The Correlation Risk Premium: International Evidence

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ABSTRACT

In this paper we carry out a 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 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 strong empirical relationship between the global correlation risk premium and international equity market option returns. We document the dependence of the correlation risk premium on macroeconomic uncertainty and related variables. (*JEL* G10, G12, G13)

Keywords: correlation risk premium, implied correlation, realized correlation, variance risk premium, international equity options

I. Introduction

"*The S&P 500 Index's three-month realized correlation has steadied around the 0.8 level, its highest in about eight years, even though other gauges of market stress such as the Cboe Volatility Index have retreated toward normal levels. The divergence suggests investors continue to focus on just one main driver - the global coronavirus pandemic - making it harder for active fund managers to beat their benchmarks." "From beginning the year with a correlation of 0.19, the gauge of how closely the top stocks in the S&P 500 move in relation to one another spiked to 0.85 in mid-March, toward the peak of the coronavirus sell-off before leveling off around 0.8.*"[1]

The global financial crisis and more recently the global coronavirus pandemic, have again shown that correlations in equity markets can unexpectedly increase, thus constraining the investment opportunity set available to investors. Recent academic research has documented how correlation risk can arise endogenously in theory[2] 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.[3] Correlation risk has been shown to be priced in the cross-section of US option returns and hedge fund returns, and recent empirical evidence supports the fact that option implied correlation has predictive power for long-term market return.[4] This paper shows that there is a strong empirical relationship between the global correlation risk premium and international equity market option returns.

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[1] "Steep U.S. Stock Correlations Show Virus's Impact on Markets", Cormac Mullen, Bloomberg 27th May 2020, https://www.bloomberg.com/news/articles/2020-05-27/steep-u-s-stock-correlations-show-virus-death-grip-on-markets

[2] See Martin (2013), Buraschi, Trojani and Vedolin (2014), Piatti (2015) and Ehling and Heyerdahl-Larsen (2017).

[3] See Driessen, Maenhout and Vilkov (2009).

[4] See Driessen, Maenhout, and Vilkov (2013), Buraschi, Kosowski and Trojani (2014) and Buss, Schonleber and Vilkov (2019).

If we view asset returns in different countries as portfolios in an international 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 the correlation risk premium in equity markets is exclusively focused on US data. Is the equity option implied correlation risk premium significant in non-US markets? What is the relationship between the correlation risk premium in different markets? What are the economic drivers of the correlation risk premium? In this paper we address these questions by carrying out a 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.

In practice, understanding the dynamics, the informational content and the co-movement of correlation risk premium in international equity markets is crucial for the design of risk management strategies by international asset managers, including pension funds and hedge funds, since unexpected increases in correlation risk are associated with large equity portfolio drawdowns. 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.

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. Correlation swaps are simple correlation derivatives in which counterparties exchange realized versus implied correlation (the correlation swap quote).[5] To measure the correlation risk premium 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

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

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 equity markets in our baseline specification, which supports insights from US studies (Driessen, Maenhout and Vilkov (2009, 2013)). For instance, the monthly correlation risk premium (with a 30-day maturity) is statistically significant at the 1% level for the French, German, Swiss and US equity indexes, and at the 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 9% for the US index for 30-day and 91-day maturity, respectively.

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. 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 also 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 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 co-movement of the correlation risk premiums across well-developed European and US markets can be interpreted as an expected feature of integrated equity markets and is related to recent research such as Bekaert et al (2009) and Bekaert and Mehl (2019).

The high level of co-movement of the correlation risk premiums across different markets 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 exposure to a global correlation risk premium, computed using a weighted average of correlation risk premiums in different countries, accounts for more than 70% 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 reflected in international equity options markets returns. 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 relevant. 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. Some literature on consumption-based asset pricing has been exploring equity option prices to understand what structure best fits the data. Examples are Du (2011) and Bekaert and Engstrom (2017) for habit models; Bollerslev, Tauchen and Zhou (2009) and Drechsler and Yaron (2011) for long run risk models; Gabaix (2012) and Wachter and Seo (2019) for disaster risk models. Bekaert, Engstrom and Ermolov (2021) explore how these models fit stylized facts regarding the variance risk premium and where they fail. They introduce a habit model which fits the data, showing that the variance risk premium depends positively (negatively) on “bad” (“good”) consumption growth uncertainty. Martin (2013), Buraschi, Trojani and Vedolin (2014), Piatti (2015) and Ehling and Heyerdahl-Larsen (2017) use different model settings to explain how correlation risk premium can arise. Empirically, we analyze the role of macroeconomic uncertainty, among other variables, 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), as well as for the global correlation risk premium, the economic uncertainty variable has a significant effect, while most of the alternative variables have insignificant effects after controlling economic uncertainty. This result is found to be robust to the use of alternative measures of economic uncertainty.

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

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

The correlation risk premium for the time period *(t, T)*, $CR_{t,T}$, corresponds to the difference between the time *t* risk neutral (measure *Q*) and the physical (measure *P*) expectations of the average pairwise correlation between *t* and *T*:

$$CR_{\mathrm{t,T}} \equiv \mathrm{E}_{\mathrm{t}}^{Q}\left(\mathrm{RC}_{\mathrm{t,T}}\right) - \mathrm{E}_{\mathrm{t}}^{P}\left(\mathrm{RC}_{\mathrm{t,T}}\right). \quad (1)$$

The most direct way of computing the risk-neutral expected value $\mathrm{E}_{\mathrm{t}}^{\mathrm{Q}}\left(\mathrm{RC}_{\mathrm{t,T}}\right)$ is to use the correlation swap rate $\mathrm{SC}_{\mathrm{t,T}}$, if available, at date *t* in the form of a correlation swap quote.[6] Since correlation and

