The Correlation Risk Premium: International Evidence

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ABSTRACT

In this paper we carry out the first cross-country analysis of the correlation risk premium. We examine the statistical properties of the implied and realized correlation in European equity markets and relate the resulting premium to the US equity market correlation risk and a global correlation risk premium. We find evidence of strong co-movement of correlation risk premiums in European and US equity markets. Our results support the existence of a global correlation risk premium that is priced in international equity option markets. We document the dependence of the correlation risk premium on macroeconomic policy uncertainty and related variables. (*JEL* G10, G12, G13)

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I. Introduction

"Traders are speculating correlation among equities, already the highest since the crash of 1987, will increase as the threat of a banking crisis in Europe drowns out news about individual companies. Equity prices moving in unison have hurt returns for money managers who seek relative value among stocks and industries, leaving hedge fund managers with fewer ways to beat their benchmark measures. Europe is a big macro issue and it's so pervasive that at the top of investors' minds, there's nothing to do with individual companies." "Fear drives correlations". Bloomberg News, 16 Sep 2011.

The global financial crisis has again shown that diversification benefits in equity markets can suddenly evaporate when correlations unexpectedly increase, thus constraining the investment opportunity set available to investors. Recent academic research has documented how correlation risk can arise endogenously in theory[1] and how it can be hedged and traded in equity derivatives markets in practice. Although the correlation risk premium, that is the difference between implied and realized correlation, is known to be the main driver of the variance risk premium, it has not been studied as extensively.[2] Correlation risk has been shown to be priced in the cross-section of US option returns and hedge fund returns.[3]

If we view asset returns in different countries as portfolios in a global market, then asset pricing theory suggests that cross-sectional differences in countries' risk exposures should explain cross-sectional variation in expected returns, that is the risk should be *priced*. However, existing research on correlation risk in equity markets is exclusively focused on US data. Is the equity option implied correlation risk premium significant in non-US markets and is it priced? What is the relationship between the correlation risk premium in different markets? What are the macroeconomic drivers of the correlation risk premium? In this paper we address these questions by carrying out the first cross-country analysis of the correlation risk premium. We examine the statistical properties of the implied and realized correlations in European equity markets and relate the resulting premium to both the US equity market correlation risk and a global correlation risk premium.

[1] See Martin (2013), Buraschi, Trojani and Vedolin (2014) and Piatti (2015).
[2] Driessen, Maenhout and Vilkov (2009).
[3] See Driessen, Maenhout, and Vilkov (2013) and Buraschi, Kosowski and Trojani (2014).

In practice, understanding the dynamics, the informational content and the co-movement of correlation risk in global equity markets is crucial for the design of risk management strategies by international asset managers, including pension funds and hedge funds that are exposed to correlation risk. It is also relevant for macro- and micro-prudential regulation and supervision activities by regulators and supervisors, who are concerned with systemic risk at the macro level and risk management policies at the micro level. The ability to understand correlations is important for the design and use of derivatives and structured products that are sensitive to domestic and international equity markets in general and to the volatility and correlation of equity returns in particular.

Our first contribution is to show that the correlation risk premium in European equity markets, as well as in the US, is economically and statistically significant. Our sample includes France, Germany, the UK, Switzerland, the Eurostoxx 50 and the US.[4] Correlation swaps are simple correlation derivatives in which counterparties exchange realized versus implied correlation (the correlation swap quote).[5] To measure correlation risk we follow Buraschi, Kosowski and Trojani (2014) and construct a correlation risk proxy. This is based on the difference between the implied correlation from a synthetic correlation swap contract and the realized correlation for different equity markets.

We find that the ex-post correlation risk premium, which is also sometimes referred to as the realization of the correlation risk premium, is economically and statistically significant for all the equity markets in our baseline specification, which supports insights from US studies.[6] For instance, the monthly correlation risk premium (with a 30-day maturity) is statistically significant at 1% level for the French, German, Swiss and US equity indexes, and at 10% level for the Pan-European index. The average levels of the correlation risk premium in European equity markets are also economically significant. They vary between -1% and 19 % for 30-day maturity and between 6% and 24% for 91-day maturity. This compares to 5% and 7% for the US index for 30-day and 91-day maturity, respectively.

[4] We restrict our analysis to these countries due to option data availability. The Eurostoxx 50 is a pan-European index.
[5] Buraschi, Kosowski and Trojani (2014) discuss the advantages of implied correlations from correlation swap quotes as opposed to dispersion trade strategies.
[6] The only exception is the 30-day maturity for the UK's FTSE 100 index.

The second contribution of this paper is an analysis of the co-movement of the correlation risk premium in the US and different European equity markets. To the best of our knowledge, this is the first cross-country analysis of the correlation risk premium. On the one hand, our study is motivated by evidence that close linkages across financial markets are a major source of large spillovers (Boyoumi and Vitek, 2013) – as opposed to trade and commodity price channels. On the other hand, it is motivated by the role that financial markets play in creating systemic risk through channels such as capital flows, funding availability, risk premiums and liquidity shocks, as opposed to common macroeconomic shocks on economic fundamentals (Ang and Longstaff (2013) and Cespa and Foucalt (2014)). We find that the co-movement of realized correlations, implied correlations and the correlation risk premiums across different European equity markets and between European and US equity markets, is very high. The correlation risk premium based on the EuroStoxx 50 index, for example, has a correlation of 60% with that based on the S&P 500 index. A Principal Component Analysis corroborates these findings.

The high level of co-movement and the significance of the first component suggest the existence of a global correlation risk premium, which would be consistent with the finding by Bollerslev, Marrone, Xu and Zhou (2014) of a global variance risk premium. Our third contribution is, therefore, to show that indeed exposure to a global correlation risk premium, computed using a weighted average of correlation risk premiums in different countries, accounts for 75% of the cross-sectional variation of the European and US equity index option returns. According to our results, exposure to the global correlation risk premium is cross-sectionally priced in international equity options markets. Consistent with existing evidence for the US market (Driessen, Maenhout and Vilkov, 2009) we find that exposure to the average individual variance risk premium and to the *residual* index variance risk premium is not priced. The residual premium here is measured by the residuals of the regression of the index variance risk premium on the correlation risk benchmark.

The fourth contribution of this paper is to empirically document the drivers of the correlation risk premium. Drechsler and Yaron (2011) use a generalized long-run risk model to demonstrate that the variance risk premium reflects attitudes towards uncertainty, while Buraschi, Trojani and Vedolin (2014) present a theoretical model that links the correlation risk premium to investors' disagreement about future dividends. We analyze the effect of the uncertainty of macroeconomic policy on correlation risk. Empirically, we analyze the relative role of a VIX-type index and macroeconomic policy related uncertainty on the correlation risk premium. For *broad* indexes (the S&P 500 index for the US and EuroStoxx 50 index for the Pan-European equity markets, respectively), the policy related economic uncertainty variable has a significant effect, while the VIX-type index has insignificant effects after controlling the policy uncertainty premium.

Related literature

Our research is related to four streams of the literature. First, recent economic models from Martin (2013), Buraschi, Trojani and Vedolin (2014) and Piatti (2015), explain how correlation risk can arise endogenously and why it should carry a risk premium. We build on this theoretical literature and show that the correlation risk premium is positive in many countries, strongly co-moves across those countries and that correlation risk is priced in global markets.

The second stream of literature to which our paper is related, includes recent empirical studies that use option data[7] and hedge fund return data (Buraschi, Trojani and Vedolin, 2014), to document that stochastic correlation risk is priced and a good predictor of market returns. DMV (2009) show that equity index options will appear more expensive when correlation risk is priced. In DMV (2013) they document the existence and significance of a correlation risk premium. Buraschi, Kosowski and Trojani (2014) study the relation between correlation risk, hedge fund characteristics and their risk-return profile. Buss, Schoenleber and Vilkov (2017) show that option implied correlation predicts the market return by predicting a concentration of market risk and, consequently, decreasing systematic diversification. We complement these findings by showing that the correlation risk premium is correlated across equity markets, which means that it cannot be easily diversified away, thus leading to a hedging motive.

Third, our paper is linked to broad studies of the variance risk premium. Bakshi and Kapadia (2003), Carr and Wu (2009) provide both a theoretical foundation and an empirical

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[7] See, for example, Driessen, Maenhout and Vilkov (2009) and (2013), which we henceforth abbreviate DMV (2009) and DMV (2013); Buraschi, Kosowski and Trojani (2014); and Buss, Schoenleber and Vilkov (2017).

result for the variance (volatility) risk premium. Bollerslev, Tauchen and Zhou (2009) derive the variance risk premium from an equilibrium model with time-varying economic uncertainty and further test the predictability for equity risk premium. Similarly, Bollerslev, Marrone, Xu and Zhou (2014) extend the analysis to international markets. We extend these studies by documenting evidence of a global correlation risk premium and the relationship between the correlation risk premium and measures of (macroeconomic) uncertainty.

Fourth, our paper is related to work on equity market integration, the world price of covariance risk and international stock market return predictability. Harvey (1991) finds that time-varying covariances are able to capture some of the dynamic behavior of country returns. Rapach, Strauss and Zhou (2013) investigate the lead-lag relationship among monthly country stock returns. They find that US returns predict other country indexes, which they interpret in the context of a two-country Lucas-tree framework with gradual information diffusion. We contribute to this literature by documenting strong correlation between correlation risk premiums in European and US markets and evidence of a global correlation risk premium.

