File ID	uvapub:69300
Filename	278263.pdf
Version	final

SOURCE (OR PART OF THE FOLLOWING SOURCE):

Type	report
Title	The world price of jump and volatility risk
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Faculty	FEB: Amsterdam Business School Research Institute (ABS-RI)
Year	2006

FULL BIBLIOGRAPHIC DETAILS:
http://hdl.handle.net/11245/1.278263

The World Price of Jump and Volatility Risk*

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February 2006

Abstract

Jump and volatility risk are important for understanding equity returns, option pricing and asset allocation. This paper is the first to study international integration of markets for jump and volatility risk, using data on index options for each of the three main global markets: US (S&P 500 index options), Europe (FTSE index options) and Asia (Nikkei index options). To explain the cross-section of expected returns on these options across strikes and maturities, we focus on return-based multi-factor models, using returns on straddles and out-of-the-money put options as proxies for volatility and jump risk factors. For each market separately, we provide evidence that volatility and jump risk are priced risk factors. There is little evidence, however, of global unconditional pricing of jump and volatility risk. We then investigate the presence of time-variation in the cross-market relationships and find evidence that UK and US option markets have become increasingly interrelated. Incorporating these time-varying patterns in conditional factor pricing models improves their fit substantially and generates some evidence of international pricing. Finally, we show that the benefits of diversifying jump and volatility risk internationally are substantial, but declining over our sample, in line with the hypothesis of increased but imperfect integration of world markets for jump and volatility risk.

*We would like to thank Gurdip Bakshi, Peter Carr, Rajna Gibson, René Stulz and participants at AFA 2005 and BSI Gamma Foundation (Zurich, 2004) for useful comments. We gratefully acknowledge the financial support of the BSI Gamma Foundation.

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The World Price of Jump and Volatility Risk

Abstract

Jump and volatility risk are important for understanding equity returns, option pricing and asset allocation. This paper is the first to study international integration of markets for jump and volatility risk, using data on index options for each of the three main global markets: US (S&P 500 index options), Europe (FTSE index options) and Asia (Nikkei index options). To explain the cross-section of expected returns on these options across strikes and maturities, we focus on return-based multi-factor models, using returns on straddles and out-of-the-money put options as proxies for volatility and jump risk factors. For each market separately, we provide evidence that volatility and jump risk are priced risk factors. There is little evidence, however, of global unconditional pricing of jump and volatility risk. We then investigate the presence of time-variation in the cross-market relationships and find evidence that UK and US option markets have become increasingly interrelated. Incorporating these time-varying patterns in conditional factor pricing models improves their fit substantially and generates some evidence of international pricing. Finally, we show that the benefits of diversifying jump and volatility risk internationally are substantial, but declining over our sample, in line with the hypothesis of increased but imperfect integration of world markets for jump and volatility risk.

A large literature has analyzed local versus global pricing of stock market risk (see Karolyi and Stulz (2002) for a survey). For developed equity markets, most evidence points towards a high degree of integration. This paper is the first to analyze international integration of markets for equity index options and to study international pricing of volatility and jump risk. There are several reasons why the degree of integration of option markets may differ from equity market integration and why this is an interesting topic to study. First of all, unlike equity markets, option markets are relatively young, with low trading volume in the 1980s and a tremendous increase in trading over the last 15 years. Secondly, it is by now well understood that the market for index options is incomplete and that index option prices reflect risk premia that are not directly present in equity markets, such as volatility and jump risk premia. Even when equity markets are highly integrated, markets for index options may be more segmented. Trading volatility and jump risk internationally - either directly by trading options, or indirectly by investing in hedge funds - could then entail important international diversification benefits. Third, while the option pricing literature has documented large volatility and jump risk premia with US data, little is known about whether this is compensation for local or global volatility and jump (or 'crash') risk, or whether these risks are even priced in other index option markets.

To analyze these important questions, we consider a large cross-section of index option returns for each of the three main global markets: the US (S&P 500 index options), Europe (FTSE 100 index options) and Asia (Nikkei 225 index options). We focus on parsimonious linear factor models to explain these cross-sections of index option returns for the period April 1992 to June 2001. Analyzing option returns has a number of benefits.[1] First, there is no need to specify a particular parametric option pricing model. Second, the presence of other risk factors (volatility and jump risk) can easily be tested for. Finally, excess returns are intuitive to interpret and immediately highlight the economic significance of the results. We first show that the CAPM (where only stock market risk matters) is strongly rejected in all 3 markets and that explicitly accounting for a local priced volatility and jump risk factor improves the cross-sectional fit of the factor model substantially. Second, we find little empirical support for unconditional international pricing of jump and volatility risk. Incorporating conditioning information makes the evidence of international pricing much stronger, especially between the US and the UK. The conditional analysis also suggests

[1] The only other paper that studies index options from an international perspective is Foresi and Wu (2005), who focus on implied volatility functions. While implied volatility functions provide interesting and intuitive information, they do not permit a formal test of the presence of other risk factors and risk premia on these factors, or of international integration.

that integration has increased over time. Finally, a study of optimal portfolio choice with index options still reveals large gains from diversifying jump and volatility risk internationally.

As a first contribution, we extend the international finance literature by investigating international integration of index option markets, which are relatively young, but have become very large over the last two decades. The second contribution is to the option pricing literature, where a variety of authors (e.g. Bakshi and Kapadia (2003), Buraschi and Jackwerth (2001), Coval and Shumway (2001), Pan (2001), and Jones (2005)) have shown that exposure to stock market risk is not sufficient to explain option returns and that some additional sources of risk seem to be priced, with volatility risk and jump risk as obvious candidates. This paper offers an extensive analysis of risk factors affecting option returns, both in an unconditional and a conditional asset pricing framework. Our findings about the pricing of jump and volatility risk also have important implications for pricing and asset allocation in equity markets and hedge funds. Recent work has demonstrated that hedge funds feature option-like risk-return characteristics (Fung and Hsieh (1997), Mitchell and Pulvino (2001), and Agarwal and Naik (2004)) and in particular that variance risk constitutes a key priced risk factor that explains their performance (Bondarenko (2004)). We will show that the intuitive measure of volatility risk that we use in this paper is closely related to Bondarenko's measure, so that our empirical results about international pricing of volatility risk shed light on the extent to which hedge funds could obtain international diversification benefits. In a different strand of the literature, Ang et al. (2004) find that volatility risk also matters for the cross-section of stock returns, while Harvey and Siddique (2000) emphasize the importance of conditional coskewness, to which our measure of jump risk can be related. Finally, our findings are also relevant for the literature on contagion and international financial crises (see Bekaert and Harvey (2003), Claessens and Forbes (2001), and Karolyi and Stulz (2002) for surveys). For example, we show that US and UK option returns are substantially more highly correlated in periods of high global volatility.

Our methodology and findings can be summarized as follows. As a first step, an unconditional local asset pricing model is estimated with time-series of returns on S&P 500 index options, FTSE 100 index options and Nikkei 225 index options. For each market, we have a large cross-section of options, with several moneyness levels and maturities. In this country-by-country analysis we extend Coval and Shumway (2001) by explicitly incorporating a volatility and a jump risk factor, and Jones (2005) by studying European and Asian markets. At-the-money straddles and out-of-the-money puts constitute the economic factor-mimicking portfolios for volatility and jump risk factors, respectively. We validate this interpretation by linking these factors empirically to the quadratic and cubic contracts of Bakshi, Kapadia and Madan (2003). The model is first estimated for the 3 individual markets and then for the pooled global market, attempting to uncover the existence of international risk factors.

The local pricing results are as follows. In line with the results for the US, we find clear evidence that the CAPM does not correctly describe expected option returns in the UK and Japan. Next, we show that for the US and UK the inclusion of our factor-mimicking portfolios for local volatility and jump risk considerably improves the cross-sectional fit, while this is not the case for Japan. In line with the option pricing literature, we find for both the US and UK a negative volatility risk premium and a positive jump risk premium. Turning to the results for the international unconditional pricing models, we provide clear evidence against international pricing of US, UK, and Japan equity index options. Especially for Japan there is no evidence that non-Japan risk factors help in explaining expected option returns. If we exclude Japan from the analysis, the performance of the international pricing model is considerably better, but still worse than the local models.

In a second step, we focus on conditional asset pricing models. Our main goal is to analyze whether allowing for time-variation in the factor loadings (risk exposure) and risk premia changes our findings on local versus international pricing of options. We first analyze cross-market correlations of option returns and find an upward trend for US-UK correlations, consistent with increased market integration. Turning to more high-frequency dynamics, US-UK correlations between straddle returns depend positively on a natural instrument for international turbulence, namely option-implied volatility. The same is true for cross-country correlations between out-of-the-money put returns, where the instrument is the implied volatility skew, which can be interpreted as a forward-looking measure of crash-o-phobia (Rubinstein (1994)). We explore this idea more formally in the linear factor model by using both instruments to scale the respective factor returns. Interestingly, accounting for conditioning information in this way further decreases the pricing errors of the US/UK model towards the pricing errors of the local models. The full international model, which attempts to explain all 3 markets simultaneously, is still rejected. In sum, we find some evidence of conditional international pricing, but local factors also matter.

Finally, we show that international diversification of option-based investment strategies has large benefits, owing to both the large risk premia on jump and volatility risk across different markets and the relatively low cross-market correlations of these strategies. Consistent with our findings of increased cross-market correlations, these international diversification benefits decrease over time, but remain important. This result provides further support for the hypothesis of increased but imperfect integration of world markets for jump and volatility risk.

Section 1 introduces the model and empirical set-up that we use to study international integration of option markets. The datasets, summary statistics and tests of the CAPM for option returns are described in Section 2. Section 3 analyzes country-specific option risk factors in unconditional models. The unconditional international analysis is presented in Section 4. Conditional results are reported in Section 5, both for local and international models. Section 6 studies international portfolio choice with option-based investment strategies. Concluding remarks follow in Section 7.

1 Model and Empirical Set-up

We study the cross-section of index option returns in 3 markets and analyze to what extent volatility and jump risk are priced, both locally and internationally. Rather than imposing a particular option pricing model, we focus on parsimonious linear factor models, where expected option returns are explained by their exposure to some priced risk factors, namely volatility and jump risk. Obviously, we also include an equity return factor in the model.

We use the well-known two-pass regression methodology (see Cochrane (2001)). In the first step we regress (for each option i) the time series $\{R_{it}\}_{t=1}^{T}$ of option returns in excess of the riskfree rate on the time series $\{Y_{kt}\}_{t=1}^{T}$ of factor portfolio returns, which generates factor beta's and time-series α's:

$$R_{it} = \alpha_i + \sum_{k=1}^{K} \beta_{ikt} Y_{kt} + \varepsilon_{it}. \tag{1}$$

We first estimate a single time-series regression per option instead of the rolling-regression approach (Fama and MacBeth (1973)), thus imposing $\beta_{ikt} = \beta_{ik}$, $\forall t$. In Section 5 we allow for time-varying beta's. In the second step, we perform the well-known cross-sectional regression in which average returns across options, $\widehat{E}\left[R_{it}\right]$, are regressed on their estimated factor beta's $\widehat{\beta}_{ik}$:

$$\widehat{E}\left[R_{it}\right] = \sum_{k=1}^{K} \widehat{\beta}_{ik} \lambda_k + \eta_i \tag{2}$$

The slope coefficients λ_k in this regression can be interpreted as the factor risk premia, and the error term η_i contains the cross-sectional pricing error (α_i). To calculate standard errors and test statistics for the cross-sectional regression, we use results of Shanken (1992) to correct for the estimation error in the first-step beta's. Finally, it is straightforward to perform a Wald test for the hypothesis that pricing errors are equal to zero.

This methodology is applied both locally and internationally, without and with conditioning information. As economically meaningful factor-mimicking portfolios for volatility and jump risk, short-maturity straddles and OTM puts, respectively, are natural candidates. In particular, we use a 'crash-neutral' ATM straddle and an OTM put with 0.96 strike-to-spot ratio. The crash-neutral ATM straddle consists of a long position in an ATM straddle and a short position in a deep OTM put option (0.92 strike-to-spot ratio). By adding an opposite position in a deep OTM put option, the straddle is protected against large crashes or jumps. Coval and Shumway (2001) introduced the crash-neutral straddle (commonly known as a ratio-call spread) in their study of straddle returns in order to mitigate a potential Peso-problem (the ex-post absence of major crashes in the sample). In contrast, we propose the ATM straddle as a factor-mimicking portfolio for a volatility risk factor that may explain expected option returns cross-sectionally (across strikes, maturities, calls and puts and across different markets). We crash-neutralize the straddle not to address potential Peso-problems, but rather in an attempt to partially 'orthogonalize' the factors in an economically meaningful way: by crash-neutralizing the straddle we reduce its exposure to jump risk, so that the importance and pricing of separate volatility and jump risk factors can be isolated and analyzed. In section 3.1 we show empirically that these factors can indeed be interpreted as proxying for volatility and jump risk.

2 Data Description

The empirical analysis is based on time series of returns on three equity indices (S&P 500, FTSE 100, and Nikkei 225), and associated index options. We use Datastream to obtain weekly returns on the three indices, including dividends. We also use Datastream for data on the 1-week Eurodollar US interest rate, the relevant currency rates, and 1-month currency forward rates. For all countries, the sample runs from April 1992 until the end of June 2001.

