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Document de recherche

DR 16-04

The Correlation Risk Premium: International Evidence

Mai 2016

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April 30, 2016

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 factor. We find evidence of strong co-movement of correlation risk premia in European and US equity markets. Our results support the hypothesis that a global correlation risk factor exists and that it is priced in international equity option markets. We document the dependence of the correlation risk premium on macroeconomic policy uncertainty and related variables.

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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 recent financial crisis has again shown that diversification benefits in equity markets can suddenly evaporate when correlations unexpectedly increase, thus constraining the investment opportunity set of investors. Recent academic research has documented how correlation risk can arise endogenously in theory¹ 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 correlation in European equity markets and relate the resulting premium to the US equity market correlation risk and a global correlation risk factor.

¹ See Martin (2013), Buraschi, Trojani and Vedolin (2014) and Piatti (2015).

² Driessen, Maenhout and Vilkov (2009).

³ See Driessen, Maenhout, and Vilkov (2012) 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 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 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 factor, 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 30 days maturity) is statistically significant at 1% level for the French, German, Swiss and US equity indices, and at 10% level for the Pan-European index. The average levels of the correlation risk premium in the European equity markets are also economically significant and vary between -1% and 19 % for the 30 day maturity and between 6% and 24% for the 91 day maturity. This compares to 5% and 7% for the US index for a 30 day and 91 day maturity, respectively.

⁴We restrict our analysis to these countries due to option data availability. The Eurostoxx 50 is a pan-European index.

⁵Buraschi, Kosowski and Trojani (2014) discuss the advantages of implied correlations from correlation swap quotes as opposed to dispersion trade strategies.

⁶The only exception is the 30 day maturity for the UK's FTSE 100 index.

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. 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 premia 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 premia 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 as a country-market value weighted average of correlation risk premia 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 factor and to the *residual* index variance risk factor, as measured by the residuals of the regression of the index variance risk factor on the correlation risk benchmark, is not priced.

The fourth contribution of this paper is to 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 the 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* indices (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 have insignificant effects after controlling the policy uncertainty factor.

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 (e.g. Driessen, Maenhout and Vilkov (2009) and (2013), which we henceforth abbreviate DMV (2009) and DMV (2013), Buraschi, Kosowski and Trojani (2014)) and hedge fund return data (Buraschi, Trojani and Vedolin (2014)) to document that stochastic correlation is a priced risk factor. DMV (2009) show that equity index options will appear more expensive when correlation risk is priced. DMV (2013) 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. 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 the broad studies about variance risk premium. Bakshi and Kapadia (2003), Carr and Wu (2009) provide both a theoretical foundation and empirical 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 factor and the relationship between the correlation risk factor 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 and find that US returns predict other country indices 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 premia in European and US markets and evidence of a global correlation risk factor.

The rest of the paper is organized as follows. Section II reviews the methodology to calculate implied correlation, realized correlation and the correlation risk factor. 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 equity correlation risk factor for the time period (t, T) can be calculated as the difference between the average value-weighted pairwise realized correlation of equity index constituents during that time period, $RC_{t,T}$, and its risk-neutral expected value at time t , $E_t^Q(RC_{t,T})$. This is also commonly referred as the correlation risk premium, and effectively

corresponds to the realization of the correlation risk factor, representing the cost incurred by an investor aiming to hedge the exposure to negative correlation shocks. To ensure a predominantly positive sign for the correlation risk factor (CR), in this paper we define it as follows,⁷

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

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 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 by 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 :

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

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 indices (and their constituents) that we study in this paper, we compute

⁷ There is extensive evidence in the literature (for e.g., DMV (2013), Buraschi, Kosowski and Trojani (2014) and Faria and Kosowski (2016)) that during normal market circumstances $RC_{t,T} < E_t^Q(RC_{t,T})$. Our definition of the correlation risk factor in equation (1) ensures that it is on average positive as in DMV (2013), and as in the literature on the variance risk premium (Bollerslev, Tauchen and Zhou (2009)). We define the ‘‘variance risk factor’’ in an analogous manner.

synthetic correlation and variance swap rates. We synthesize $SV_{t,T}^l$ 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, $SV_{t,T}^l$ 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 puts as follows:

$$SV_{t,T} = \int_{S_t}^{\infty} \left[\frac{2 \left(1 - \ln \left(\frac{K}{S_t} \right) \right)}{K^2} \right] C(t, T-t; K) dK + \int_0^{S_t} \left[\frac{2 \left(1 + \ln \left(\frac{S_t}{K} \right) \right)}{K^2} \right] P(t, T-t; K) dK, \quad (3)$$

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, which is described in detail in Section III.

