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Marinela Adriana FINTA
Singapore Management University, mfinta@smu.edu.sg

Sofiane ABOURA
Université de Paris XIII

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Marinela Adriana Finta[ab] Sofiane Aboura[c]

a Department of Accountancy and Finance, Otago Business School, University of Otago, Po Box 56, 9054 Dunedin, New Zealand

b Sim Kee Boon Institute for Financial Economics, Lee Kong Chian School of Business, Singapore Management University, 50 Stamford Road, 178899 Singapore

c Université de Paris XIII, Sorbonne Paris Cité, 99 avenue Jean-Baptiste Clément, 93430 Villetaneuse, France

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Abstract

We investigate the volatility and skewness risk premium spillovers among the U.S., U.K., German, and Japanese stock markets. We define risk premia as the difference between risk-neutral and realized moments. Our findings highlight that during periods of stress, cross-market and cross-moment spillovers increase and that these increases are mirrored by a decrease in within-market effects. We document strong bidirectional spillovers between volatility and skewness risk premia and emphasize the prominent role played by the volatility risk premium. Finally, we show that several announcements drive the time-varying risk premium spillovers.

Keywords: Spillovers, Volatility, Skewness, Risk-neutral, Risk premium

1. Introduction

The collapse of Lehman Brothers in September 2008 demonstrates the importance of understanding risk transmission among stock markets. Although risk occurs in one country, it can spread to other countries, leading to potentially large financial losses. There are a number of papers in the literature on the premium that investors require for bearing various risks, such as variance and skewness risks (Bollerslev et al., 2009; Bekaert and Hoerova, 2014; Sasaki, 2016). As such, it is essential to be aware of the interactions among these risk premia.

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∗ Corresponding author. Department of Accountancy and Finance, Otago Business School, University of Otago, Po Box 56, 9054 Dunedin, New Zealand. E-mail addresses: mfinta@smu.edu.sg (M.A. Finta), marinela.finta@otago.ac.nz (M.A. Finta), marinela.finta@gmail.com (M.A. Finta), sofiane. aboura@univparis13.fr (S. Aboura)

The present paper focuses on how different risk premia (e.g., variance risk premium (VRP) and skewness risk premium (SRP)) contribute to the transmission of shocks across international equity markets. For example, the onset of a financial crisis in one country might cause global investors to increase the premia they require in order to bear volatility and higher-order moment risks for equity in other countries. As such, although shocks occur in one market, investors might tend to reassess the risk of other markets as well, leading to cross-market and cross-moment risk premium spillovers regardless of whether the markets are related through trade or financial linkages. Indeed, Longstaff and Rajan (2008) and Longstaff (2010) document that a negative shock in one market leads to a rise in the risk premium in other markets. Bollerslev et al. (2009) and Londono (2015) find that the U.S. variance risk premium has significant predictive power for international stock returns, such as those in Germany, the United Kingdom, and Japan. Do et al. (2016) show that a shock to one market that increases the realized volatility and higher-order moments of its return distribution leads to a large spillover in the moments of other equities' return distribution. Moreover, investors might become more risk-averse and rebalance their portfolio by reducing their exposure to risky assets and to assets in other markets as well (Kumar and Persaud, 2002). Therefore, we anticipate substantial cross-market and cross-moment spillovers.

In this study, we investigate the time-varying risk premium spillovers among the stock markets in the U.S., the U.K., Germany, and Japan from 2008 to 2016.[1] We construct these risk premium measures as the difference between risk-neutral moments extracted from options data and realized moments computed using high-frequency data.[2] Specifically, applying the approach of Diebold and Yilmaz (2012, 2014) and Greenwood-Nimmo et al. (2015), we first examine spillovers between the VRP and SRP from a cross-market and cross-moment perspective.[3] That is, we assess the spillovers among aggregate stock markets across risk premia (within-market effects and cross-market spillovers) and the spillovers among aggregate risk premia across stock markets (within-moment effects and cross-moment spillovers). Additionally, we extend the investigation to the kurtosis risk premium (KRP) and briefly report the relations between the VRP, SRP, and KRP. Second, we examine how several important events (e.g., economic and political events) contribute to the aggregate cross-market and cross-moment spillovers. Our choice of econometric setup is motivated by our interest in (i) quantifying the magnitude of cross-market and cross-moment spillovers; (ii) computing directional spillovers to identify the receivers and transmitters of shocks; and (iii) accounting for each of the risk premia when investors desire to hedge against intertemporal shifts with their degree of concern.

Our findings highlight the importance of considering the interactions of risk premia across markets and moments. First, we provide insight on time-varying risk premium spillovers. We observe that during periods of stress, there is an increase in cross-market and cross-moment spillovers (i.e., from the VRP to the SRP and vice versa), as well as a reduction in the magnitude of the within-market effects. Second, we document strong bidirectional spillovers between volatility and the skewness risk premia. In addition, we show that cross-moment effects, namely, volatility and the skewness risk premia, are stronger than within-moment effects. These findings suggest that international investors require compensation for bearing not only their own-moment risks but also cross-moment risks. Third, we emphasize that various announcements explain changes in aggregate spillover among markets and moments, as well as in cross-market and -moment spillovers. In general, the results reveal that our risk premium spillovers substantially decline and rise following the expansionary and contractionary announcements, respectively, except for expansionary news occurring during crisis periods. Further, to confirm the robustness of our results, we also consider the aggregate cross-market and cross-moment implied spillovers and those including the KRP. We show that, over time, the patterns of these implied spillovers are similar to those of risk premium spillovers. Moreover, considering the KRP yields little empirical benefits on the risk premium spillovers. Overall, our results reflect (i) the increasing importance given to cross-market and cross-moment spillovers, especially during high-stress periods and following various announcements; (ii) the more prominent role of the VRP; and (iii) the substantial effects of various announcements on the risk premium spillovers.

Our paper builds upon the literature on the variance risk premium and higher-order moments. While many studies emphasize the predictive ability of risk premia for domestic markets (Bollerslev et al., 2009; Drechsler and Yaron, 2011; Sasaki, 2016), the relationship between the VRP and higher-order risk premia is also important. The VRP reflects the investors' jump fears (Bollerslev and Todorov, 2011), whereas the higher-order risk premia capture the investors' downside risk and tail fears. Indeed, several studies show that higher-order moments explain a large fraction of the variance risk premium and hence, that the VRP increases after a negative shock or market crash (Todorov, 2010; Bollerslev and Todorov, 2011; Ait-Sahalia et al., 2018). For instance, Bakshi and Madan (2006) and Chabi-Yo (2012) theoretically demonstrate that higher-order moments are the main determinants of the VRP. Specifically, these authors show that the VRP is higher when the return distribution is left-skewed

[1] There are several reasons for the choice of the U.S., U.K., German, and Japanese stock markets. First, we include four of the largest nations measured by nominal GDP that represent almost 40% of the world's GDP in 2016, according to the World Bank. Second, these countries are important trading partners, and their financial centers are well connected (Baker et al., 2012). For instance, New York City and London are related through the cultural geography of finance, global trade, financial deregulation, and the implementation of the newest technologies (Degl'Innocenti et al., 2017; Wójcik, 2013), London and Frankfurt through the flows of knowledge, culture, and governance (Beaverstock et al., 2005), and Tokyo is among the most important financial centers in Asia. By considering the sample period from 2008 to 2016 for our analysis, we take into account several important events that had substantial impacts on financial markets. The extension of this research to other markets and for a longer sample period would be interesting, but we note that the liquidity of those markets may be problematic in the calculation of risk-neutral measures.

[2] To compute the model-free risk-neutral volatility, skewness, and kurtosis, we use a collection of out-the-money European call and put options (Bakshi and Madan, 2000; Carr and Madan, 2001; Bakshi et al., 2003). The realized volatility, skewness, and kurtosis are estimated from the 5 min intraday squared, cubic, and quartic returns (Andersen et al., 2003; Amaya et al., 2015).

[3] This approach has been employed by several recent studies (Cipollini et al., 2013; Greenwood-Nimmo et al., 2015, 2016; Do et al., 2016; Baruník et al., 2016; Zhang, 2017).

and leptokurtic. Adrian and Rosenberg (2008) find that the short-run volatility premium strongly relates to the SRP. Similarly, Kozhan et al. (2013) show that the SRP drives the VRP.

We contribute to the above literature by exploring the relationships between volatility and higher-order risk premia, and in particular the SRP. To the best of our knowledge, no study addresses these spillovers using risk premia. The limited exceptions include Cipollini et al. (2013), who examine the variance risk premium spillovers among stock markets,[4] and a few other studies that focus on either currencies' implied (Greenwood-Nimmo et al., 2016) or currency and stock markets' realized (Hong et al., 2009; Do et al., 2016) skewness and kurtosis spillovers. Hence, our paper is the first to document the cross-market and cross-moment spillover effects between two risk premia that are directly attributable to the fear of volatility and downside risks and to discuss these effects when accounting for tail risk.

The remainder of this paper is organized as follows. In Section 2, we outline the methodology. We describe the data in Section 3. In Section 4, we present the findings. In Section 5, we discuss the relations between various announcements and our spillovers. Concluding remarks are in Section 6.

2. Methodology

To investigate spillovers among the risk premia in stock markets, we first compute the risk-neutral and realized volatility and skewness moments. Second, we define our measures of risk premia as the difference between these implied and realized moments computed from options and high-frequency data, respectively. Finally, we apply the connectedness approach of Diebold and Yilmaz (2012, 2014). This approach relies on the variance decompositions of a vector autoregressive (VAR) model; that is, it allows us to explore the H-step-ahead forecast error variance in market i's risk premium that is due to innovations (shocks) in other markets' risk premia. Moreover, it also allows us to measure the directional spillover received by market i's risk premium from the risk premia of all other markets j. To account for the spillovers among block aggregations of the connectedness matrix (i.e., the spillovers among stock markets and risk premia), we apply Greenwood-Nimmo et al.'s (2015) generalization of the standard framework of Diebold and Yilmaz (2012, 2014).

Following Menkhoff et al. (2012) and Greenwood-Nimmo et al. (2016), we first filter the daily time series of risk premia using a first-order autoregressive AR (1) model in order to reduce the persistence of these series.[5] Specifically, we recover the innovations in the VRP ($\widetilde{VRP}_{it}$) and SRP ($\widetilde{SRP}_{it}$) for $i = 1, 2, \ldots, N$ stock markets at a daily frequency over $t = 1, 2, \ldots, T$ trading days.[6] The 2×1 vector $\widetilde{\boldsymbol{x}}_{\boldsymbol{it}} = (\widetilde{VRP}_{it}; \widetilde{SRP}_{it})'$ captures the innovations in the market-specific risk premium for the i-th stock market, and the $2N \times 1$ vector $\widetilde{\boldsymbol{x}}_{\boldsymbol{t}} = (\widetilde{\boldsymbol{x}}_{1t'}, \widetilde{\boldsymbol{x}}_{2t'}, \ldots, \widetilde{\boldsymbol{x}}_{\boldsymbol{Nt}}{}')$ contains the risk premium innovations for each stock market. The total number of variables in the system is $d = 2N$.