The rest of the paper is organized as follows. Section II reviews the methodology used to calculate implied correlation, realized correlation and the correlation risk premium. The data is discussed in section III. In section IV the empirical results are described. Robustness checks are presented in section V. We conclude in section VI.

II. Methodology

A. The correlation risk benchmark

To measure correlation risk, we follow DMV (2013) and Buraschi, Kosowski and Trojani (2014) and construct a correlation risk proxy, based on the difference between option-implied correlation between stock returns (obtained by combining index option prices with prices of options on all index components) and the realized correlation for different equity markets.

The correlation risk premium for the time period (t, T), CR_t, corresponds to the difference between the time t risk neutral (measure Q) and actual (measure P) expectations of the average pairwise correlation between t and T:

$$CR_t \equiv E_t^Q(RC_{t,T}) - E_t^P(RC_{t,T}). \quad (1)$$

The most direct way of computing the risk-neutral expected value $E_t^Q(RC_{t,T})$ is to use the correlation swap rate $SC_{t,T}$, if available, at date *t* in the form of a correlation swap quote. Alternatively, if correlation swap quotes are not available, or the underlying swap contracts are highly illiquid, the computation of $E_t^Q(RC_{t,T})$ in equation (1) can be approximated. This can be achieved by using a synthetic correlation swap rate $SC_{t,T}$, based on a basket of index and individual stock variance swaps, which, in turn, can be synthesized from the cross-section of index and individual stock options. We follow Buraschi, Kosowski and Trojani (2014) and approximate the correlation swap rate $SC_{t,T}$ by the implied correlation rate IC_t:

$$IC_t = \frac{E_t^Q\left[RV_{t,T}^I\right] - \sum_{i=1}^n w_i^2 E_t^Q\left[RV_{t,T}^i\right]}{\sum_{i\neq j} w_i w_j \sqrt{E_t^Q\left[RV_{t,T}^i\right] E_t^Q\left[RV_{t,T}^j\right]}} = \frac{SV_{t,T}^I - \sum_{i=1}^n w_i^2 SV_{t,T}^i}{\sum_{i\neq j} w_i w_j \sqrt{SV_{t,T}^i SV_{t,T}^j}}\ , \quad (2)$$

where $SV_{t,T}^I$ and $SV_{t,T}^i$ are the index and single stock variance swap rates over the period *(t,T)*, respectively. $SV_{t,T}^I$ and $SV_{t,T}^i$ correspond to the risk-neutral expectation for variance of the index and of each index constituent respectively, and w_i is the value-weight of stock i in the index. Since correlation and variance swap quotes are not available for all the European equity indexes (and their constituents) that we study in this paper, we compute synthetic correlation and variance swap rates. We synthesize $SV_{t,T}^I$ and $SV_{t,T}^i$ from listed vanilla options prices and use interpolated implied volatility surfaces for 30-day and 91-day maturities and a range of option deltas (from OptionMetrics). [8]

To estimate the index and single stock variance swap rates, $SV_{t,T}^I$ and $SV_{t,T}^i$ in (2), we follow the methodology of Bakshi, Kapadia and Madan (2003). As long as prices are continuous and volatility is stochastic, this model-free implied variance approach delivers an accurate estimate of the risk-neutral integrated variance up until the option's maturity. Implied variance can be calculated from market prices of out-of-the-money (OTM) European calls and

[8] See for example, Britten-Jones and Neuberger (2000), Bakshi, Kapadia and Madan (2003) and Carr and Wu (2009).

puts as follows:

$$SV_{\mathrm{t,T}} = \int_{S_t}^{\infty} \left[\frac{2\left(1 - ln\left(\frac{K}{S_t}\right)\right)}{K^2} \right] C(t, T-t; K) dK \ + \int_{0}^{S_t} \left[\frac{2\left(1 + ln\left(\frac{S_t}{K}\right)\right)}{K^2} \right] P(t, T-t; K) dK, \qquad (3)$$

where $C(t, T-t; K)$ and $P(t, T-t; K)$ are the market prices of European calls and European puts at time *t*, with time to maturity of (*T*-*t*), and with strike price *K*. To obtain option prices we use volatility surfaces data from OptionMetrics. This is described in detail in Section III.

Now let us discuss how the physical expectation of average pairwise correlation $\mathrm{E_t^P}\left(\mathrm{RC_{t,T}}\right)$ can be obtained and estimated. By taking expectations under measure *P* rather than *Q* in Equation (2), we obtain the actual expected average pairwise correlation at time *t* for the time period *(t, T)*:

$$\mathrm{E_t^P}\left(\mathrm{RC_{t,T}}\right) = \frac{E_t^P\left[RV_{t,T}^I\right] - \sum_{i=1}^{n} w_i^2 E_t^P\left[RV_{t,T}^i\right]}{\sum_{i \neq j} w_i w_j \sqrt{E_t^P\left[RV_{t,T}^i\right] E_t^P\left[RV_{t,T}^j\right]}} \ , \qquad (4)$$

Following DMV (2013), we estimate $\mathrm{E}_\mathrm{t}^{P}\left(\mathrm{RC_{t,T}}\right)$ in Equation (4) from the average value-weighted pairwise realized correlation of the equity index constituents during the time period *(t, T)*, $\mathrm{RC_{t,T}}$. The reasoning behind this procedure is that (i) the difference between the realized correlations calculated from Equation (4) and from the standard definition, tend to be very small and economically insignificant (DMV, 2013) and (ii) our empirical analysis is based on the effective realization of the correlation risk premium.[9] An alternative way of estimating $\mathrm{E}_\mathrm{t}^{P}\left(\mathrm{RC_{t,T}}\right)$ in Equation (4) consists of using the average value-weighted pairwise realized correlation of the equity index constituents, during the previous *T* days *(t-T, t)*. This would lead

[9] Time-series regression analysis requires realized returns to measure co-movement and carry out a risk and performance attribution analysis. Asset pricing model tests, in principle, call for a cross-sectional regressions analysis using expectations, but expectations that are often approximated by means of realized returns in empirical tests.

to an ex-ante measure of the correlation risk premium in (1).[10]

In our setting, the correlation risk premium in Equation (1), therefore, effectively corresponds to the realization of the correlation risk premium, representing the cost incurred by an investor aiming to hedge the exposure to negative correlation shocks,

$$CR_t \equiv IC_t - RC_{t,T} \ , \qquad (5)$$

with IC_t being the synthetic correlation swap rate from Equation (2). The variance risk premium is defined and implemented in an analogous manner.

B. Currency adjusted correlation risk premium

One of our contributions is to examine the co-movement between correlation risk premiums in different countries. The correlation risk premium is based on a correlation swap pay-off expressed in local currency. An international comparison in the same currency therefore requires a currency adjustment.

The spot exchange rate at date *t*, the start date of the correlation swap, is represented by S_t, the dollar exchange rate per unit of foreign currency. So, the percentage change of the spot exchange rate for the time period *(t, T)* is $\mathrm{s} = (S_T - S_{t)}/S_t$. We assume here the perspective of a US investor who is perfectly hedged against the currency risk. The local currency denominated correlation swap pay-off is converted into US dollars, using the spot exchange rate. Thus, similarly to Andersen, Todorov and Ubukata (2018), we define the currency adjusted correlation risk premium as: [11]

$$CR_{currency\ adjusted} = CR + s \qquad (6)$$

The variance risk premium is adjusted in a similar way.

III. Data

We use daily data from the OptionMetrics Ivy DB database for options on the CAC40 index (France), the DAX index (Germany), the EuroStoxx 50 index, the FTSE100 index (UK),

[10] In unreported results we find that our conclusions are robust to the use of an ex-ante measure of realized correlation.
[11] Similarly to the treatment used in international asset pricing literature, the cross product of exchange rate movements and correlation risk premiums can be neglected. It is assumed to be very small for short time periods.

the SMI index (Switzerland) and the S&P 500 index (US) and options on their constituents from January 2002 until December 2012[12]. All indexes are value-weighted. Changes in index composition occur on quarterly rebalancing dates. We calculate the daily weight for each stock based on its closing price and the number of shares outstanding.

As is clear from Table 1, each index had many changes in its composition during the sample period. All indexes exhibit a high option coverage; that is, there are tradable options on most of their constituents. The exception is the FTSE 100 index, which has a relatively low option coverage.

[Insert Table 1 here]

To estimate synthetic correlation swap rates in accordance with Equation (2), we make use of the OptionMetrics Volatility surface file to obtain standardized volatilities for maturities of 30 and 91 days. The volatility surface file contains a smoothed implied-volatility surface for a range of maturities and option delta points. We only use out-of-the-money (OTM) calls with deltas below 0.5 and puts with deltas above -0.5. However, from Equation (3), it is necessary to have a continuum of option prices to obtain synthetic variance swap rates to compute the implied correlation in Equation (2). The methodology we use to address this issue is the one used by DMV (2013) and also Faria and Kosowski (2016).

After computing the daily series of model-free implied variances for index and individual options and the index weights, the model-free implied correlation IC for day t with maturity T, can be obtained based on Equation (2). On days when there are missing implied variances, particularly for the index constituents, weights of the available stocks are normalized so that they sum up to one.