The US option data consist of S&P 500 futures options, which are traded on the Chicago Mercantile Exchange. The dataset contains daily settlement prices for call and put options with various strike prices and maturities, as well as the associated futures price. We apply the following data filters to eliminate possible data errors. First, we exclude all option prices that are lower than the direct early exercise value. Second, we check the put-call parity relation, which consists of two inequalities for American futures options. Using a bid-ask spread of 1% of the option price and the riskfree rate data, we eliminate all options that do not satisfy this relation.

Since these options are American with the futures as underlying, we apply the following procedure to correct the prices for the early exercise premium. We use a standard binomial tree with 200 time steps to calculate the implied volatility of each call and put option in the dataset. Given this implied volatility, the same binomial tree is then used to compute the early exercise premium for each option and to deduct this premium from the option price. By having a separate volatility parameter for each option at each trading day, we automatically incorporate the volatility skew and changes in volatility over time. Based on this procedure, the early exercise premia turn out to be small, ranging from about 0.2% of the option price for short-maturity options to 1.5% for options with around 1 year to maturity. Compared to options that have the index itself as underlying, these early exercise premia are small because the underlying futures price does not necessarily change at a dividend date. Therefore, even if the model used to calculate the early exercise premia is misspecified, we do not expect that this will lead to important errors in the option returns that are constructed below.

To convert the option price data into returns we follow a similar procedure as in Buraschi and Jackwerth (2001) and Coval and Shumway (2001). First, we fix several targets for the strike-to-spot ratio: 92%, 94%, up to 108%. At the first day of each month, we select for each delivery month the option with strike-to-spot ratio closest to the target rate. We exclude options that mature in the given month (on the third Friday of that month), since these options may suffer from illiquidity (Bondarenko (2003)). We divide the month in four (approximately equally-spaced) time periods, and we shall refer to these as (pseudo-)weekly periods. Next, we calculate the (pseudo-)weekly returns on the selected options up to the first day of the subsequent month. In the end, this gives us time series of weekly option returns for several strike-to-spot ratios and maturities.

The choice of the frequency in an international study like ours involves the following trade-off: higher-frequency returns are attractive as they may exhibit interesting conditional dynamics. Simultaneously however, the effect of the difference in international time-zones is exacerbated when the frequency is increased, since returns for different markets are then computed over time-periods with less overlap. Martens and Poon (2001) have shown that this non-synchronicity problem can seriously bias estimates of daily covariances and conditional correlations. Cappiello, Engle and

Sheppard (2003) face a similar trade-off in their study of asymmetric conditional second moments in international bond and equity returns and analyze weekly returns. We use pseudo-weekly returns rather than weekly returns because it allows us to construct a homogeneous sample in terms of option maturities; since options expire on the third Friday of each month, weekly returns cannot generate a homogeneous sample, as the length of a month is not an integer multiple of the length of a week. Furthermore, given the 9 to 10 hour time-difference between the US close and Singapore close, pseudo-weeks of on average 5.25 trading days (= 252/48) correspond to overlapping time-periods that are closer to 5 days than actual weeks.

For the UK, we use European options on the FTSE 100 index, traded on LIFFE. Data are obtained from LIFFEData, and contain daily settlement prices for options and associated underlying index values. We apply similar data filters as for the US options, now using the lower bounds and put-call parity for European index options. We use the futures prices in the UK data to circumvent estimating the dividend rate.

For the Japanese Nikkei 225 index, we use data from Singapore Exchange (formerly known as SIMEX) on Nikkei 225 index futures and American options on these index futures. While Nikkei futures options also trade 'at home' in Osaka, the time-difference with the US and UK is smaller for Singapore, mitigating somewhat the non-synchronicity problem without sacrificing quality of the price data due to illiquidity (Nikkei contracts also trade on CME, which would further reduce the non-synchronicity, but these contracts are extremely illiquid). The data filtering and construction of the returns series are identical to the procedure described above for the US, since both use American options with index futures as underlying.

Since we want to be able to interpret our results in terms of mispricing that is exploitable by tradable portfolios, we currency-hedge all non-US returns using currency forward rates. Because 1-week forward exchange rates are not available for the entire sample period, we transform 1-month forward rates into 1-week forward rates, assuming that 1-week and 1-month interest rates coincide. Because of the short forward maturity, the error caused by this assumption is most likely small.

2.1 Summary Statistics

As a starting point it is useful to review the summary statistics of the underlying indices, reported in Table 1. For consistency with the option returns analyzed throughout the paper, the index returns have been currency-hedged using forward contracts and thus translated into USD returns. The US index has an average weekly excess return of 0.14% over the sample, resulting in a 6.72% annualized excess return. The US Sharpe ratio for our sample is in line with typical estimates obtained for longer samples: multiplying the weekly Sharpe ratio of 0.0697 with $\sqrt{48}$ (under the assumption of i.i.d. returns) gives an annual Sharpe ratio of 0.4829. The UK currency-hedged index has a very similar average excess return and volatility. The annualized Sharpe ratio is slightly higher at 0.5182. The Japanese index on the other hand behaved quite differently over the sample period. Remarkably, its average excess return is negative. The Japanese index return was furthermore subject to substantially higher volatility. The annualized Sharpe ratio is -0.1954.

Panels A through C of Table 2 report summary statistics for the weekly option excess returns we use. These returns are currency-hedged and in excess of the (US) riskfree rate (since non-US option returns are currency-hedged). For US short-maturity options, with average remaining maturity of around 1.5 month at the time when the return is computed, call option returns are large, but highly volatile, resulting in modest Sharpe ratios that are actually smaller than for the underlying. Short-maturity put options have negative mean excess returns that are very large in absolute value (e.g. 9.46% per week for puts that have a 0.92 strike-to-spot ratio). The Sharpe ratios are almost three times larger in absolute value than for calls or for the underlying, corresponding to annualized (absolute) Sharpe ratios close to or above 1. Turning to long-maturity options, with average remaining maturity of 10 months at the time when the return is computed, the findings are somewhat different for both calls and puts. Calls have higher Sharpe ratios than their short-maturity equivalent, while puts have less negative Sharpe ratios. From Panel A, it is clear that short-maturity puts have both the highest (absolute) mean excess return and the highest (absolute) Sharpe ratio.

Although excess returns on the UK index have a similar mean and volatility as the US index, short-maturity call options have remarkably smaller excess returns, as shown in Panel B. Since the volatility of call option excess returns is not sufficiently lower than in the US sample, the Sharpe ratio is also an order of magnitude smaller. Long-maturity calls on the other hand have somewhat higher mean returns and Sharpe ratios, although still far below their US equivalents, especially far OTM. UK put returns are less negative, and more volatile than US puts, again resulting in lower absolute Sharpe ratios.

When considering the Japan sample in Panel C, it is crucial to keep in mind the negative mean excess return on the underlying index. This explains the negative mean excess returns on call options and the positive mean excess returns on puts. Most returns for Nikkei index options are more volatile than for the corresponding S&P index options in Panel A (or than for FTSE index options in Panel B). Sharpe ratios are smaller in absolute value than in Panel A.[2]

2.2 CAPM Results

As a first step in the analysis, we follow Coval and Shumway (2001) and study the ability of the CAPM to explain option returns. The evidence against the CAPM presented here motivates the analysis in the rest of the paper, where we explicitly account for other potential sources of priced risk, namely jump and volatility risk.

According to the CAPM, expected returns on an asset are driven only by its exposure to non-diversifiable market risk, as measured by its market beta. When applied to option returns, rejecting the CAPM implies a rejection of the single-factor Black-Scholes model or of market completeness and the redundancy of options (Coval and Shumway (2001)). Since we are interested in the relevance and pricing of other sources of risk, like volatility and jump risk, testing the CAPM is a natural first step.

For each of the three markets analyzed we test the CAPM as follows. We use currency-hedged excess returns for both calls and puts, each with 5 levels of moneyness (as in Table 2) and 5 maturity bins, ranging from short-maturity (with an average remaining maturity of 1.5 months when returns are computed) to long-maturity (10 months of average remaining maturity), for a total of 50 options per sample. The excess (currency-hedged) return on the underlying index is taken as a proxy for the excess return on the market. Table 3 summarizes results from the cross-sectional (or second-step) OLS regression for the unconditional CAPM, reporting the average pricing error or α for all 50 options per sample (as well as the average absolute value), the estimated slope or price of risk, the R^2 and finally the p-value for a Wald test that the pricing errors for the 8 test assets are jointly equal to zero. The 8 test assets consist of calls and puts, both ATM and 8% OTM, and both short-maturity and long-maturity.[3]

The first column of Table 3 shows that options in the US sample are on average underpriced by

[2] The sample includes the Kobe earthquake of January 17 1995 and the resulting turbulence of the Nikkei index, followed on February 27 by the collapse and receivership of Barings subsequent to Nick Leeson's speculation in Nikkei-related assets. These events had a major impact on Nikkei options. The 96% OTM put for instance had a return of 1700% during the week of January 17. It is important to point out that all results reported in the paper are robust to the exclusion of this extreme observation.

[3] We do not use all 50 options to construct the Wald test statistic, as the covariance matrix of their returns is close to singular.

the CAPM. Options have average returns that are much lower than is justified by their exposure to market risk, and seem overpriced relative to the CAPM. The average α across all 50 assets used in the cross-sectional regression is almost -1% per week. Since the average absolute α is 0.0095%, virtually all options must have negative α's. The market risk premium (λ) estimated in the US cross-section is 0.24% and statistically significant. This estimate, however, exceeds the time-series average for the excess return on the US market (0.14%). This can easily be seen in Figure 1A, which plots both the security market line according to the time-series version of the CAPM (where the slope is restricted to be the time-series average of the market excess return) and the cross-sectional security market line. Since puts are most mispriced in the time-series regressions (unreported to conserve space), and since these assets have negative beta's, the cross-section minimizes mean squared pricing error by overstating the market risk premium, resulting in the steeper security market line. The R^2 for the CAPM cross-section is high: this is quite natural and reflects the fact that the market index is the underlying of the options and therefore the most important determinant of their returns. The cross-sectional Wald test for the test assets rejects the CAPM.

The CAPM also generates large negative pricing errors for the UK cross-section: on average weekly options returns are 1.54% lower than would be expected based on their beta. Again, virtually all options are underpriced by the CAPM since the average absolute α is 1.55%. The cross-sectional estimate of the market risk premium is 0.15% and now close to the time-series average of the market excess return (0.16%). This can easily be understood from Figure 1B: both puts (with negative beta's) and calls (positive beta's) are roughly equally overpriced relative to the time-series CAPM. Therefore the cross-sectional fit cannot be improved by changing the slope of the security market line. The fit is worse than in the US sample, as is clear from the lower cross-sectional R^2 of 55.24%. The CAPM is also for the UK formally rejected by a Wald test. As in the US sample, mispricing is largest for short-maturity options, with negative α's.

In contrast to US and UK index options, Nikkei options are on average overpriced by the CAPM, with an average pricing error of 0.94% and average absolute α of 1%. The cross-sectional estimate of the market price of risk is negative and insignificant. The estimate is more negative than the time-series average of the market excess return (-0.14% versus -0.09%). The downward-sloping security market line for Japanese index options is plotted in Figure 1C. Index options with negative beta's (puts) are slightly more mispriced in the time-series model than positive-beta assets, which explains the steeper cross-sectional security market line and therefore the discrepancy between the time-series average of the market excess return and the cross-sectional estimate of the market risk premium. The figure also shows that there is substantial variation in mean option returns that is left unexplained by the CAPM, as is reflected by the R^2. Short-maturity OTM Nikkei options are most mispriced. However, none of the individual α's are statistically significant.

Since the evidence against the CAPM is strong both economically and statistically, we explore in the rest of the paper whether other risk factors are priced into option returns. This may be most promising for the US and UK sample, and more challenging for the Japan sample, since the plots seem to suggest that the mispricing is more systematic for the US and UK, while Nikkei option returns seem more subject to idiosyncratic risk factors affecting particular options.

3 Local Unconditional Pricing of Jump and Volatility Risk

The CAPM generates large pricing errors for index options in all 3 markets analyzed. For the US option market, a large literature in option pricing has documented the rejection of the single-factor Black-Scholes model and suggested that systematic volatility and jump risk make options non-redundant assets and affect their prices and returns. In order to examine this in detail in our framework, we now consider an unconditional linear multi-factor model. This extends the work of Coval and Shumway by explicitly allowing for other priced factors.

As explained in detail in section 1, we use a standard two-pass methodology, obtaining factor loadings in the first step and regressing average returns cross-sectionally on factor loadings in a second step. To conserve space, we only report results for the second-step regression, i.e. for the cross-sectional regression.

3.1 Construction and Interpretation of the Factors

As introduced in section 1, we use a short-maturity 'crash-neutral' ATM straddle and OTM put with 0.96 strike-to-spot ratio as economically meaningful factor-mimicking portfolios for volatility and jump risk, respectively. We now discuss the construction of these factors in more detail and provide some empirical motivation to support the interpretation of these factors, before turning to the factor models and their explanatory power for the cross-section of option returns in the next subsection.