Diebold and Yilmaz (2012, 2014) suggest a p-th order reduced-form VAR for the $d \times 1$ vector of variables $\widetilde{\boldsymbol{x}}_{\boldsymbol{t}}$:

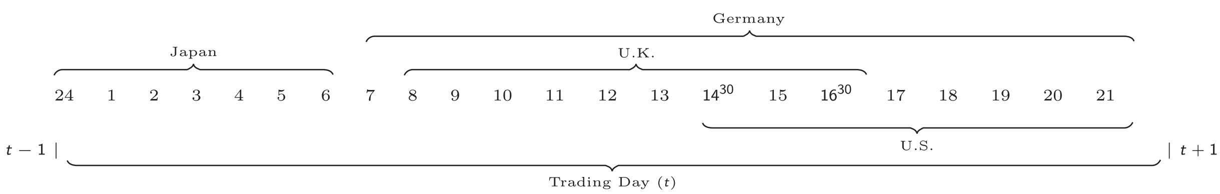
$$\widetilde{\boldsymbol{x}}_{\boldsymbol{t}} = \Sigma_{j=1}^{p} \boldsymbol{\Phi}_{\boldsymbol{j}} \widetilde{\boldsymbol{x}}_{\boldsymbol{t-j}} + \boldsymbol{e}_{\boldsymbol{t}} \tag{1}$$

where the $\boldsymbol{\Phi}_{\boldsymbol{j}}$ for $j = 1, 2, \ldots, p$ are $d \times d$ coefficient matrices and $\boldsymbol{e}_{\boldsymbol{t}} \hookrightarrow N(0, \boldsymbol{\Sigma}_{\mathbf{e}})$ are the reduced-form residuals with covariance matrix $\boldsymbol{\Sigma}_{\mathbf{e}}$. The H-step-ahead generalized forecast error variance decomposition for the risk premium of the i-th stock market is

[4] The authors use a wavelet analysis based on the orthogonalization of stock market shocks in France, Germany, the U.K., Switzerland, and the U.S.

[5] The main reason for using the AR (1) model is to remove the serial correlation in risk premia, namely, the variance and skewness risk premia. Specifically, as the daily risk premia are highly persistent, the AR (1) model is akin to differentiating these series. Afterwards, the VAR model would capture any remaining serial correlation in the data, and hence, using a first-order VAR is sufficient. Similarly, we also recover the KRP innovations ($\widetilde{\text{KRP}}$).

[6] We define our trading day, for which all times are taken to be the Greenwich Mean Time, as follows:



Given this trading day definition, that is, the normal trading hours of the stock markets, we then compute the realized moments. Our findings are also robust to the inclusion of overnight returns in the computation. We also acknowledge the potential of spurious spillover effects due to the simultaneity issue and the lack of congruence in active trading hours. For instance, in a hypothetical, perfectly liquid global market, stock markets' risk premium reactions to various news/shocks would be simultaneous. As one solution for this simultaneity issue, few studies split the returns into overnight and daytime returns (e.g., Baur and Jung, 2006). However, markets might be closed or if 24-h electronic trading is permitted, they might be inactive and illiquid. Accordingly, other studies use the markets' normal trading hours and focus on lead-lad dynamics (e.g., Clements et al., 2014). Our study addresses this simultaneity concern by focusing on the lead-lag relations among risk premia; that is, it examines the transmission of the risk premium that is incorporated during normal trading hours in one market to other markets in the next period. Therefore, by using high-frequency data covering normal trading hours, we avoid illiquid trading and at the same time provide better daily realized measures. We would like to thank an anonymous referee for highlighting the importance of these concerns.

given by the following (Pesaran and Shin, 1998):

$$\vartheta_{i\leftarrow j}^{(H)}=\frac{\sigma_{e,jj}^{-1}\sum_{h=0}^{H-1}(\epsilon_{\mathbf{i}}'\boldsymbol{A_h}\boldsymbol{\Sigma_e}\boldsymbol{\epsilon_j})^2}{\sum_{h=0}^{H-1}\epsilon_{\mathbf{i}}'\boldsymbol{A_h}\boldsymbol{\Sigma_e}\boldsymbol{A_h}'\epsilon_{\mathbf{i}}} \tag{2}$$

for $i,j = 1,\ldots,d$, where the standard deviation σ_{ejj} is the j-th diagonal element of $\boldsymbol{\Sigma_e}$ and $\boldsymbol{\epsilon_i}$ is a $d \times 1$ vector with its i-th element set to one and zero otherwise; $\boldsymbol{A_h}$ is defined recursively as $\boldsymbol{A_h} = \boldsymbol{\Phi_1 A_{h-1}} + \boldsymbol{\Phi_2 A_{h-2}} + \cdots + \boldsymbol{\Phi p A_{h-p}}$ for $h = 1,2,\ldots$, with $\boldsymbol{A_0}$ being a $d \times d$ identity matrix, and $\boldsymbol{A_h} = 0$ for $h < 0$. $\vartheta_{i\leftarrow j}^{(H)}$ captures the share of the H-step-ahead forecast error variance of stock market i that is due to stock market j's shocks. Generalized forecast error variance decomposition has the benefit of being order invariant (i.e., the variance decompositions are invariant to ordering). Due to the nonzero correlation among shocks, $\sum_{j=1}^{d}\vartheta_{i\leftarrow j}^{(H)} > 1$. Following Diebold and Yilmaz (2012, 2014), the percentage interpretation of the forecast error variance shares can be achieved by normalizing each entry of the variance decomposition matrix by the row sum as follows: $\psi_{i\leftarrow j}^{(H)} = 100\times\left(\vartheta_{i\leftarrow j}^{(H)}/\sum_{j=1}^{d}\vartheta_{i\leftarrow j}^{(H)}\right)\%$. $\psi_{i\leftarrow j}^{(H)}$ is a measure of pairwise spillovers from variable j to variable i at horizon H, and $\psi_{i\leftarrow j}^{(H)} \neq \psi_{j\leftarrow i}^{(H)}$.

Diebold and Yilmaz (2012, 2014) further construct the H-step-ahead $d \times d$ connectedness matrix among the d variables in $\widetilde{\boldsymbol{x}}_{\boldsymbol{t}}$ as:

$$\mathbf{C}^{(H)}=\begin{bmatrix}\psi_{1\leftarrow 1}^{(H)} & \psi_{1\leftarrow 2}^{(H)} & \cdots & \psi_{1\leftarrow d}^{(H)}\\ \psi_{2\leftarrow 1}^{(H)} & \psi_{2\leftarrow 2}^{(H)} & \cdots & \psi_{2\leftarrow d}^{(H)}\\ \vdots & \vdots & \ddots & \vdots\\ \psi_{d\leftarrow 1}^{(H)} & \psi_{d\leftarrow 2}^{(H)} & \cdots & \psi_{d\leftarrow d}^{(H)}\end{bmatrix} \tag{3}$$

As the variables are in the order $\widetilde{\boldsymbol{x}}_{\boldsymbol{t}} = (\widetilde{VRP}_{1t}, \widetilde{SRP}_{1t}; \widetilde{VRP}_{2t}, \widetilde{SRP}_{2t}; \ldots; \widetilde{VRP}_{Nt}, \widetilde{SRP}_{Nt})'$, we next evaluate the connectedness among the N markets in the model in a combined manner that encompasses both variables in each market. Specifically, we can define the connectedness matrix $\mathbf{C}^{(H)}$ in block form, with $g = N$ groups each composed of $m = 2$ variables as follows:

$$\mathbf{C}^{(H)}=\begin{bmatrix}\mathbf{B}_{1\leftarrow 1}^{(H)} & \mathbf{B}_{1\leftarrow 2}^{(H)} & \cdots & \mathbf{B}_{1\leftarrow N}^{(H)}\\ \mathbf{B}_{2\leftarrow 1}^{(H)} & \mathbf{B}_{2\leftarrow 2}^{(H)} & \cdots & \mathbf{B}_{2\leftarrow N}^{(H)}\\ \vdots & \vdots & \ddots & \vdots\\ \mathbf{B}_{N\leftarrow 1}^{(H)} & \mathbf{B}_{N\leftarrow 2}^{(H)} & \cdots & \mathbf{B}_{N\leftarrow N}^{(H)}\end{bmatrix} \tag{4}$$

$$\mathbf{B}_{i\leftarrow j}^{(H)}=\begin{bmatrix}\psi_{\widetilde{\mathsf{VRP}}_i\leftarrow\widetilde{\mathsf{VRP}}_j}^{(H)} & \psi_{\widetilde{\mathsf{VRP}}_i\leftarrow\widetilde{\mathsf{SRP}}_j}^{(H)}\\ \psi_{\widetilde{\mathsf{SRP}}_i\leftarrow\widetilde{\mathsf{VRP}}_j}^{(H)} & \psi_{\widetilde{\mathsf{SRP}}_i\leftarrow\widetilde{\mathsf{SRP}}_j}^{(H)}\end{bmatrix}$$

for $i,j = 1,2,\ldots,N$ and where the block $\mathbf{B}_{i\leftarrow i}^{(H)}$ collects all within-market effects for market i, while $\mathbf{B}_{i\leftarrow j}^{(H)}$ collects all spillover effects from market j to market i. Greenwood-Nimmo et al. (2015) stress that, due to the order-invariance of generalized forecast error variance decomposition, the variables in $\widetilde{\boldsymbol{x}}_{\boldsymbol{t}}$ can be reordered as necessary to support any desired block structure. Using the connectedness matrix, we can define the following spillovers:

$$M_{i\leftarrow i}^{(H)}=\frac{1}{m}\boldsymbol{u_m}'\mathbf{B}_{i\leftarrow i}^{(H)}\boldsymbol{u_m} \tag{5}$$

$$S_{i\leftarrow j}^{(H)}=\frac{1}{m}\boldsymbol{u_m}'\mathbf{B}_{i\leftarrow j}^{(H)}\boldsymbol{u_m} \tag{6}$$

where $M_{i\leftarrow i}^{(H)}$ captures the *total within-market* forecast error variance contribution for market i and $\boldsymbol{u_m}$ is an $m \times 1$ vector of ones, i.e., $M_{i\leftarrow i}^{(H)}$ measures the share of the H-step-ahead of the i-th stock market that is due to own shocks. $S_{i\leftarrow j}^{(H)}$ captures the *total between-market* directional spillover from market j to market i at horizon H.

The aggregate *from* and *to* spillover of market i is defined as:

$$S_{i\leftarrow\bullet}^{(H)}=\sum_{j=1,j\neq i}^{N}S_{i\leftarrow j}^{(H)};\; S_{\bullet\leftarrow i}^{(H)}=\sum_{j=1,j\neq i}^{N}S_{j\leftarrow i}^{(H)}, \tag{7}$$

where $S_{i\leftarrow\bullet}^{(H)}$ shows the total spillover from all stock markets to the i-th stock market (the *from* spillover) and $S_{\bullet\leftarrow i}^{(H)}$ captures the total spillover from the i-th stock market to all stock markets (the *to* spillover). Finally, the *aggregate* spillover among markets is defined as:

$$S^{(H)} = \frac{1}{N}\sum_{i=1}^{N} S^{(H)}_{i\leftarrow\bullet}. \tag{8}$$

The details of the block approach by moment are provided in Appendix A.1.