Using the synthetic correlation swap rate IC_t from equation (2), the correlation risk factor in equation (1) is given by:

$$CR_t = IC_t - RC_{t,T} \quad (4)$$

b. Currency adjusted correlation risk factor

One of our contributions is to examine the comovement between correlation risk factors in different countries. The correlation risk factor is based on a correlation swap payoff 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 and gives the amount of dollars per unit of the foreign currency. So the percentage

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

change of spot exchange rate for the time period (t, T) is $s = (S_T - S_t)/S_t$. We assume the perspective of an 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, we define the currency adjusted correlation risk factor as ⁹

$$CR_{currency\ adjusted} = CR + s \quad (5)$$

The variance risk factor 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), the SMI index (Switzerland) and the S&P 500 index (US) and options on their constituents from January 2002 until December 2012¹⁰. All indices 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 it is clear from Table 1, each index had many changes in its composition during the sample period. All indices exhibit a high option coverage, that is there are tradable options on most of their constituents, with the exception of the FTSE 100 index which has a relatively low option coverage.

[Insert Table 1 here]

In order 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-

⁹ Similar as in international asset pricing literature, the cross product of exchange rate movement and correlation risk factor can be neglected, and it is assumed to be very small for short time periods.

¹⁰ For the CAC40 index the sample period starts in May 2003. For the computation of the correlation risk factor 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.

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 for the purpose of computing the implied correlation in Equation (2). The methodology we use to address this issue is the one used by DMV (2013) and 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, indices' 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 necessary. In order 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.

In order to test whether correlation risk is priced an index level analysis is required. We select index options with 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 filter 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 indices are constructed by Baker, Bloom and Davis (2015)¹¹ 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

¹¹ For further details please see <http://www.policyuncertainty.com/index.html>. The uncertainty index data is available for downloading in this website.

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.¹² Since April 2014 the authors use only newspaper articles components for the construction of the European indices and do not use consensus economics forecaster dispersion data anymore^{13, 14}.

IV. Empirical Results

Our empirical analysis consists of four main steps. We start by comparing the summary statistics and dynamics of the correlation risk factor and the index and individual variance risk factors for the French, German, Swiss, UK, European, and US equity markets. All of these markets have liquid option markets. In the second step, we analyse the co-movement of the correlation risk factors in Europe and the US. Next, we study whether a global correlation risk factor is priced in the cross-section of European and US equity index option returns. In the final step, we analyse the determinants of the correlation risk factor dynamics.

a. Summary statistics of the individual and index variance risk factors

Since the correlation risk factor 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 these papers conclude that the index variance risk premium is statistically significant.¹⁵ Our findings below confirm these results for the index variance risk factor.

We complement the existing literature on the individual variance risk premium¹⁶ by

¹² More details are provided in section IV.e.

¹³ Our results are quantitatively and qualitatively similar if we only use the component that quantifies newspaper coverage of policy-related economic uncertainty in US and Europe.

¹⁴ According to the authors, “this has a limited impact upon our overall country-level series, with the old and the new index having a high correlation”.

¹⁵ 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.

¹⁶ See, for example, Carr and Wu (2009) and DMV (2013).

documenting the results for the individual stock variance risk factor in the European equity markets under analysis. Analogous to the correlation risk factor in Equation (4) we calculate the variance risk factor as follows:

$$VR_t = IV_t - RV_{t,T}. \quad (6)$$

As documented in Table 2, we find evidence of a positive variance risk factor 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 factor 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 factor ranges from 0.60 to 0.90 for various European markets and is statistically significant for the DAX, FTSE100 and Eurostoxx 50 indices. These results are comparable to those reported for European markets by Bollerslev, Marrone, Xu and Zhou (2014).

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

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

[Insert Table 2 here]

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

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

The average individual variance risk factor, however, obscures more complex patterns that become apparent when evaluating the number of constituents with statistically significantly negative or positive variance risk factors. Table 3 shows that although the majority of individual variance risk factors 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 factor

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 indices for 91 days maturity. For the CAC40 index the sample period starts in May 2003 and for the computation of the correlation risk factor 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.

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 indices, the implied measure of correlation indeed closely follows the dynamics of the RCs and that for the most part of the sample period the level of IC is higher than RC. This suggests the existence of an average positive correlation risk factor. Correlation can be traded through option and swap markets. Some of the fluctuation of the implied versus the realized correlation may be due to the amount of arbitrage capital available at different points in time as documented in other markets (see, for example, Jylha and Suominen (2011) and Baltas and Kosowski (2013)). This analysis is outside the scope of this paper but an interesting avenue for future research.

Table 4 confirms the inference from Figure 1 and shows that the correlation risk factor is economically and statistically significant for all indices using 91 day maturities. The same conclusion obtains for 30 day maturities with the exception of the FTSE 100 index. The different indices exhibit a correlation risk factor that is of a similar order of magnitude. For the S&P500 index, for example, the correlation risk factor 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), who using US data, find a correlation risk premium of 0.0765, 0.0748 and 0.1615 for the S&P 500 for the sample 2008-2012, 2002-2007 and 1996-2001, respectively, using 91 day maturity. Similar to our results, they also find a lower average correlation risk premium of 0.0448 using 30 day maturities for the 2008-2012 sample.

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 factor and Principal Component Analysis

One of the key questions that we study is whether correlation risk is priced internationally. If correlation risk factors co-move across different countries, this would make it more likely that they 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 indices 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 factors (CR) as Figures 3 and 4 show for local currency and US dollars versions of the CR.