[6]In the variance risk premium and correlation risk premium literature, there is no clear rule of how to define the premium. There are examples where the premium is defined as the risk neutral expectation (Q) minus the physical expectation (P), as in equation (1), and examples where it is defined as P – Q. Under both definitions the economic interpretation of our findings remains the same. In this paper, for the same convenience reasons as suggested by Bekaert and Hoerova (2014) when defining variance risk premium, we adopt the Q – P approach for the definition of the correlation risk premium: as most of the times $\mathrm{E}_{\mathrm{t}}^{Q}\left(\mathrm{RC}_{\mathrm{t,T}}\right) > \mathrm{E}_{\mathrm{t}}^{P}\left(\mathrm{RC}_{\mathrm{t,T}}\right)$, this leads CR as defined in (1) to be, most of the times, positive.

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. In fact, 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 $IC_{t,T}$:

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

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, and *n* is the number of index constituents. $SV_{t,T}^I$ 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. 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).[7] According to evidence reported in Faria and Kosowski (2016) with respect to the S&P500 index, the synthetic replication based on equation (2) matches real-world correlation swap rates for different maturities.

To estimate the index and single stock variance swap rates, $SV_{t,T}^I$ and $SV_{t,T}^i$ in (2), we follow

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

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:

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

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 we discuss how the physical expectation of average pairwise correlation $\mathrm{E}_{\mathrm{t}}^{\mathrm{P}}(\mathrm{RC}_{\mathrm{t,T}})$ can be estimated. By taking the 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)*:

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

Following Driessen, Maenhout and Vilkov (2013), we estimate $\mathrm{E}_{\mathrm{t}}^{P}(\mathrm{RC}_{\mathrm{t,T}})$ in Equation (4) from the average value-weighted pairwise realized correlation of the equity index constituents during the time period *(t, T)*, $\mathrm{RC}_{\mathrm{t,T}}$. 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 (Driessen, Maenhout and Vilkov, 2013) and (ii) our empirical analysis is based on the effective realization of the correlation risk premium.[8] An alternative way of estimating $E_t^P(RC_{t,T})$ 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 leads to an ex-ante measure of the correlation risk premium in (1): in section V we report the corresponding ex-ante measure results, which are broadly unchanged compared to those for the the ex-post measure.[9]

In our setting, the correlation risk premium for the period *(t, T)*, $CR_{t,T}$ in Equation (1), is therefore computed at time T and effectively corresponds to the realization of the correlation risk premium,

$$CR_{t,T} \equiv IC_{t,T} - RC_T \ , \tag{5}$$

with $IC_{t,T}$ being the synthetic correlation swap rate from Equation (2) computed at time *t*, and RC_T being the realized correlation between t and T computed at time T. A few further assumptions are required to reconcile the realized correlation risk premium given in equation (5) with the effective payoff for a correlation swap. In related work on variance swaps, Martin (2013b) and Bondarenko (2014) show (albeit with different approaches) that the replication or hedging of variance swap payoffs may require additional assumptions. The variance risk premium is defined and implemented in an analogous manner. For reasons of space, we do not add the term 'realized' to each mention of the correlation risk premium in the following sections of the paper.

[8] 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.

[9] An alternative way of estimating $E_t^P(RC_{t,T})$ consists of decomposing the realized correlation into continuous and discontinuous (jump) components and to use past observations of these components to estimate future realized correlation. This approach has been applied to the realized variance, e.g. Bekaert and Hoerova (2014), and represents an interesting avenue to explore in future research. Another alternative and practically more straightforward way of estimating $E_t^P(RC_{t,T})$ consists of using some regression specification for realized correlation, in line with what Corsi (2009) and Corsi, Pirino, and Reno (2010) do for the realized variance.

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 2012[10]. 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 Driessen, Maenhout and Vilkov (2013) and Faria and Kosowski (2016).

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[10] 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.

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 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 analyse the relationship between the cross-section of equity index options returns and the correlation risk, 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. We therefore consider 36 options (6 options x 6 indexes). We use the equal-weight average of each bucket.

The economic uncertainty indexes that we use are constructed by Baker, Bloom and Davis (2016) for France, Germany, the UK, the US and Europe. The authors construct the economic uncertainty index from newspaper coverage. In addition, we use an alternative economic uncertainty measure by Bekaert, Engstrom and Xu (2021). The authors estimate the monthly conditional variance of industrial production growth and then project it onto the financial instruments used to span the risk aversion index. The fitted value is the economic uncertainty index. More details and data for both uncertainty measures are available from the authors' websites.

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. In the second step, we analyse the co-movement of the correlation risk premiums in Europe and the US equity markets. 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.

IV.1 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.[11] Our findings below confirm these results for the index variance risk premium.

We complement the existing literature on the individual variance risk premium (e.g., Carr and Wu (2009); Driessen, Maenhout and Vilkov (2013)) 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, at time T the realization of the variance risk premium for the period *(t, T)* as follows:

$$VR_{t,T} \equiv IV_{t,T} - RV_T \ , \qquad (7)$$

with $IV_{t,T}$ being the synthetic variance swap rate computed at time *t*, and RV_T being the realized

[11] 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.

variance between t and T computed at time T.

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).

The annualized variance risk premium for the S&P500 in the 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 Driessen, Maenhout and Vilkov (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 Driessen, Maenhout and Vilkov (2013) for the 2008 to 2012 sub-sample.

[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 B is 0.90% (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.

IV.2 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.