Since we are interested in the international pricing of jump and volatility risk, and do not want to take a stand on the issue of international integration (or lack thereof) of the markets for the underlying equity indices, we estimate and test the multi-factor model with equity-hedged option returns. The option returns are hedged against movements in the local underlying according to the estimated beta from the CAPM. In other words, we apply the jump and volatility risk factors to excess returns over the CAPM. This procedure is conservative since the CAPM may already take out some exposure to jump and volatility risk to the extent that these sources of risk are correlated with market risk. Using CAPM-based excess returns isolates the orthogonal parts of volatility and jump risks and investigates whether these are priced separately.

The factor returns themselves are also taken to be the CAPM-based excess returns. Therefore, we use as factors the equity-hedged crash-neutral ATM straddle and the equity-hedged 0.96 OTM put. Table 4 reports the means, standard deviations and Sharpe ratios of the (excess) returns on these factors. Not surprisingly, all mean CAPM-based excess returns are negative. The US OTM put stands out with a -0.0478 excess return (per week) and a Sharpe ratio of -0.1832. This Sharpe ratio is higher in absolute value than in Table 2 (Panel A), because the OTM put is now equity-hedged. For the UK, the straddle dominates the OTM put in terms of risk-return tradeoff, suggesting a particularly high price of variance risk. For Japan, the Sharpe ratios are substantially lower, since the factors have excess returns that are less negative on average and more volatile.

We now analyze the nature of the factor returns in more detail. Bakshi, Kapadia and Madan (2003) demonstrate that risk-neutral variance and risk-neutral skewness of the return distribution of the underlying asset can be obtained from a cross-section of option prices. The construction relies on the identification of the so-called quadratic, cubic and kurtotic contracts, which can be spanned from traded options. We now investigate how our factors are related to these contracts.

Bakshi, Kapadia and Madan (2003) derive that the quadratic and cubic contracts, with payoffs the squared and cubed log price relative $(R(t,\tau)^2$ and $R(t,\tau)^3$, with $R(t,\tau) \equiv \ln\left[\frac{S_{t+\tau}}{S_t}\right])$, have prices:

$$\begin{aligned} V(t,\tau) &\equiv E_t^Q\left[e^{-r\tau}R(t,\tau)^2\right] \\ &= 2\int_{S_t}^{\infty}\frac{\left(1-\ln\left[\frac{K}{S_t}\right]\right)}{K^2}C(t,\tau;K)\,dK + 2\int_0^{S_t}\frac{\left(1+\ln\left[\frac{S_t}{K}\right]\right)}{K^2}P(t,\tau;K)\,dK \qquad (3) \end{aligned}$$

and

$$W(t,\tau) \equiv E_t^Q\left[e^{-r\tau}R(t,\tau)^3\right] \tag{4}$$
$$= \int_{S_t}^{\infty} \frac{6\ln\left[\frac{K}{S_t}\right] - 3\left(\ln\left[\frac{K}{S_t}\right]\right)^2}{K^2} C(t,\tau;K)\,dK - \int_0^{S_t} \frac{6\ln\left[\frac{S_t}{K}\right] + 3\left(\ln\left[\frac{S_t}{K}\right]\right)^2}{K^2} P(t,\tau;K)\,dK$$

where $C(t,\tau,K)$ denotes the time-t price of a call option with maturity τ and strike price K. Similar notation is used for the put option price $P(t,\tau,K)$. The variance contract in (3) is closely related to the model-free implied variance of Britten-Jones and Neuberger (2000), Carr and Madan (1998) and Dumas (1995), who build on the seminal work of Breeden and Litzenberger (1978).[4] The idea is that a portfolio of calls and puts can be used to trade pure variance risk, when the portfolio weights are inversely proportional to K^2. The cubic contract on the other hand trades (non-central) 'third moment risk', and can be used to construct the skewness of the risk-neutral distribution, by centering and normalizing.[5] Similarly, risk-neutral kurtosis can be obtained from a combination of the quadratic, cubic and quartic contracts.

While risk-neutral skewness (and kurtosis) is not itself a traded asset (because of the normalizations), we could have used the returns on the quadratic and cubic contracts as priced risk factors in our analysis. However, as is clear from (3) and (4), synthesizing both contracts involves trading the entire cross-section of options and may be costly or difficult to implement in practice. Instead we prefer to use the OTM put (a single contract) and the crash-neutral straddle (easily constructed from 3 contracts) as factor-mimicking portfolios. Importantly, we now show that the returns on both factors are intimately linked to the returns on the variance and the cubic contract.[6]

Table 5 reports the results from univariate and bivariate regressions of the CAPM-excess returns on our factor-mimicking portfolios (the 'crash-neutral' ATM straddle and the 0.96 OTM put) on the returns of the quadratic and/or cubic contracts, for all 3 markets we analyze. For the US and the UK, it is clear that the straddle is very closely related to the return on the variance contract and therefore indeed an excellent proxy for variance risk. In univariate regressions of straddle excess returns on variance contract returns, the slope coefficient is highly significant and the R^2 is 91.7%

[4] Further applications and extensions are provided in Bondarenko (2004), Carr and Wu (2004), Bollerslev, Gibson and Zhou (2004) and Jiang and Tian (2005).

[5] Bakshi, Kapadia and Madan (2003) also show how risk-neutral coskewness can be recovered. Harvey and Siddique (2000) demonstrate that conditional coskewness helps explain the cross-section of expected stock returns.

[6] The return on the quartic contract is extremely highly correlated with the return on the quadratic contract. For space reasons, we therefore omit the quartic contract from the subsequent analysis.

for the US and 81.5% for the UK. The cubic contract return does not seem to play an economically significant role in explaining straddle excess returns, judging from the second and third columns of Table 5. In Japan, the bivariate regression suggests that both factors are driving the straddle excess return. However, the univariate results show that only the variance contract does so in a robust way. These results motivate our use throughout the paper of the crash-neutral straddle as the factor-mimicking portfolio for volatility risk.

The last 3 columns investigate the determinants of the OTM put excess returns. Note that if only variance risk were relevant in explaining option excess returns, then the cubic contract return would have no explanatory power for the straddle excess return (as is the case in Table 5) or for the OTM put excess return. Therefore, if the cubic contract return matters for the OTM excess return even when allowing for the variance contract return, then this would be evidence for the presence of a second risk factor, namely one related to 'skewness risk'. The most intuitive interpretation of skewness risk is downward jump risk, although skewness risk (in addition to variance risk) could in principle also be driven by a second priced stochastic volatility factor. Empirically, it is clear that the OTM put return loads on variance risk. The return on the variance contract explains 33% of the variation in the US OTM put excess return and 47% of the variation in the UK put excess return. However, adding the cubic contract return increases the explanatory power substantially (the R^2's become around 97% for both countries). Unlike the straddle excess return, which seems empirically solely driven by variance risk, the OTM put excess return is also closely linked to skewness risk. Therefore, when including both the ATM straddle and the OTM put in the linear factor model, the role of the put is to pick up what is missing from the straddle, namely skewness or jump risk. The results for Japan are slightly different, but still provide some evidence that both variance and jump risk are present in Nikkei index options.

3.2 Multi-Factor Results

As discussed above, we apply a multi-factor model to CAPM-based excess option returns. This avoids having to take a stand on the extent to which the markets for the underlying equity indices are integrated internationally (since the option returns are hedged against movements in the (domestic) underlying asset) and allows us to isolate the orthogonal parts of volatility and jump risk. As a final expositional advantage, we can interpret and contrast the mispricing and explanatory power of the regressions against the CAPM results from the previous section. Note that when referring to a two-factor model, it is understood that the two factors are applied to CAPM-based excess returns, so that the model applied to actual (not excess) returns is in fact a three-factor model. As for the CAPM, we report only the cross-sectional regressions, which estimate the following relationship for each index option market:

$$\widehat{E}\left[R^e_{it}\right] = \widehat{\beta}_{i,straddle}\lambda_{straddle} + \widehat{\beta}_{i,OTM\ put}\lambda_{OTM\ put} + \eta_i \tag{5}$$

where R^e_{it} denotes the excess return on option i at time t relative to the local CAPM.

In the US sample, the average α in Table 6 is reduced substantially relative to the CAPM when introducing a volatility and jump risk factor (from -0.0094 to -0.0023). The average absolute α shrinks somewhat less, suggesting that some options appear now underpriced. The estimates for the risk premia $\lambda_{straddle}$ and $\lambda_{OTM\ put}$ are negative, implying a negative volatility risk premium and a positive jump risk premium as has previously been documented empirically.[7] The estimates are in line with the time-series averages for the excess returns on the factors (-0.0167 for the crash-neutral ATM straddle and -0.0478 for the OTM put). The jump risk premium is strongly statistically significant, while the volatility risk premium is almost significant. The cross-sectional R^2 is quite high: local jump and volatility risk factors explain 82.99% of the cross-sectional variation in expected option returns that is left unexplained by the CAPM. The remarkable improvement in cross-sectional fit over the CAPM is also apparent from the Wald test's p-value of 7.84%.

Adding a jump and volatility risk factor also helps a lot to explain the cross-section of UK option returns: both the average α and average absolute α become much smaller than in Table 3. Both jump and volatility risk carry risk premia that are very significant economically and statistically. The estimates of these risk premia are close to the mean excess returns on the factor-mimicking portfolios (-0.0219 and -0.0217 respectively), which provides further support in favor of the model. Finally, the cross-sectional R^2 is very large and the model is only marginally rejected by the Wald test.

Mispricing of Nikkei index options is also reduced when accounting for additional sources of risk. The risk premia, however, associated with these risk factors are quite striking. The volatility risk premium is estimated to be positive and the jump risk premium negative, highlighting once

[7] A negative estimate for $\lambda_{OTM\ Put}$, i.e. for the jump risk factor, corresponds to a positive jump risk premium, defined as the difference between the product of the risk-neutral jump probability and risk-neutral expected jump size, and the product of the actual jump probability and actual expected jump size. A positive jump risk premium generates high prices of put options and low expected returns.

more that the Nikkei sample is quite peculiar. The discrepancy between the estimated volatility and jump risk premia and the mean excess returns on the corresponding factor-mimicking portfolios (-0.0090 and 0.0209) suggests that the model is misspecified. Moreover, only the negative jump risk premium ($\lambda_{OTM\ put} > 0$) is statistically significant. The cross-sectional R^2 is lower than for the US and UK samples, but still very high. Finally, of all three samples, the multi-factor model can be rejected with most confidence for Nikkei option returns.

We can tentatively conclude that the unconditional multi-factor model that allows for priced jump and volatility risk, performs quite well for the US and UK, but is somewhat problematic when confronted with Japanese data. Before examining in Section 5 whether conditional models can improve on this, we first study unconditional international pricing in the next section.

4 Unconditional International Pricing of Jump and Volatility Risk

Having analyzed the local pricing of index options in the three main global markets, we now study whether there is any evidence of international (unconditional) pricing of volatility and jump risk. In order to be agnostic about international integration of the markets for the local underlying indices, we continue to use excess returns based on the local CAPM, i.e. locally equity-hedged option returns. When pooling the 50 option returns for all three markets, a first question is whether foreign factors help to explain (excess) option returns. According to a stronger version of international pricing only global factors should matter. To test whether a parsimonious global model of this type can explain the world cross-section of index option returns, we aggregate the six local volatility and jump risk factors into two international risk factors (Section 4.3).

4.1 Correlations

Before analyzing international pricing of systematic volatility and jump risk, it is useful to know the cross-country correlations between the local factors. Table 7 reports the cross-country correlations of option returns from our 3 samples. Although equity-hedged option returns are used, correlations between the returns on the underlying indices are included for completeness and comparison with option return correlations. While the US and UK equity returns are highly correlated, correlations with the Japanese index are quite low. A similar pattern arises for returns on the two factor-mimicking portfolios. The US-UK correlation for both crash-neutral straddle excess returns and OTM put excess returns are modest, but nontrivial. The returns on the Japanese factors are much less correlated, especially with US returns. This may already suggest that 'full-fledged' global pricing with only international factors being priced, should probably not be taken for granted.

4.2 Pooling the Local Models: an International Six Factor Model

The first international model simply pools all the local assets and factors, resulting in a cross-section of 150 option excess returns and 6 factors (as before, applied to excess returns relative to the local CAPM):

$$\widehat{E}\left[R_{it}^{e}\right] = \sum_{c} \widehat{\beta}_{i,straddle}^{c} \lambda_{straddle}^{c} + \sum_{c} \widehat{\beta}_{i,OTM\ put}^{c} \lambda_{OTM\ put}^{c} + \eta_{i} \tag{6}$$

where $c \in \{US,\ UK,\ Japan\}$.

Analyzing the average α and $|\alpha|$ in Table 8, mispricing is marginally smaller for the US, essentially unchanged for the UK and somewhat larger for Japan when pooling the assets and factors into an international model. The estimated factor risk premia are also very similar to the local estimates in Table 6: like the local multi-factor models, the international model does explain the cross-sectional variation in expected option returns quite well, but mispricing remains sufficiently important to formally reject the model with the Wald test.

Interestingly, mispricing of Nikkei options actually gets worse for 6 out of 8 test assets, which provides further evidence against general international pricing.