[Insert Figure 3 here]

[Insert Figure 4 here]

The insights gained from a visual inspection of Figures 2-4 are confirmed by the pairwise correlation coefficients reported for different RCs and CRs in Table 5. According to Panel A, for RCs, the lowest pairwise correlation is 0.54 (for the SMI/SX5E pair) 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 C are 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 factor structure across correlation risk factors in different countries. In order to analyse this hypothesis more formally we perform a Principal Component Analysis (PCA) of the RCs and CRs. Results are presented in Figure 5.¹⁷ The first principal component explains 80.6% the total variance and the first two components explain more than 90% for the total variance of the RC. For the CR, the first principle component explains 66.0% of the total variance and the first two components have an explanatory power of around 80%.

[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 risk factor may exist. Such a factor may affect the dynamics of international equity markets and 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 factor mentioned in the previous sub-section 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 factor constructed 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 factor 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 factor exists. Our cross-section contains

¹⁷ We exclude the SMI from the PCA analysis due to its short sample. This does not change our conclusions.

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 .

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

$$CR_t^{\text{Global}} \equiv \sum_i w_t^i CR_t^i, \quad (7)$$

where $i = 1, 2 \dots 6$ refer to each of the six indices included in our analysis. The country market capitalizations used for the calculation of weights w_t^i are obtained from Datastream, and they are US dollar denominated. The global average individual variance risk factors are constructed following the same procedure. One concern that may arise from an inspection of the global correlation risk factor composition is that there is a risk of double counting of some European stocks that appear in the Eurostoxx 50 index and 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 factor.

In the first step, we obtain the loadings of all options on the global correlation risk factor. In a second step we regress average returns cross-sectionally on these loadings and obtain the factor risk premia. 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 factor 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 of model 1 which has only one independent variable, namely the global correlation risk factor CR^{Global} given by equation (7), show that the option return betas or loadings in the first step are all significant. The implied correlation risk premium in the second step is estimated 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 1996-2012 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 until 2004 or the fact that the authors include a market risk factor.

The high level of adjusted R^2 (73.60%) is similar to that reported in DMV (2009) who document adjusted R^2 between 70% and 80% for US index options depending on the model specification. Our results suggest that global correlation risk factor 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 individual variance risk factor (Model 2). The individual variance risk factor is insignificant cross-sectionally and this is consistent with the insignificant individual variance risk factors discussed in Section IV.a.

[Insert Table 6 here]

An alternative that we consider as a robustness test is Model 3, in which we add the residuals from regression (8) below, that is from a regression of the index variance risk factor from Equation (6) on the correlation risk factor from Equation (4). The rationale behind Model 3 is to control for the effect of the correlation risk factor embedded in the index variance factor.

$$Index\ VR_t = \beta_0 + \beta_1 CR_t + \varepsilon_t. \quad (8)$$

We find that the results are economically and statistically robust and the coefficient estimates from Model 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 factor and the correlation risk factor. However, in unreported robustness tests we find that including the market excess return makes our results even stronger as the correlation risk factor 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 factor 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 factor priced in international equity index option markets.

e. The determinants of the correlation risk factor

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

We regress the correlation risk factor 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 later) by Baker, Bloom and Davis (2015), which is available for each country, (iii) the VIX-type index for each market,¹⁸ 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. We find that the lagged level of the correlation risk premium has significant explanatory power, which is consistent with the high persistency of correlation documented in the literature (Buraschi, Porchia and Trojani (2010) and Faria and Kosowski

¹⁸ We construct the model-free 30 days risk-neutral implied variance using a method similar to the one applied by the CBOE for the computation of the VIX index.

(2016)).

Our VIX-type index is a risk-neutral expectation of future volatility and 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 (2015) 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 index¹⁹.

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

[Insert Table 7 here]

Our results are consistent with those of Kelly, Pastor and Veronesi (2016) who find that options provide valuable protection against the risk associated with major political events including elections and summits. It is therefore not surprising that the correlation risk factor is statistically significantly 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 factor has a significant positive effect on the current level of the correlation risk factor. This is consistent with evidence of persistence of the correlation risk factor 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 factor on a firm-level earnings forecast uncertainty factor for the US equity market. Our results confirm the importance of investor disagreement about the future economic performance as a determinant of correlation risk. The market return, interest rate term structure and TED spread all have insignificant effects.

¹⁹ We exclude the SMI index of this analysis because there is no policy-related economic uncertainty data for Switzerland and also due to the short sample of the correlation risk factor based on the SMI option data.

V. Robustness Check: different sample periods

In order to study the dynamics of the correlation risk factor during normal and crisis conditions, we repeat the analysis for the correlation risk factor in two different sample periods²⁰, namely 2002-2007 and 2008-2012.

[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 2008-2012 period than during the 2002-2007, reflecting the effects of the global financial crisis (GFC). In the first subsample, the differences between IC and RC among the indices and maturities diverge significantly. The EuroStoxx 50 index has insignificant difference (IC-RC) for 30 and 91 days maturities, while the DAX index has a positive and significant difference, with an average level of correlation risk factor of 6.3% (t-statistics of 4.62) and 10.5% (t-statistics of 5.39) respectively. The CAC40 and FTSE100 indices have statistically significant correlation risk factors only for the 91 days maturity.