[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 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. 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 3 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 8.6%, for the Eurostoxx 50 index it is 6.7% and for the FTSE100 it is 8.9% for 91-day maturity. These results are consistent with those reported in Driessen, Maenhout and Vilkov (2013); that study, using US data, finds a correlation risk premium of 7.65%, 7.48% and 16.15% 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 4.48%, using 30-day maturities for the 2008 to 2012 sample, which is similar to our results.

[Insert Table 3 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 during our sample period.

IV.3 Co-movement of the correlation risk premiums and Principal Component Analysis

One of the key questions that we study is whether correlation risk is reflected in international equity option markets returns. 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 91-day 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. The co-movement in RCs extends to correlation risk premiums (CR), as shown in Figure 3.

[Insert Figure 2 here]

[Insert Figure 3 here]

The insights gained from a visual inspection of Figures 2 and 3 are confirmed by the pair-wise correlation coefficients reported for different 91-day maturity RCs and CRs in Table 4. 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 4. 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.

[Insert Table 4 here]

The evidence presented in the above Figures and Table 4 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 4. 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 the "global" variance risk premium in Bollerslev, Marrone, Xu and Zhou (2014).

[Insert Figure 4 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 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 international equity markets, when "*there is no place to hide*" (Buraschi, Kosowski and Trojani, 2014).

IV.4 The cross-section of index option returns and 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. Driessen, Maenhout and Vilkov (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 study the relation between global correlation risk premium and international equity index option markets returns. Our cross-section contains 36 short maturity options, six options for each index, and is constructed as described in section III. The options are not delta-hedged. Transaction costs are not taken into account. We use non-overlapping monthly hold-to-maturity excess returns; that is, the excess 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*, in excess to the risk-free rate. 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,

$$\mathrm{CR}_{t,T}^{\mathrm{Global}} \equiv \sum_{i} w_t^i \, \mathrm{CR}_{t,T}^i, \tag{8}$$

where $i = 1,2 \ldots .6$ refers to each of the six indexes included in our analysis. A similar approach is used to compute a global variance risk premium ($\mathrm{VR}_{\mathrm{t,T}}^{\mathrm{Global}}$). 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.

Adopting the standard Fama-MacBeth procedure, in the first step we obtain the loadings of all options returns on the global correlation risk premium given by equation (8). 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.

Table 5 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), with results being broadly the same. Our estimates for model 1, which has the market risk premium and the global correlation risk premium CR^{Global} given by equation (8) as independent variables, show that the option return betas or loadings in the first step are all significant. In the second step we estimate the implied correlation risk premium to be 3.8% per month (*t*-statistics of 2.03). 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. Driessen, Maenhout and Vilkov (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.

The high level of adjusted R^2 (73.01%) compares favourably with the thresholds suggested by Lewellen, Nagel, and Shanken (2010), pp 176, "*We show that a sample adjusted R2 might need to be as high as 44% to be statistically significant in models with one factor, 62% in models with three factors, and 69% in models with five factors*". Additionally, it is similar to that reported in Driessen, Maenhout and Vilkov (2009); they document an 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 5 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 taken from a regression of the global index variance risk premium on the global correlation risk premium. The rationale behind Model 3 is to control for the effect of the global correlation risk premium embedded in the global index variance premium, i.e., it is a way of disentangling the component of global index variance premium that is not related with global correlation risk premium.

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

We find that the results are economically and statistically robust and the coefficient estimates from Models 2 and 3 are very similar. The reason why we include the market risk premium as an independent variable in the tested models presented in Table 5 is that we want to exclude the possibility of having its eventual effect embedded in the loading on the global correlation risk premium. We do this while cognizant of potential issues associated with multi-collinearity, since the market risk premium is naturally correlated with the variance risk premium and the correlation risk premium.

Overall, we obtain strong evidence supporting the hypothesis that exposure to the global correlation risk premium accounts for a sizable part of the cross-sectional variation in 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 strong relationship between the global correlation risk premium and international equity index option returns. A potential extension of this analysis would be to study if correlation risk is indeed priced in international equity index option markets. This is important, especially for practitioners, since it would imply that assets with higher correlation risk exposure would have higher average returns. We leave this for future research.

IV.5 The dependence of the correlation risk premium

Motivated by the literature that theoretically links the variance and correlation risk premiums to uncertainty, we next examine the dependence of the correlation risk premium in different countries, as well as the global correlation risk premium as computed in equation (8), on measures of uncertainty and macroeconomic conditions.

We regress the 30-day correlation risk premium on the following variables: (i) the underlying index returns, as a proxy for general market conditions; (ii) the economic uncertainty index (EPU index) by Baker, Bloom and Davis (2016), which is available for each country; [12] (iii) the premium component

[12] We also evaluate an alternative uncertainty measure, as given by Bekaert, Engstorm and Xu (2021), available for download from https://www.nancyxu.net/risk-aversion-index. The result is robust and similar to the main test, and it is reported in Appendix Table 1.

of VIX-type index, which we denote as VIX residual, computed for each market, proxied by the residual from the regression of VIX-type index on uncertainty index; (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; (v) the TED spread for each market, measured by the interest rates on interbank loans and short-term government debt, as a proxy for liquidity conditions in equity markets; (vi) the lagged correlation risk premium; (vii) and the financial stress index by Hu, Pan, and Wang (2013).

