Equity Volatility

Not surprisingly, we find that **equity and FX volatility markets are related on a contemporaneous basis**. Chart 2 (second page) shows the rolling correlation between the average log change in equity implied volatility (our 3 selected markets) and the average log change in FX implied volatility (average across our selected 3 pairs and also the broad list). We see positive and upward-trending correlation between changes in Equity and FX implieds over the whole sample (see Kolanovic, *Rise in Cross Asset Class Correlations*, *J.P.Morgan*). Moreover, Diebold and Yilmaz, *Better to Give than to Receive, International Journal of Forecasting* (2012) argue that volatility spillover among different asset classes has become stronger after the global financial crisis, particularly from equities to other asset classes.

In order to test spillover, we use the same approach as in previous sections, but we limit the number of variables that we use. On the equities side, we use an equally-weighted average of the three markets (US, Europe and Japan). On the FX side, similarly we use an equally-weighted average of selected pairs.

First, we test spillover in the volatility measures using average implied volatility and average realized volatily. Table 10 shows the result of this analysis. Overall, we find spillover in both directions. We should note that the spillover effect in variance swap returns is less evident, but the next step is to consider the implications for trading.

FX Volatility Carry

We leave more details for future publications, but here we take a quick look at the potential benefit of considering FX volatility carry strategies and combinations with Equity volatility carry.

Systematic short volatility FX strategies have overall been profitable over the full available sample (Chart 14). Note that periods of underperformance would not necessarily be profitable for long volatility positions after accounting for transaction costs. We exclude two of the outliers in the

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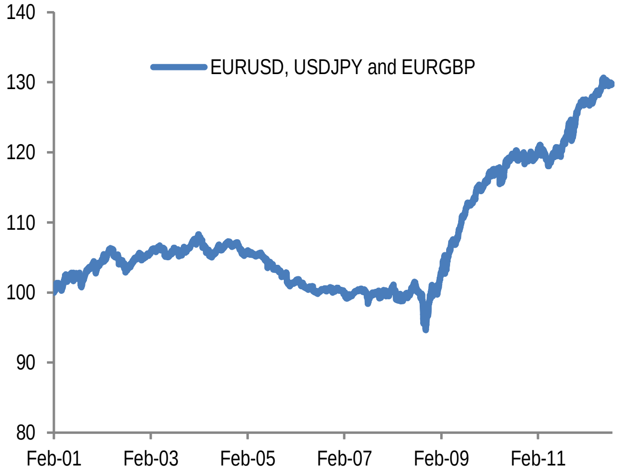
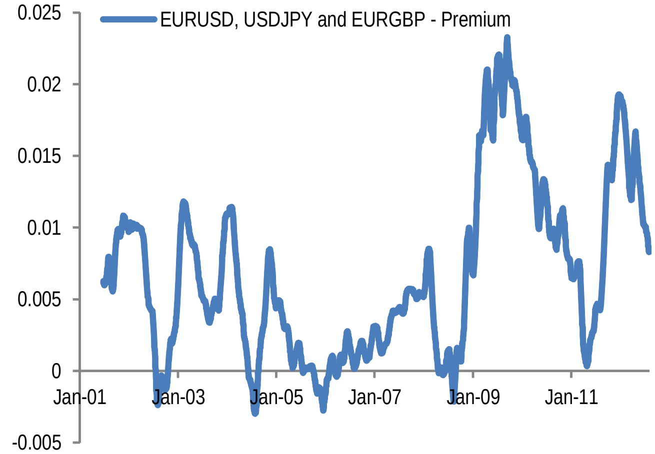
Chart 15: Performance of Systematic FX Short Volatility Strategies
Excess Return Index, Net-of-costs performance.



Source: J.P. Morgan, Bloomberg. Calculations are net of transaction costs. Risk-weighted portfolio fo EURUSD, USDJPY and EURGBP.