Regarding the second subsample period, results change significantly, with all correlation risk factors being statistically significant. The average correlation risk factor for the EuroStoxx 50 index during the 2008-2012 period is higher in terms of economic value and statistical significance reflecting 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 factor is higher for the S&P500 index during the 2008-2012 period than the 2002-2007 period. For European country-level indices, the results are more mixed. The average correlation risk factor 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 indices the level of the correlation risk factor decreases significantly for the 30 day maturity, while for the 91 day

²⁰ 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.

maturity it remains relatively unchanged.

VI. Conclusion

This paper contributes to the recent 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 factor to the US equity market correlation risk and a global correlation risk factor.

Our first contribution is to show that the correlation risk factor 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 factor in the US and different European equity markets. We find that the co-movement of realized correlations, implied correlations and the correlation risk factors 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 factor. Our third contribution is to show that indeed exposure to a global correlation risk factor, computed as a market value weighted of local correlation risk factor, 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 factor 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 factor and to the *residual* index variance risk factor, as measured by the residuals of the regression of the index variance risk factor on the correlation risk benchmark, is not priced.

The fourth contribution of this paper is to document the drivers of the correlation risk premium. For *broad* indices (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 have insignificant effects after controlling the policy uncertainty factor. We find that the lagged level of the correlation risk premium has significant explanatory power, which is consistent with the high persistency of correlation

documented in the literature.

Interesting avenues for future research include studying theoretically, within an open-economy representative investor framework, how a global correlation risk factor consistent with the results documented in this paper could be endogenously generated. One potential class of models could be that used in Faria and Kosowski (2016) to explain the term structure of the correlation risk premium in the US equity market.

References

- Ang, A., and Longstaff., F., 2013, Systemic Sovereign Credit Risk: Lessons from the US and Europe, *Journal of Monetary Economics*, 60(5), 493-510.
- Baker, S.R., Bloom, N., Davis, S.J., 2015, Measuring economic policy uncertainty, *Forthcoming Quarterly Journal of Economics*.
- Bakshi, G. S., Kapadia, N., and Madan., D.B., 2003, Stock Returns Characteristics, Skew Laws, and the Differential Pricing of Individual Equity Options, *Review of Financial Studies*, 16(1), 101-143.
- Bakshi, G.S., Kapadia, N., 2003, Delta-Hedged Gains and the Negative Market Volatility Risk Premium, *Review of Financial Studies*, 16, 527-566.
- Baltas, N. and Kosowski, R., 2013, Momentum Strategies in Futures Markets and Trend-following Funds, Working paper.
- Bayoumi, T and Vitek, F., 2013, Macroeconomic Model Spillovers and Their Discontents, IMF Working Paper.
- Bollerslev, T., Marrone, J., Xu, L., H. Zhou., 2014, Stock Return Predictability and Variance Risk Premia: Statistical Inference and International Evidence. *Journal of Financial and Quantitative Analysis*, 49(3), 633-661.
- Bollerslev, T., Tauchen, G., and Zhou, H., 2009, Expected Stock Returns and Variance Risk Premia. *Review of Financial Studies*, 22, 4463–4492.
- Britten-Jones, M. and Neuberger, A., 2000, Option Prices, Implied Price Processes, and Stochastic Volatility, *Journal of Finance*, 55(2), 839-866.
- Buraschi, A., Kosowski, R., and Trojani, F., 2014, When there is no place to hide: Correlation risk and the Cross section of Hedge Fund Returns, *Review of Financial Studies*, 27(2), 581-616.
- Buraschi, A., Porchia, P., and Trojani, F., 2010, Correlation Risk and Optimal Portfolio Choice, *Journal of Finance*, 65(1), 393-420.
- Buraschi, A., Trojani, F., and Vedolin, A., 2014, When uncertainty blows in the orchard: comovement and equilibrium variance risk premia, *Journal of Finance*, 69(1), 101-137.
- Carr, P. and Wu, L., 2009, Variance Risk Premiums, *Review of Financial Studies*, 22(3), 1311-1341.
- Cespa, G. and Foucalt, T., 2014, Illiquidity Contagion and Liquidity Crashes, *Review of*

Financial Studies, 27(6), 1615-1660.

Drechsler, I. and Yaron, A., 2011, What's Vol Got to Do with It, Review of Financial Studies, 24(1), 1-45.

Driessen, J., Maenhout, P. and Vilkov, G., 2009, The price of correlation risk: evidence from equity options, Journal of Finance, 64(3), 1377-1406.

Driessen, J., Maenhout, P. and Vilkov, G., 2013, Option-Implied Correlations and the Price of Correlation Risk, Working paper.

Faria, G., Kosowski, R., 2016, The Correlation Risk Premium Term Structure, Working paper.

Han, B., Zhou, Y., 2011, Variance Risk Premium and Cross-Section of Stock Returns, Working paper.

Harvey, C., 1991, The World Price of Covariance Risk, Journal of Finance, 46(1), 111-157.