3. Data

We explore the connectedness between innovations in the VRP and SRP for stock markets in the U.S., the U.K., Germany, and Japan. The option and high-frequency data are obtained from the Thomson Reuters Tick History and cover the period from January 2008 to December 2016.[7] Using high-frequency data, we compute the realized volatility and skewness as in Amaya et al. (2015), where their computation relies on sums of five minute returns. The risk-neutral moments, namely, implied volatility and skewness, are estimated by following the model-free methodology of Bakshi et al. (2003). Further details on their computation are provided in Appendix A.2. We then follow Bollerslev et al. (2009) to compute the risk premia as the difference between implied and realized moments. Finally, note that throughout the analysis, we refer to $\widetilde{\text{VRP}}$ and $\widetilde{\text{SRP}}$ as the innovations.

Table 1 reports the descriptive statistics, namely, the means and standard deviations of the realized moments (Panel A), implied moments (Panel B), risk premia (Panel C), and risk premium innovations (Panel D). Panels A and B show that for all countries, implied volatility is higher than its realized counterpart. The implied skewness is negative, with its highest mean in the U.S. stock market. Realized skewness is also negative in all countries. These findings indicate that the risk-neutral distribution of stock returns is more left-skewed than the realized distribution of stock returns.

The statistics in Panel C show that the risk-neutral moments are generally larger (in absolute value) than the realized moments. Specifically, this is the case for volatility (Bollerslev et al., 2009) and skewness (Christoffersen et al., 2017). The fact that the implied moments are larger than the realized moments indicates that, on average, investors' fears of negative future outcomes are not reflected in the realized moments. Note that the VRP is positive in all countries, ranging from 0.007 in Germany to 0.0049 in Japan. This positive VRP is related to investors' dislike of volatility risk, meaning that risk-averse investors would like to hedge against a rise in volatility. Hence, the implied volatility would be higher than the realized volatility, leading to a positive VRP (Bollerslev et al., 2009; Bekaert et al., 2013).

The skewness risk premia are negative, and the highest mean value is observed in the U.S. stock market. The negative SRP stems from investors' preference for positive skewness. Specifically, because risk-averse investors want to hedge against a drop in skewness, the implied skewness is higher in absolute value than the realized skewness (Bakshi et al., 2003; Rauch and Alexander, 2016; Zhao et al., 2013). Panels A–D show that for each of the volatility and skewness moments and risk premia, the magnitude of the standard deviation is similar across all stock markets,.

4. Results

In this section, we begin by studying the connectedness across the full sample. We then explore the relations among the aggregate stock markets across moments (total within-market effects and cross-market risk premium spillovers) and among the aggregate risk premia across stock markets (total within-moment effects and cross-moment risk premium spillovers). Finally, using rolling window estimation, we emphasize the importance of time variation in these interactions.

4.1. Connectedness among risk premia

The starting point of our analysis is the estimation of a VAR model over the full sample period using a forecast horizon of ten trading days (Greenwood-Nimmo et al., 2016). Using the Akaike information criterion, we find a lag length of one day to be optimal. Table 2 shows the (8×8) connectedness matrix between the volatility and skewness risk premium innovations of the stock markets in the U.S., the U.K., Germany, and Japan. While the main diagonal captures the spillovers due to own-market effects, the off-diagonal entries capture the directional spillovers due to the risk premium effects from other markets. Specifically, Table 2 presents the ten-day-ahead percentage contribution of shocks to each risk premium in explaining the share of the total variance of the risk premium in stock markets.

A large share of the $\widetilde{\text{VRP}}$ in stock markets is due to own-moment effects, ranging from approximately 63% in Germany to 87% in the U.K. Moreover, the cross-$\widetilde{\text{VRP}}$ effects on different stock markets have high impacts on volatility premia, accounting for more than 10% of their own variance, which is 22% in the U.S., 11% in the U.K., 35% in Germany, and 17% in Japan. We also document a substantial contribution of own- and cross-$\widetilde{\text{SRP}}$ effects to $\widetilde{\text{VRP}}$.

We further identify stronger own effects for the $\widetilde{\text{SRP}}$ than for the $\widetilde{\text{VRP}}$. Specifically, we find that while own effects explain between approximately 91% and 98% of its variance, the cross-$\widetilde{\text{SRP}}$ spillover accounts for less than approximately 3.5%. In addition to the above effects, the $\widetilde{\text{VRP}}$ to $\widetilde{\text{SRP}}$ spillover is approximately 5% in the U.S., 0.01% in the U.K., 2% in Germany, and 1% in

[7] We use the S&P 500, FTSE 100, DAX 30, and NIKKEI 225 indices as proxies for the stock markets in the U.S., U.K., Germany, and Japan, respectively.

Table 1
Summary statistics.

		U.S.	U.K.	Germany	Japan
Panel A: Realized moments					
Volatility	Mean	0.0075	0.0072	0.0110	0.0091
	25th	0.0045	0.0048	0.0079	0.0066
	75th	0.0083	0.0081	0.0125	0.0099
	Std. Dev.	0.0054	0.0038	0.0047	0.0045
	Skewness	3.02	2.29	1.84	3.12
	Kurtosis	13.80	10.02	6.95	16.71
Skewness	Mean	−0.0091	−0.0224	−0.0361	−0.0032
	25th	−0.0507	−0.0723	−0.0797	−0.0629
	75th	0.0325	0.0214	0.0137	0.0472
	Std. Dev.	0.0691	0.0856	0.0795	0.0981
	Skewness	−0.1764	0.7658	−0.0282	0.5518
	Kurtosis	3.91	6.62	4.60	4.29
Panel B: Implied moments					
Volatility	Mean	0.0110	0.0103	0.0118	0.0140
	25th	0.0073	0.0072	0.0091	0.0105
	75th	0.0129	0.0118	0.0134	0.0152
	Std. Dev.	0.0056	0.0049	0.0040	0.0056
	Skewness	1.87	2.20	1.56	2.43
	Kurtosis	7.44	9.75	5.73	10.92
Skewness	Mean	−0.3792	−0.2114	−0.1153	−0.1730
	25th	−0.4567	−0.2517	−0.1452	−0.21
	75th	−0.3022	−0.1698	−0.0852	−0.1226
	Std. Dev.	0.1098	0.0620	0.0503	0.0727
	Skewness	−0.0743	−0.1650	−0.1174	−0.6796
	Kurtosis	2.55	3.08	3.71	4.08
Panel C: Risk premia					
VRP	Mean	0.0035	0.0031	0.0007	0.0049
	25th	0.0019	0.0018	0.0001	0.0033
	75th	0.0047	0.0041	0.0019	0.0059
	Std. Dev.	0.0028	0.0024	0.0021	0.0026
	Skewness	0.6415	0.9110	−1.1296	0.5389
	Kurtosis	7.25	9.28	6.95	7.89
SRP	Mean	−0.3701	−0.1890	−0.0792	−0.1698
	25th	−0.4527	−0.2534	−0.1441	−0.2392
	75th	−0.2776	−0.1151	−0.0139	−0.0904
	Std. Dev.	0.1184	0.0997	0.1006	0.1221
	Skewness	−0.4581	−0.3715	−0.1687	−0.2529
	Kurtosis	2.73	3.78	3.58	3.59
Panel D: Risk premium innovations					
$\widetilde{\text{VRP}}$	Mean	0.0000	0.0000	0.0000	0.0000
	25th	−0.0003	−0.0004	−0.0003	−0.0004
	75th	0.0004	0.0003	0.0003	0.0003
	Std. Dev.	0.0011	0.0010	0.0007	0.0010
	Skewness	0.4657	0.3245	0.1538	2.9800
	Kurtosis	15.79	18.93	11.26	50.41
$\widetilde{\text{SRP}}$	Mean	−0.0000	0.0000	−0.0000	−0.0000
	25th	−0.0214	−0.0185	−0.0156	−0.0196
	75th	0.0234	0.0194	0.0148	0.0191
	Std. Dev.	0.0448	0.0378	0.0315	0.0446
	Skewness	−0.6515	−1.7430	0.7191	0.0204
	Kurtosis	9.40	30.10	13.12	15.38

Note: This table reports the descriptive statistics (i.e., the mean, the 25th and 75th percentiles, the standard deviation, the skewness, and kurtosis) for the daily realized moments, implied moments, risk premia and risk premium innovations (volatility and skewness) of the U.S., U.K., German and Japanese stock markets. Using high-frequency data, we estimate the daily realized moments as in Andersen et al. (2003) and Amaya et al. (2015). Then, following Bollerslev et al. (2009), we define the daily risk premia, namely, the volatility risk premium (VRP) and skewness risk premium (SRP), as the difference between the implied and realized moments. Finally, following Menkhoff et al. (2012) and Greenwood-Nimmo et al. (2016), we recover the risk premium innovations from an AR (1) model.

Table 2
Connectedness among risk premia.

To\From		U.S. $\widetilde{\mathrm{VRP}}$	U.S. $\widetilde{\mathrm{SRP}}$	U.K. $\widetilde{\mathrm{VRP}}$	U.K. $\widetilde{\mathrm{SRP}}$	Germany $\widetilde{\mathrm{VRP}}$	Germany $\widetilde{\mathrm{SRP}}$	Japan $\widetilde{\mathrm{VRP}}$	Japan $\widetilde{\mathrm{SRP}}$
U.S.	$\widetilde{\mathrm{VRP}}$	73.43	4.03	15.63	0.07	5.52	0.90	0.35	0.06
	$\widetilde{\mathrm{SRP}}$	5.02	92.01	1.35	0.15	1.15	0.21	0.08	0.03
U.K.	$\widetilde{\mathrm{VRP}}$	5.21	1.19	86.50	0.02	6.18	0.80	0.08	0.03
	$\widetilde{\mathrm{SRP}}$	0.07	0.24	0.005	96.09	0.09	3.18	0.19	0.14
Germany	$\widetilde{\mathrm{VRP}}$	7.37	0.92	26.13	0.04	63.07	1.37	1.06	0.03
	$\widetilde{\mathrm{SRP}}$	1.22	0.24	3.55	1.99	2.12	90.77	0.03	0.07
Japan	$\widetilde{\mathrm{VRP}}$	5.56	0.80	7.37	0.26	4.30	0.84	79.79	1.08
	$\widetilde{\mathrm{SRP}}$	0.12	0.03	0.05	0.01	0.03	0.03	1.44	98.29

Note: This table reports the full sample connectedness between the volatility risk premium ($\widetilde{\mathrm{VRP}}$) and skewness risk premium ($\widetilde{\mathrm{SRP}}$) innovations of the U.S., U.K., German, and Japanese stock markets. The connectedness matrix is estimated following Diebold and Yilmaz (2012, 2014) and captures the share of the variance of each moment risk premium across all four stock markets that is explained by shocks occurring in its own moment and in the risk premia of other markets. The variance decompositions are computed using a forecast horizon of ten trading days.

Table 3
Aggregate connectedness among stock markets.

To\From	U.S.	U.K.	Germany	Japan
U.S.	87.25	8.60	3.89	0.26
U.K.	3.35	91.31	5.12	0.22
Germany	4.88	15.85	78.67	0.60
Japan	3.25	3.85	2.60	90.30

Note: This table reports the full sample connectedness among the U.S., U.K., German, and Japanese stock markets. The connectedness matrix is estimated following Diebold and Yilmaz (2012, 2014) under the block aggregation routine of Greenwood-Nimmo et al. (2015) and captures the share of the variance of each market that is explained by shocks occurring in its own market and other markets. The variance decompositions are computed using a forecast horizon of ten trading days.