4.3 A Parsimonious International Multi-Factor Model

Although the first evidence on international pricing of jump and volatility risk is rather mixed, we now restrict the model to be more parsimonious. The six local risk factors are aggregated into two 'global' factors: a global crash-neutral ATM straddle and a global OTM put. Each international factor is constructed as a weighted average of the three corresponding local factors, with weights based on principal component analysis applied to the correlation matrix (using the first principal component).[8] The cross-sectional pricing relation to be estimated is

$$\widehat{E}\left[R_{it}^{e}\right] = \widehat{\beta}_{i,straddle}^{global} \lambda_{straddle}^{global} + \widehat{\beta}_{i,OTM\ put}^{global} \lambda_{OTM\ put}^{global} + \eta_{i} \tag{7}$$

Table 9 presents clear evidence against unconditional international pricing. On average, the

[8] For both international factors the first principal component has positive weights in all three local factors.

model substantially underprices US and UK calls and puts, and overprices Japanese assets. The factor risk premia $\lambda^{global}_{straddle}$ and $\lambda^{global}_{OTM\ put}$ are close to zero, insignificant and quite different from the average excess returns on the factors (-0.0184 for the global volatility risk factor and -0.0251 for the global jump risk factor). This is less surprising when keeping in mind that US/UK estimates versus Japan estimates have opposite signs in Table 6. The very low R^2 and Wald p-value further illustrate the poor performance of the global two-factor model.

To illustrate the large mispricing generated by the international model, the US OTM call and put have α's of 4.25% and -6.25%, respectively. For S&P and Nikkei options, mispricing is often even larger than for the local CAPM: the global factors are in fact counter-productive. It is not surprising then that the Wald test strongly rejects the model in Table 9.

4.4 Does US/UK International Pricing Hold?

While the failure of the international model might certainly be due to the absence of any conditioning information so far (Section 5 will remedy this), it may also be caused by the presence of the very peculiar Nikkei sample. Japan behaves totally differently from the US and UK market: the correlations of Japanese factor returns with those of other markets are very low, the Nikkei factor risk premia (including the market risk premium) have the wrong sign, adding multiple factors does not improve much over the CAPM and adding foreign factors actually worsens the mispricing of options. For those reasons, we now exclude the Nikkei option returns from the analysis and focus on a less ambitious international model comprised solely of US and UK assets and factors. The international factors can again be obtained using PCA on the correlation matrix, for US and UK only. But given that there are only two local factors to average, the weight is now 50/50 by construction. We then estimate for US and UK expected option returns $\widehat{E}\left[R^e_{it}\right]$ in excess of the CAPM:

$$\widehat{E}\left[R^e_{it}\right] = \widehat{\beta}^{US/UK}_{i,straddle}\lambda^{US/UK}_{straddle} + \widehat{\beta}^{US/UK}_{i,OTM\ put}\lambda^{US/UK}_{OTM\ put} + \eta_i \tag{8}$$

The parsimonious model in Table 10 fares much better when Japan is excluded. The average absolute α decreases from 0.0158 to 0.0101 for US options and from 0.0127 to 0.0102 in the UK. Mispricing is larger though than in the local multi-factor model or in the international 6-factor model. While the US/UK factors reduce mispricing substantially for UK options relative to the CAPM, the average absolute α actually becomes marginally larger in the US. The estimated risk premia are very reasonable ($\lambda^{US/UK}_{straddle}$ = -0.0098 and $\lambda^{US/UK}_{OTM\ put}$ = -0.0344) and significant (t-stats of -3.52 and -9.24). The market prices of international volatility and jump risk lie in between the corresponding local values found previously for the US and UK separately. The R^2 of the cross-sectional regression is fairly high: the international factors explain roughly half the variation in CAPM-based excess option returns.

5 Conditional Analysis

The weak evidence of international pricing established in the previous section might be attributable to the lack of conditioning information. International pricing of volatility and jump risk might hold conditionally, even though it is rejected unconditionally. Furthermore, introducing conditioning information allows us to address interesting questions concerning low-frequency changes in market integration and high-frequency time-variation in global correlations in option markets.

5.1 Time-Varying Correlations

Before analyzing formal conditional factor models in detail, it is useful to try and detect any time-variation in cross-market correlations without relying on particular models.[9] To examine whether markets for volatility and jump risk have become more integrated internationally and whether this resulted in higher cross-market correlations, we calculate cross-country correlations for excess returns on crash-neutral straddles (the volatility risk factor) and on OTM puts (the jump risk factor) over a two-year rolling window. Consistent with the hypothesis of increased market integration, correlations between US straddles and UK straddles, and between US puts and UK puts exhibit a clear upward trend in Figures 2A and 2B, respectively. Correlations between Nikkei risk factors and US or UK risk factors are low throughout the sample period and do not reveal any pattern of time-variation. Japanese option returns have been demonstrated before to be by and large independent of foreign factors and market movements, and this independence seems rather stable over time. The US-UK comovement on the other hand is quite interesting and motivates the subsequent formal conditional analysis.

To handle conditioning information more formally, we introduce instruments that will be used in the next subsection to estimate conditional versions of the linear multi-factor models considered in Sections 3 and 4. Natural choices for instruments that might predict changes in expected

[9] Bekaert and Harvey (1995), Bekaert, Hodrick and Zhang (2005) and Goetzmann, Li and Rouwenhorst (2002) study time-variation in world market integration and in international cross-market correlations for equities.

option returns are the implied volatility of (short-maturity) ATM options and the implied volatility skew (defined as the difference between the implied volatility of (short-maturity) 0.92 OTM puts and of (short-maturity) ATM puts). Since option-implied volatility carries information about the pricing of future volatility risk, it is used as an instrument for the volatility risk factor. The implied volatility skew is often thought of as some measure of 'crash-imminence' or crash-o-phobia (Rubinstein (1994)), making it a potential instrument for jump or crash risk.

As a first step, we now use the instruments to investigate whether there is any high-frequency time-variation in cross-country correlations. We divide the sample period in subperiods according to quartiles for the two instruments (each are equally-weighted world averages of the corresponding three local instruments). We can then calculate cross-country correlations for option returns for each subperiod or regime for the relevant instrument. This yields correlations that are conditional on whether the instrument is in the 'high' (top quartile), 'intermediate' (middle quartiles), or 'low' (bottom quartile) regime.

Table 11 shows that cross-country correlations do change depending on the value of the instrument, but not always as would be expected. During periods of low global implied volatility, US and UK excess straddle returns have a lower correlation than when IV is higher. The same is true for the US-Japan correlation: when global IV is low, excess straddle returns are actually negatively correlated. Less intuitive however is that the correlation between US and Japan, and between UK and Japan is actually highest when global implied volatility is in the intermediate regime. Below, we will see that the results for US-UK correlations change when we exclude Japan for the calculation of the global IV.

Conditional correlations between US and UK put returns are highest during periods of low and high IV skew. Put returns tend to comove more closely when markets are globally least or most crash-averse. Japanese put returns are most highly correlated with returns on US and UK puts when the global skew is lowest. During high-skew regimes, Japanese puts are actually negatively correlated with the rest of the world.

To gain further insight into these results, it is important to understand the time-series correlations between the local instruments, since the global instruments used so far are simple equally-weighted averages of the local ones. As can be seen informally from Figure 3A and 3B, US implied volatility and UK implied volatility comove rather closely. US skew and UK skew do as well, but less so. The Japanese instrument however is less correlated with its US or UK equivalent, especially for the IV skew (the correlation coefficient is essentially zero). This suggests that crisper conditional correlations between US and UK excess returns may obtain if the influence of the Japanese instrument on the international aggregate is removed, very much like was done in the 'global' US/UK unconditional pricing model in section 4.4. Results for the US/UK instruments (plotted in Figure 3C) are presented in the last column of Table 11 (labeled US-UK*) and are quite compelling. US-UK cross-market correlations are now strongly monotonically increasing with the instrument. When US/UK implied volatility is high, straddle returns become quite correlated (correlation coefficient of 38%). The effect is most pronounced for the correlation between US and UK put returns, which exceeds 51% during the high-skew regime. At least for the US and UK, the markets for jump and volatility risk seem more interrelated during turbulent times. This is consistent with a downside correlation hypothesis (see Ang, Chen and Xing (2005) for an equity-market application), which emphasizes the importance of increases in correlations during down-markets. Das and Uppal (2001) argue that downward jumps in international equity indices tend to occur at the same time, and Longin and Solnik (2001) show that there is increased cross-country equity index correlation in bear markets, but not in bull markets. Our results complement this work by showing that jump and volatility risk factors also exhibit downside correlation patterns.

5.2 Conditional Factor Models

We now estimate and test formal conditional factor models. Starting from the unconditional models studied before, we allow for conditioning information by introducing the two instruments suggested in the previous subsection, ATM implied volatility and the implied volatility skew, so as to allow for time-variation in beta's and risk premia. For brevity, we again focus on cross-sectional regressions.

5.2.1 Local Conditional Factor Model

As before, we start with local factor models. First, it can be noted that given the relatively small number of test assets combined with the larger number of factors in the local conditional models, the local conditional models are never rejected by a Wald test. We will therefore focus on economic significance, and not on Wald tests. The conditional versions of the local two-factor model of section 3.2, as well as of the parsimonious international two-factor model of section 4.3, imply generally an unconditional six-factor model when a single instrument is used to 'scale' each factor (following the terminology of Cochrane (2001)). The first two factors are the original unscaled factors, the next two are the scaled factors (the excess return on ATM straddles times ATM implied volatility, and the excess return on OTM puts times the implied volatility skew), while the last two factors are simply the instruments themselves. When implementing these models in our context, the majority of the time-series beta's for the fifth and sixth factors are insignificant, for all samples. Factors 5 and 6 may thus well end up acting as 'useless factors' (Kan and Zhang (1999)). We therefore dropped these last two factors from the analysis and instead report results only for more tightly parameterized four-factor models (both locally and globally). The omitted factors have in fact no cross-sectional pricing implications, except for the Nikkei sample. In summary, we estimate for each country in a first (unreported) step:

$$\begin{aligned} R^e_{it} &= \alpha_i + \beta_{i,straddle} R^e_{straddle,t} + \beta_{i,OTM\ put} R^e_{OTM\ put,t} \\ &\quad + \beta_{i,IV\ \times\ straddle}\ IV_t\ R^e_{straddle,t} + \beta_{i,skew\ \times\ OTM\ put}\ Skew_t\ R^e_{OTM\ put,t} + \varepsilon_{it}, \end{aligned} \tag{9}$$

and in a second step:

$$\begin{aligned} \widehat{E}\left[R^e_{it}\right] &= \widehat{\beta}_{i,straddle} \lambda_{straddle} + \widehat{\beta}_{i,OTM\ put} \lambda_{OTM\ put} \\ &\quad + \widehat{\beta}_{i,IV\ \times\ straddle} \lambda_{IV\ \times\ straddle} + \widehat{\beta}_{i,skew\ \times\ OTM\ put} \lambda_{skew\ \times\ OTM\ put} + \eta_i. \end{aligned} \tag{10}$$

Adding scaled factors to the US local model improves mispricing substantially (Table 12). The average α shrinks from -0.0023 to -0.0012, while the average absolute α is reduced from 0.53% per week to 0.42% per week. The unconditional factor risk premia ($\lambda_{straddle}$ and $\lambda_{OTM\ put}$) survive and are very close to the estimates of Table 6. The volatility risk premium becomes more significant and is now closer to the time-series average of the excess return on the factor-mimicking portfolio. Conditionally only skew timing ($\lambda_{skew\ \times\ OTM\ put}$) seems to be priced. The R^2 improves somewhat and the conditional two-factor model explains almost 92% of the variation in US equity-hedged option returns.

Results for the UK sample are essentially unaffected by the incorporation of conditioning information. The mispricing hardly changes and the risk premia associated with the scaled factors are zero. Both the volatility and jump risk premia remain very significant and are close in value to the time-series mean excess return on the factors. The fact that conditioning information does not seem to help to explain the UK cross-section is also clear from the unchanged R^2. As for the UK sample, adding scaled factors has no impact on local pricing of Nikkei options in the last column of Table 12.

In sum, we find mixed evidence that the performance of local models improves when we allow for conditioning information. However, it may still be the case that international models benefit from incorporating conditioning information. In fact, the time variation in cross-country correlations documented above suggests a role for conditioning information. This is what we explore next.

5.2.2 International Conditional Factor Model

The parsimonious unconditional international pricing model that attempts to explain the pooled cross-section of option excess returns based solely on a global volatility risk and a global jump risk factor was strongly rejected in section 4.3. It was conjectured that this rejection might be due to the lack of conditioning information. Adding scaled factors to (7), we consider the following pooled model:

$$\begin{aligned}\widehat{E}\left[R_{it}^{e}\right] &= \widehat{\beta}_{i,straddle}^{global}\lambda_{straddle}^{global} + \widehat{\beta}_{i,OTM\ put}^{global}\lambda_{OTM\ put}^{global} \\ &\quad + \widehat{\beta}_{i,IV\ \times\ straddle}^{global}\lambda_{IV\ \times\ straddle}^{global} + \widehat{\beta}_{i,skew\ \times\ OTM\ put}^{global}\lambda_{skew\ \times\ OTM\ put}^{global} + \eta_i \end{aligned} \tag{11}$$

Average mispricing and average absolute mispricing is substantially reduced in Table 13 by the introduction of the two scaled factors. The improvement in α's is most impressive for US assets and smallest for Nikkei options. Furthermore, all risk premia, including the ones associated with the scaled factors, are large and significantly negative. This is a major improvement over the unconditional international two-factor model, where neither the volatility risk premium nor the market price of global jump risk was significantly different from zero. Equally remarkable is the increase in R^2 from 7.75% to 65.2%. Nonetheless, the conditional international model is still formally rejected at the 1% confidence level, albeit less overwhelmingly than before.