Chart 16: Average Implied vs Realized Premium
Rolling 63-day average, average across currencies



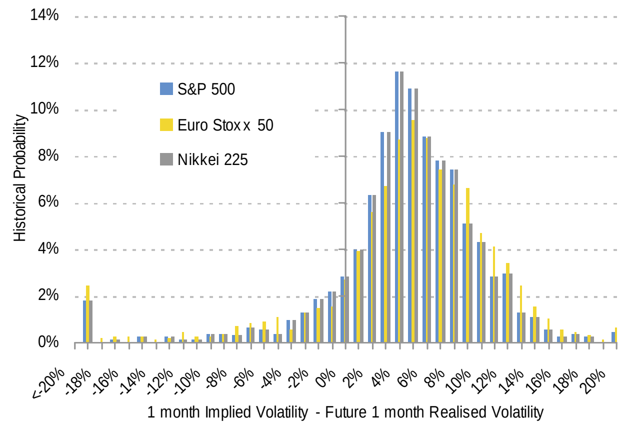
Source:J.P. Morgan, Bloomberg.

analysis (USDPLN and USDMXN) as they distort the scale of the chart but these were actually the best performers. These calculations are based on the return of short straddles (delta-hedged) with a constant vega (2.5bps per day).

We did our best to account for the likely transaction costs. All our calculations are based on mid 1M implied vols available on Bloomberg. But we included a spread dependent on the level of volatility to account for the likely transaction costs. Based on these numbers and the price evolution of each pair, we computed the return of being short delta-hedged straddles. In the rest of the note we focus on major pairs where we feel confortable our cost assumptions are reasonable for the overall sample (Chart 15). Anyway, these are markets where on average the risk premium has been positive (Chart 16). Due to their liquidity and risk characteristics, the impact of transaction costs is smaller than in the case of EM currencies for example.

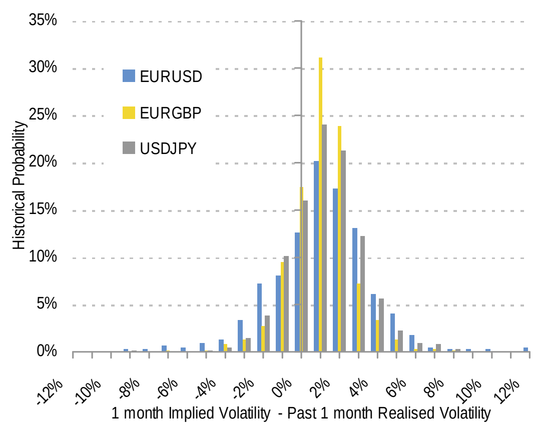
Overall we find **evidence of positive realized premia in FX volatility markets**[7]. According to our FX strategist Arindam Sandilya, there are no natural buyers of volatility that can exacerbate the premium, but the premium is overall positive due to market makers demanding a premium for writing options. As a general rule of thumb though, selling liquid options (e.g. EUR/USD) is more beneficial than highly correlated but less liquid alternatives (e.g. USD/NOK or USD/SEK). The latter seem to display bigger jumps, and it is worth paying the small premium that option markets demand

Chart 17: Empirical Distribution of Equity Volatility Risk Premium
Histogram, Realized Risk Premia



Source: J.P. Morgan, Bloomberg.

Chart 18: Empirical Distribution of FX Volatility Risk Premium
Histogram, Realized Risk Premia



Source: J.P. Morgan, Bloomberg.

7 See Chart 18 for empirical distribution of risk premia for our three selected pairs (separately) and Chart 19 for a joint cross-sectional and time series distribution including all 15pairs we analysed. For comparison, Chart 17 shows the same calculation for Equities. Chart 20 shows the same calculation for Gold. We analyze Gold in a future publication.

over EUR vols. Therefore, there can be interesting opportunities across pairs.

There can also be interesting opportunities across asset classes. For instance, it is common to see crossover players (equity/credit) looking to buy FX options as portfolio hedges against shorts/carry trades in their core asset classes, particularly when premium is relatively smaller.

Diversification Benefits

Another question is whether it **makes sense to combine both equity and FX volatility carry strategies**. We consider a simple risk-weighted allocation into FX and Equity simple volatility carry and compare to the simple versions of each strategy (Table 11). In this analysis, we ignore the benefit of timing volatility carry. By combining these strategies we improve the main perfomance characteristics. In particular, Sortino ratio is significantly improved.

Timing FX Volatility Carry

Equity volatility can help us in timing the FX volatility carry strategy. We use our probability forecasting model to trade FX based on regressions estimated with 3-year rolling windows. We estimate a separate model per currency. Table 12 compares the Sharpe ratio of our strategy pair by pair to a case where we are always short volatility.