Jylha, P., and Suominen, M., 2011, Speculative capital and currency carry trades, Journal of Financial Economics, 99, 60-75.

Kelly, B., Pastor, L., Veronesi, P., 2016, The Price of Political Uncertainty: Theory and Evidence from the Option Market. Forthcoming *Journal of Finance*.

Martin, I., 2013, The Lucas Orchard, Econometrica, 81(1), 55 - 111.

Piatti, I., 2015, Heterogeneous Beliefs about Rare Event Risk in the Lucas Orchard, Working paper.

Rapach, D., Strauss, J. K. and Zhou, G., 2013, International Stock Return Predictability: What Is the Role of the United States?. The Journal of Finance, 68(4), 1633-1662.

Shanken, J., 1992, On the estimation of beta-pricing models, Review of Financial Studies, 5(1), 1-55.

Table 1: Index composition

This table reports information about the composition of the six indices under study, namely the CAC40, the DAX, the FTSE100, the SMI, the EuroStoxx 50 (SX5E) and the S&P500 indices. 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 factor

This table reports the variance risk factor for the six indices as well as the weighted average of the variance risk factors of the index constituents. Panel A reports the variance risk factor for each index in local currency terms. Panel B reports the variance risk factor in US dollars after a currency adjustment. Panel C and D report the equal-weighted individual variance risk factor 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 factor

	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	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)	(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	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	-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	20.82	14.33	18.97	14.55	15.95	29.68

Panel B: Index variance risk factor-currency adjusted

	30 Days						91 Days					
mean	0.76	0.95*	0.89*	1.15**	1.23**	0.61	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)	(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	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	-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	11.85	9.68	16.77	7.63	9.40	29.68

Panel C: Individual variance risk factor

	30 Days						91 Days					
mean	1.66**	0.90	4.54***	1.79***	3.72***	1.71*	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)	(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	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	-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	19.66	22.63	17.79	12.62	16.88	30.54

Panel D: Individual variance risk factor-currency adjusted

	30 Days						91 Days					
mean	1.79**	1.22*	4.68***	2.28***	4.03***	1.71*	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)	(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	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	-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	14.29	17.95	16.43	9.67	14.09	30.54

Table 3: Statistical significance of individual variance risk factor

The table reports results for the test of whether the individual variance risk factor for the constituents of the six indices (CAC40, DAX, FTSE100, SMI, EuroStoxx50(SX5E) and 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
30 Days	$IV - RV > 0$ rejected	15	20	56	21	23	228
	$IV - RV = 0$ not rejected	14	18	26	10	17	138
	$IV - RV < 0$ rejected	55	9	83	22	61	628
91 Days	$IV - RV > 0$ rejected	21	17	67	24	36	270
	$IV - RV = 0$ 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 factor

This table reports the summary statistics for the implied correlation (IC), realized correlation (RC), and the correlation risk factor (IC-RC), for the six indices(CAC40, DAX, FTSE100, SMI, EuroStoxx50(SX5E) and 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, and standard deviation. IC 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 factors. *, **, *** 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 factor

	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	
30 Days																			
mean	0.478	0.443	0.035*** (2.82)	0.501	0.456	0.045*** (4.66)	0.336	0.349	-0.013 (-1.35)	0.417	0.228	0.189*** (12.50)	0.511	0.490	0.021* (1.76)	0.429	0.375	0.054*** (6.46)	
t-stat																			
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-quant	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-quant	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																			
mean	0.513	0.449	0.064*** (4.21)	0.564	0.461	0.103*** (7.11)	0.445	0.356	0.089*** (6.13)	0.478	0.238	0.240*** (11.31)	0.563	0.495	0.067*** (4.23)	0.459	0.373	0.086*** (5.58)	
t-stat																			
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-quant	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-quant	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 factor–currency adjusted

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

Table 5: Correlation between correlation risk factors in different countries

Panel A reports the pairwise correlations for the realized correlations of the six indices under analysis. Panel B reports the pairwise correlations of the correlation risk factor (IC-RC) for the indices. Panel C reports the pairwise correlations of the the currency adjusted correlation risk factor (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 factor

	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 factor–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, SMI and SX5E) on their exposures to the global correlation risk factor. The exposures are estimated in a first step, regressing the time series of each excess option return on the global correlation risk factor. Model 1 includes only the global correlation risk factor, while Model 2 adds the average individual variance risk factor. Model 3 adds the residuals of regressing index variance risk factor on the correlation risk factor. Panel B reports estimates for the risk premium on the global correlation risk factor 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 factor. 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 factor	0.038** (2.39)	0.023** (2.34)	0.028** (2.45)
Individual variance risk factor		0.015 (1.31)	
Index variance risk factor (residual)			0.01 (1.71)
<i>Adjusted_R²</i>	73.60%	75.10%	76.33%