We obtain daily stock prices and index levels, indexes' market capitalization and the interest rate term structure from Compustat and Datastream. The risk-free rate is approximated by the zero-curve rate of appropriate maturity from OptionMetrics and interpolated when

[12] For the CAC40 index, the sample period starts in May 2003. For the computation of the correlation risk premium for the SMI index, we only use data after January 2006, due to the low level of option coverage of its underlying stocks before that date.

necessary. To obtain the realized variance time series, the procedure is as follows. For day *t*, daily returns for the index and the stocks from day *t+1* until the end of the maturity window are considered and the corresponding realized variance is computed.

To test whether correlation risk is priced, an index level analysis is required. We select index options with a time to maturity of 30 calendar days. We eliminate options in extreme moneyness conditions (Black-Scholes delta below 0.15 and above 0.8 for calls and above -0.15 and below -0.8 for puts) as outliers, which filters out options with abnormal price, return and extreme implied volatilities. The index options are further divided by their call/put types and moneyness into six different groups for each index, with absolute moneyness level between 0.15 and 0.4, 0.4 and 0.6 and 0.6 and 0.8.

The policy related economic uncertainty indexes are constructed by Baker, Bloom and Davis (2016)[13] for France, Germany, the UK, the US and Europe. The authors construct the US uncertainty index from three types of underlying components. One component quantifies newspaper coverage of policy related economic uncertainty. A second component reflects the number of federal tax code provisions set to expire in future years. The third component uses disagreement among economic forecasters with respect to a group of variables, as a proxy for uncertainty.[14] Since April 2014, the authors use only newspaper articles as components for the construction of the European indexes and do not use consensus economics forecaster dispersion data anymore[15].[16]

IV. Empirical Results

Our empirical analysis consists of four main steps. We start by comparing the summary statistics and dynamics of the correlation risk premium with the index and individual variance risk premiums for the French, German, Swiss, UK, European, and US equity markets. All of these markets have liquid option markets, as we show in unreported results (available upon

[13] For further details please see http://www.policyuncertainty.com/index.html. The uncertainty index data is available for downloading in this website.
[14] More details are provided in section IV.e.
[15] Our results are quantitatively and qualitatively similar if we only use the component that quantifies newspaper coverage of policy related economic uncertainty in the US and Europe.
[16] According to the authors, “this has a limited impact upon our overall country level series, with the old and the new indexes having a high correlation”.

request). In the second step, we analyse the co-movement of the correlation risk premiums in Europe and the US. Next, we study whether a global correlation risk premium is priced in the cross-section of European and US equity index option returns. In the final step, we analyse the dependence of the correlation risk premium dynamics.

A. Summary statistics of the index and individual variance risk premiums

Since the correlation risk premium is constructed from index and individual variances, we first report summary statistics for index and individual variances for European and US markets during our sample period. Most papers in the literature study the index variance premium as opposed to the individual variance risk premium and conclude that the index variance risk premium is statistically significant.[17] Our findings below confirm these results for the index variance risk premium.

We complement the existing literature on the individual variance risk premium[18] by documenting the results for the individual stock variance risk premium in the European equity markets under analysis. Analogous to the correlation risk premium in Equation (5) we calculate the variance risk premium as follows:

$$VR_t \equiv IV_t - RV_{t,T}. \qquad (7)$$

As documented in Table 2, we find evidence of a positive variance risk premium for all European equity markets and the US. Panel A shows that similar conclusions can be drawn about the economic significance for the index variance risk premium whether we use 30-day or 91-day option maturities, but the statistical significance is somewhat lower for the latter. Using a 30-day maturity, the annualized index variance risk premium ranges from 0.60 to 0.90 for various European markets and is statistically significant for the DAX, FTSE100 and Eurostoxx 50 indexes. These results are comparable to those reported for European markets by Bollerslev, Marrone, Xu and Zhou (2014).

[17] See, for example, Bakshi and Kapadia (2003), and Bollerslev, Tauchen and Zhou (2009), for the US; and Bollerslev, Marrone, Xu and Zhou (2014) for European and Japanese equity markets.
[18] See, for example, Carr and Wu (2009) and DMV (2013).

The annualized variance risk premium for the S&P500 in our 2002 to 2012 sample, is 0.61 (with a *t*-statistic of 1.4). Our findings can be reconciled with the S&P500 index variance risk premium of 1.05 (with a *p*-value below 0.01) for the period January 1996 to 2012, reported in DMV (2013). Differences in the economic and statistical significance are due to different sub-samples, as can be seen from the index variance risk premium of 0.43 reported by DMV (2013) for the 2008 to 2012 sub-sample.

If we take the perspective of a US-based investor comparing variance risk premiums across international markets, or who could hypothetically access them through variance swaps, we need to convert the variance risk premium into US dollars. The currency-adjusted index variance risk premiums, reported in Panel B of Table 2, are qualitatively similar to the local currency versions, with the average levels all being higher after the currency adjustment. This is due to the depreciation of the US dollar with respect to the Euro, GBP and the Swiss Franc in the period between 2002 and 2012.

[Insert Table 2 here]

For the individual variance risk premiums and 30-day maturities, we find generally stronger evidence of economic and statistical significance than for the index variance risk premiums. The lowest average individual variance risk premium in Panel C is 0.9% (for the DAX index) and the highest is 4.54% (for the FTSE 100 index).

The conclusions change dramatically when we examine individual variance risk premiums based on 91-day maturity options. For this longer maturity, the estimate of the average variance risk premium for individual stocks decreases for all indexes compared to the results based on 30-day maturity. This finding is not sensitive to currency adjustments, as Panel D shows.

The average individual variance risk premium, however, obscures more complex patterns, which become apparent when evaluating the number of constituents with statistically significant negative or positive variance risk premiums. Table 3 shows that although the majority of individual variance risk premiums are positive, there are some for which we cannot reject the null hypothesis of being negative. This finding is consistent with Han and Zhou

(2011), who find that two-thirds of the individual stocks in their sample have significantly positive variance risk premiums. Moreover, they report that the variance risk premium is significantly higher for stocks with certain characteristics, such as small stocks, value stocks, past loser stocks and stocks with high volatility and analyst disagreement.

[Insert Table 3 here]

B. Summary statistics of the correlation risk premium

Figure 1 plots the time-series of the one-month moving average of the implied correlation (IC) and the realized correlation (RC), for the CAC40, DAX, EuroStoxx 50, FTSE100, SMI and S&P 500 indexes for 91-day maturity. For the CAC40 index, the sample period starts in May 2003. For the computation of the correlation risk premium for the SMI index, we only use data after January 2006, due to the low level of option coverage of its underlying stocks before that date.

[Insert Figure 1 here]

The first insight from Figure 1 is that the one-month moving average of both the IC and RC fluctuates significantly during the sample period. Moreover, Figure 1 shows that, for all studied indexes, the implied measure of correlation indeed closely follows the dynamics of the RCs and that for most of the sample period, the level of IC is higher than RC. This suggests the existence of an average positive correlation risk premium. Correlation can be traded through option and swap markets. Some of the fluctuations of the implied versus the realized correlation may be due to the amount of arbitrage capital available at different times, as documented in other markets (see, for example, Jylha and Suominen (2011) and Baltas and Kosowski (2013)). That analysis is outside the scope of this paper, but suggests an interesting avenue for future research.

Table 4 confirms the inference from Figure 1 and shows that the correlation risk premium is economically and statistically significant for all indexes using 91-day maturities. The same conclusion obtains for 30-day maturities, with the exception of the FTSE 100 index.

The different indexes exhibit a correlation risk premium that is of a similar order of magnitude, with the exception of the SMI index. For the S&P500 index, for example, the correlation risk premium is 0.086, for the Eurostoxx 50 index it is 0.067 and for the FTSE100 it is 0.089 for 91-day maturity. These results are consistent with those reported in DMV (2013); that study, using US data, finds a correlation risk premium of 0.0765, 0.0748 and 0.1615 for the S&P 500 for the samples 2008 to 2012, 2002 to 2007 and 1996 to 2001, respectively, using 91-day maturity. They also find a lower average correlation risk premium of 0.0448, using 30-day maturities for the 2008 to 2012 sample, which is similar to our results.

Our conclusions remain qualitatively the same when we incorporate a currency adjustment in Panel B, which has very little impact on the quantitative results.

[Insert Table 4 here]

In summary, using US and European data we find that the average implied correlations are economically and statistically higher than the realized correlations, which lends support to a positive correlation risk premium.

C. Co-movement of the correlation risk premiums and Principal Component Analysis

One of the key questions that we study is whether correlation risk is priced internationally. If correlation risk premiums co-move across different countries, this would make it more likely that they will reflect a common global risk that cannot be diversified across countries and that therefore should carry a risk premium cross-sectionally. In a preliminary step, Figure 2 shows that RCs co-move across different European markets and the US. The SMI index is somewhat of an exception, as its range is lower. For all indexes, RC peaks during crisis times, such as the 2008 financial crisis and the 2011 European sovereign credit crisis.

[Insert Figure 2 here]

The co-movement in RCs extends to correlation risk premiums (CR) as Figures 3 and

4 show for the local currency and US dollar versions of the CR.