The FX strategy only goes short the pair if probability of a positive premium is higher than a certain level (e.g. 60% probability of positive premium). We use lower cut-off points in the FX case as the predicted probability of a positive premium is on average around 60% in our sample (since 2001). Hence, it is lower than the level found in equities. Note that this is partially due to the bias in our measure of variance swap rates. Also note that the spikes in FX volatility are less pronounced so we feel more comfortable using a lower cut-off point than in the equities case.

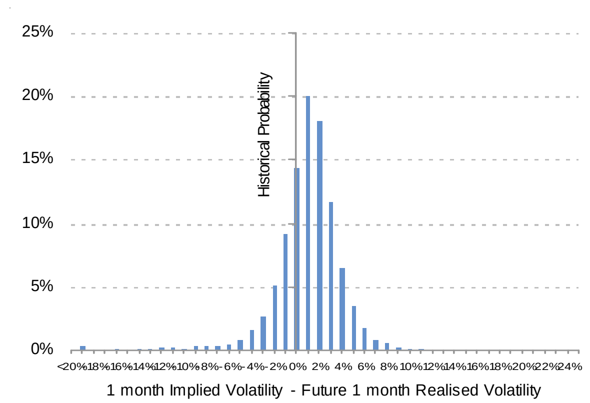
These calculations are based on variance swap return approximations and underestimate the actual performance for both strategy and benchmark. We also considered short ATM straddles (delta-hedged) where this bias is eliminated with similar qualitative results. The spillover/clustering rule improved the performance of all these short FX volatility positions, but this is not the only model that does well. We leave other variations for a future publication.

Conclusions

We find supporting evidence that there are spillover effects between international equity markets and that these effects extend into other asset classes. These results are consistent with the previous results in the academic literature. We

Chart 19: Empirical Distribution of FX Volatility Risk Premium

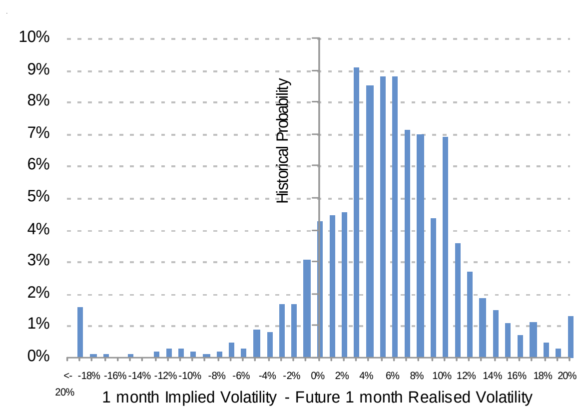
Histogram, All 15 pairs at the same time, both times series and cross-section, Realized Risk Premia



Source: J.P. Morgan, Bloomberg.

Chart 20: Empirical Distribution of Gold Volatility Risk Premium

Histogram, Realized Risk Premia



Source: J.P. Morgan, Bloomberg.

Table 11: Combining Simple FX and Equity Volatility Carry

Performance Statistics

	FX	S&P 500 Only	Risk-Weighted
Exc. Return	2.5%	5.4%	3.4%
Volatility	4.1%	13.8%	4.4%
Sharpe	0.61	0.39	0.79
Down Volatility	5.4%	21.9%	5.9%
Sortino	0.47	0.24	0.58
Max Drawdown	-17.8%	-55.3%	-21.3%

Source: J.P. Morgan, Bloomberg. Calculations are net of transaction costs. Sample one month shorter than Table 5, starting Feb 2001. FX is risk-weighted portfolio of EURUSD, USDJPY and EURGBP short volatility.

Table 12: FX Short Volatility Strategy - Sharpe Ratio

Model estimated separately for each pair

	EURUSD	EURGBP	USDJPY
Always Short	0.71	0.61	0.18
Spillover/Clustering	0.83	0.66	0.41

Source: J.P. Morgan, Bloomberg.

extended these well-known results by showing that both spillover and clustering are quite important when implementing short volatility strategies. We design a range of strategies that benefit from the spillover and persistence in volatility markets. These strategies have outperformed simple systematic short-only volatility strategies.

Many investors are aware there is a premium in volatility markets (implied vs realized is one of the examples and our focus here). Here we show that volatility markets are interconnected and that we can enhance our allocation by acknowledging these empirical relationships between different equity markets and between equities and other asset classes.

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