Panel B: With US index options

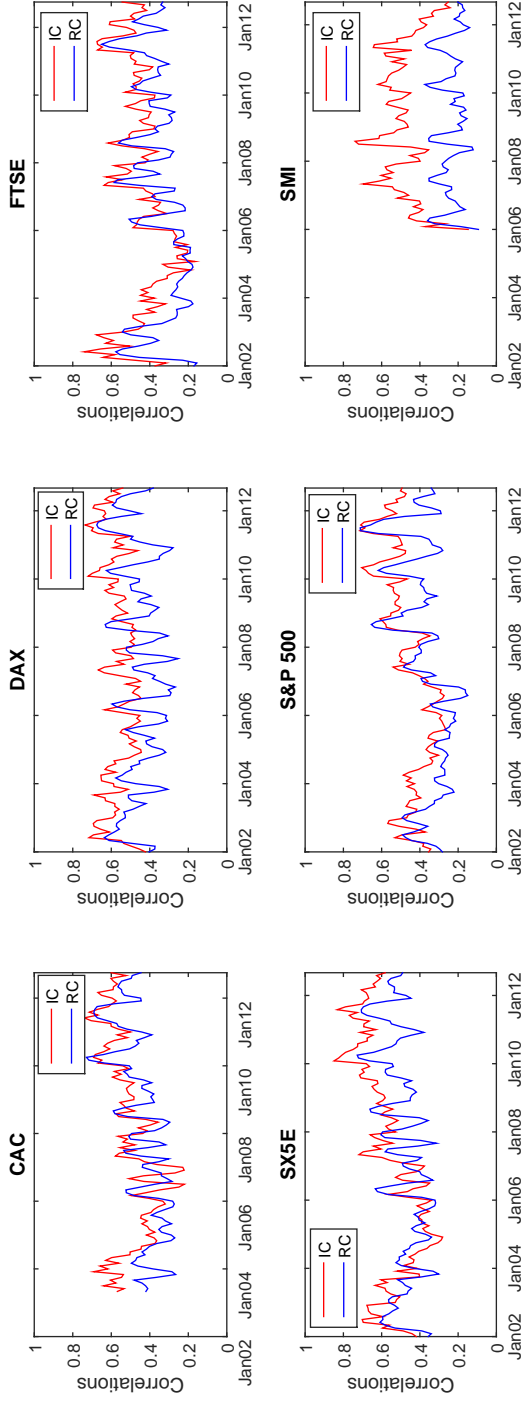
	Model 1	Model 2	Model 3
Global correlation risk factor	0.024** (2.34)	0.017** (2.35)	0.024** (2.15)
Individual variance risk factor		0.021 (0.80)	
Index variance risk factor (residual)			-0.001 (-0.94)
<i>Adjusted_R²</i>	73.97%	74.60%	74.22%

Table 7: The determinants of the correlation risk factor

This table reports the results of regressions of the correlation risk factor on different variables linked to macroeconomic conditions and uncertainty. The analysis includes 5 indices: CAC40, DAX, FTSE100, SX5E and S&P500. The independent variables include policy-related economic uncertainty factor, VIX-type index, Lagged correlation risk factor, index returns, interest rate term structure, and TED spread. Policy-related economics uncertainty factor is based on the paper by Baker, Bloom and Davis (2014) 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.

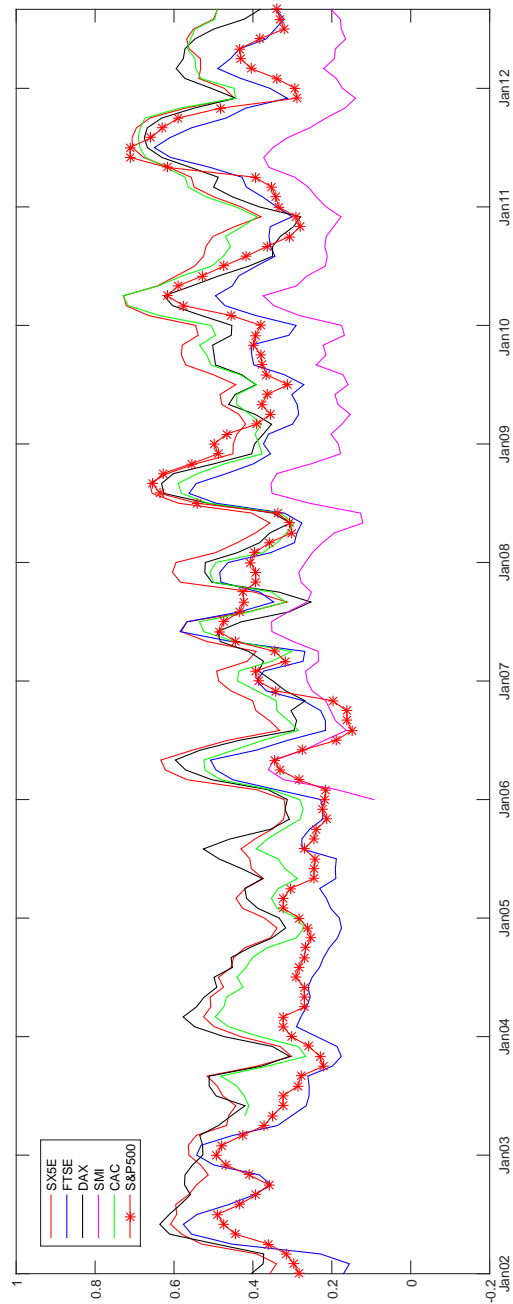
	S&P500	SX5E	DAX	FTSE100	CAC40
Uncertainty	0.123*** (5.55)	0.082*** (4.39)	0.012 (0.81)	-0.036*** (-3.69)	0.007 (0.52)
VIX-type index	0.117*** (4.88)	0.066*** (3.35)	-0.005 (-0.28)	-0.025** (-2.32)	-0.007 (-0.50)
lag_crp	0.348*** (2.46)	0.589*** (2.95)	0.283** (2.10)	0.516*** (3.49)	0.519** (2.23)
Index	0.185 (1.30)	0.172 (0.95)	0.308*** (2.10)	0.528*** (2.79)	0.568** (2.33)
Term	0.266*** (2.80)	0.517*** (6.17)	0.326*** (4.01)	0.249*** (2.77)	0.400*** (3.10)
TED	-0.111 (-0.62)	-0.083 (-0.77)	-0.052 (-0.27)	0.069 (0.42)	-0.207 (-1.02)
Constant	-0.001 (-0.12)	-0.010 (-0.61)	-0.020* (-1.88)	-0.009 (-0.59)	0.027 (1.37)
	-0.008 (-0.41)	-0.041 (-0.27)	-0.017 (-0.61)	-0.068 (-0.56)	-0.009 (-0.29)
	-0.035* (-0.41)	-0.047 (-1.54)	0.029 (1.37)	0.012 (0.49)	0.002 (0.11)
Observations	-0.050*** (-2.69)	-0.089*** (-2.94)	0.032 (1.55)	0.005 (0.28)	0.024 (0.93)
Adjusted_R2	(3.22)	(-1.12)	(1.73)	(-3.06)	(0.11)
	130	130	130	130	114
	0.194	0.082	0.032	0.066	0.045
	0.200	0.143	0.179	0.203	0.047
	0.255	0.382	0.382	0.138	0.047