[Insert Figure 3 here]

[Insert Figure 4 here]

The insights gained from a visual inspection of Figures 2 to 4 are confirmed by the pair-wise correlation coefficients reported for different 91-day maturity RCs and CRs in Table 5. According to Panel A, for RCs, the lowest pairwise correlation is 0.54 (for the SMI/SX5E and FTSE100/S&P500 pairs) and the highest is 0.96 (for the FTSE100/CAC40 and SMI/CAC40 pairs). The correlations remain high for CRs in Panel B of Table 5. The lowest pairwise correlation is 0.46, for the S&P 500 /SMI index pair, and the highest is 0.73 for the DAX/FTSE100 and DAX/SMI pairs. The results based on currency adjusted CRs in Panel Care quantitatively similar to the local currency ones presented in Panel B.

[Insert Table 5 here]

The evidence presented in the above figures and Table 5 suggests the existence of a potential premium structure across correlation risk premiums in different countries. To analyse this hypothesis more formally, we perform a Principal Component Analysis (PCA) of the RCs and CRs. Results are presented in Figure 5.[19] The first principal component explains 80.6% of the total variance and the first two components explain more than 90% of the total variance of the RC. For the CR, the first principal component explains 66.0% of the total variance and the first two components explain around 80%. This result is consistent with the evidence on "global" variance risk premium in Bollerslev, Marrone, Xu and Zhou (2014).

[Insert Figure 5 here]

Overall, the results in this subsection support the hypothesis of strong co-movement among CRs across European and US equity markets. The corollary is that a global correlation

[19] We exclude the SMI from the PCA analysis due to its short sample. This does not change our conclusions.

risk premium may exist. Such a premium may affect the dynamics of international equity markets. Also, the underlying co-movement could constrain diversification opportunities during periods of enhanced turbulence in global equity markets, when "*there is no place to hide*" (Buraschi, Kosowski and Trojani, 2014).

D. The cross-section of index option returns: the price of correlation risk

In this section, we examine whether the global correlation risk premium mentioned in the previous subsection can capture the cross-sectional variation in index option returns. A basket of index options is an ideal testing ground for this hypothesis, since, by construction, returns on index options are directly affected by both the index variance and correlation shocks. DMV (2009) show that S&P100 index option returns have significant loadings on a correlation risk premium based on payoffs from option-based dispersion trade strategies. The authors conclude from this that correlation risk is priced in option returns. Buraschi, Kosowski and Trojani (2014) use a correlation swap-based correlation risk premium and show that correlation risk is priced in the cross-section of hedge fund returns.

We use a standard Fama-MacBeth procedure to test whether correlation risk is priced internationally and whether a global correlation risk premium exists. Our cross-section contains 36 short maturity options and is constructed as follows. We divide calls and puts into three different moneyness levels, with deltas ranging from -0.8 to -0.15 for puts and from 0.15 to 0.8 for calls. We use non-overlapping monthly hold-to-maturity returns; that is, the return at time T on an option purchased at time t is given by the option payoff at maturity (T), divided by the option price at t. Note that because this option return analysis is run on a holding period basis, there is no inconsistency in using the ex-post correlation risk premium CR as defined in (5). The implied correlation IC is known at the beginning of the holding period and the (ex-post) RC is computed at the end of the holding period.

Analogous to the definition of a global variance risk premium by Bollerslev, Marrone, Xu and Zhou (2014), we construct the global correlation risk premium ($\mathrm{CR}^{\mathrm{Global}}$) based on the market capitalization weighted average of the proxies for the correlation risk premium in each country,

$$CR_t^{Global} \equiv \sum_i w_t^i \, CR_t^i, \qquad (8)$$

where $i = 1,2 \dots .6$ refers to each of the six indexes included in our analysis. A similar approach is used to compute a global variance risk premium (VR_t^{Global}). The country market capitalizations used for the calculation of weights w_t^i are obtained from Datastream and are US dollar denominated. One concern that may arise from an inspection of the global correlation risk premium composition, is that there is a risk of double counting of some European stocks that appear in the Eurostoxx 50 index and also in their respective national equity market index. In robustness tests, we find that our conclusions remain unchanged if the Eurostoxx 50 index is excluded from the definition of the global correlation risk premium.

In the first step, we obtain the loadings of all options for the global correlation risk premium. In a second step, we regress average returns cross-sectionally on these loadings and obtain the risk premiums. The standard errors for the cross-sectional regression are calculated with the methodology of Shanken (1992), to correct for the estimation error in the first step betas.

For practitioners it is important to know whether correlation risk is priced, since it would imply that assets with higher correlation risk exposure would have higher average returns. Table 6 presents the results for the cross-sectional regression of average index option returns on their premium loadings. We first exclude US index options from the set of dependent variables (Panel A) and then we repeat the analysis with US index options (Panel B). Our estimates for model 1, which has only one independent variable, namely the global correlation risk premium CR^{Global} given by equation (8), show that the option return betas or loadings in the first step are all significant. The implied correlation risk premium in the second step we estimate to be 3.8% per month (*t*-statistics of 2.39). This result is consistent with the implied correlation risk premium of around 4.3% per month (*t*-statistic of 4.06) reported by Buraschi, Kosowski and Trojani (2014) for hedge fund returns and correlation swaps during the 1996 to 2012 period. DMV (2009) report a higher implied correlation risk premium of 17.5% per month. The difference may be due to their sample, which is from 1996 to 2004, or to the fact that the authors include a market risk premium.

The high level of adjusted R^2 (73.60%) is similar to that reported in DMV (2009); their document adjusted R^2 between 70% and 80% for US index options, depending on the model specification. Our results suggest that a global correlation risk premium can explain most of the cross-sectional variation of the index option returns. Our conclusion regarding the statistical significance of the correlation risk premium does not change if we add the global average individual variance risk premium (Model 2), constructed following the same procedure as in Equation (8). The global individual variance risk premium is found to be insignificant cross-sectionally.

[Insert Table 6 here]

An alternative, which we consider as a robustness test, is Model 3 in which we add the residuals from regression (9) below. These residuals are drawn from a regression of the global index variance risk premium on the global correlation risk premium. The rationale behind Model 3 is to control the effect of the global correlation risk premium embedded in the global index variance premium.

$$\mathrm{VR}_{\mathrm{t}}^{\mathrm{Global}} = \beta_0 + \beta_1 \mathrm{CR}_{\mathrm{t}}^{\mathrm{Global}} + \varepsilon_t. \tag{9}$$

We find that the results are economically and statistically robust and the coefficient estimates from Models 2 and 3 are very similar. This robustness is unchanged when US index option returns are considered alongside the European option returns, as Panel B shows. To avoid issues associated with multi-collinearity, we do not include the market excess return in the above models in Table 6, since the market excess return has a high correlation with the variance risk premium and the correlation risk premium. However, in unreported robustness tests we find that including the market excess return makes our results even stronger, as the correlation risk premium becomes more significant. Therefore, our reported results can be viewed as conservative.

Overall, we obtain strong evidence supporting the fact that exposure to the global correlation risk premium accounts for a sizable part of the cross-sectional variation in the average index option returns in the European and US markets, which cannot be explained by exposure to equity market risk. We therefore find robust empirical support for the existence of a global correlation risk premium priced in international equity index option markets.

E. The dependence of the correlation risk premium

Motivated by the work of Drechsler and Yaron (2011) and Buraschi, Trojani and Vedolin (2014), who theoretically link the variance and correlation risk premiums to uncertainty, we next examine the dependence of the correlation risk premium in different countries on measures of uncertainty and macroeconomic conditions.

We regress the correlation risk premium on the following variables: (i) the underlying index returns, as a proxy for general market conditions; (ii) the policy related economic uncertainty index (EPU index) by Baker, Bloom and Davis (2016), which is available for each country; (iii) the VIX-type index for each market,[20] as a measure of the implied volatility in option markets; (iv) a measure of the interest rate term structure, as captured by the difference between the yields on 10-year and 2-year Treasury securities; and (v) the TED spread for each market, measured by the interest rates on interbank loans and short-term government debt.

Our VIX-type index is a risk-neutral expectation of future volatility; it is often interpreted as a proxy of investor's risk aversion, or a measure of economic uncertainty. The VIX-type index is based on the quotes of index option prices. Baker, Bloom and Davis (2016) report a high level of correlation between the VIX-type index with respect to the S&P500 index and the US policy related economic uncertainty index[21].

Table 7 reports the results of the regression analysis. The policy uncertainty economic index (EPU index) has significant effects on *broader* indexes, such as the S&P 500 and EuroStoxx 50 indexes, while the estimated coefficients for the EPU index are insignificant for regressions involving the other three narrower country indexes.

[Insert Table 7 here]

[20] We construct the model-free 30-day risk-neutral implied variance using a method similar to the one applied by the CBOE for the computation of the VIX index.
[21] We exclude the SMI index from this analysis, because there is no policy related economic uncertainty data for Switzerland and also due to the short sample of the correlation risk premium based on the SMI option data.

Our results are consistent with those of Kelly, Pastor and Veronesi (2016), who find that options provide valuable protection against the risks associated with major political events, including elections and summits. It is therefore not surprising that the correlation risk premium is statistically significantly when related to the EPU index, which is a general measure of economic policy uncertainty based on daily newspaper coverage.

The results in Table 7 also show that the lagged correlation risk premium has a significant positive effect on the current level of the correlation risk premium. This is consistent with evidence of persistence of the correlation risk premium, documented in Buraschi, Kosowski and Trojani (2014). These findings are also in line with the results documented by Buraschi, Trojani and Vedolin (2014), who regressed the correlation risk premium on a firm level earnings forecast uncertainty for the US equity market. Our results confirm the importance of investor disagreement about the likely future economic performance as a determinant of correlation risk premium. The market return, interest rate term structure and TED spread, all have insignificant effects.