Japan. These findings indicate the existence of strong bidirectional spillovers between own-moment risk premia (i.e., volatility and skewness), especially in the U.S. and Germany.

Our results thus far reveal strong spillovers between volatility and skewness risk premia within each of the stock markets. We highlight the importance of cross-moment effects, especially $\widetilde{\mathrm{VRP}}$ spillovers. In addition, we emphasize the relevance of considering $\widetilde{\mathrm{SRP}}$, as it has a large impact on the volatility premium.

4.2. Connectedness among aggregate stock markets and aggregate risk premia

In this subsection, following Greenwood-Nimmo et al. (2016), we investigate the relations among block aggregations of the connectedness matrix presented in Table 2. Specifically, we explore the percentage share of shocks to each of the aggregate stock markets across risk premia (within-market and cross-market risk premia) and to the aggregate risk premia across stock markets (total within-moment and cross-moment risk premia) in explaining the share of the total variance of stock markets and risk premia, respectively. Tables 3 and 4 report the connectedness among stock markets and risk premia, respectively.

Table 3 presents a (4×4) connectedness matrix that, along the prime diagonal, captures for each stock market the total risk premium spillovers that are due to own-market effects, namely, the within-market effects; the off-diagonal elements contain the total directional risk premium spillovers between stock market pairs, that is, the cross-market effects. Note that while the own-market risk premium effects play a dominant role, accounting for 87%, 91%, 79%, and 80% of the U.S., U.K., German, and Japanese variances, respectively, the magnitude of the cross-market risk premium spillovers from other stock markets varies from approximately 9%–21%. The spillover effects from the Japanese stock market to the other stock markets have coefficients below 1%. These findings indicate that European markets and the U.S. stock market are less affected by the Japanese stock market. In contrast, the U.K. risk premia appear to have the highest influence on the other risk premia. The U.K. is a major hub for global equity trading and the world's largest net exporter of financial services.[8] These key facts demonstrate the potential

[8] For instance, at the end of 2017, over 428 foreign companies were listed on the London Stock Exchange. This number is relatively close to the 495 foreign companies trading on the New York Stock Exchange. Additionally, in 2018, financial services were worth $88 billion for the U.K. versus $44 billion for the U.S. (see, for example, https://www.thecityuk.com/research/key-facts-about-the-uk-as-an-international-financial-centre-2018/).

Table 4
Aggregate connectedness among risk premia.

To\From	$\widetilde{\mathrm{VRP}}$	$\widetilde{\mathrm{SRP}}$
$\widetilde{\mathrm{VRP}}$	96.89	3.11
$\widetilde{\mathrm{SRP}}$	4.13	95.87

Note: This table reports the full sample connectedness between the aggregated volatility risk premium ($\widetilde{\mathrm{VRP}}$) and the skewness risk premium ($\widetilde{\mathrm{SRP}}$) innovations of the U.S., U.K., German, and Japanese stock markets. The connectedness matrix is estimated following Diebold and Yilmaz (2012, 2014) under the block aggregation routine of Greenwood-Nimmo et al. (2015) and captures the share of the variance of each moment risk premium that is explained by shocks occurring in its own moment and other risk premia. The variance decompositions are computed using a forecast horizon of ten trading days.

channels for cross-market transmission of the U.K.'s risk premia. Further, in Section 5, we highlight that the European Central Bank's (ECB) expansionary announcements substantially strengthen these cross-market effects.

Table 4 presents the (2×2) connectedness matrix among the aggregate risk premia. Specifically, it shows the interactions among groups of risk premia, namely, $\widetilde{\mathrm{VRP}}$ and $\widetilde{\mathrm{SRP}}$, across all four stock markets. The main diagonal and off-diagonal entries consist of the total within-moment effects and total cross-moment spillovers, respectively. Our findings show that at approximately 97% versus 96%, the within-$\widetilde{\mathrm{VRP}}$ effect is stronger than the within-$\widetilde{\mathrm{SRP}}$ effect, respectively. In line with the full sample connectedness results reported in Table 2, approximately 3% and 4% of the $\widetilde{\mathrm{VRP}}$ and $\widetilde{\mathrm{SRP}}$ variances are explained by the other's risk premium effects.

In sum, our results indicate that cross-market spillover effects appear to be economically more important than cross-moment spillover effects. Additionally, we again confirm strong bidirectional volatility and skewness risk premium spillovers and highlight the influential effect of $\widetilde{\mathrm{VRP}}$ on $\widetilde{\mathrm{SRP}}$.

4.3. *Connectedness over time*

As the relationships among risk premia might vary over time, this section focuses on capturing this time variation by applying a rolling window estimation. Specifically, we conduct our investigation based on a rolling window of 250 trading days with a forecast horizon of 10 trading days.[9]

Fig. 1 shows the time-varying connectedness among aggregate stock markets across the two risk premia, namely, volatility and skewness (i.e., the total within-market effects and cross-market and other-market risk premium spillovers). This aggregation enables us to assess how the risk premium relationships among stock markets vary over time and, especially, during stress periods. Specifically, Fig. 1 consists of four panels for each i-th stock market, and each panel consists of three plots showing the within-market effect, the total inward (outward) spillover from all stock markets (stock market i) to stock market i (all stock markets), namely, the *from* (*to*) spillover, and the individual spillover from each of the stock markets to stock market i. Essentially, for each of the stock markets, the latter plot allows us to identify which stock market contributes the most to the total inward spillover.

Fig. 1 shows that the risk premium effects within each stock market are high, with values varying between approximately 60% and 90%. This indicates that, over time, investors are mainly paying attention to the idiosyncratic risk premia of stock markets. The exceptions are financial crises, such as the Global Financial Crisis and the European Debt Crisis, during which we observe a decrease in their magnitude.[10] During most such periods, we also observe an increase in between-market spillovers, namely, the inward and outward risk premium spillovers. Thus, during stress periods, the cross-market risk premia appear to be of major concern to investors. However, starting in 2014, there is a substantial decrease in the magnitude of within-market

[9] The choices of the rolling window and forecast horizon are in line with Greenwood-Nimmo et al. (2016). They show that neither the choice of the rolling window (200, 250 or 300 trading days) nor the choice of the forecast horizon (5, 10 or 15 trading days) has a substantial impact on the spillovers among returns or the implied volatility and skewness of the currencies.

[10] We consider the Lehman Brothers' collapse in September 2008 to be the starting date of the Global Financial Crisis. According to the Business Cycle Dating Committee of the National Bureau of Economic Research (NBER), the ending date of the financial crisis was June 2009, whereas according to the Federal Reserve Bank of St. Louis, it was between June and July 2009 (see e.g., http://www.nber.org/cycles.html and https://www.stlouisfed.org/financial-crisis/full-timeline). For instance, on June 3, 2009, the U.S. Federal Deposit Insurance Corporation Chair Sheila Bair made the following statement:"Banks have been able to raise capital without having to sell bad assets through the LLP, which reflects renewed investor confidence in our banking system." Several days later, on July 21, 2009, Federal Reserve Chairman Ben Bernanke declared that "...the extreme risk aversion of last fall has eased somewhat, and investors are returning to private credit markets." Given this information, we refer to the Global Financial Crisis from September 2008 to July 2009. We further consider the middle of October 2009 to be the start of the European Debt Crisis. This period coincides with the Greek government's announcement of a budget deficit double that previously estimated, namely, 12.7% of GDP. According to Ehrmann and Fratzscher (2017), the end of the first phase of the European Debt Crisis was in March 2012 and coincided with the implementation of most of the ECB's policies. Chairman Mario Draghi's intervention on July 2012, doing "whatever it takes", also emphasizes the end of the crisis. Hence, the period from October 2009 to July 2012 can be treated as the European Debt Crisis, and the post-ECB announcement of the Outright Monetary Transactions program period is from October 2012 to December 2014.

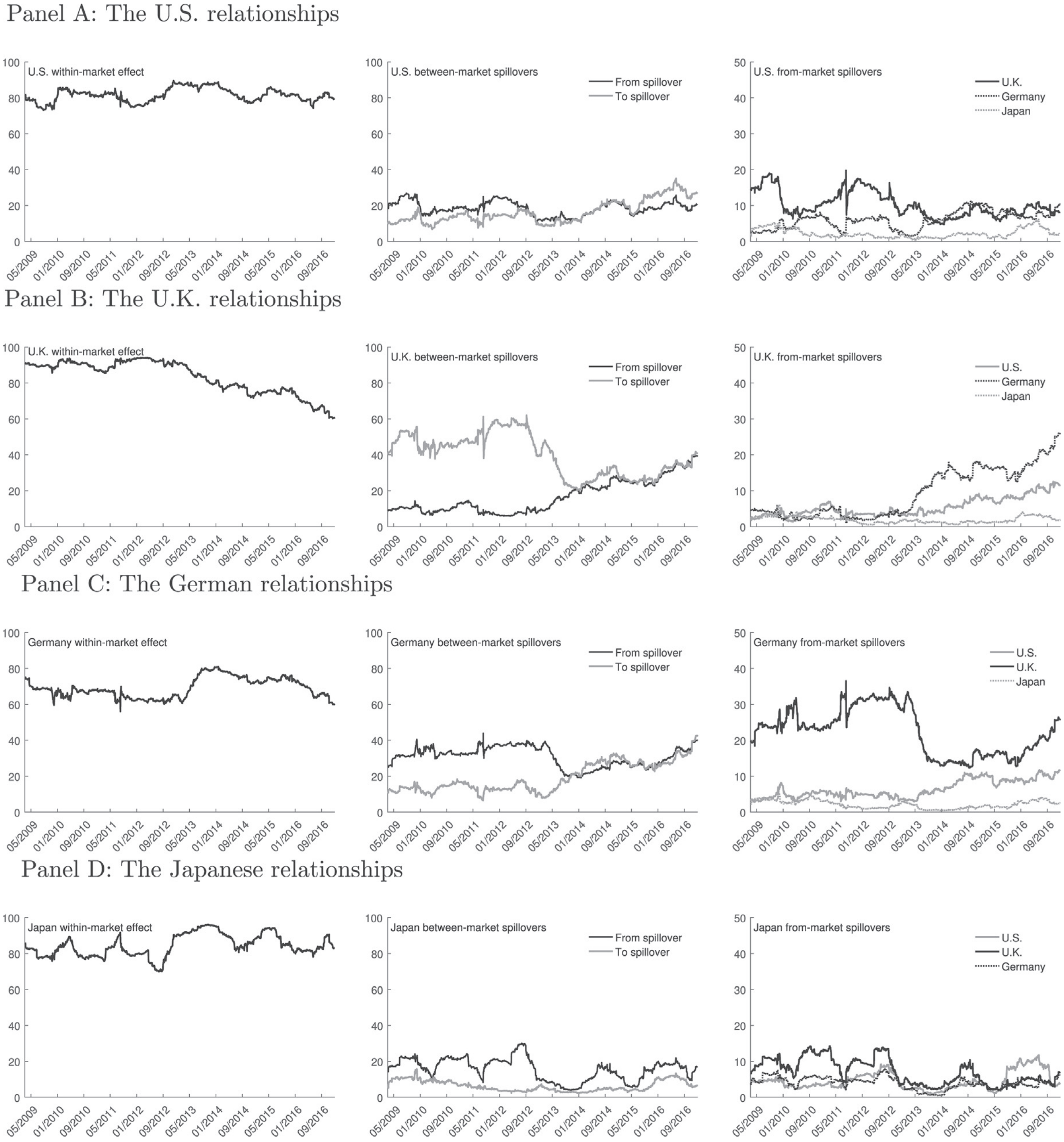


Fig. 1. Time − varying connectedness among stock markets.