Figure 1: Implied correlation and realized correlation



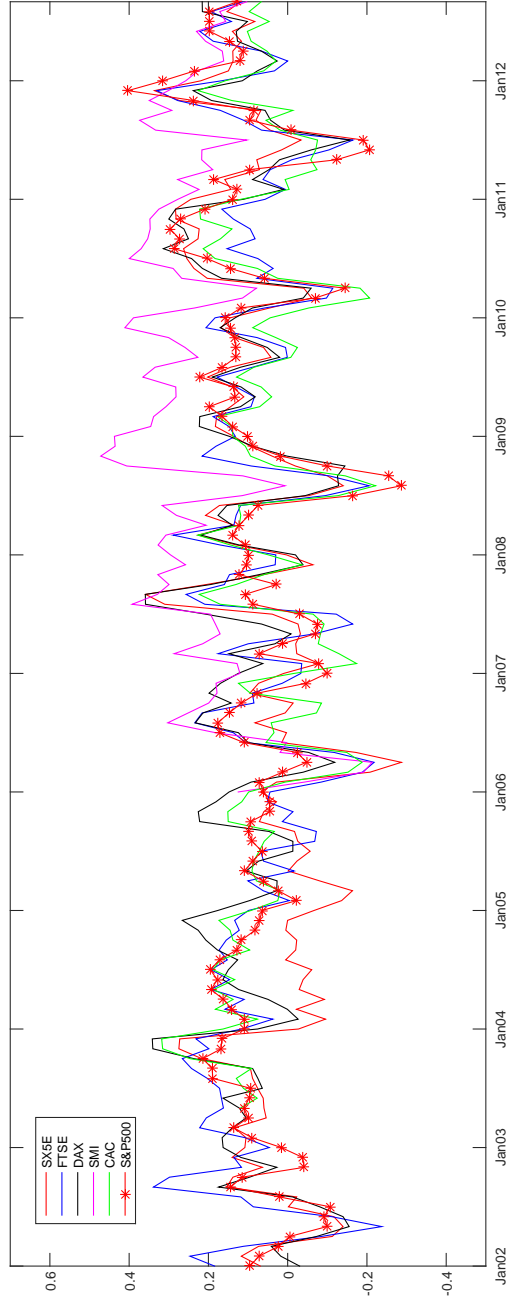
This figure shows the time series of the monthly average implied correlation (IC) and realized correlation (RC) for the 91 days maturity for the six indices under analysis (CAC, DAX, FTSE100, SX5E, S&P500 and SMI). IC is calculated from daily observations of model-free implied variances for the index 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