The regression model that we estimate through ordinary least squares (OLS) is given by:

$$CR_i = \alpha_i + \sum_{j=1}^{7} \beta_{i,j} X_j + \varepsilon_i \ , \qquad (10)$$

where CR_i stands for the 30-day correlation risk premium of equity index *i*, with *i* = CAC40, DAX, FTSE100, EuroStoxx 50 (SX5E), S&P500 and the global correlation risk premium, and X_j stands for the independent variable *j*, with *j* = economic uncertainty index, VIX residual, lagged correlation risk premium, equity index returns, interest rate term structure, TED spread and financial stress index. For each equity index, we run a univariate version of model (10), considering the economic uncertainty index as the sole independent variable, and a multivariate version of model (10), simultaneously considering all independent variables. Table 6 reports the results of the regression analysis. The economic uncertainty index (EPU index) has significant effects on *broader* indexes, such as the S&P 500 and EuroStoxx 50 indexes, as well as for the global correlation risk premium. For regressions involving the narrower country indexes the estimated coefficients for the EPU index are either insignificant (DAX, CAC40) or with an economic unexpected signal (FTSE100).

[Insert Table 6 here]

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 significant when related to the EPU index, which is a general measure of economic uncertainty based on daily newspaper coverage.

The results in Table 6 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 firm level earnings forecast uncertainty for the US equity market. Although we are using a different proxy for the uncertainty, our results also suggest the importance of investor disagreement about the likely future economic performance (as embedded in the economic uncertainty index) as a determinant of correlation risk premium. The market return, interest rate term structure, TED spread and financial stress index all have insignificant effects.

V. Robustness tests

V.1 Empirical asset pricing tests

Following Lewellen, Nagel, and Shanken (2010), we run some of their suggested prescriptions to improve empirical asset pricing tests. Starting with their prescription 2, "*Take the magnitude of the cross-sectional slopes seriously",* the authors at some point state "*A related restriction, mentioned earlier, is that the risk premium associated with a factor portfolio should be the factor's expected excess return.*". As reported in Table 5, the cross-sectional slope associated with the correlation risk premium varies between 3.8% and 5.7% depending on the model specification and set of index options included. Table 3 reports the summary statistics regarding the correlation risk premium. The average value of the correlation risk premium can be interpreted as the factor's expected return (for example as the expected payoff for the seller of a correlation swap contract). According to reported summary statistics, that expected return is 3.5%, 4.5%, 2.1% and 5.4% for the CAC40, DAX, SX5E and S&P500, respectively (for the FTSE the reported figure is not statistically significant and for the SMI the figure is clearly an outlier at 18.9%). In our view, this set of results fulfils the requirements from prescription 2 suggested by Lewellen, Nagel, and Shanken (2010).

Next, we evaluate Lewellen, Nagel, and Shanken (2010)'s prescription 3 "*Report the GLS cross-sectional R2.". The authors state that "obtaining a high GLS R2 represents a more stringent hurdle than obtaining a high OLS R2.*". As reported in Table 5, the reported GLS adjusted R2 are between 67.65% and 79.39%. Therefore, based on this criterion suggested by Lewellen, Nagel, and Shanken (2010), it is reasonable to say that our reported empirical findings are robust. At last, following the authors' suggested prescription 5, in Table 5 are reported the confidence intervals for the OLS adjusted-R^2: the minimum lower bound across all models tested is 60.86% which, in our view, further reinforces the robustness of the reported empirical findings.

V.2 Alternative subsamples

We explore the robustness of our findings by considering different subsample periods.

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, namely 2002 to 2007 and 2008 to 2012.

[Insert Table 7 here]

As can be seen in Table 7, almost all average implied correlations (ICs) and realized correlations (RCs) are larger during the 2008 to 2012 period than during 2002 to 2007, reflecting the effects of the global financial crisis. 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.

V.3 Alternative measure of correlation risk premium

As discussed in section II, an alternative way of estimating $E_t^P(RC_{t,T})$ 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 leads to an ex-ante measure of the correlation risk premium in (1). We find that our results are robust to the use of this ex-ante measure of the realized correlation, as reported in Table 8.

[Insert Table 8 here]

Although conceptually the expectation under the physical measure differs from the lagged correlation, results reported in Table 8 suggest that empirically the lagged correlation is a good forecast of the realized correlation. This is consistent with the high levels of autocorrelation of the average value-weighted pairwise realized correlation of the equity index constituents. [13]

VI. Conclusion

This paper contributes to the literature on the equity market correlation risk premium, by carrying out a 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 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 more than 70% of the cross-sectional variation in the European and US equity index option returns.

[13] We evaluate the autoregression properties of the daily series (monthly lag) of the average value-weighted pairwise realized correlation of the equity index constituents. For all equity indexes the autocorrelation coefficient is found to be statistically significant at 1% level (t-statistics are based on Newey and West (1987) standard errors) with an absolute value of 0.8 or higher (with exception of 0.6 for the SMI index).

According to our results, exposure to the global correlation risk premium is reflected in international equity market option returns. 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 relevant. 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 economic 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) and the global correlation risk premium, the economic uncertainty variable has a significant effect, while the residual component of the VIX-type indexes has insignificant effects after controlling for economic 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.

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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. Variance risk premium is computed as the difference between implied variance and realized variance. Panel A reports the variance risk premium for each index. Panel B reports the equal-weighted individual variance risk premium. The mean and standard deviation are in percentage form and expressed in annual terms. Sample period is from January 2002 to December 2012, except for CAC 40 (May 2003 to December 2012) and SMI (January 2006 to December 2012). *, **, *** denotes significance at the 10%, 5%, and 1% level, respectively. The t-statistics are based on Newey and West (1987) standard errors.

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: 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

Table 3: 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, using equation (2). 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. Sample period is from January 2002 to December 2012, except for CAC 40 (May 2003 to December 2012) and SMI (January 2006 to December 2012). *, **, *** denotes significance at the 10%, 5%, and 1% level, respectively. The t-statistics are based on Newey and West (1987) standard errors.

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

Table 4: 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. Sample period from January 2006 to December 2012.