Note: This figure shows the rolling window estimates for the relations among the U.S., U.K., German, and Japanese stock markets (i.e., within-market, cross-market, and own-market risk premium effects). The connectedness matrix is estimated following Diebold and Yilmaz (2012, 2014) and under the block aggregation routine of Greenwood-Nimmo et al. (2015). We use a rolling window length of 250 trading days with a forecast horizon of ten trading days. The panels capture the share of the variance of the risk premium (i.e., volatility and skewness) in each stock market that is explained by shocks occurring in its own risk premium market and in other risk premium markets. The from (to) spillover represents the total spillover from all stock markets (stock market *i*) to stock market *i* (all stock markets).

effects that reflects the increasing importance that investors assign to risk premium effects in other stock markets (i.e., cross-market effects). In the next section, we uncover that contractionary announcements and expansionary events occurring during the stress periods explain the rises in these cross-market spillovers. These findings are also in line with Chabi-Yo et al. (2018), who show that investors tend to overstate their fear of a future market crash when they can acknowledge the occurrence of an existing one (Gennaioli et al., 2015). In our case, the results indicate that investors are accounting for the financial crises and thus likely require higher compensation for bearing cross-market risks.

Considering the U.S. risk premium relations in Panel A of Fig. 1, we find that until close to the beginning of 2014, the inward spillover is greater than the outward spillover. In Section 5, we emphasize that the dynamics of these cross-market effects reflect

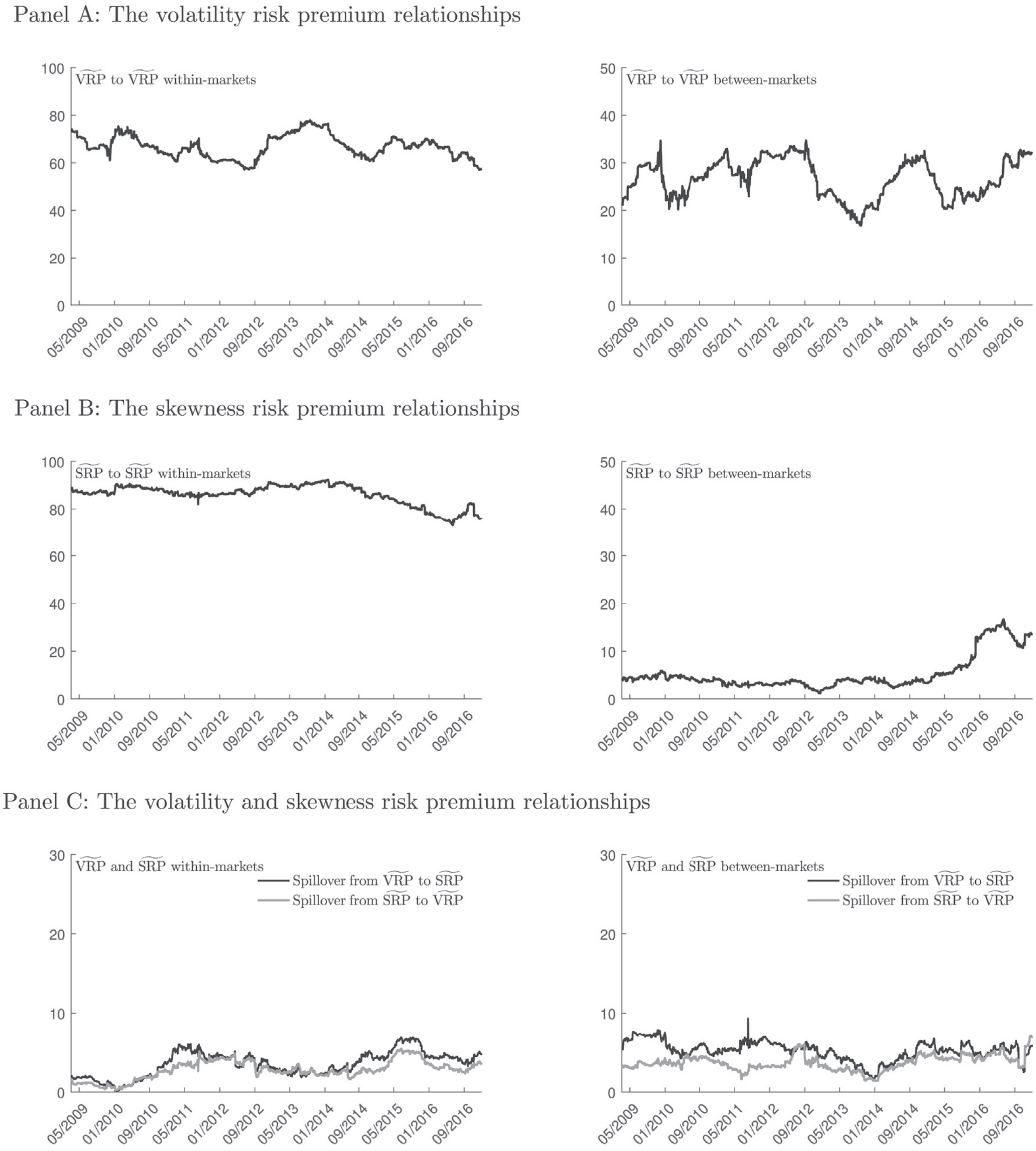


Fig. 2. Time − varying connectedness between volatility and skewness risk premia.
Note: This figure shows the rolling window estimates for the risk premium relations among the U.S., U.K., German, and Japanese stock markets. The connectedness matrix is estimated following Diebold and Yilmaz (2009, 2014) and under the block aggregation routine of Greenwood-Nimmo et al. (2015) using a rolling window length of 250 trading days with a forecast horizon of ten trading days. The panels capture the share of the variance of each market that is explained by shocks occurring in its own market and other markets. We note that each of the panels' left plots shows the connectedness among moments within the same stock market (within-moment), while the right plots show the connectedness among moments between stock markets (cross-moment).

the impacts of Federal Open Market Committee's (FOMC's) and ECB's expansionary events, which usually decrease and increase the cross-U.S. and cross-U.K. spillovers, respectively. During this period, the U.K.'s risk premia exhibit a higher contribution to the total inward spillover than do the risk premia of the German and Japanese stock markets. Approaching summer 2013, we document an increase in the spillover from Germany's risk premia to the U.S.'s risk premia. This spillover fluctuates as does the spillover from the U.K. until the end of our sample period. Given that the spillover from the U.S. to Germany also increases, these findings could be related to taper tantrum episodes. Indeed, in the next section, we show that the taper tantrum and the FOMC's contractionary announcements increase the spillover among moments and the cross-U.S. spillover, respectively.

Panel B of Fig. 1, which presents the U.K. risk premium relations, shows that until approximately the beginning of 2013, the inward spillover is lower than the outward spillover, fluctuating between approximately 10% and 15% versus 30% and 60%, respectively. Moreover, its highest magnitude is during the Global Financial Crisis and the European Debt Crisis. The risk premia in Germany also have considerable impacts on the U.K. risk premia, suggesting that Germany increased its influence in the wake of the European Debt Crisis. Moreover, the upcoming Section 5 notes that the ECB's expansionary events explain these cross-Germany effects.

Regarding the German risk premium interactions, Panel C of Fig. 1 displays the high total inward versus outward spillover observed until the beginning of 2014, at which point there is an increase in the outward spillover. We find that of the risk premia considered here, the U.K. risk premia have the largest influence on the German risk premia.

In Panel D of Fig. 1, we note that Japan's inward spillover is slightly higher than its outward spillover. Moreover, the increase in the magnitude of the inward spillover is due primarily to the effects of the U.K.'s risk premia and towards 2016 is due to the U.S's risk premia. In Section 5, we highlight that these risk premia increase primarily following the ECB's contractionary announcements and certain political events.

Overall, during the stress periods and after 2014, our findings reveal large cross-market risk premium spillovers. We underline the influential role of the U.K.'s risk premia in the risk premia of the other stock markets we consider. Taken together, these findings clearly emphasize that investors might consider requiring compensation for their own-market risks, those of other markets, and cross-market risks. As such, these results might also imply cross-market predictive power for own-market risk premia. Moreover, these outcomes also raise a question regarding the impact of announcements on cross-market risk premia. Indeed, in Section 5, we show that various announcements led to changes in cross-market and cross-moment spillovers.

Fig. 2 presents the time-varying connectedness among aggregate risk premia across stock markets in the U.S., U.K., Germany, and Japan (i.e., within-moment effects, cross-moment, and each moment risk premium spillovers). By doing so, we provide insight on how the $\widetilde{\mathsf{VRP}}$ (Panel A) and $\widetilde{\mathsf{SRP}}$ (Panel B) stock market interactions, as well as those between them (Panel C), vary over time. These relations are presented in two panels, the structure of which maps onto the structure of Table 4 and follows the structure of Fig. 1. In addition, we decompose each element of Table 4 (i.e., the total within-moment effects and total cross-moment spillovers), into a moment-within-market and moment-between-market effect. To facilitate interpretation, we refer to these effects as the within-moment and between-moment (cross-moment) effects. Specifically, the panels' left plots show the connectedness among moments within the same stock market (within-moment), while the right plots show the connectedness among moments between stock markets (cross-moment).

Panel A of Fig. 2, which reports the $\widetilde{\mathsf{VRP}}$ relations, shows that the within-$\widetilde{\mathsf{VRP}}$ effect is larger than the cross-$\widetilde{\mathsf{VRP}}$ effect, varying between approximately 60% and 80%. Starting in 2014, however, there is a substantial time variation in the importance of cross-$\widetilde{\mathsf{VRP}}$ spillover effects; for example, the coefficient of these effects varies between approximately 20% and 32%. These findings demonstrate the increasing importance of the transmission of uncertainty across stock markets; that is, investors are more exposed to the cross-$\widetilde{\mathsf{VRP}}$ effects.[11] We posit that the investors' acknowledgment of the effects of financial crises could lead to an increase in their risk aversion. Therefore, it would also lead to an increase in their willingness to pay a higher premium not only to protect against an increase in volatility risk in their own market but also to protect against the future cross-market volatility risk (Gennaioli et al., 2015; Chabi-Yo et al., 2018).

Examining the $\widetilde{\mathsf{SRP}}$ relations reported in Panel B of Fig. 2, we document that with its coefficient varying between approximately 70% and 90%, the within-$\widetilde{\mathsf{SRP}}$ effect is stronger than the cross-$\widetilde{\mathsf{SRP}}$ effect. The cross-$\widetilde{\mathsf{SRP}}$ spillover increased considerably between the beginning of 2015 and 2016, from 4% to more than 13%. This rise captures the effects of several contractionary and political events that considerably strengthened the risk premium transmission across markets and moments. Our subsequent results in Section 5 provide insight on the drivers of these dynamics.