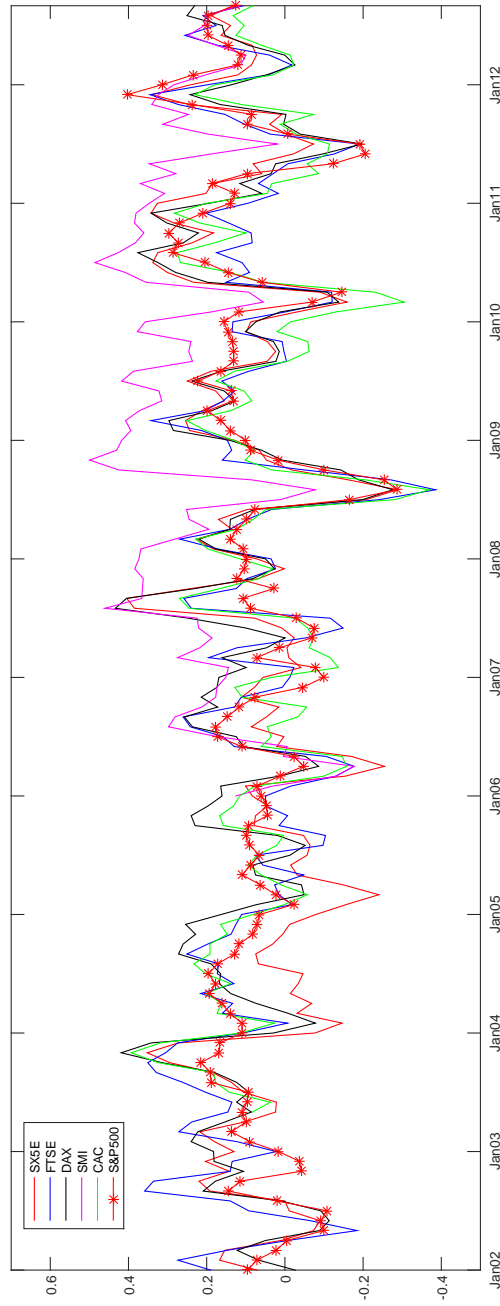
This figure plots the time series of the monthly average realized correlation (RC) for the six indices under analysis (CAC, DAX, FTSE100, SX5E, S&P500 and SMI). RC is a cross-sectional weighted average (using the appropriate weights from the respective index) of all pairwise correlations.

Figure 3: Correlation risk factor



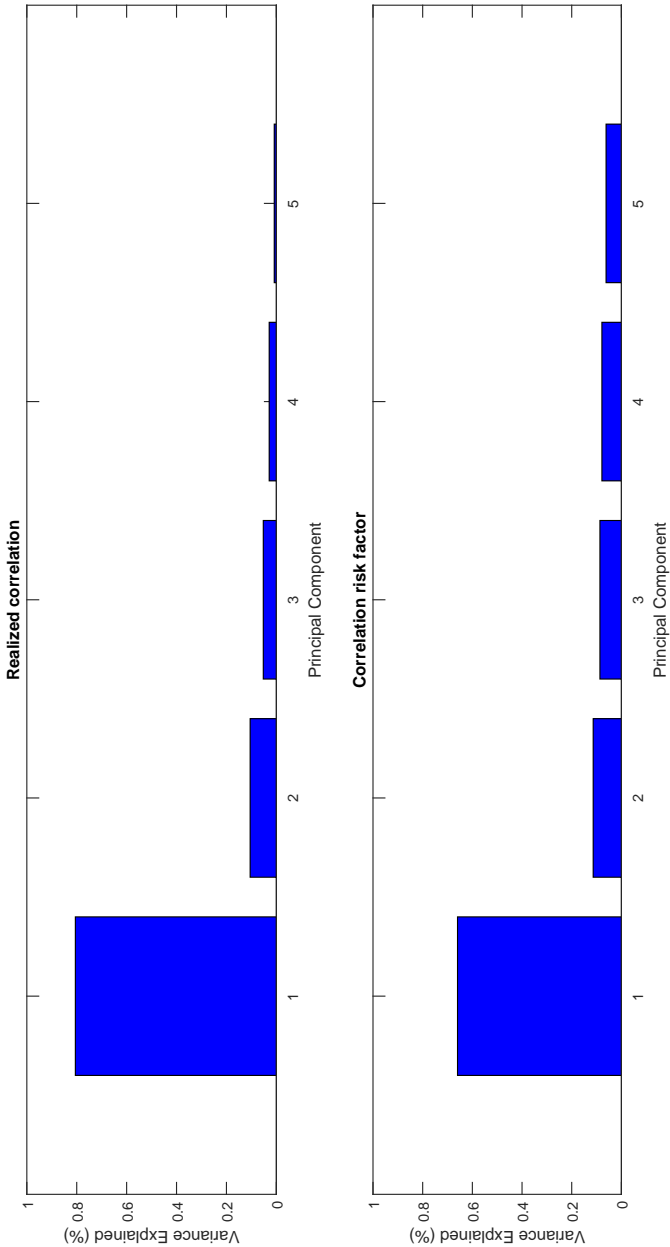
This figure shows the correlation risk factor for 91 days maturity for the six indices under analysis (CAC, DAX, FTSE100, SX5E, S&P500 and SMI). IC is calculated from daily observations of model-free implied variances for the index and for all index components, using equation (2). RC is a cross-sectional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

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



This figure shows the currency-adjusted correlation risk factor for 91 days maturity for the six indices under analysis (DAX, FTSE100, EuroStoxx (SX5E), S&P500, CAC40 and SMI). 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 factor (IC-RC) time series.