5.2.3 US/UK International Conditional Factor Model

As a final step, we now omit the Nikkei options, factors and instruments from the international model to investigate whether the US/UK international model sees the same improvement in explanatory power when adding scaled factors. This would be expected based on the conditional correlations presented in the previous subsection (the US/UK* column in Table 11). The conditional US/UK model is:

$$\widehat{E}\left[R_{it}^{e}\right] = \widehat{\beta}_{i,straddle}^{US/UK}\lambda_{straddle}^{US/UK} + \widehat{\beta}_{i,OTM\ put}^{US/UK}\lambda_{OTM\ put}^{US/UK} + \widehat{\beta}_{i,IV\ \times\ straddle}^{US/UK}\lambda_{IV\ \times\ straddle}^{US/UK} + \widehat{\beta}_{i,skew\ \times\ OTM\ put}^{US/UK}\lambda_{skew\ \times\ OTM\ put}^{US/UK} + \eta_i \quad (12)$$

Conditioning information lowers the average absolute α in Table 14 from 0.0101 to 0.0059 for the US and from 0.0102 to 0.0081 for the UK. This brings the (conditional) 'global' model quite close to the (unconditional) local model in terms of pricing error, especially for the US (average $|\alpha|$ of 0.0053 for the US local model and 0.0051 for the UK model). As in the unconditional model, both $\lambda_{straddle}^{US/UK}$ and $\lambda_{OTM\ put}^{US/UK}$ are sensible and significant. Additionally, the scaled factors are priced, carrying risk premia that are larger in absolute value than in Table 13. The change in point estimates for $\lambda_{IV\ \times\ straddle}^{US/UK}$ and $\lambda_{skew\ \times\ OTM\ put}^{US/UK}$ is quite natural since the omission of Japan from the sample has substantially changed the third and fourth factor (both through the effect on the unscaled factor and through the effect on the instrument used to scale the factor). The R^2 increases from 48% in Table 10 to 72%. Finally, the restrictions of the international model are no longer rejected at the 1% confidence level based on a Wald test (p-value becomes 0.0352 instead of 0.0017). Therefore, without the particular Nikkei sample, there is evidence of international pricing of volatility and jump risk, at least conditionally.

6 International Portfolio Diversification

In this section we take a complementary perspective to studying international option returns. The previous sections provide evidence that international option returns exhibit local risk factors carrying a risk premium. In addition, we documented that cross-country correlations of option returns are relatively low. This suggests that there is scope for international diversification of option investments. To study this in more detail, we examine in this section to what extent a US investor can benefit from investing in foreign option markets, in addition to investing in the US option market. Specifically, we focus on the diversification benefits of adding UK option strategies to a portfolio that initially consists of US equity and options. We do not include positions in Nikkei options, since we do not want to generate diversification benefits that are based on the apparently anomalous sample for Japan.

Our methodology is based on Brandt (1999) and Ait-Sahalia and Brandt (2001).[10] We consider a US investor who derives utility from terminal wealth and has access to the riskfree asset, US and UK equity indices and options on these indices. As before, all foreign investments are hedged for currency risk.

Denoting the fraction of wealth invested in US equity by α_E^{US} and the fraction of wealth invested in the US derivative by α_D^{US}, and using similar notation for UK investments, the portfolio weights to be chosen by the investor are $\underline{\alpha} \equiv \left\{\alpha_E^{US}, \alpha_D^{US}, \alpha_E^{UK}, \alpha_D^{UK}\right\}$. The investor then solves:

$$\max_{\underline{\alpha}} E\left[U\left(W_T\right)\right] \tag{13}$$

Given initial wealth W_0 and denoting the return on asset i by R_i (where R_f is the gross return on the riskless asset), we have

$$\begin{aligned} W_T &= W_0\left[R_f + \alpha_E^{US}\left(R_E^{US} - R_f\right) + \alpha_D^{US}\left(R_D^{US} - R_f\right)\right. \\ &\quad \left. + \alpha_E^{UK}\left(R_E^{UK} - R_f\right) + \alpha_D^{UK}\left(R_D^{UK} - R_f\right)\right]. \end{aligned} \tag{14}$$

In the absence of market frictions and for a differentiable utility function $U(.)$, the first-order conditions for $i \in \{E, D\}$ and $c \in \{US, UK\}$ are:

$$E\left[U'\left(W_T\right)\left(R_i^c - R_f\right)W_0\right] = 0. \tag{15}$$

This asset allocation problem can be solved without imposing a parametric structure on the return dynamics and risk premia by using the methodology developed in Brandt (1999) and Ait-Sahalia and Brandt (2001). When returns are i.i.d. and stationary, the expectations operator in the Euler equations associated with the portfolio problem can be replaced by the sample moments and the optimal portfolio shares are estimated from the first-order conditions in GMM fashion. The number of parameters (unconditional portfolio weights) and Euler restrictions coincide and exact identification obtains. The methodology also produces standard errors of the portfolio weights since the portfolio weights are parameters that are estimated using a standard GMM setup. Formal tests can then be conducted to determine whether the demand for options is significantly different from zero and whether the inclusion of derivatives in the asset space leads to welfare gains as measured

[10] Previous work that studied portfolio choice with options in an incomplete-market setting includes Liu and Pan (2003) and Driessen and Maenhout (2004).

by certainty equivalents.

We present results for a CRRA investor. In this case, initial wealth W_0 can be normalized to 1 without loss of generality. The coefficient of relative risk aversion γ is taken to be 5, and we consider two types of option strategies. First, we consider OTM put options. As discussed before, an OTM put option is a useful asset to exploit a jump risk premium. Second, we consider a crash-neutral straddle, which can be interpreted as a vehicle for trading volatility risk (Table 5) and exploiting a volatility risk premium.

Table 15 presents results for different asset sets. To provide a benchmark for the results on option strategies, we first consider a US investor who only invests in US equity and the risk-free asset (asset set 1). In this case we find a modest (and statistically insignificant) position in the US equity index. Adding a position in the US OTM put has a strong effect on the optimal portfolio (asset set 2). The investor chooses a large short position in the OTM put, which is in line with the strong evidence for a jump risk premium in US option returns, as reported in Table 6. The put weight is statistically significant. To understand the negative equity weight, note that a short put position can be hedged partially by a negative equity weight, but the positive equity premium makes this hedge expensive.[11] However, the investor prefers to forego the equity premium and exploit the much larger jump risk premium. Similar results are obtained for other values of the risk aversion parameter γ.

To evaluate the economic significance of adding US puts to the portfolio, we calculate the certainty equivalent wealth that the investor would demand as compensation for not being able to invest in the US put option. Since the investor's preferences are homothetic, the certainty equivalent is computed in percentage terms. Also, this is a percentage of initial wealth over a period that corresponds to the investor's horizon (one week). The results, also reported in Table 15, show that the certainty equivalent of the short position in the US put is 0.61% per week, which is very large, but not surprising given the large short position in this put contract and the large estimate for the jump risk premium ($\lambda_{OTM\ put}$) reported in Table 6.

Next, we analyze the diversification benefits of adding UK equity and a UK OTM put option to the investment set (asset set 3). Table 15 shows that the optimal weight for the UK put option is negative, and this position is supported by a short position in UK equity. These results are in line with Table 6, where a significant jump risk premium is found for UK option returns. The portfolio

[11] This hedge is not perfect, since the correlation between equity and put option returns does not equal -1. This is natural if one assumes that the underlying continuous-time model contains jumps and/or stochastic volatility.

weights for US equity and the US put do not change much, which is in line with the relatively low cross-country correlations reported in Table 7. However, compared to the position in the US put, the short position in the UK put is much smaller and not statistically significant. Economically, the impact is also smaller than the US put: having access to UK equity and UK put options corresponds to a certainty equivalent of 0.035% per week. This reflects the results in Table 6, where it is shown that the jump risk premium is largest for the US sample. It is important to note that this certainty equivalent of 0.035% is mostly due to having access to UK put options, and not to investments in UK equity. Adding UK equity only to the US equity and put portfolio leads to a certainty equivalent of only 0.005%. This can be interpreted as evidence that international diversification using option strategies is much more beneficial than diversification using equity investments only.

We next focus on crash-neutral straddles instead of put options, and perform an otherwise similar analysis. This enables us to study the diversification benefits associated with trading local volatility risk and the associated risk premia. First, we allow for a US straddle position, in addition to US equity and the risk-free asset (asset set 4). Consistent with the negative volatility risk premium ($\lambda_{straddle}$) reported in Table 6, the optimal portfolio contains a short position in the straddle, along with a modest long position in equity. In contrast to the put option, the straddle is hardly correlated with equity returns, so that equity cannot be used as a hedging instrument. The straddle weight has a t-statistic of 1.78. The certainty equivalent wealth that corresponds to adding US straddles equals 0.085% per week. This is smaller than the certainty equivalent of adding US puts (0.61%), in line with the US volatility risk premium being smaller in absolute value than the US jump risk premium (Table 6).

Allowing for investments in UK equity and straddles has considerable effects on the portfolio weights. The portfolio weight for UK straddles is statistically significant and much more negative than the US straddle weight. This can be understood from the fact that our estimate for the UK volatility risk premium is much larger in absolute value than the US estimate. The economic benefit of diversifying internationally is also large, given the certainty equivalent wealth of 0.129% per week. This benefit is almost fully due to having access to the UK straddle, since only adding UK equity to US equity and straddles corresponds to a certainty equivalent wealth of 0.002%. Again, this shows that international diversification of option strategies is more important than equity diversification. These large international diversification benefits of option strategies are a result of (i) large risk premia on jump and volatility risk, and (ii) relatively low cross-country correlations of option strategies (see Table 7).

Finally, it is interesting to analyze whether international diversification benefits have decreased over time, as could be conjectured from the results in section 5.1, where we showed that US-UK cross-market correlations exhibit an upward trend (Figures 2A and 2B). A simple way to study this is to split the sample into two equal-length subperiods and to solve the portfolio choice problem for each subsample. Based on these optimal portfolios (unreported to conserve space), we then compute the international diversification benefits for each subsample in the form of wealth certainty equivalents. Although the sample split generates short samples (and thus estimation error), the bottom rows in Table 15 clearly show that the economic benefits of diversifying volatility and jump risk internationally are much larger in the first subsample than in the second. In the first subsample, the US investor is willing to pay more than 0.2% of her wealth per week to gain access to the UK derivatives market, for both puts and straddles. In the second subsample, these certainty equivalents decline substantially, but remain economically substantial, consistent with the previous results about rising cross-market correlations and the hypothesis of increased (but imperfect) market integration.

7 Conclusion

Using data on index options for the three main global markets, we study whether jump and volatility risk are priced locally or internationally. We first show that the CAPM is unable to explain the cross-section of expected option returns in the US, UK and Japan. For the US and UK, the inclusion of factors that mimick local volatility and jump risk considerably improves the pricing results, while this is not the case for Japan. In line with the option pricing literature, we find for both the US and UK a negative volatility risk premium and a positive jump risk premium.

We then analyze whether the country-specific factor pricing models can be reduced to a single international pricing model, which would imply perfectly integrated option markets. The results provide clear evidence against global pricing of US, UK, and Japan equity index options. Especially for Japan there is no evidence that non-Japan risk factors help in explaining expected option returns. If we exclude Japan from the analysis, the performance of the global pricing model is considerably better. Including conditioning information (implied volatility and the implied volatility skew) further decreases the pricing errors of this US/UK model towards those of the local models and provides evidence of conditional international pricing of jump and volatility risk in these two markets. In addition, a detailed analysis of the time variation in option returns indicates that US and UK markets have become increasingly interrelated over the sample period. Turning to the implications for international asset allocation with derivatives, the benefits to diversifying jump and volatility risk internationally are large, but decline over the sample period.

Besides extensions to other markets and countries, a direct analysis of international hedge fund returns warrants more work. Existing research has argued that hedge fund returns exhibit option-like risk-return properties, while this paper focused directly on explaining option returns internationally. In addition to the portfolio analysis we conducted, where the investor has direct access to international option markets, it is interesting to study the international diversification benefits of indirect investments in options, namely through hedge funds.

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Table 1: Excess Return Summary Statistics for Underlying Indices

We report mean, standard deviation and Sharpe ratio for excess returns on the S&P 500, FTSE 100 and Nikkei 225 indices for our April 1992 to June 2001 sample at pseudo-weekly frequency (4 pseudo-weeks per month). Non-US returns are currency-hedged using currency forward rates and all are in excess of the US riskfree rate.