V. Robustness test

We explore the robustness of our findings by considering different subsample periods, with results reported in this section and an ex-ante measure of the realized correlation, with results not reported for reasons of space.

To study the dynamics of the correlation risk premium during normal and crisis conditions, we repeat the analysis for the correlation risk premium in two different sample periods[22], namely 2002 to 2007 and 2008 to 2012.

[Insert Table 8 here]

As can be seen in Panel A of Table 8, almost all average implied correlations (ICs) and realized correlations (RCs) are larger during the 2008 to 2012 period than during

[22] For the CAC40 index, the first period is from May 2003 to December 2007. We do not include the SMI index in this section, since SMI data is available only from 2006.

2002 to 2007, reflecting the effects of the global financial crisis (GFC). In the first subsample, the differences between IC and RC among the indexes and maturities diverge significantly. The difference (IC-RC) for the EuroStoxx 50 index is negative for the 30-day maturity and is statistically insignificant for the 91- day maturity, while the DAX index has a positive and significant difference. The average levels for the correlation risk premium were 6.3% (*t*-statistics of 4.62) and 10.5% (*t*-statistics of 5.39) respectively. The CAC40 and FTSE100 indexes only have statistically significant correlation risk premiums for the 91- day maturity group.

In the second subsample period the results change significantly, with all correlation risk premiums being statistically and economically significant. The average correlation risk premium for the EuroStoxx 50 index during the 2008 to 2012 period, has higher economic value and statistical significance. This reflects an increased correlation risk in the Pan-European area during this period of time, which was characterized by the severe sovereign debt crisis between 2010 and 2012.

Similarly, the correlation risk premium is higher for the S&P500 index during the 2008 to 2012 period than for the 2002 to 2007 period. For European country-level indexes, the results are mixed. The average correlation risk premium of the CAC40 index in the second sample is almost unchanged compared to the first period for both maturities, although the statistical significance increases. For the DAX and FTSE 100 indexes the level of the correlation risk premium decreases significantly for the 30-day maturity, while for the 91-day maturity it remains relatively unchanged.

We also find that our results are robust to the use of an ex-ante measure of the realized correlation (unreported results).

VI. Conclusion

This paper contributes to the literature on the equity market correlation risk premium, by carrying out the first cross-country analysis of the correlation risk premium. We examine the statistical properties of the implied and realized correlation in European equity markets and relate the resulting premium to the US equity market correlation risk and a global correlation risk premium.

Our first contribution is to show that the correlation risk premium in European equity markets, as well as in the US, is economically and statistically significant. The second contribution of this paper is the analysis of the co-movement of the correlation risk premium in the US and different European equity markets. We find that the co-movement of realized correlations, implied correlations and the correlation risk premiums across different European equity markets and between European and US equity markets is very high. The high level of co-movement and the significance of the first component suggest the existence of a global correlation risk premium. Our third contribution is to show that exposure to a global correlation risk premium, computed as a market value weighted local correlation risk premium, accounts for 75% of the cross-sectional variation in the European and US equity index option returns.

According to our results, exposure to the global correlation risk premium is cross-sectionally priced in international equity options markets. Consistent with existing evidence for the US market, we find that exposure to the average individual variance risk premium and to the *residual* index variance risk premium is not priced. The latter is measured by the residuals of the regression of the index variance risk premium on the correlation risk benchmark.

The fourth contribution of this paper is to document the drivers of the correlation risk premium. For *broad* indexes (the S&P 500 index for the US and the EuroStoxx 50 index for the Pan-European equity markets, respectively), the policy related economic uncertainty variable has a significant effect, while the VIX-type indexes have insignificant effects after controlling for the policy uncertainty .

Interesting avenues for future research include studying, within an open-economy representative investor framework, how a global correlation risk premium consistent with the results documented in this paper could be endogenously generated. Additionally, it is relevant to assess the concrete performance and hedging implications from the existence of the global correlation risk premium in the context of a globally diversified equity investor.

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Table 1: Index composition

This table reports information about the composition of the six indices under analysis (CAC, DAX, FTSE100, EuroStoxx 50 (SX5E), S&P500 and SMI). For each index, we report the number of stocks that appears in the index history, the number of constituent additions and deletions and the number of stocks that have options coverage. The sample periods for the DAX, FTSE 100, SX5E and S&P500 indices are from January 2002 until December 2012, for the CAC40 index is from May 2003 until December 2012 and the SMI index is from January 2006 to December 2012, respectively.

	CAC40	DAX	FTSE100	SMI	SX5E	S&P500
Number of constituents	40	30	101	20	50	500
Number of add/del (in pair)	24	18	155	16	26	255
Number of total constituents	61	45	205	36	76	738
Number of constituents option coverage	57	45	117	34	70	734

Table 2: Variance risk premium

This table reports the variance risk premium for the six indices under analysis (CAC40, DAX, FTSE100, EuroStoxx 50 (SX5E), SMI, S&P500) as well as the weighted average of the variance risk premiums of the index constituents. Panel A reports the variance risk premium for each index in local currency terms. Panel B reports the variance risk premium in US dollars after a currency adjustment. Panel C and D report the equal-weighted individual variance risk premium in local currency and in US dollars (after currency adjustment) terms, respectively. The mean and standard deviation are in percentage form and expressed in annual terms. *, **, *** denotes significance at the 10%, 5%, and 1% level, respectively. The t-statistics are based on Newey and West (1987) standard errors with lags equal to the measurement horizon minus 1.

Panel A: Index variance risk premium

30 Days							91 Days						
	CAC40	DAX	FTSE100	SMI	SX5E	S&P500		CAC40	DAX	FTSE100	SMI	SX5E	S&P500
mean	0.61	0.62*	0.78**	0.60	0.90**	0.61	mean	0.66	0.48	0.81	0.60	0.68**	0.68
t-stat	(1.30)	(1.66)	(2.13)	(1.57)	(2.22)	(1.40)	t-stat	(0.82)	(0.66)	(1.28)	(1.01)	(1.98)	(0.86)
st_dev	5.90	5.34	4.99	5.17	5.80	5.73	st_dev	6.18	5.98	5.29	5.09	3.52	6.32
skewness	-4.98	-4.08	-4.20	-3.84	-3.47	-5.41	skewness	-3.51	-2.80	-2.85	-2.05	-1.89	-4.45
kurtosis	40.25	34.76	40.29	40.70	28.57	47.10	kurtosis	20.82	14.33	18.97	14.55	15.95	29.68

Panel B: Index variance risk premium–currency adjusted

30 Days							91 Days						
mean	0.76	0.95*	0.89*	1.15**	1.23**	0.61	mean	1.10	1.52	1.18	2.12**	1.76	0.68
t-stat	(1.25)	(1.93)	(1.93)	(2.43)	(2.33)	(1.40)	t-stat	(0.84)	(1.36)	(1.04)	(2.21)	(1.49)	(0.86)
st_dev	7.52	6.81	6.15	6.38	7.32	5.73	st_dev	9.60	8.93	8.72	7.89	9.41	6.32
skewness	-3.97	-3.25	-4.03	-2.42	-3.01	-5.41	skewness	-2.33	-1.94	-2.73	-1.28	-1.81	-4.45
kurtosis	30.04	27.42	35.09	27.24	23.49	47.10	kurtosis	11.85	9.68	16.77	7.63	9.40	29.68

Panel C: Individual variance risk premium

30 Days							91 Days						
mean	1.66**	0.90	4.54***	1.79***	3.72***	1.71*	mean	0.94	0.14	1.65	0.32	1.31	1.00
t-stat	(2.34)	(1.47)	(4.96)	(2.73)	(4.77)	(1.86)	t-stat	(0.74)	(0.11)	(1.22)	(0.28)	(1.02)	(0.57)
st_dev	9.02	8.49	12.99	9.26	10.50	9.26	st_dev	9.72	10.09	10.39	9.15	10.48	13.63
skewness	-4.72	-4.22	-0.49	-3.44	-2.65	-5.10	skewness	-3.38	-3.53	-2.81	-2.70	-3.01	-4.58
kurtosis	40.22	39.70	14.46	22.51	23.82	40.45	kurtosis	19.66	22.63	17.79	12.62	16.88	30.54

Panel D: Individual variance risk premium–currency adjusted

30 Days							91 Days						
mean	1.79**	1.22*	4.68***	2.28***	4.03***	1.71*	mean	1.38	1.18	2.03	1.85	2.35	1.00
t-stat	(2.14)	(1.68)	(4.58)	(3.11)	(4.56)	(1.86)	t-stat	(0.79)	(0.75)	(1.08)	(1.31)	(1.42)	(0.57)
st_dev	10.43	9.84	14.01	10.21	11.77	11.81	std	12.76	12.63	13.86	11.31	13.10	13.63
skewness	-4.31	-3.81	-0.87	-2.73	-2.68	-5.10	skewness	-2.73	-3.04	-2.72	-2.02	-2.59	-4.58
kurtosis	35.61	34.88	14.84	18.11	23.50	40.45	kurtosis	14.29	17.95	16.43	9.67	14.09	30.54

Table 3: Statistical significance of individual variance risk premium

The table reports results for the test of whether the individual variance risk premium for the constituents of the six indices under analysis (CAC40, DAX, FTSE100, EuroStoxx 50 (SX5E), SMI, S&P500) is statistically significantly different from zero. We report the number of constituents for which the variance risk premium is statistically significantly different from zero. The tests are based on Newey and West (1987) adjusted t-statistics with lags equal to the measurement horizon minus 1.