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

Table 5: Option returns and correlation risk premium: Fama-MacBeth regression

This table reports the Fama-MacBeth regressions of option return (S&P500, CAC40, DAX, FTSE100, EuroStoxx 50 (SX5E), SMI) on the global correlation risk premium, computed using equation (8). Model 1 includes the global correlation risk premium and market 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 A reports the results for the sample without US data, and Panel B shows the whole sample results. Sample period is from January 2002 to December 2012, except for CAC 40 (May 2003 to December 2012) and SMI (January 2006 to December 2012). *, **, *** denotes significance at the 10%, 5%, and 1% level, respectively. The standard errors for the cross-sectional regression are calculated with the methodology of Shanken (1992). The table reports the cross-sectional OLS adjusted R^2, GLS adjusted R^2, and 95% confidence interval for OLS adjusted R^2 from 10,000 replications.

Panel A: Without US index options

	Model 1	Model 2	Model 3
Global correlation risk premium	0.039**	0.051**	0.057***
	(2.44)	(2.37)	(2.63)
Individual variance risk premium		0.023	
		(2.03)	
Index variance risk premium (residual)			0.011
			(1.91)
Market risk premium	0.006	0.005	0.005
	(1.19)	(0.93)	(0.91)
OLS $Adjusted\_R^2$	75.07%	77.69%	82.36%
GLS $Adjusted\_R^2$	67.65%	76.78%	79.39%
OLS $Adjusted\_R^2$ Confidence Interval	[61.35%, 88.59%]	[67.54%, 91.31%]	[72.35%, 92.29%]

Panel B: With US index options

	Model 1	Model 2	Model 3
Global correlation risk premium	0.038**	0.047**	0.044**
	(2.03)	(2.28)	(2.26)
Individual variance risk premium		0.029	
		(2.67)	
Index variance risk premium (residual)			0.009
			(1.99)
Market risk premium	0.005	0.006	0.006
	(0.96)	(1.06)	(0.97)
OLS $Adjusted\_R^2$	73.01%	77.69%	76.88%
GLS $Adjusted\_R^2$	72.50%	70.86%	75.93%
OLS $Adjusted\_R^2$ Confidence Interval	[60.86%, 89.51%]	[64.53%, 90.53%]	[61.61%, 90.02%]

Table 6: 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), S&P500) and global CRP. The independent variables include policy-related economic uncertainty index, VIX residual, lagged correlation risk premium, equity index returns, interest rate term structure, TED spread, and financial stress index (Hu, Pan, and Wang, 2013). 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. Sample period from January 2002 to December 2012 (May 2003 to December 2012 for CAC40). *, **, *** denotes significance at the 10%, 5%, and 1% level, respectively. The t-statistics are based on Newey and West (1987) standard errors.

	S&P500		SX5E		DAX		FTSE100		CAC40		Global	
Uncertainty	0.123***	0.087***	0.082***	0.051**	0.012	0.027	-0.024**	-0.011**	0.007	-0.012	0.081***	0.057***
	(5.55)	(3.15)	(4.39)	(2.39)	(0.81)	(1.02)	(-2.50)	(-2.27)	(0.52)	(-0.81)	(5.12)	(3.07)
VIX Residual		0.208		0.204		0.312**		0.539***		0.320		0.234
		(1.32)		(1.19)		(2.10)		(2.93)		(1.13)		(2.54)
lag_crp		0.267***		0.507***		0.323***		0.248***		0.400***		0.300
		(2.80)		(5.87)		(3.84)		(2.74)		(3.09)		(4.64)
Index		-0.130		-0.093		-0.053		0.067		-0.194		-0.145*
		(-0.74)		(-0.77)		(-0.27)		(0.42)		(-1.02)		(-1.88)
Term		-0.001		-0.012		-0.021*		-0.010		0.029		0.001
		(-0.12)		(-0.77)		(-1.86)		(-0.61)		(1.37)		(0.14)
TED		-0.007		-0.058		-0.016		-0.071		-0.009		-0.005
		(-0.35)		(-0.38)		(-0.57)		(-0.57)		(-0.28)		(-0.19)
Stress		-0.005		-0.008		-0.002		-0.002		0.005		-0.008*
		(-0.63)		(-0.75)		(-0.20)		(-0.22)		(0.52)		(-1.80)
Constant	-0.050***	-0.034	-0.089***	-0.047	0.032	0.012	0.022	0.012	0.024	-0.016	-0.042**	-0.029**
	(-2.69)	(-1.58)	(-2.94)	(-1.54)	(1.55)	(0.55)	(1.22)	(0.49)	(0.93)	(-0.55)	(-2.23)	(-2.28)
Observations	130	130	130	130	130	130	130	130	114	114	130	130
*Adjusted_*R^2	0.194	0.256	0.128	0.384	0.004	0.179	0.036	0.203	0.002	0.238	0.138	0.196

Table 7: 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, 2002-2007 (2003-2007 for the CAC40 index) and 2008-2012, 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, using equation (2). 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. *, **, *** denotes significance at the 10%, 5%, and 1% level, respectively. The t-statistics are based on Newey and West (1987) standard errors.

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)

Table 8: The *ex ante* correlation risk premium

This table reports the summary statistics for the implied correlation (IC), realized correlation (RC), and the *ex ante* 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, using equation (2). 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 backward window of daily stock returns. Sample period is from January 2002 to December 2012, except for CAC 40 (May 2003 to December 2012) and SMI (January 2006 to December 2012). *, **, *** denotes significance at the 10%, 5%, and 1% level, respectively. The t-statistics are based on Newey and West (1987) standard errors.