The relations between $\widetilde{\mathsf{VRP}}$ and $\widetilde{\mathsf{SRP}}$ in Panel C of Fig. 2 indicate the existence of strong bidirectional spillovers that closely comove within and between markets (cross-market). In line with the interactions presented in Tables 2 and 4, we again demonstrate support for the marginally higher effect of $\widetilde{\mathsf{VRP}}$ on $\widetilde{\mathsf{SRP}}$ than that of the movement in the reverse direction. Moreover, the cross-moment spillover effects are, in general, substantially stronger than the within-moment effects; that is, while the within-moment relations between $\widetilde{\mathsf{VRP}}$ and $\widetilde{\mathsf{SRP}}$ vary between approximately 0.2% and 7%, the cross-moment spillovers fluctuate between 2% and 8%. In the following Section 5, we show that this cross-moment variation is significantly related to expansionary and political announcements.

Overall, investigating the spillovers among risk premia, we find that the within-moment effects are larger than the cross-moment effects. However, these cross-moment risk premium effects are relevant. We especially emphasize the large cross-moment premium spillovers from volatility to skewness (within and between markets). In line with the results in Table 4, we also find time-varying, bidirectional risk premium spillovers between volatility and skewness that are generally of similar magnitude.

[11] Although we capture the $\widetilde{\mathsf{VRP}}$ spillover from one market to another and not the investors' attention, these are related notions. For instance, Andrei and Hasler (2015) show that the volatility risk premium increases with attention. Specifically, the authors emphasize that attentive investors quickly incorporate new information into prices, leading to highly volatile returns; then, to bear this risk, they require a large premium. Thus, high attention to news might induce a high VRP.

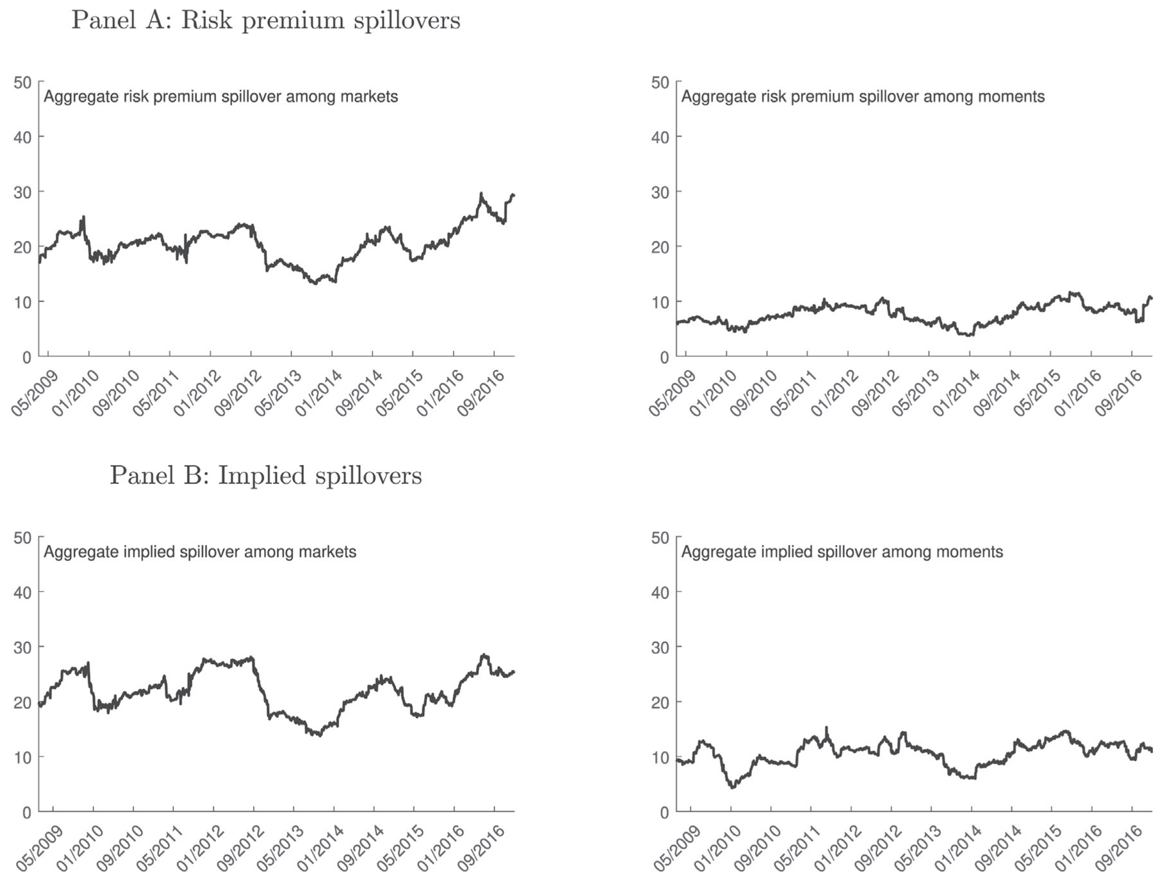


Fig. 3. Time − varying aggregate spillovers.
Note: This figure shows the time-varying aggregate spillovers among markets and moments. Panel A shows these spillovers based on the risk premia. Panel B shows them based on the implied moments. The aggregate risk premium spillover among markets is computed as the mean of the *from* spillovers from Fig. 1. The aggregate risk premium spillover among moments is computed as the mean of the total within-moment effects and the between-moment spillovers from Fig. 2 (i.e., the sum of the spillover from $\widetilde{\text{VRP}}$ to $\widetilde{\text{SRP}}$ and from $\widetilde{\text{SRP}}$ to $\widetilde{\text{VRP}}$). We analogously compute the implied spillovers. The connectedness matrix is estimated following Diebold and Yilmaz (2012, 2014) under the block aggregation routine of Greenwood-Nimmo et al. (2015). We use a rolling window length of 250 trading days with a forecast horizon of ten trading days.

4.4. *Extensions and robustness checks*

In this subsection, we first examine the extent to which the risk premia spillover effects we document in our paper are solely driven by the spillover in implied moments. To save space, we focus on the time-varying aggregate spillovers among markets and moments, namely, the aggregate cross-market and aggregate cross-moment spillovers. The other analyses are available upon request. In particular, using the risk premium spillovers from the middle panels of Fig. 1, we compute the time-varying aggregate cross-market spillover as the mean of the total spillover from all markets to each of the other markets (i.e., the *from* spillovers). The cross-moment spillover is computed as the mean of the total within-moment effects and between-moment spillovers of Panel C from Fig. 2 (i.e., the sum of the spillovers from $\widetilde{\text{VRP}}$ to $\widetilde{\text{SRP}}$ and from $\widetilde{\text{SRP}}$ to $\widetilde{\text{VRP}}$). Similarly, we compute the time-varying aggregate cross-market and cross-moment spillovers based on implied volatility and skewness. Fig. 3, Panels A and B, depicts the time-varying risk premium and implied spillover effects.

Fig. 3 shows that, over time, the risk premium and implied spillovers across both markets and moments behave in a similar way. Moreover, while the spillovers have similar magnitudes across markets, the risk premium spillover among moments has a slightly smaller magnitude than that of the implied spillover among moments. The results suggest that although there is a correlation between the aggregate spillover effects based on risk premia versus implied moments, this correlation is far from perfect. Hence, these results indicate that spillovers in the realized moments also play a nontrivial role.

Second, the choice of the rolling window is important for the estimation of the time-varying spillovers. Diebold and Yilmaz (2014) and Baruník et al. (2016) use a rolling window of 100 and 200 trading days, respectively. As there is no consensus on the correct window, we assess the robustness of our results to these alternative windows. Additionally, we consider a forecast horizon of one trading day. In line with Greenwood-Nimmo et al. (2016), the patterns in Fig. 4 highlight the robust time-varying spillovers when using various rolling windows, such as 100 and 200 trading days and forecast horizons of one day and ten

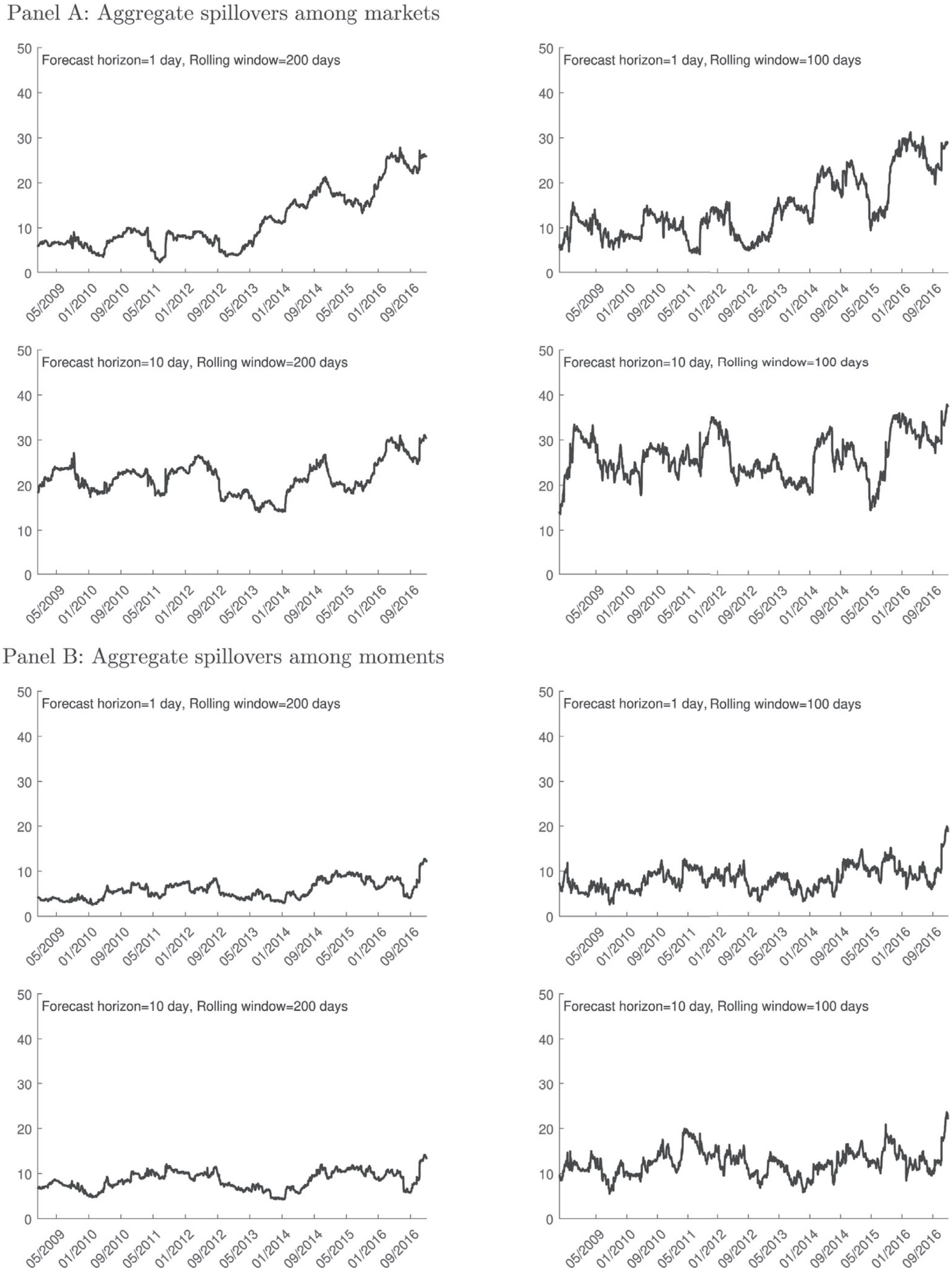


Fig. 4. Time-varying aggregate spillovers with various forecast horizons and rolling windows.
Note: This figure shows, in Panels A and B, the time-varying aggregate spillovers among markets and moments. The aggregate risk premium spillover among markets is computed as the mean of the *from* spillovers from Fig. 1. The aggregate risk premium spillover among moments is computed as the mean of the *from* spillovers from Fig. 2. We use a rolling window length of 200 and 100 trading days with a forecast horizon of one day and ten days. The connectedness matrix is estimated following Diebold and Yilmaz (2012, 2014) under the block aggregation routine of Greenwood-Nimmo et al. (2015).

trading days. In sum, neither the choice of rolling window nor the choice of forecast horizon exerts a considerable impact on the results in Panel A of Fig. 3.