		CAC40	DAX	FTSE100	SMI	SX5E	S&P500
	$IV - RV > 0$ rejected	15	20	56	21	23	228
30 Days	$IV - RV = 0$ not rejected	14	18	26	10	17	138
	$IV - RV < 0$ rejected	55	9	83	22	61	628
	$IV - RV > 0$ rejected	21	17	67	24	36	270
91 Days	$IV - RV = 0$ not rejected	14	36	24	6	18	114
	$IV - RV < 0$ rejected	49	20	69	14	49	532
Total		57	45	117	34	70	734

Table 4: Correlation risk premium

This table reports the summary statistics for the implied correlation (IC), realized correlation (RC), and the correlation risk premium (IC-RC), for the six indices under analysis (CAC40, DAX, FTSE100, EuroStoxx 50 (SX5E), SMI, S&P500). The rows report the mean, t-statistics, median, 10th and 90th percentiles, and standard deviation. IC is calculated from daily observations of model-free implied variances for the index and for all index constituents. RC is a cross-sectional weighted average (using the appropriate weights from the respective index) of all pairwise correlations at time t, each with the 30 and 91 days window of daily stock returns. Panel B presents summary statistics for the currency adjusted correlation risk premium. *, **, *** denotes significance at the 10%, 5%, and 1% level, respectively. The t-statistics are based on Newey and West (1987) standard errors with lags equal to the measurement horizon minus 1.

Panel A: Correlation risk premium

30 Days

	CAC40			DAX			FTSE100			SMI			SX5E			S&P500		
	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC
mean	0.478	0.443	0.035***	0.501	0.456	0.045***	0.336	0.349	-0.013	0.417	0.228	0.189***	0.511	0.490	0.021*	0.429	0.375	0.054***
t-stat			(2.82)			(4.66)			(-1.35)			(12.50)			(1.76)			(6.46)
median	0.486	0.436	0.043	0.491	0.466	0.047	0.322	0.329	-0.018	0.425	0.230	0.204	0.528	0.494	0.031	0.412	0.356	0.053
10th_quan	0.296	0.259	-0.146	0.366	0.275	-0.133	0.144	0.187	-0.184	0.232	0.104	-0.032	0.269	0.316	-0.195	0.257	0.212	-0.076
90th_quan	0.662	0.630	0.215	0.667	0.634	0.208	0.533	0.544	0.165	0.605	0.360	0.372	0.718	0.652	0.222	0.619	0.562	0.197
st_dev	0.158	0.140	0.165	0.117	0.132	0.139	0.156	0.139	0.138	0.172	0.097	0.163	0.170	0.128	0.163	0.138	0.139	0.116

91 Days

	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC
mean	0.513	0.449	0.064***	0.564	0.461	0.103***	0.445	0.356	0.089***	0.478	0.238	0.240***	0.563	0.495	0.067***	0.459	0.373	0.086***
t-stat			(4.21)			(7.11)			(6.13)			(11.31)			(4.23)			(5.58)
median	0.520	0.442	0.076	0.565	0.466	0.108	0.440	0.346	0.103	0.486	0.222	0.252	0.577	0.496	0.068	0.458	0.353	0.103
10th_quan	0.359	0.302	-0.111	0.447	0.315	-0.060	0.282	0.209	-0.093	0.336	0.158	0.063	0.367	0.353	-0.102	0.310	0.239	-0.081
90th_quan	0.662	0.588	0.209	0.683	0.605	0.254	0.621	0.534	0.241	0.619	0.344	0.393	0.743	0.629	0.235	0.610	0.554	0.215
st_dev	0.122	0.113	0.123	0.091	0.106	0.123	0.127	0.119	0.131	0.129	0.072	0.140	0.143	0.102	0.131	0.115	0.121	0.121

Panel B: Correlation risk premium–currency adjusted

30 days	CAC40	DAX	FTSE100	SMI	SX5E	S&P500	91 days	CAC40	DAX	FTSE100	SMI	SX5E	S&P500
	IC-RC	IC-RC	IC-RC	IC-RC	IC-RC	IC-RC		IC-RC	IC-RC	IC-RC	IC-RC	IC-RC	IC-RC
mean	0.036***	0.049***	-0.011	0.195 ***	0.025**	0.054***	mean	0.069***	0.114***	0.093***	0.254***	0.078***	0.086***
t-stat	(2.78)	(4.66)	(-1.10)	(12.44)	(1.99)	(6.46)	t-stat	(3.36)	(6.35)	(5.28)	(10.57)	(4.17)	(5.58)
median	0.043	0.049	-0.018	0.208	0.032	0.053	median	0.084	0.119	0.107	0.271	0.075	0.103
10th quantile	-0.156	-0.136	-0.192	-0.029	-0.195	-0.076	10th quantile	-0.118	-0.078	-0.110	0.056	-0.111	-0.081
90th quantile	0.228	0.221	0.173	0.388	0.240	0.197	90th quantile	0.248	0.288	0.280	0.431	0.274	0.215
st_dev	0.168	0.146	0.144	0.167	0.168	0.116	st_dev	0.148	0.146	0.150	0.155	0.152	0.121

Table 5: Correlation between correlation risk premiums in different countries

Panel A reports the pairwise correlations for the 91 days realized correlations of the six indices under analysis (CAC40, DAX, FTSE100, EuroStoxx 50 (SX5E), SMI, S&P500). Panel B reports the pairwise correlations of the 91 days correlation risk premium (IC-RC) for the indices. Panel C reports the pairwise correlations of the the currency adjusted 91 days correlation risk premium (IC-RC).

Panel A: Realized correlation

	CAC40	DAX	FTSE100	SMI	SX5E	S&P500
CAC40	1.00	0.84	0.96	0.96	0.85	0.77
DAX		1.00	0.82	0.82	0.68	0.63
FTSE100			1.00	0.68	0.85	0.54
SMI				1.00	0.54	0.60
SX5E					1.00	0.78
S&P500						1.00

Panel B: Correlation risk premium

	CAC40	DAX	FTSE100	SMI	SX5E	S&P500
CAC40	1.00	0.61	0.64	0.64	0.71	0.69
DAX		1.00	0.73	0.73	0.60	0.64
FTSE100			1.00	0.65	0.72	0.67
SMI				1.00	0.48	0.46
SX5E					1.00	0.60
S&P500						1.00

Panel C: Correlation risk premium–currency adjusted

	CAC40	DAX	FTSE100	SMI	SX5E	S&P500
CAC40	1.00	0.63	0.70	0.70	0.73	0.64
DAX		1.00	0.75	0.75	0.70	0.75
FTSE100			1.00	0.67	0.78	0.68
SMI				1.00	0.54	0.51
SX5E					1.00	0.55
S&P500						1.00

Table 6: The cross-section of index option returns

Panel A reports the estimates of the risk premium implied by a regression of average monthly excess returns on 30 index options (CAC40, DAX, FTSE100, EuroStoxx 50 (SX5E), SMI) on their exposures to the global correlation risk premium. The exposures are estimated in a first step, regressing the time series of each excess option return on the global correlation risk premium. Model 1 includes only the global correlation risk premium, while Model 2 adds the average individual variance risk premium. Model 3 adds the residuals of regressing global index variance risk premium on the global correlation risk premium. Panel B reports estimates for the risk price on the global correlation risk premium obtained from a cross-sectional regression of the average monthly excess returns on 36 index options (includes US options) on their exposures to the global correlation risk premium. All the option returns are denominated in US dollars. *, **, *** denotes significance at the 10%, 5%, and 1% level, respectively. The table reports t-statistics as in Shanken (1992) and the cross-sectional R^2.

Panel A: Without US index options

	Model 1	Model 2	Model 3
Global correlation risk premium	0.038**	0.023**	0.028**
	(2.39)	(2.34)	(2.45)
Individual variance risk premium		0.015	
		(1.31)	
Index variance risk premium (residual)			0.01
			(1.71)
*Adjusted_*R^2	73.60%	75.10%	76.33%

Panel B: With US index options

	Model 1	Model 2	Model 3
Global correlation risk premium	0.024**	0.017**	0.024**
	(2.34)	(2.35)	(2.15)
Individual variance risk premium		0.021	
		(0.80)	
Index variance risk premium (residual)			-0.001
			(-0.94)
*Adjusted_*R^2	73.97%	74.60%	74.22%

Table 7: The determinants of the correlation risk premium

This table reports the results of regressions of the correlation risk premium on different variables linked to macroeconomic conditions and uncertainty. The analysis includes 5 indices: CAC40, DAX, FTSE100, EuroStoxx 50 (SX5E) and S&P500. The independent variables include policy-related economic uncertainty index, VIX-type index, lagged correlation risk premium, equity index returns, interest rate term structure, and TED spread. Policy-related economics uncertainty index is based on Baker, Bloom and Davis (2016) computed for each market under analysis, and it is available at http://www.policyuncertainty.com/index.html. *, **, *** denotes significance at the 10%, 5%, and 1% level, respectively. The t-statistics reported in parentheses below the estimated coefficient are adjusted with Newey-West (1987) method.