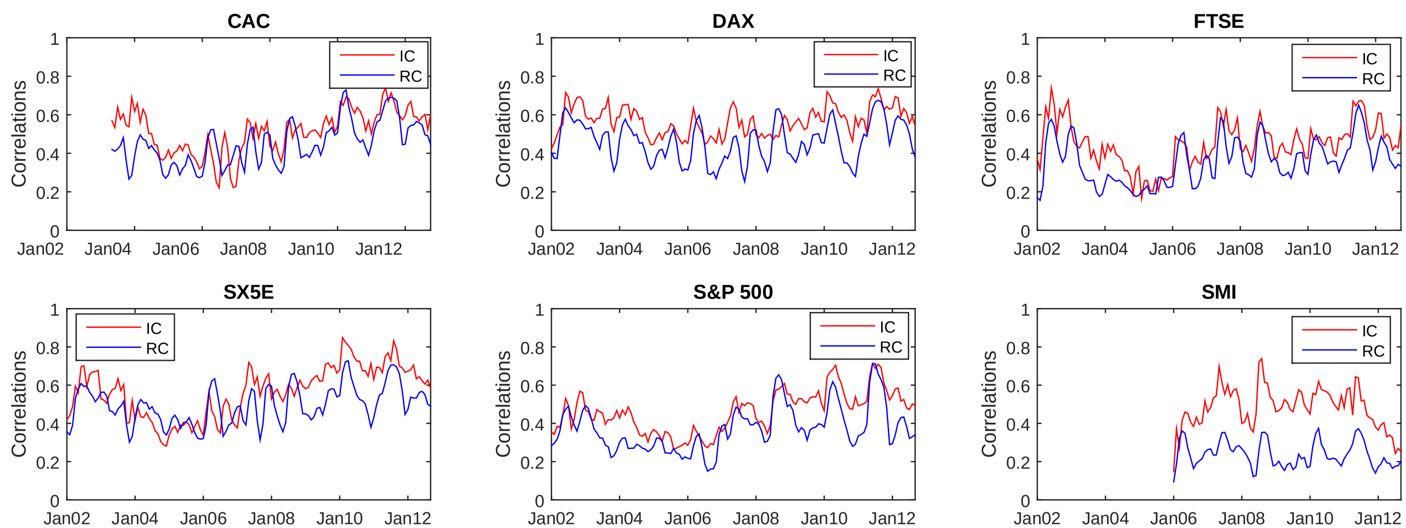
30 Days

	CAC40			DAX			FTSE100			SMI			SX5E			S&P 500		
	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	0.442	0.035	0.502	0.456	0.046	0.337	0.348	-0.011	0.416	0.227	0.188	0.512	0.490	0.022	0.430	0.375	0.056
t-stat			(3.23)			(5.90)			(-1.28)			(13.32)			(2.02)			(8.12)
median	0.485	0.436	0.032	0.492	0.466	0.046	0.322	0.328	-0.017	0.424	0.228	0.203	0.529	0.494	0.034	0.42	0.36	0.05
10th quantile	0.296	0.258	-0.117	0.366	0.276	-0.102	0.149	0.187	-0.169	0.229	0.104	-0.003	0.269	0.317	-0.171	0.257	0.212	-0.063
90th quantile	0.661	0.627	0.208	0.667	0.633	0.192	0.533	0.543	0.157	0.603	0.355	0.360	0.718	0.652	0.194	0.619	0.562	0.189
st_dev	0.157	0.140	0.151	0.117	0.132	0.117	0.155	0.138	0.128	0.172	0.096	0.157	0.169	0.128	0.149	0.137	0.138	0.100

91 Days

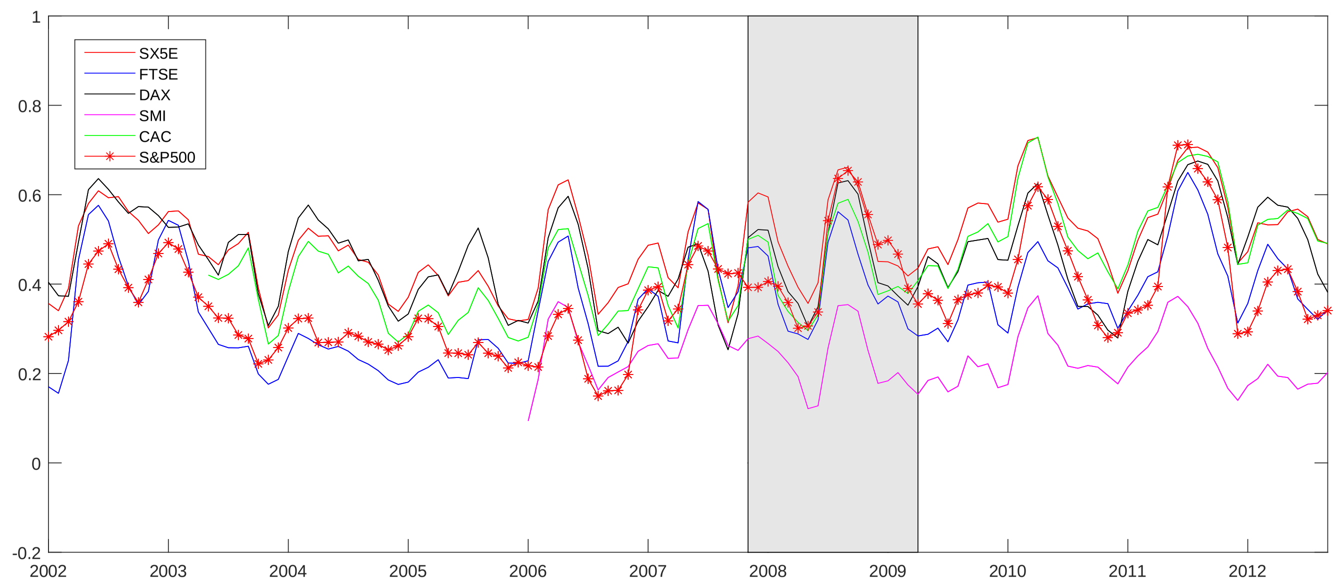
	CAC40			DAX			FTSE100			SMI			SX5E			S&P 500		
	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC	IC	RC	IC-RC
mean	0.515	0.449	0.065	0.568	0.461	0.107	0.446	0.355	0.091	0.470	0.234	0.236	0.566	0.495	0.071	0.462	0.373	0.089
t-stat			(5.22)			(11.45)			(10.83)			(14.75)			(5.13)			(9.63)
median	0.523	0.442	0.070	0.568	0.466	0.111	0.441	0.346	0.090	0.482	0.219	0.243	0.584	0.496	0.086	0.46	0.35	0.09
10th quantile	0.359	0.302	-0.065	0.455	0.315	0.001	0.282	0.208	-0.025	0.305	0.149	0.102	0.367	0.353	-0.085	0.310	0.239	-0.013
90th quantile	0.662	0.588	0.182	0.683	0.605	0.210	0.621	0.534	0.206	0.616	0.344	0.363	0.743	0.629	0.206	0.610	0.554	0.190
st_dev	0.133	0.113	0.107	0.088	0.106	0.089	0.126	0.119	0.091	0.075	0.112	0.142	0.102	0.115	0.123	0.114	0.121	0.078