Index	Mean	Std. Dev.	Sharpe
S&P 500	0.0014	0.0201	0.0697
FTSE 100	0.0016	0.0214	0.0748
Nikkei 225	-0.0009	0.0319	-0.0282

Table 2: Option Excess Return Summary Statistics

The table reports mean, standard deviation and Sharpe ratio for excess returns on S&P 500 (Panel A), FTSE 100 (Panel B) and Nikkei 225 (Panel C) index options for different moneyness levels and maturities over our April 1992 to June 2001 sample. Average remaining maturity (at the time when the return is computed) is around 1.5 months for short-maturity options and around 10 months for long-maturity options. Non-US returns are currency-hedged using currency forward rates and all are in excess of the US riskfree rate.

Panel A of Table 2: US Sample

Moneyness	Call Option Returns			Put Option Returns		
(% OTM)	Mean	Std. Dev.	Sharpe	Mean	Std. Dev.	Sharpe
			Short-maturity options			
0%	0.0203	0.4326	0.0468	-0.0609	0.4189	-0.1455
2%	0.0334	0.5588	0.0597	-0.0637	0.4484	-0.1421
4%	0.0500	0.7464	0.0670	-0.0759	0.4754	-0.1597
6%	0.0536	0.8889	0.0603	-0.0857	0.5005	-0.1713
8%	0.0694	1.0292	0.0675	-0.0946	0.5257	-0.1799
			Long-maturity options			
0%	0.0122	0.1373	0.0886	-0.0152	0.1468	-0.1039
2%	0.0143	0.1558	0.0917	-0.0166	0.1567	-0.1057
4%	0.0146	0.1791	0.0818	-0.0172	0.1602	-0.1073
6%	0.0136	0.2051	0.0665	-0.0185	0.1664	-0.1111
8%	0.0222	0.2460	0.0901	-0.0205	0.1777	-0.1153

Panel B of Table 2: UK Sample

Moneyness	Call Option Returns			Put Option Returns		
(% OTM)	Mean	Std. Dev.	Sharpe	Mean	Std. Dev.	Sharpe
			Short-maturity options			
0%	0.0028	0.4719	0.0060	-0.0458	0.4732	-0.0968
2%	0.0019	0.5091	0.0037	-0.0495	0.4842	-0.1022
4%	-0.0031	0.6451	-0.0048	-0.0539	0.5400	-0.0998
6%	0.0024	0.7349	0.0032	-0.0690	0.5982	-0.1154
8%	0.0004	0.7532	0.0005	-0.0686	0.6724	-0.1021
			Long-maturity options			
0%	0.0089	0.1750	0.0510	-0.0163	0.1667	-0.0979
2%	0.0089	0.1955	0.0457	-0.0155	0.1791	-0.0865
4%	0.0077	0.2089	0.0370	-0.0137	0.1873	-0.0733
6%	0.0066	0.2385	0.0276	-0.0138	0.1995	-0.0692
8%	0.0090	0.2725	0.0331	-0.0105	0.2255	-0.0466

Panel C of Table 2: Japan Sample

Moneyness	Call Option Returns			Put Option Returns		
(% OTM)	Mean	Std. Dev.	Sharpe	Mean	Std. Dev.	Sharpe
			Short-maturity options			
0%	-0.0234	0.4640	-0.0503	0.0125	0.5662	0.0221
2%	-0.0191	0.5115	-0.0374	0.0239	0.7026	0.0341
4%	-0.0158	0.5849	-0.0270	0.0365	1.0151	0.0359
6%	-0.0064	0.6896	-0.0093	0.0587	1.2255	0.0479
8%	0.0057	0.7962	0.0072	0.0599	1.2763	0.0470
			Long-maturity options			
0%	-0.0019	0.2053	-0.0093	0.0105	0.1956	0.0539
2%	-0.0042	0.2167	-0.0195	0.0133	0.2108	0.0630
4%	-0.0034	0.2371	-0.0144	0.0145	0.2223	0.0653
6%	-0.0035	0.2520	-0.0138	0.0078	0.2249	0.0348
8%	-0.0065	0.2601	-0.0251	0.0123	0.2321	0.0530

Table 3: Unconditional CAPM results

The table reports the results of cross-sectional OLS regressions for the unconditional CAPM applied to index option excess returns for 3 markets (S&P 500, FTSE 100 and Nikkei 225). The cross-section in each market contains 50 options: calls and puts, each with 5 levels of moneyness (0%, 2%,..., 8% OTM) and 5 maturity bins (from short-maturity with average remaining maturity of approximately 1.5 months to long-maturity with approximately 10 months average remaining maturity). The beta's are obtained from (unreported) first-stage regressions of option excess returns on the corresponding market excess return (taken to be the underlying index excess return) for our April 1992 to June 2001 samples. Non-US returns are currency-hedged using currency forward rates and all are in excess of the US riskfree rate. Standard errors and test statistics are calculated using results of Shanken (1992) to correct for the estimation error in the first-step beta's. The Wald p-value in the last row is for the Wald test that the pricing errors for 8 test assets are jointly zero. The 8 test assets consist of calls and puts, both ATM and 8% OTM, and both short-maturity and long-maturity.

	US	UK	Japan
Average α	-0.0094	-0.0154	0.0094
Average $\|\alpha\|$	0.0095	0.0155	0.0100
λ	0.0024	0.0015	-0.0014
(t-stat)	(4.42)	(3.32)	(-1.68)
R^2	0.8771	0.5524	0.5846
Wald (prob)	0.00036	0.0064	0.0028

Table 4: Factor CAPM-Excess Returns: Summary Statistics

The table reports mean, standard deviation and Sharpe ratio for CAPM-excess returns on the 2 factor-mimicking portfolios (for volatility and jump risk) for each of the 3 markets (US (S&P 500), UK (FTSE 100) and Japan (Nikkei 225)) for our April 1992 to June 2001 sample. The excess returns are relative to the local unconditional CAPM, which is estimated for excess returns relative to the US riskfree rate (after currency-hedging using currency forward rates for non-US returns). The crash-neutral ('CN') straddle consists of a long position in a (short-maturity) ATM straddle and a short position in a (short-maturity) 0.92 put.

	Mean	Std. Dev.	Sharpe
US CN straddle	-0.0167	0.1583	-0.1056
US 0.96 Put	-0.0478	0.2612	-0.1832
UK CN straddle	-0.0219	0.1472	-0.1486
UK 0.96 Put	-0.0217	0.3424	-0.0635
Japan CN straddle	-0.0090	0.1909	-0.0471
Japan 0.96 Put	0.0209	0.8650	0.0241

Table 5: Regressions of Factor Returns on Variance and Cubic Contract Returns

The table reports results from univariate and bivariate time-series regressions of CAPM-excess returns on the risk factors on the returns of the quadratic and cubic contract, for the 3 markets we analyze (US (S&P 500), UK (FTSE 100) and Japan (Nikkei 225)) over our April 1992 to June 2001 samples. The risk factors are the crash-neutral straddle (consisting of a long position in a (short-maturity) ATM straddle and a short position in a (short-maturity) 0.92 put) and the 0.96 short-maturity put. *** indicates significance at the 1% level.

	US Straddle			US OTM Put		
Variance contract	0.819***		0.784***	0.813***		1.048***
Cubic contract		-0.060***	-0.031***		0.171***	0.210***
R^2	91.7%	4.87%	95.4%	33.2%	44.2%	97.0%

	UK Straddle			UK OTM Put		
Variance contract	0.685***		0.745***	1.210***		0.889***
Cubic contract		-0.009	-0.040***		0.249***	0.212***
R^2	81.5%	0.5%	90.9%	47.1%	72.8%	96.5%

	Japan Straddle			Japan OTM Put		
Variance contract	0.358***		0.726***	2.081***		0.8523***
Cubic contract		0.016***	-0.058***		0.270***	0.1254***
R^2	52.2%	6.5%	82.4%	76.1%	82.1%	92.0%

Table 6: Unconditional Two-Factor Results for Equity-Hedged Option Returns

The table reports the results of cross-sectional OLS regressions for the unconditional local two-factor model given by (5) applied to index option CAPM-based excess returns for each market (US (S&P 500), UK (FTSE 100) and Japan (Nikkei 225)). The risk factors are the crash-neutral straddle (consisting of a long position in a (short-maturity) ATM straddle and a short position in a (short-maturity) 0.92 put) and the 0.96 short-maturity put. The cross-section in each market contains 50 options: calls and puts, each with 5 levels of moneyness (0%, 2%,..., 8% OTM) and 5 maturity bins (from short-maturity with average remaining maturity of approximately 1.5 months to long-maturity with approximately 10 months average remaining maturity). The beta's are obtained from (unreported) first-stage regressions of CAPM-based option excess returns on the corresponding factors for our April 1992 to June 2001 samples. Standard errors and test statistics are calculated using results of Shanken (1992) to correct for the estimation error in the first-step beta's. The Wald p-value in the last row is for the Wald test that the pricing errors for 8 test assets are jointly zero. The 8 test assets consist of calls and puts, both ATM and 8% OTM, and both short-maturity and long-maturity.

	US	UK	Japan
Average α	-0.0023	-0.0009	0.0007
Average $\|\alpha\|$	0.0053	0.0051	0.0057
$\lambda_{straddle}$	-0.0060	-0.0190	0.0082
(t-stat)	(-1.63)	(-6.17)	(1.28)
$\lambda_{OTM\ put}$	-0.0489	-0.0300	0.0327
(t-stat)	(-12.22)	(-6.69)	(5.19)
R^2	0.8299	0.8602	0.7383
Wald (prob)	0.0784	0.0485	0.0071

Table 7: Cross-Country Correlations

The table reports cross-country correlations for the returns on the underlying indices and for CAPM-based excess returns on both risk factors across 3 markets (US (S&P 500), UK (FTSE 100) and Japan (Nikkei 225)) over our April 1992 to June 2001 sample. The risk factors are the crash-neutral straddle (consisting of a long position in a (short-maturity) ATM straddle and a short position in a (short-maturity) 0.92 put) and the 0.96 short-maturity put.

	US-UK	US-Japan	UK-Japan
Equity index	0.6061	0.3151	0.3252
Factor 1 (CN straddle)	0.2897	-0.0371	0.0970
Factor 2 (0.96 put)	0.3239	0.0552	0.0908

Table 8: Unconditional International Six-Factor Model

The table reports the results of the pooled cross-sectional OLS regression for the unconditional international six-factor model given by (6) applied to index option CAPM-based excess returns in 3 markets (US (S&P 500), UK (FTSE 100) and Japan (Nikkei 225)). The six risk factors are the crash-neutral straddle (consisting of a long position in a (short-maturity) ATM straddle and a short position in a (short-maturity) 0.92 put) and the 0.96 short-maturity put, each in all 3 markets. The pooled cross-section contains 150 options: calls and puts, each with 5 levels of moneyness (0%, 2%,..., 8% OTM) and 5 maturity bins (from short-maturity with average remaining maturity of approximately 1.5 months to long-maturity with approximately 10 months average remaining maturity), and each for the 3 markets. The beta's are obtained from (unreported) first-stage regressions of CAPM-based option excess returns on the factors for our April 1992 to June 2001 samples. Standard errors and test statistics are calculated using results of Shanken (1992) to correct for the estimation error in the first-step beta's. The Wald p-value in the last row is for the Wald test that the pricing errors for 24 test assets are jointly zero. The 24 test assets consist of calls and puts, both ATM and 8% OTM, and both short-maturity and long-maturity, for all 3 markets.

	US	UK	Japan
Average α	-0.0019	-0.0009	0.0008
Average $\lvert\alpha\rvert$	0.0048	0.0048	0.0066
$\lambda^{US}_{straddle}$		-0.0065	
(t-stat)		(-1.79)	
$\lambda^{UK}_{straddle}$		-0.0192	
(t-stat)		(-6.28)	
$\lambda^{Japan}_{straddle}$		0.0104	
(t-stat)		(1.66)	
$\lambda^{US}_{OTM\ put}$		-0.0483	
(t-stat)		(-12.02)	
$\lambda^{UK}_{OTM\ put}$		-0.0280	
(t-stat)		(-6.32)	
$\lambda^{Japan}_{OTM\ put}$		0.0364	
(t-stat)		(5.87)	
R^2		0.8213	
Wald (prob)		0.0014	

Table 9: Unconditional International Two-Factor Model

The table reports the results of the pooled cross-sectional OLS regression for the unconditional international two-factor model given by (7) applied to index option CAPM-based excess returns in 3 markets (US (S&P 500), UK (FTSE 100) and Japan (Nikkei 225)). The two risk factors are the 'global' crash-neutral straddle and the 'global' 0.96 short-maturity put, each constructed as a weighted average of the three corresponding local factors, with weights based on principal component analysis applied to the correlation matrix (using the first principal component). The pooled cross-section contains 150 options: calls and puts, each with 5 levels of moneyness (0%, 2%,..., 8% OTM) and 5 maturity bins (from short-maturity with average remaining maturity of approximately 1.5 months to long-maturity with approximately 10 months average remaining maturity), and each for the 3 markets. The beta's are obtained from (unreported) first-stage regressions of CAPM-based option excess returns on the factors for our April 1992 to June 2001 samples. Standard errors and test statistics are calculated using results of Shanken (1992) to correct for the estimation error in the first-step beta's. The Wald p-value in the last row is for the Wald test that the pricing errors for 24 test assets are jointly zero. The 24 test assets consist of calls and puts, both ATM and 8% OTM, and both short-maturity and long-maturity, for all 3 markets.