To incorporate the KRP in addition to the VRP and SRP, we now consider a significant extension of the empirical analysis. We briefly discuss spillovers among the volatility, skewness and kurtosis risk premia and the reasons for not considering kurtosis in our main investigations. Appendix A.3 presents the aggregate connectedness among stock markets, whereas Appendix A.4 shows the aggregate connectedness among risk premia. These findings are of similar magnitude to those in Tables 3 and 4. For instance, we again find bidirectional spillovers between $\widetilde{\text{VRP}}$ and $\widetilde{\text{SRP}}$ that are twice as large as those between $\widetilde{\text{VRP}}$ and

$\widetilde{\text{KRP}}$. These results indicate the reduced influence of $\widetilde{\text{KRP}}$ on $\widetilde{\text{VRP}}$ and vice versa. In addition, the largest bidirectional spillovers occur between $\widetilde{\text{SRP}}$ and $\widetilde{\text{KRP}}$. These findings demonstrate that including $\widetilde{\text{KRP}}$ has little influence on the aggregate connectedness among stock markets, as well as to the $\widetilde{\text{VRP}}$.

When considering the time-varying risk premium spillovers, although we discover similar patterns as in Figs. 1 and 2, there are also various "jumps."[12] These spikes in spillover effects could be driven by those occurring in especially, realized kurtosis. For instance, Amaya et al. (2015) emphasize that realized skewness captures the asymmetry in the return distribution (i.e., the sign of the average jump size), whereas realized kurtosis captures the magnitude of the jumps (i.e., the extremes of the return distribution). Although the rolling VAR slopes should evolve smoothly over time, upon incorporating the KRP, the occasional spikes in the risk premium spillovers we observe might stem from the extreme values in the distribution of the VAR forecast errors.[13] We also note that implied spillovers evolve smoothly over time, suggesting that, once again, the time variation in the risk premium spillovers might be the artifact of a few outlier outcomes in realized kurtosis. Additionally, we recognize the potential illiquidity issues associated with the underlying options needed to compute the implied moments. The U.S. options market is an exception, as it is the world's most developed and liquid market.[14]

5. Explaining risk premium spillovers

In the previous section, we show that spillover effects exhibit substantial time variation. In this section, we focus on the drivers of these risk premium spillovers. In particular, we first explore the effects of several announcements on the aggregate spillover among markets and moments and cross-market spillovers. Second, we assess the announcements' impacts on the relationships between $\widetilde{\text{VRP}}$ and $\widetilde{\text{SRP}}$ within and between markets (cross-markets).[15]

5.1. Relationship of aggregate and cross-market spillovers to events

In this subsection, we investigate the extent to which large changes in spillover effects are related to various announcements. These announcements are mainly important unconventional monetary policy announcements from the FOMC, ECB, Bank of England (BoE), and Bank of Japan (BoJ) (Bekaert et al., 2013; Mamaysky, 2018; Fawley and Neely, 2013). For instance, Bekaert et al. (2013) show that the VRP decreases under a loose monetary policy. Mamaysky (2018) notes that the implied volatilities in the U.S., U.K., and Europe exhibit large declines around three to four weeks after quantitative easing (QE) announcements. Given these findings, in general, we expect a reduction in aggregate spillovers following our mostly expansionary announcements. Instead, for the contractionary events, namely, the taper tantrum, FOMC's policy normalization, the bund tantrum,[16] Mario Draghi's announcement, the Fed's increase rate announcements, and political events, we anticipate a rise in spillovers. Accordingly, we compute the change in spillover as the difference between the mean of spillover effects one month after and before each of the events.[17] Table 5 reports the change in the aggregate spillover among markets and moments from Panel A in Fig. 3. Table 6 presents the change in cross-market spillovers from Fig. 1, i.e., the outward (*to*) spillover from each stock market to all stock markets. The previous tables also show the effects of various political events on the risk premium spillovers.

We next discuss the largest impacts of the announcements, which are shown in Table 5. We demonstrate the large decline in both the aggregate spillover among markets and that among moments for the announcements of the FOMC's third round of the QE program including its extension. In addition, around the time of the Operation Twist program from September 2011 and June 2012, there is an increase in aggregate spillover among markets and moments, respectively. These findings indicate that investors may have viewed Operation Twist with suspicion and questioned its efficacy. Moreover, we emphasize the increase in aggregate spillover among moments that is due to the taper tantrum episodes during the summer of 2013. For instance, Federal Reserve Chairman Ben Bernanke's remark on May 22, 2013 that in "… the next few meetings, we could take a step down in our pace of purchases" led to a rise in the volatility of financial markets, although the first reduction in QE was officially announced on December 18, 2013. Further, in September 2014, the FOMC presented information on its monetary policy normalization that aimed at increasing the federal funds rate and reducing the Federal Reserve's securities holdings. However, it was not until December 16, 2015 that it decided to increase for the first time in nearly a decade the nearly 0% federal funds rate by 25 bps, from 0.25% to 0.5%.[18] We show that the former announcement led to a rise in both the aggregate spillover among markets and moments, whereas the latter had an impact on the aggregate spillover among markets.

[12] The results are available upon request.

[13] Specifically, the spillovers might exhibit erratic jumps up and then back down when the irregular realized kurtosis outcomes enter and exit the rolling window. As such, much of their apparent time variation could solely be a manifestation of these infrequent extreme outcomes. Additionally, $\widetilde{\text{KRP}}$ might have an outsized influence on the overall pattern of the time variation in risk premium spillovers. We thank an anonymous referee for pointing this out.

[14] In particular, the intuition is that there are cross-country differences in the finite sample biases associated with the estimates of higher-order implied moments extracted from options data. Note that implied moments are extracted from out-of-the-money options contracts that may be illiquid and that their liquidity levels could vary substantially across markets. We thank an anonymous referee for suggesting this.

[15] We thank an anonymous referee for providing valuable feedback on these analyses.

[16] We use the term "bund tantrum" in referring to the German Bund sell-off between May and June 2015 that led to high volatility in the German bond market.

[17] We calculate the *t*-statistics by dividing the change in spillover by the standard deviations one month after and before the events. Our results are also robust to using the period one and three weeks after and before the events in our calculations.

[18] See, for instance, https://www.federalreserve.gov/monetarypolicy/policy-normalization.htm.

Table 5
Change in spillovers surrounding events.

		Spillover among markets	Spillover among moments
FOMC's announcements			
QE 2 (November 3, 2010)	Pre	20.72	7.19
	Post	20.66	7.22
	Diff	−0.06	0.03
		(−0.68)	(0.61)
Maturity extension (Operation Twist) (September 21, 2011)	Pre	20.74	9.34
	Post	21.42	8.69
	Diff	0.68***	−0.64***
		(5.79)	(−6.50)
Maturity extension (Operation Twist) (June 20, 2012)	Pre	23.32	8.25
	Post	23.77	9.89
	Diff	0.46***	1.63***
		(4.83)	(11.77)
QE 3 (September 13, 2012)	Pre	23.28	9.17
	Post	21.45	7.42
	Diff	−1.83***	−1.75***
		(−7.22)	(−7.08)
Extension of the QE 3 (December 12, 2012)	Pre	17.70	7.83
	Post	16.42	6.68
	Diff	−1.28***	−1.15***
		(−3.91)	(−7.95)
Taper tantrum (May 22, 2013)	Pre	16.27	5.82
	Post	15.94	6.34
	Diff	−0.33***	0.52***
		(−3.03)	(6.52)
Monetary policy normalization (September 17, 2014)	Pre	20.77	7.13
	Post	21.36	7.97
	Diff	0.59***	0.85***
		(3.81)	(8.23)
Fed increases interest rates (December 16, 2015)	Pre	21.07	8.77
	Post	22.64	8.37
	Diff	1.57***	−0.39***
		(7.04)	(−4.27)
ECB's announcements			
Covered bond purchase program (CBPP1) (July 2, 2009)	Pre	20.93	6.84
	Post	22.47	7.00
	Diff	1.54***	0.16***
		(8.56)	(3.28)
Securities Markets Program (SMP) (May 10, 2010)	Pre	17.72	4.85
	Post	18.17	6.05
	Diff	0.45***	1.20***
		(3.06)	(12.99)
Covered bond purchase program (CBPP2) (November 3, 2011)	Pre	21.69	8.94
	Post	22.64	9.21
	Diff	0.95***	0.28***
		(9.05)	(2.94)
Installment of the QE (July 11, 2012)	Pre	23.72	9.27
	Post	23.74	10.18
	Diff	0.02 (0.33)	0.91***
			(6.85)
Outright Monetary Transactions (OMT) (September 6, 2012)	Pre	23.33	9.74
	Post	22.21	7.45
	Diff	−1.13***	−2.29***
		(−4.57)	(−17.85)
Asset-backed securities purchase program (ABSPP) (November 21, 2014)	Pre	22.92	9.34
	Post	22.80	8.87
	Diff	−0.12	−0.47***
		(−1.15)	(−5.28)

(*continued on next page*)

Table 5 *(continued)*

		Spillover among markets	Spillover among moments
Public sector purchase program (PSPP) (March 9, 2015)	Pre	21.01	8.92
	Post	19.37	8.77
	Diff	−1.64***	−0.14
		(−8.95)	(−0.99)
Bund tantrum (May 7, 2015)	Pre	18.44	9.39
	Post	17.77	10.39
	Diff	−0.68***	0.99***
		(−3.69)	(14.67)
ECB's announcements			
Mario Draghi's announcement (December 3, 2015)	Pre	20.57	9.53
	Post	22.32	8.56
	Diff	1.75***	−0.98***
		(13.27)	(−5.97)
Corporate sector purchase program (CSPP) (June 8, 2016)	Pre	26.24	9.26
	Post	28.40	8.78
	Diff	2.16***	−0.48***
		(9.03)	(−4.18)
BoE's and BoJ's announcements			
BoE QE 2 (October 6, 2011)	Pre	21.18	8.82
	Post	21.92	9.03
	Diff	0.75***	0.20*
		(5.86)	(1.93)
BoJ quantitative and qualitative easing (April 3, 2013)	Pre	17.05	6.45
	Post	16.52	5.95
	Diff	−0.52***	−0.50***
		(−7.09)	(−11.27)
BoJ launch of an additional QE (September 21, 2016)	Pre	25.77	8.05
	Post	24.70	6.56
	Diff	−1.07***	−1.49***
		(−13.07)	(−11.42)
Political announcements			
The U.K. European Union Referendum Act of 2015 (May 28, 2015)	Pre	17.92	10.78
	Post	19.50	10.32
	Diff	1.58***	−0.46***
		(10.68)	(−13.51)
The U.K. referendum (June 23, 2016)	Pre	27.90	9.31
	Post	27.81	8.24
	Diff	−0.09	−1.07***
		(−0.39)	(−10.79)
The U.S. presidential election (November 7, 2016)	Pre	24.62	6.51
	Post	27.80	9.25
	Diff	3.19***	2.73***
		(17.18)	(16.65)

Note: This table reports the change in aggregate spillover among markets and moments from Panel A in Fig. 3. For these spillover effects, the values reported show their change, which is measured as the difference one month after (post) and prior (pre) to the various announcements from the Federal Open Market Committee (FOMC), European Central Bank (ECB), Bank of England (BoE), and the Bank of Japan (BoJ). The results are generally also robust to one week prior and after the events. We calculate the *t*-statistics (i.e., the numbers in parentheses) by dividing the change in spillover by the standard deviations one month after and before the events. ***, **, and * denote significance at 1%, 5%, and 10% levels, respectively.