	S&P500				SX5E				DAX				FTSE100				CAC40			
Policy Uncertainty	0.123***		0.117***	0.085***	0.082***		0.066***	0.044**	0.012		-0.005	0.019	-0.024**		-0.036***	-0.025**	0.007		-0.007	-0.011
	(5.55)		(4.88)	(3.07)	(4.39)		(3.35)	(2.10)	(0.81)		(-0.28)	(1.02)	(-2.50)		(-3.69)	(-2.32)	(0.52)		(-0.50)	(-0.76)
VIX-type index		0.348**	0.139	0.185		0.589***	0.295	0.172		0.293**	0.312**	0.308**		0.516***	0.668***	0.528***		0.519**	0.568**	0.349
		(2.46)	(1.40)	(1.30)		(2.95)	(1.49)	(0.95)		(2.10)	(2.10)	(2.10)		(3.49)	(4.44)	(2.79)		(2.23)	(2.33)	(1.27)
lag_crp				0.266***				0.517***				0.326***				0.249***				0.400***
				(2.80)				(6.17)				(4.01)				(2.77)				(3.10)
Index				-0.111				-0.083				-0.052				0.069				-0.207
				(-0.62)				(-0.77)				(-0.27)				(0.42)				(-1.02)
Term				-0.001				-0.010				-0.020*				-0.009				0.027
				(-0.12)				(-0.61)				(-1.88)				(-0.59)				(1.37)
TED				-0.008				-0.041				-0.017				-0.068				-0.009
				(-0.41)				(-0.27)				(-0.61)				(-0.56)				(-0.29)
Constant	-0.050***	0.036***	-0.052***	-0.035*	-0.089***	-0.022	-0.089***	-0.047	0.032	0.025*	0.029	0.012	0.022	-0.038***	0.005	0.012	0.024	0.002	0.009	-0.016
	(-2.69)	(3.22)	(-2.80)	(-1.66)	(-2.94)	(-1.12)	(-2.90)	(-1.54)	(1.55)	(1.73)	(1.37)	(0.55)	(1.22)	(-3.06)	(0.28)	(0.49)	(0.93)	(0.11)	(0.33)	(-0.55)
Observations	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	114	114	114	114
*Adjusted_*R^2	0.194	0.041	0.200	0.255	0.128	0.082	0.143	0.382	0.004	0.032	0.032	0.179	0.036	0.066	0.138	0.203	0.002	0.045	0.047	0.237

Table 8: Sub-period analysis of correlation risk premium

This table reports the average levels for the implied correlation (IC), realized correlation (RC), and correlation risk premium (IC-RC), for the CAC40, DAX, FTSE100, EuroStoxx 50 (SX5E) and S&P500 indices for two different sub-periods, namely, 2002-2006 (2003-2006 for the CAC40 index) and 2007-2012, for maturities of 30 and 91 days. IC is calculated from daily observations of model-free implied variances for the index and for all index components. RC is a cross-sectional weighted average (using the appropriate weights from the respective index) of all pairwise correlations at time t, each with the 30 and 91 days window of daily stock returns. Panel B reports average levels of the currency adjusted correlation risk premiums for 30 days and 91 days. *, **, *** denotes significance at the 10%, 5%, and 1% level, respectively. The t-statistics are based on Newey and West (1987) standard errors with lags equal to the measurement horizon minus 1.

Panel A: Correlation risk premium

2002-2007

	CAC40			DAX			FTSE100			SX5E			S&P500		
	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC
30 days	0.416	0.383	0.033	0.504	0.441	0.063***	0.317	0.309	0.008	0.423	0.453	-0.030*	0.354	0.327	0.027***
t-stat			(1.52)			(4.62)			(0.58)			(-1.74)			(3.18)
91 days	0.563	0.506	0.058***	0.548	0.443	0.105***	0.404	0.315	0.090***	0.476	0.456	0.019	0.388	0.317	0.071***
t-stat			(2.95)			(5.39)			(4.13)			(1.01)			(4.67)

2008-2012

	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC
30 days	0.534	0.497	0.036***	0.498	0.473	0.025*	0.358	0.395	-0.037***	0.615	0.533	0.082***	0.518	0.430	0.087***
t-stat			(2.85)			(1.85)			(-3.04)			(6.98)			(6.06)
91 days	0.567	0.506	0.061***	0.581	0.480	0.101***	0.491	0.402	0.089***	0.663	0.540	0.122***	0.541	0.437	0.104***
t-stat			(5.65)			(4.74)			(4.72)			(6.34)			(3.75)

Panel B: Correlation risk premium–currency adjusted

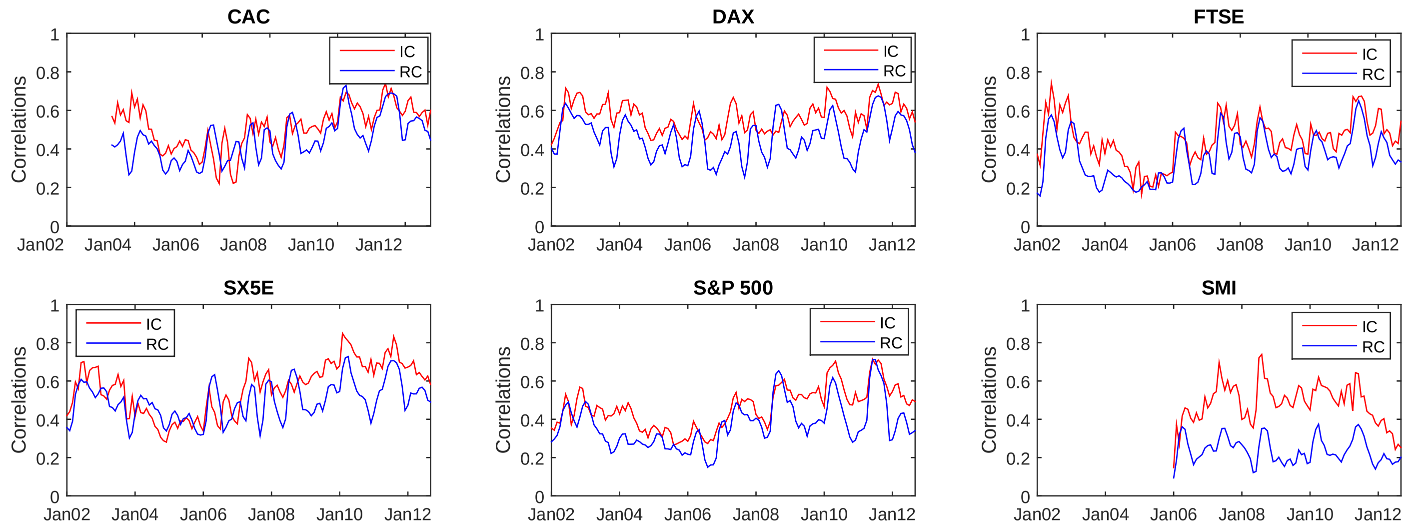
2002-2007

	CAC40	DAX	FTSE100	SX5E	S&P500
30 days	0.039*	0.071***	0.013	-0.023	0.027***
t-stat	(1.76)	(5.00)	(0.92)	(-1.24)	(3.18)
91 days	0.086***	0.128***	0.106***	0.042*	0.071***
t-stat	(3.42)	(5.98)	(4.52)	(1.84)	(4.67)

2008-2012

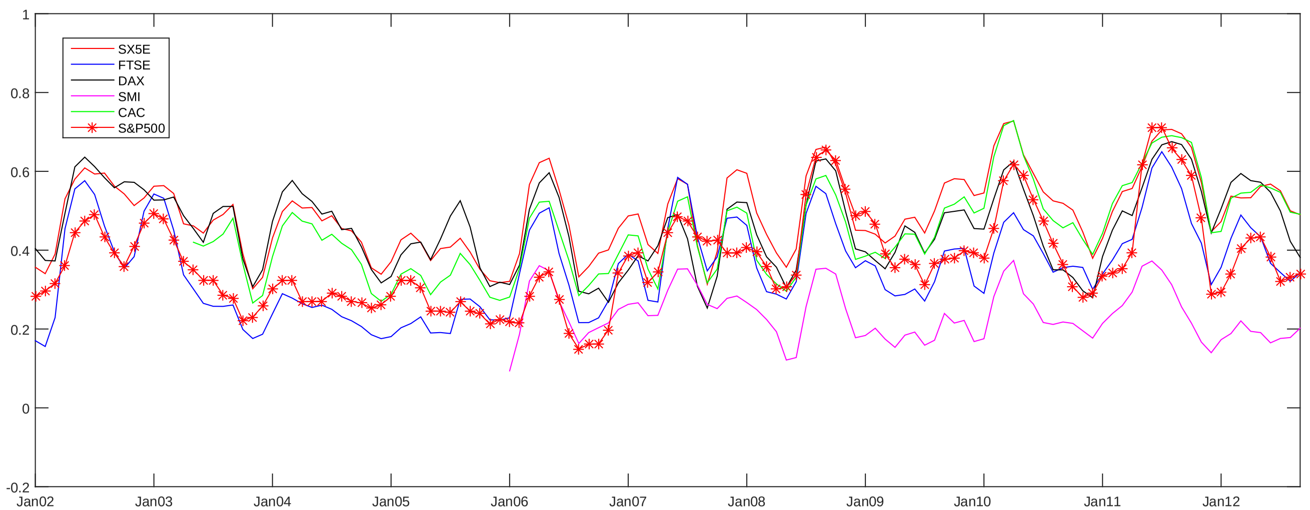
30 days	0.033**	0.023	-0.039***	0.081***	0.087***
t-stat	(2.30)	(1.55)	(-3.05)	(6.04)	(6.06)
91 days	0.053*	0.098***	0.079***	0.119***	0.104***
t-stat	(1.94)	(3.40)	(2.99)	(4.43)	(3.75)