	US	UK	Japan
Average α	-0.0046	-0.0126	0.0087
Average $\|\alpha\|$	0.0158	0.0127	0.0099
$\lambda^{global}_{straddle}$		-0.0044	
(t-stat)		(-1.44)	
$\lambda^{global}_{OTM\ put}$		0.0016	
(t-stat)		(0.17)	
R^2		0.0775	
Wald (prob)		0.000008	

Table 10: Unconditional US/UK International Two-Factor Model

The table reports the results of the pooled cross-sectional OLS regression for the unconditional international two-factor model given by (8) applied to index option CAPM-based excess returns in 2 markets (US (S&P 500) and UK (FTSE 100)). The two risk factors are the US/UK crash-neutral straddle and the US/UK 0.96 short-maturity put, each constructed as the average of the two corresponding local factors. The pooled cross-section contains 100 options: calls and puts, each with 5 levels of moneyness (0%, 2%,..., 8% OTM) and 5 maturity bins (from short-maturity with average remaining maturity of approximately 1.5 months to long-maturity with approximately 10 months average remaining maturity), and each for the 2 markets. The beta's are obtained from (unreported) first-stage regressions of CAPM-based option excess returns on the factors for our April 1992 to June 2001 samples. Standard errors and test statistics are calculated using results of Shanken (1992) to correct for the estimation error in the first-step beta's. The Wald p-value in the last row is for the Wald test that the pricing errors for 16 test assets are jointly zero. The 16 test assets consist of calls and puts, both ATM and 8% OTM, and both short-maturity and long-maturity, for both markets.

	US	UK
Average α	-0.0009	-0.0055
Average $\|\alpha\|$	0.0101	0.0102
$\lambda^{US/UK}_{straddle}$	-0.0098	
(t-stat)	(-3.52)	
$\lambda^{US/UK}_{OTM\ put}$	-0.0344	
(t-stat)	(-9.24)	
R^2	0.4816	
Wald (prob)	0.0017	

Table 11: Conditional Cross-Country Factor Correlations

The table reports conditional cross-country correlations for CAPM-based excess returns on both risk factors across 3 markets (US (S&P 500), UK (FTSE 100) and Japan (Nikkei 225)) over our April 1992 to June 2001 sample. The risk factors are the crash-neutral straddle (consisting of a long position in a (short-maturity) ATM straddle and a short position in a (short-maturity) 0.92 put) and the 0.96 short-maturity put. Conditional correlations are obtained by first dividing the sample period in subperiods according to quartiles for an internationally-averaged instrument (ATM implied volatility for the first risk factor and the implied volatility skew (defined as the difference between the implied volatility of the 0.92 put and of the ATM put) for the second factor). We then calculate cross-country correlations for CAPM-based excess option returns for each subperiod or regime for the instrument ('low' (bottom quartile), 'intermediate' (middle quartiles) and 'high' (top quartile)). The last column (US/UK*) reports results for US-UK cross-country correlations when the instruments are taken to be US-UK averages (removing the Nikkei instruments).

Factor	Regime	US-UK	US-Japan	UK-Japan	US-UK*
CN Straddle	low IV	0.2116	-0.2211	-0.0277	0.2031
	intermed. IV	0.3364	0.0821	0.2354	0.3162
	high IV	0.3242	-0.0285	-0.0153	0.3833
OTM Put	low skew	0.4268	0.3017	0.1974	0.0849
	intermed. skew	0.2073	0.0812	0.1244	0.3091
	high skew	0.4359	-0.0517	-0.0132	0.5128

Table 12: Conditional Local Two-Factor Models

The table reports the results of cross-sectional OLS regressions for the conditional local two-factor model given by (10) applied to index option CAPM-based excess returns for each market (US (S&P 500), UK (FTSE 100) and Japan (Nikkei 225)). The risk factors are the crash-neutral straddle (consisting of a long position in a (short-maturity) ATM straddle and a short position in a (short-maturity) 0.92 put), the 0.96 short-maturity put, the crash-neutral straddle multiplied by ATM implied volatility and the 0.96 put multiplied by the implied volatility skew (defined as the difference between the implied volatility of the 0.92 put and of the ATM put). The cross-section in each market contains 50 options: calls and puts, each with 5 levels of moneyness (0%, 2%,..., 8% OTM) and 5 maturity bins (from short-maturity with average remaining maturity of approximately 1.5 months to long-maturity with approximately 10 months average remaining maturity). The beta's are obtained from (unreported) first-stage regressions of CAPM-based option excess returns on the corresponding factors for our April 1992 to June 2001 samples. Standard errors are calculated using results of Shanken (1992) to correct for the estimation error in the first-step beta's.

	US	UK	Japan
Average α	-0.0012	-0.0006	0.0000
Average $\lvert\alpha\rvert$	0.0042	0.0051	0.0054
$\lambda_{straddle}$	-0.0106	-0.0193	0.0075
(t-stat)	(-2.71)	(-6.37)	(1.28)
$\lambda_{OTM\ put}$	-0.0444	-0.0285	0.0330
(t-stat)	(-12.15)	(-6.96)	(5.42)
$\lambda_{IV\ \times\ straddle}$	-0.0021	-0.0029	-0.0044
(t-stat)	(-0.07)	(-0.20)	(-0.20)
$\lambda_{skew\ \times\ OTM\ put}$	-0.1172	-0.0197	-0.0123
(t-stat)	(-2.11)	(-0.26)	(-0.23)
R^2	0.9183	0.8624	0.7751

Table 13: Conditional International Two-Factor Model

The table reports the results of the pooled cross-sectional OLS regression for the conditional international two-factor model given by (11) applied to index option CAPM-based excess returns in 3 markets (US (S&P 500), UK (FTSE 100) and Japan (Nikkei 225)). The first two risk factors are as in Table 9 (the 'global' crash-neutral straddle and the 'global' 0.96 short-maturity put, each constructed as a weighted average of the three corresponding local factors, with weights based on principal component analysis applied to the correlation matrix (using the first principal component)). The third and fourth risk factor are the global crash-neutral straddle multiplied by internationally-averaged ATM implied volatility and the global 0.96 put multiplied by the internationally-averaged implied volatility skew (defined as the difference between the implied volatility of the 0.92 put and of the ATM put). The pooled cross-section contains 150 options: calls and puts, each with 5 levels of moneyness (0%, 2%,..., 8% OTM) and 5 maturity bins (from short-maturity with average remaining maturity of approximately 1.5 months to long-maturity with approximately 10 months average remaining maturity)), and each for the 3 markets. The beta's are obtained from (unreported) first-stage regressions of CAPM-based option excess returns on the corresponding factors for our April 1992 to June 2001 samples. Standard errors and the test statistic are calculated using results of Shanken (1992) to correct for the estimation error in the first-step beta's. The Wald p-value in the last row is for the Wald test that the pricing errors for 24 test assets are jointly zero. The 24 test assets consist of calls and puts, both ATM and 8% OTM, and both short-maturity and long-maturity, for all 3 markets.

	US	UK	Japan
Average α	-0.0011	-0.0021	0.0052
Average $\lvert\alpha\rvert$	0.0059	0.0082	0.0082
$\lambda^{global}_{straddle}$		-0.0137	
(t-stat)		(-5.34)	
$\lambda^{global}_{OTM\ put}$		-0.0165	
(t-stat)		(-3.02)	
$\lambda^{global}_{IV\ \times\ straddle}$		-0.0383	
(t-stat)		(-2.22)	
$\lambda^{global}_{skew\ \times\ OTM\ put}$		-0.0593	
(t-stat)		(-2.38)	
R^2		0.6520	
Wald (prob)		0.00044	

Table 14: Conditional US/UK International Two-Factor Model

The table reports the results of the pooled cross-sectional OLS regression for the conditional international two-factor model given by (12) applied to index option CAPM-based excess returns in 2 markets (US (S&P 500) and UK (FTSE 100)). The first two risk factors are as in Table 10 (the US/UK crash-neutral straddle and the US/UK 0.96 short-maturity put, each constructed as the average of the two corresponding local factors). The third and fourth risk factor are the US/UK crash-neutral straddle multiplied by US/UK average ATM implied volatility and the US/UK 0.96 put multiplied by the US/UK average implied volatility skew (defined as the difference between the implied volatility of the 0.92 put and of the ATM put). The pooled cross-section contains 100 options: calls and puts, each with 5 levels of moneyness (0%, 2%,..., 8% OTM) and 5 maturity bins (from short-maturity with average remaining maturity of approximately 1.5 months to long-maturity with approximately 10 months average remaining maturity), and each for the 2 markets. The beta's are obtained from (unreported) first-stage regressions of CAPM-based option excess returns on the corresponding factors for our April 1992 to June 2001 samples. Standard errors and the test statistic are calculated using results of Shanken (1992) to correct for the estimation error in the first-step beta's. The Wald p-value in the last row is for the Wald test that the pricing errors for 16 test assets are jointly zero. The 16 test assets consist of calls and puts, both ATM and 8% OTM, and both short-maturity and long-maturity, for both markets.

	US	UK
Average α	-0.0006	-0.0009
Average $\|\alpha\|$	0.0059	0.0081
$\lambda^{US/UK}_{straddle}$	-0.0161	
(t-stat)	(-6.23)	
$\lambda^{US/UK}_{OTM\ put}$	-0.0301	
(t-stat)	(-7.18)	
$\lambda^{US/UK}_{IV\ \times\ straddle}$	-0.0572	
(t-stat)	(-2.17)	
$\lambda^{US/UK}_{skew\ \times\ OTM\ put}$	-0.0741	
(t-stat)	(-2.23)	
R^2	0.7171	
Wald (prob)	0.0352	

Table 15: Optimal Portfolio Weights for $\gamma = 5$ Investor

The table reports optimal portfolio weights and their standard errors for a CRRA investor with risk aversion of 5 obtained by estimating (15) with GMM, for different sets of available assets (asset set 1 is US equity and riskfree asset only), over the April 1992 to June 2001 sample. All UK returns are currency-hedged using currency forward rates. The straddle consists of a long position in a (short-maturity) ATM straddle and a short position in a (short-maturity) 0.92 put and the OTM put is the 0.96 short-maturity put. The certainty equivalent wealth in the bottom rows is the percentage of initial wealth needed to compensate the investor when moving from the larger to the smaller asset set. The certainty equivalent wealth for the full sample reflects the optimal portfolios estimated using the full sample and reported in the table. The last 2 rows report certainty equivalents when splitting the sample in two equal-length subperiods and are based on unreported optimal portfolios for the first and second subsample, respectively.

Asset Set	1	2	3	4	5
US equity	0.108	-3.290	-3.314	0.291	-0.068
S.E.	(0.477)	(0.894)	(0.985)	(0.492)	(1.506)
UK equity			-0.325		0.556
S.E.			(0.808)		(1.451)
US OTM put		-0.150	-0.142		
S.E.		(0.038)	(0.040)		
UK OTM put			-0.029		
S.E.			(0.030)		
US straddle				-0.105	-0.060
S.E.				(0.059)	(0.145)
UK straddle					-0.150
S.E.					(0.069)
Asset Sets		2 vs. 1	3 vs. 2	4 vs. 1	5 vs. 4
Cert. equiv. (full sample)		0.610%	0.035%	0.085%	0.129%
Cert. equiv. (1st half)		3.060%	0.238%	0.149%	0.223%
Cert. equiv. (2nd half)		0.031%	0.060%	0.142%	0.066%

Figures 1A through 1C: Security Market Line for Option Returns

The figures plot the security market line according to the time-series ('TS') version of the unconditional CAPM (where the slope is restricted to be the time-series average of the market excess return) and the cross-sectional ('CS') security market line (where the slope is the estimated market risk premium from Table 3), from OLS regressions for index option excess returns for 3 markets (US (S&P 500) in Figure 1A, UK (FTSE 100) in Figure 1B and Japan (Nikkei 225) in Figure 1C). The cross-section in each market contains 50 options: calls and puts, each with 5 levels of moneyness (0%, 2%,..., 8% OTM) and 5 maturity bins (from short-maturity with average remaining maturity of approximately 1.5 months to long-maturity with approximately 10 months average remaining maturity). The beta's are obtained from time-series regressions of option excess returns on the corresponding market excess return (taken to be the underlying index excess return) for our April 1992 to June 2001 samples. Non-US returns are currency-hedged using currency forward rates and all are in excess of the US riskfree rate.