Figure 1: Implied correlation and realized correlation



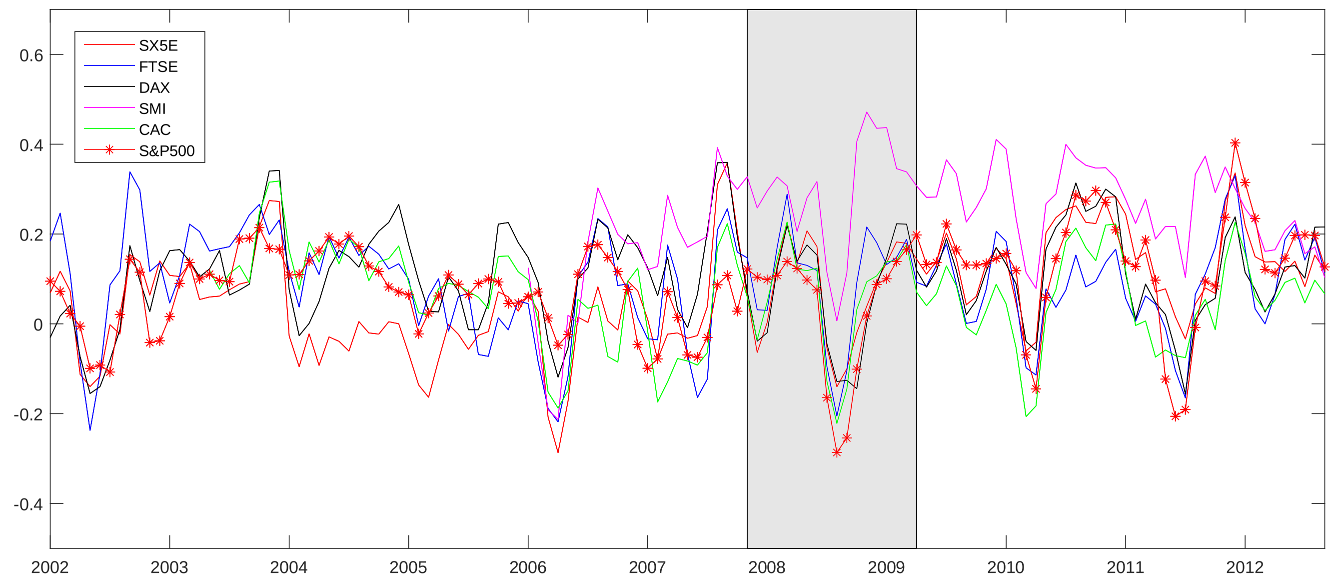
This figure shows the time series of the monthly average implied correlation (IC) and realized correlation (RC) for the 91 days maturity for the six indices under analysis (CAC40, DAX, FTSE100, EuroStoxx 50 (SX5E), SMI, S&P500). IC is calculated from daily observations of model-free implied variances for the index and for all index components, using equation (2). RC is a cross-sectional weighted average (using the appropriate weights from the respective index) of all pairwise correlations. Sample period is from January 2002 to December 2012, except for CAC 40 (May 2003 to December 2012) and SMI (January 2006 to December 2012).