Figure 1: Implied correlation and realized correlation



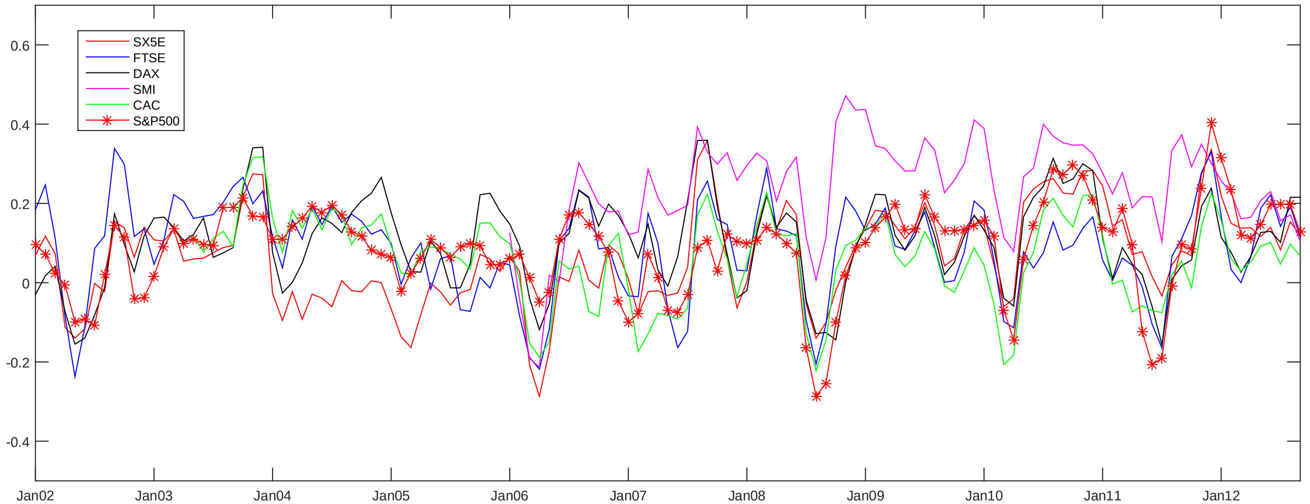
This figure shows the time series of the monthly average implied correlation (IC) and realized correlation (RC) for the 91 days maturity for the six indices under analysis (CAC40, DAX, FTSE100, EuroStoxx 50 (SX5E), SMI, S&P500). IC is calculated from daily observations of model-free implied variances for the index and for all index components. RC is a cross-sectional weighted average (using the appropriate weights from the respective index) of all pairwise correlations.

Figure 2: Realized correlation



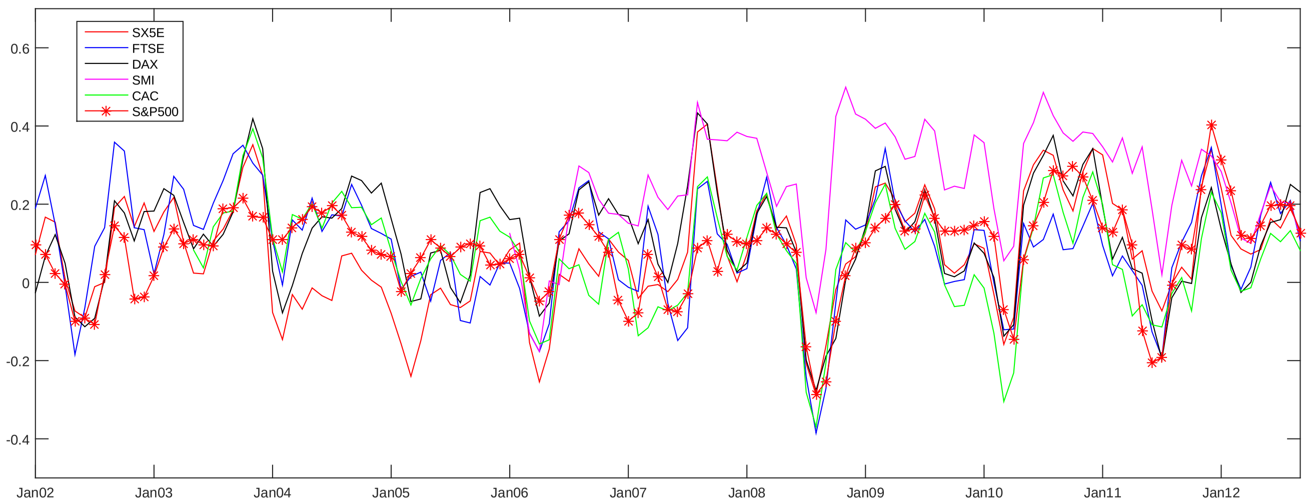
This figure plots the time series of the monthly average realized correlation (RC) for the six indices under analysis (CAC, DAX, FTSE100, EuroStoxx 50 (SX5E), S&P500 and SMI). RC is a cross-sectional weighted average (using the appropriate weights from the respective index) of all pairwise correlations.

Figure 3: Correlation risk premium



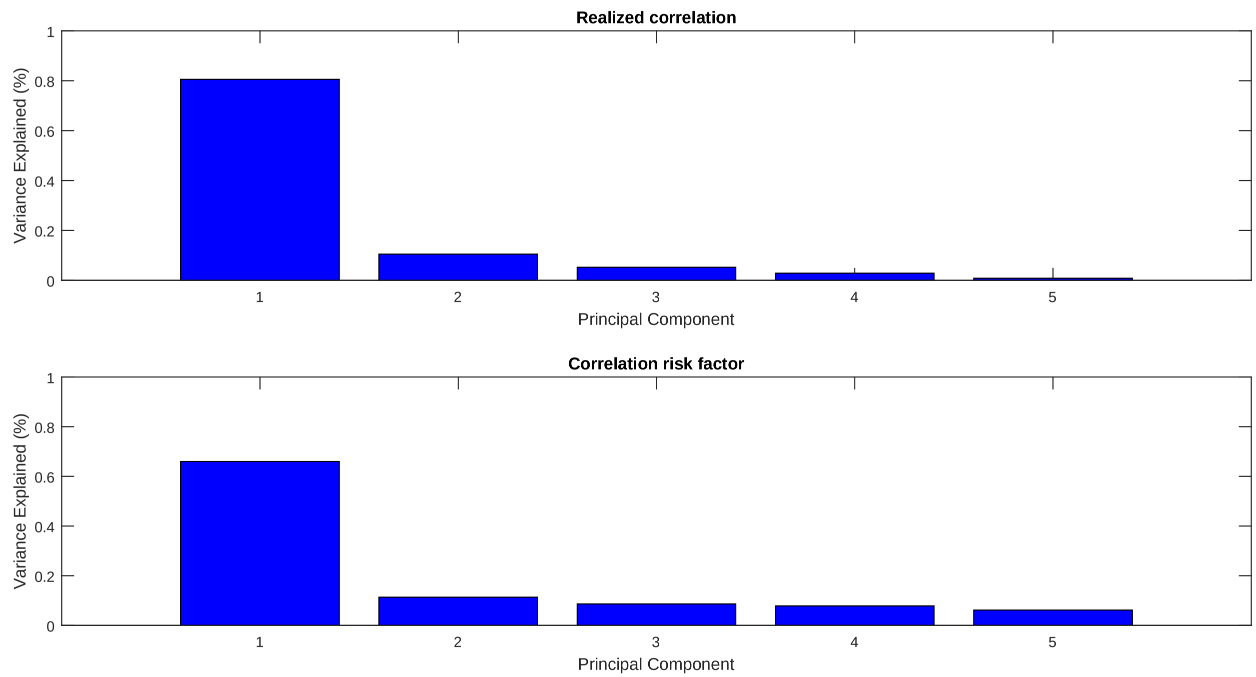
This figure shows the correlation risk premium for 91 days maturity for the six indices under analysis (CAC, DAX, FTSE100, EuroStoxx 50 (SX5E), S&P500 and SMI). IC is calculated from daily observations of model-free implied variances for the index and for all index components, using equation (2). RC is a cross-sectional weighted average (using the appropriate weights from the respective index) of all pairwise correlations.

Figure 4: Currency adjusted correlation risk premium (in US dollars)



This figure shows the currency-adjusted correlation risk premium for 91 days maturity for the six indices under analysis (CAC40, DAX, FTSE100, EuroStoxx 50 (SX5E), SMI, S&P500). IC is calculated from daily observations of model-free implied variances for the index and for all index components. RC is a cross-sectional weighted average (using the appropriate weights from the respective index) of all pairwise correlations.

Figure 5: Principal Component Analysis



This figure shows the results of a Principal Component Analysis of the realized correlation (RC) and correlation risk premium (IC-RC) time series.