Figure 1A: Security Market Line for US Option Returns

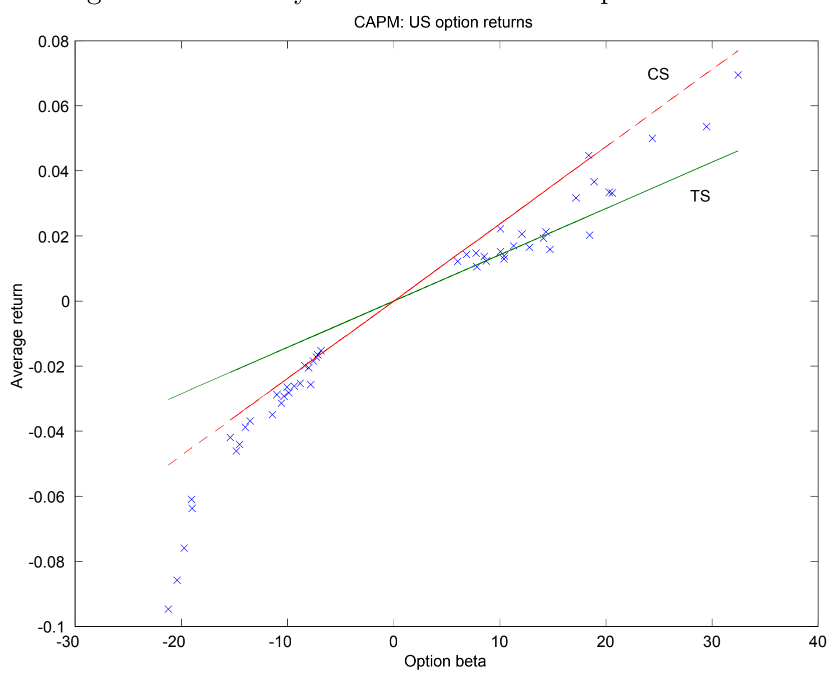


Figure 1B: Security Market Line for UK Option Returns

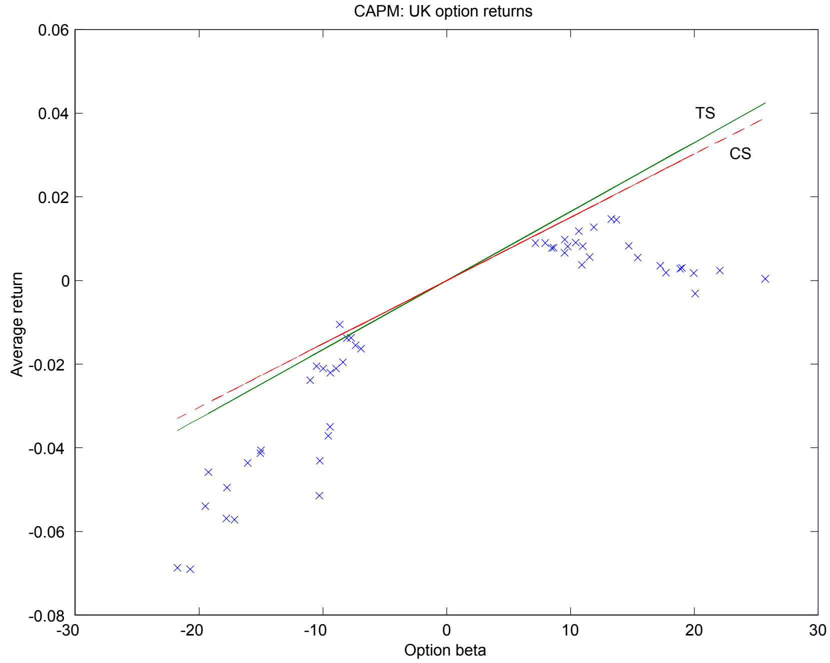
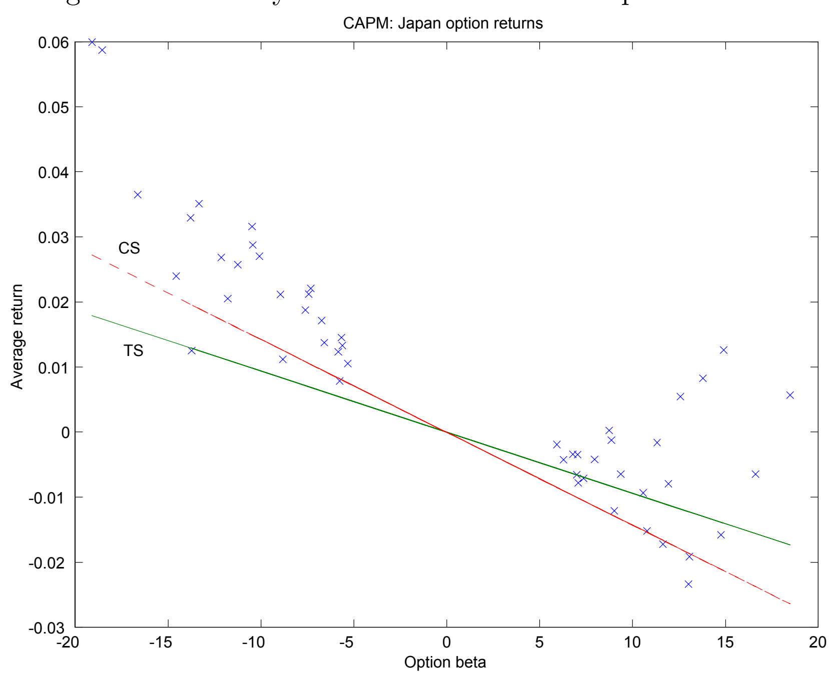


Figure 1C: Security Market Line for Nikkei Option Returns



Figures 2A and 2B: Time-Variation in Cross-Market Factor Return Correlations

The figures plot the time-series of cross-country correlations for CAPM-based excess returns on both risk factors across 3 markets (US (S&P 500), UK (FTSE 100) and Japan (Nikkei 225)) over our April 1992 to June 2001 sample. The cross-country correlations are estimated over a two-year rolling window. The risk factors are the crash-neutral straddle in Figure 2A (consisting of a long position in a (short-maturity) ATM straddle and a short position in a (short-maturity) 0.92 put) and the 0.96 short-maturity put in Figure 2B.

Figure 2A: Time-Variation in Cross-Market Correlations for Straddle Returns

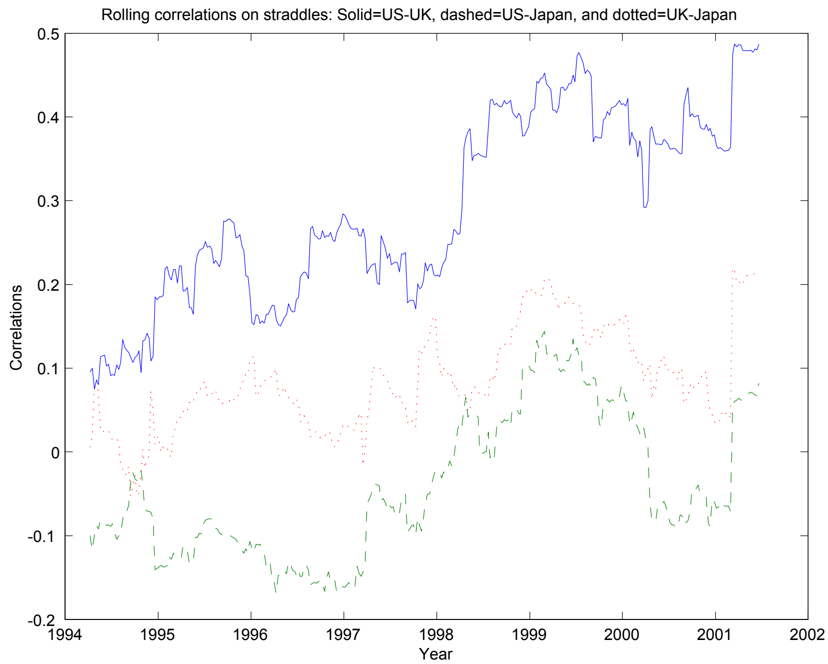
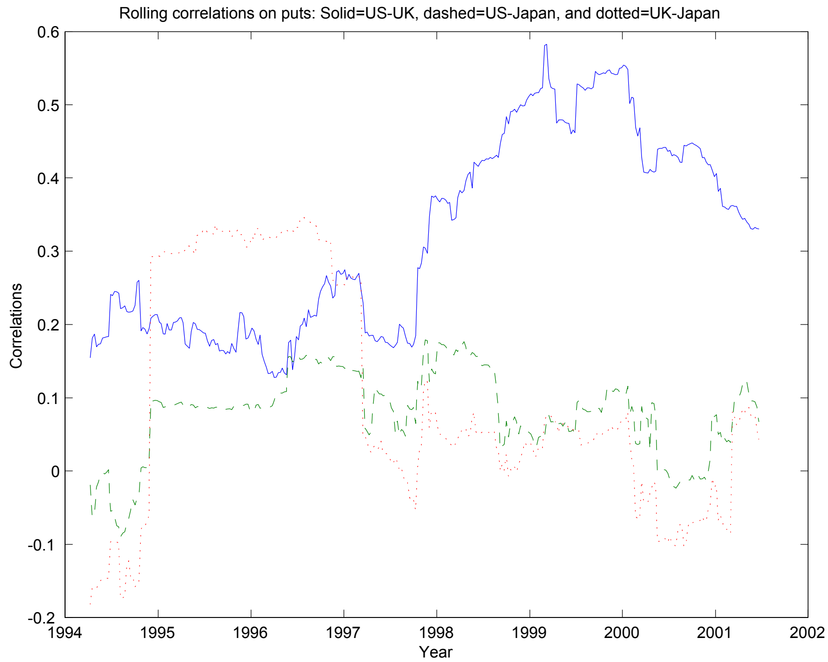


Figure 2B: Time-Variation in Cross-Market Correlations for Put Returns



Figures 3A through 3C: Time-Series of Instruments used in Conditional Analysis

The figures plot the time-series of the instruments for 3 markets (US (S&P 500), UK (FTSE 100) and Japan (Nikkei 225)) over our April 1992 to June 2001 sample. The instruments are ATM implied volatility (Figure 3A) and the implied volatility skew (defined as the difference between the implied volatility of the 0.92 put and of the ATM put) in Figure 3B. Figure 3C plots the US-UK average of ATM implied volatility and the US-UK average of the implied volatility skew.

Figure 3A: Time-Series of ATM Implied Volatility

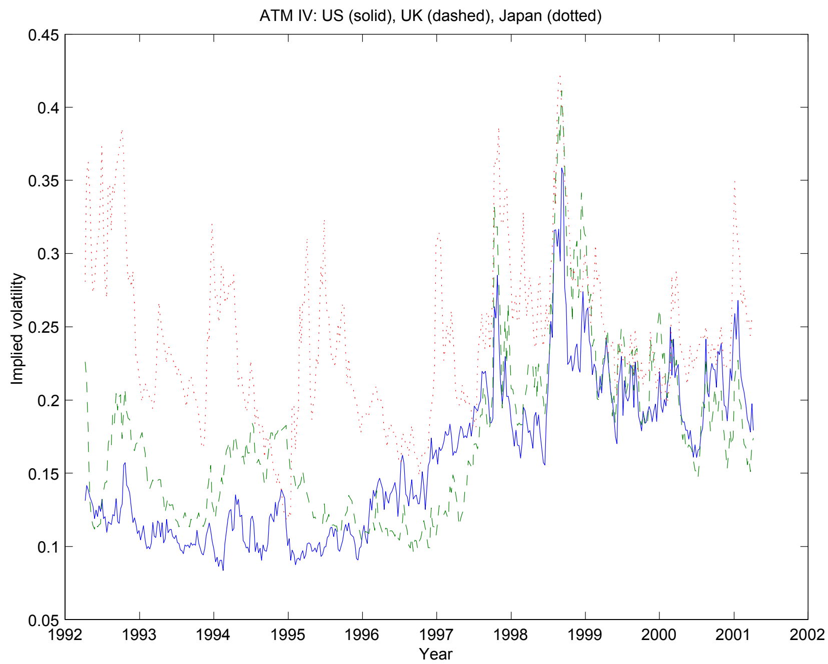


Figure 3B: Time-Series of Implied Volatility Skew

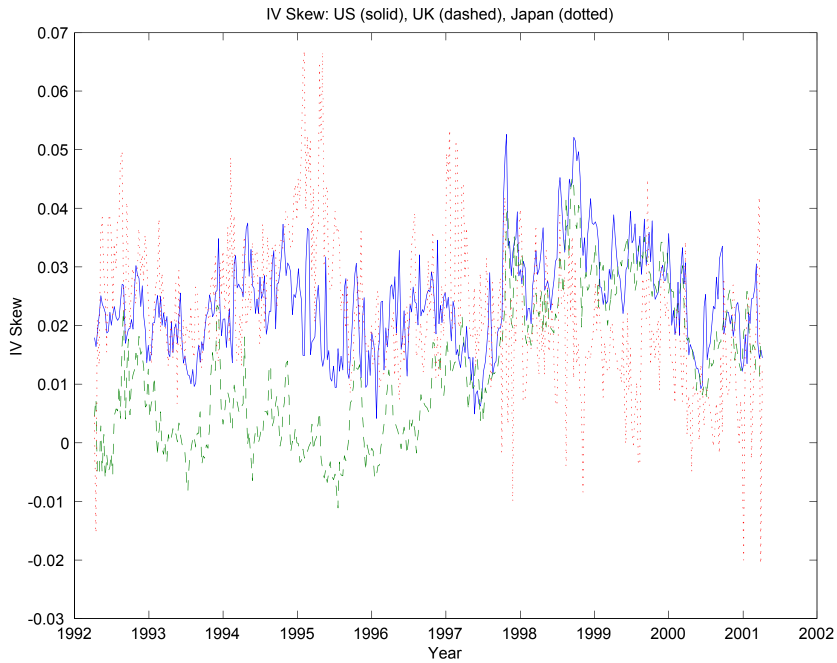


Figure 3C: Time-Series of Average US/UK ATM Implied Volatility and Implied Volatility Skew