Figure 2: Realized correlation



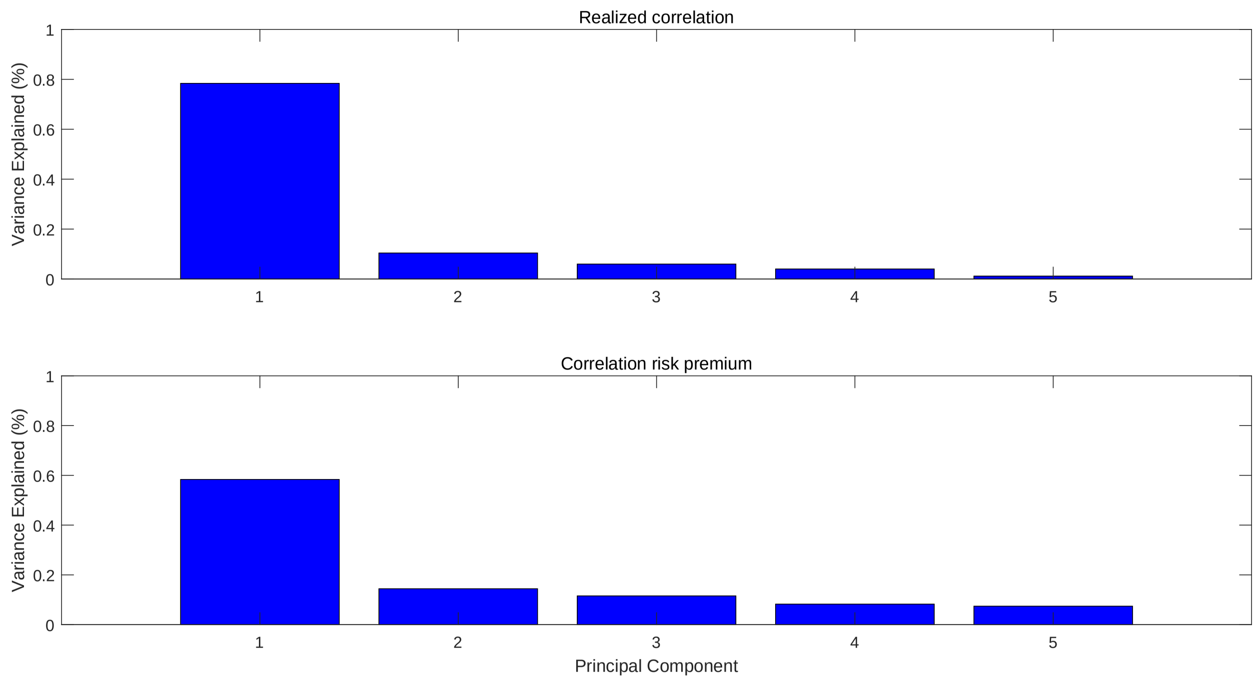
This figure plots the time series of the monthly average realized correlation (RC) for 91 days maturity for the six indices under analysis (CAC, DAX, FTSE100, EuroStoxx 50 (SX5E), S&P500 and SMI). RC is a cross-sectional weighted average (using the appropriate weights from the respective index) of all pairwise correlations. Sample period is from January 2002 to December 2012, except for CAC 40 (May 2003 to December 2012) and SMI (January 2006 to December 2012). The grey bar indicates the global financial crisis period.

Figure 3: Realized Correlation risk premium



This figure shows the realized correlation risk premium (IC-RC) 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. Sample period is from January 2002 to December 2012, except for CAC 40 (May 2003 to December 2012) and SMI (January 2006 to December 2012). The grey bar indicates the global financial crisis period.

Figure 4: 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. Sample period is from January 2002 to December 2012, except for CAC 40 (May 2003 to December 2012).

Appendix Table 1: The determinants of the correlation risk premium: alternative uncertainty measure

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), S&P500). The independent variables include policy-related economic uncertainty index, VIX residual, lagged correlation risk premium, equity index returns, interest rate term structure, TED spread, and financial stress index (Hu, Pan, and Wang, 2013). Uncertainty index is based on Bekaert, Engstrom and Xu (2021), and it is available at https://www.nancyxu.net/risk-aversion-indexl. Sample period from January 2002 to December 2012 (May 2003 to December 2012 for CAC40). *, **, *** denotes significance at the 10%, 5%, and 1% level, respectively. The t-statistics are based on Newey and West (1987) standard errors.

	S&P500		SX5E		DAX		FTSE100		CAC40		Global	
Uncertainty_BEX	0.031*	0.027*	0.082**	0.046**	0.019	0.020	0.034**	0.022	0.029	0.036	0.037**	0.025*
	(1.70)	(1.78)	(2.28)	(2.03)	(1.24)	(0.49)	(2.35)	(1.23)	(1.15)	(1.22)	(2.32)	(1.68)
VIX Residual		0.319		0.074		0.398**		0.719*		0.298		0.264
		(0.93)		(0.46)		(2.07)		(1.91)		(0.70)		(1.15)
lag_crp		0.318***		0.525***		0.326***		0.280***		0.405***		0.336***
		(2.96)		(6.83)		(5.02)		(3.11)		(4.16)		(4.33)
Index		-0.098		-0.075		-0.061		0.045		-0.184		-0.151**
		(-0.54)		(-0.77)		(-0.42)		(0.24)		(-1.09)		(-1.97)
Term		0.011		0.007		-0.016**		-0.023*		0.024*		0.012*
		(1.08)		(0.42)		(-2.26)		(-1.71)		(1.88)		(1.79)
TED		-0.016		0.121		-0.004		-0.181		-0.032		-0.004
		(-0.63)		(0.91)		(-0.06)		(-1.37)		(-0.79)		(-0.09)
Stress		-0.010		-0.001		-0.003		-0.010		0.006		-0.008
		(-1.03)		(-0.09)		(-0.31)		(-1.14)		(0.57)		(-1.34)
Constant	-0.016	-0.032	-0.168*	-0.106**	0.003	-0.002	-0.089**	-0.016	-0.033	-0.078	-0.043	-0.047*
	(-0.39)	(-1.01)	(-1.71)	(-2.07)	(0.06)	(-0.03)	(-2.14)	(-0.42)	(-0.43)	(-1.27)	(-1.09)	(-1.82)
Observations	130	130	130	130	130	130	130	130	114	114	130	130
*Adjusted*_R^2	0.024	0.169	0.104	0.340	0.001	0.133	0.024	0.138	0.008	0.191	0.047	0.170