Examining the ECB's announcements, such as the announcements of the covered bond purchase programs (i.e., CBPP 1 and CBPP 2 from July 2009 and November 2011) and the purchase of securities under the Securities Markets Program (SMP), we uncover a significant increase in aggregate spillover among markets and moments, respectively. Similarly, the aggregate spillover among moments increases at the announcement of the ECB's QE programs aimed at pushing the short-term nominal rates to the zero bound on July 11, 2012.[19] Our results accentuate the different impacts of monetary policy announcements on the spillovers during the crisis and normal periods. For example, the purchases under the Asset-Backed Securities Purchase

[19] The purpose of this program was to fuel credit growth and enhance the risk appetite among banks by extending the public and private sector monthly securities purchasing program. See, for instance, https://www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates.

Table 6
Change in cross – market spillovers surrounding pooled events.

Panel A: FOMC's announcements and the cross-U.S. spillover		
Expansionary - all	Pre	14.67
	Post	14.02
	Diff	−0.66**
		(−2.08)
Expansionary - 2009 to 2012	Pre	14.99
	Post	15.31
	Diff	0.32
		(1.23)
Expansionary - others	Pre	14.46
	Post	13.15
	Diff	−1.31***
		(−3.77)
Contractionary	Pre	18.62
	Post	20.02
	Diff	1.40***
		(7.76)
Panel B: ECB's announcements and the cross-U.K. spillover		
Expansionary - all	Pre	45.76
	Post	46.34
	Diff	0.58
		(1.57)
Expansionary - 2009 to 2012	Pre	52.18
	Post	53.41
	Diff	1.23***
		(3.14)
Expansionary - others	Pre	37.74
	Post	37.51
	Diff	−0.23
		(−0.66)
Contractionary	Pre	25.13
	Post	25.91
	Diff	0.78***
		(2.88)
Panel C: ECB's announcements and the cross-German spillover		
Expansionary - all	Pre	19.02
	Post	19.43
	Diff	0.42*
		(1.72)
Expansionary - 2009 to 2012	Pre	12.80
	Post	13.78
	Diff	0.98***
		(4.47)
Expansionary - others	Pre	26.80
	Post	26.50
	Diff	−0.29
		(−1.10)
Contractionary	Pre	25.68
	Post	25.82
	Diff	0.14
		(0.46)
Panel D: BoJ's announcements and the cross-Japanese spillover		
Expansionary	Pre	7.31
	Post	5.62
	Diff	−1.69***
		(−13.84)

		Cross−U.S. spillover	Cross−U.K. spillover	Cross−German spillover	Cross−Japanese spillover
Panel E: Political announcements and the cross-market spillovers					
Expansionary	Pre	24.70	31.36	30.12	7.73
	Post	25.90	33.43	33.90	6.93
	Diff	1.20***	2.06***	3.78***	−0.79***
		(4.47)	(7.05)	(11.84)	(−6.41)

Note: This table reports the change in cross-market spillovers from middle panels in Fig. 1, i.e., the outward (*to*) spillover from each stock market to all stock markets. Panels A, B, C, and D present the impacts of expansionary and contractionary announcements, and Panel E shows the impacts of political announcements. For these spillover effects, the values reported show their change, which is measured as the difference one month after (post) and prior (pre)to the various announcements from the Federal Open Market Committee (FOMC), European Central Bank (ECB), Bank of England (BoE), and the Bank of Japan (BoJ). We calculate the *t*-statistics (i.e., the numbers in parentheses) by dividing the change in spillover by the standard deviations one month after and before the events. ***, **, and * denote significance at 1%, 5%, and 10% levels, respectively.

Program (ABSPP, November 2014) and the Public Sector Purchase Program (PSPP, March 2015), as well as the replacement of the SMP with the Outright Monetary Transactions (OTM) program, led to large declines in the spillover among moments and markets.

In 2015, several announcements also explain the risk premium spillovers, for instance, the German bund sell-off between May and June 2015, also known as the "bund tantrum," based on the high volatility in the German bond market on May 7 and June 3, 2015. As German bonds are a key driver and the benchmark for European government bonds, they also have spillover effects on equity markets.[20] This volatility spike in the bond market also coincides with the ECB's monetary policy press release in which, when being asked whether there is a concern on the Governing Council that QE may be contributing to market volatility, the ECB President Mario Draghi declared that "… we should get used to periods of higher volatility. At very low levels of interest rates, asset prices tend to show higher volatility … . " We confirm these statements by documenting a significant rise in the spillover among moments after the announcement. Interestingly, on December 3, 2015, the announcement of Mario Draghi of a cut to the ECB's deposit rate from −0.3% to −0.2% and of an extension of the QE program induced a significant increase and decrease in spillover among markets and moments, respectively. The former finding is in line with investors' higher expectations that led to a sell-off in European equities. ECB Vice President Vitor Constancio stated that "… the markets got it wrong in forming their expectations."[21]

We also find that the BoJ's QE announcements are associated with a significant reduction in both aggregate spillover among markets and moments. Finally, we consider three political events: the presentation to Parliament of the European Union Referendum Act of 2015 on May 28, 2015, the actual U.K. referendum on leaving the European Union on June 23, 2016, and the U.S. presidential election on November 7, 2016. During these periods of high political uncertainty, we posit that there may have been an increase in the investors' risk aversion and that this also led to a rise in the risk premium spillovers (Pástor and Veronesi, 2012, 2013; Kelly et al., 2016; Gu and Hilbert, 2018). The exception is the decrease in the spillover among moments around the U.K. referendum. This result indicates that given the previous discussions on leaving the European Union, investors might have expected this event.

Overall, Table 5 shows that, in general, the announcements have led to significant impacts in the aggregate spillover among markets and moments. The increase in spillovers suggests that contractionary and political events might lead investors to expect less favorable future economic conditions. Instead, we observe that expansionary announcements generally led to a reduction in our spillover effects. We confirm these findings in Appendix A.5 for situations in which overall expansionary, contractionary, and political announcements are made (Panels A and E) and when these announcements are classified based on the central bank (Panels B, C, and D).

Considering the expansionary events during both crisis and normal periods and contractionary events, Table 6 shows the geographical variation in the announcement set.[22] That is, we assess how the cross-market effects specific to the U.S., U.K., Germany, and Japan change when their respective central banks deliver important news to markets. As an example, let us consider the FOMC announcements. Since these announcements originate in the U.S., we hypothesize that cross-market effects (i.e., the outward spillover from the U.S. to other markets), would change following such announcements. Moreover, we expect that the expansionary announcements should have different effects on risk premium spillovers during crisis and normal periods.

Panel A reveals that the FOMC's expansionary announcements generate a decrease in the U.S. cross-market effects, whereas contractionary announcements have the opposite impacts. Panels B and C also show the reduction in and enhancement of the outward spillover from the U.K. and Germany to other markets following the ECB's expansionary and contractionary announcements. In addition, we show that the expansionary events occurring during crisis periods lead to increases in our cross-market spillovers. Finally, in line with previous findings, the Japanese cross-market effects decline following the BoJ's expansionary announcements, as shown in Panel D.

5.2. Relationship between VRP and SRP following events

In this subsection, we examine the impacts of expansionary and contractionary announcements on the bidirectional relationships between $\widetilde{\text{VRP}}$ and $\widetilde{\text{SRP}}$ within and between markets (cross-markets) from Panel C in Fig. 2. Table 7 shows the change in the within-moment effects from $\widetilde{\text{VRP}}$ to $\widetilde{\text{SRP}}$ and from $\widetilde{\text{SRP}}$ to $\widetilde{\text{VRP}}$. Table 8 reports the change in cross-moment effects from $\widetilde{\text{VRP}}$ to $\widetilde{\text{SRP}}$ and vice versa. Panel A in Tables 7 and 8 documents the effects of overall expansionary and contractionary announcements, whereas the results in Panels B, C, and D show their impacts for each central bank. Panel D presents the results for the political events.

When comparing the shifts in within- and cross-moment effects between $\widetilde{\text{VRP}}$ and $\widetilde{\text{SRP}}$ in Tables 7 and 8, respectively, observe that news leads to significantly higher shifts in the cross-moment spillover effects. In agreement with the findings

[20] Indeed, following these events, the equity implied volatilities shot up above their post-Global Financial Crisis averages (January 2010 to December 2014), e.g., the VIX reached 40 percentage points for the first time since 2011 (Bank of Settlements Quarterly Review report, September 2015). The Bank of Settlements Quarterly Review report (September 2015) shows that at the beginning of September, the global equity sell-off led the Datastream world P/E ratio below its median value since 1987 (https://www.bis.org/publ/qtrpdf/r_qt1509a.pdf).

[21] See https://www.cnbc.com/2016/01/15/ecb-playing-for-time-after-disappointing-december.html.

[22] We classify expansionary events as occurring during crisis and normal periods if these take place by July 2012, i.e., before Chairman Mario Draghi's announcement, and afterwards, respectively.

Table 7
Change in $\widetilde{\text{VRP}}$ and $\widetilde{\text{SRP}}$ within-market relation surrounding events.

		Spillover from $\widetilde{\text{VRP}}$ to $\widetilde{\text{SRP}}$	Spillover from $\widetilde{\text{SRP}}$ to $\widetilde{\text{VRP}}$
Panel A: Expansionary and contractionary announcements			
Expansionary - all	Pre	3.64	2.99
	Post	3.58	2.92
	Diff	−0.05	−0.07
		(−0.63)	(−0.98)
Expansionary - 2009 to 2012	Pre	3.42	3.05
	Post	3.63	3.24
	Diff	0.21***	0.19***
		(2.70)	(3.58)
Expansionary - others	Pre	3.81	2.94
	Post	3.55	2.66
	Diff	−0.26***	−0.27***
		(−2.95)	(−3.36)
Contractionary	Pre	4.29	3.46
	Post	4.45	3.59
	Diff	0.17**	0.13**
		(2.25)	(2.05)
Panel B: FOMC's announcements			
Expansionary - all	Pre	3.67	3.28
	Post	3.62	3.08
	Diff	−0.04	−0.20**
		(−0.41)	(−2.04)
Expansionary - 2009 to 2012	Pre	4.21	3.85
	Post	4.34	3.95
	Diff	0.12	0.10*
		(1.41)	(1.75)
Expansionary - others	Pre	3.30	2.90
	Post	3.15	2.51
	Diff	−0.16	−0.40***
		(−1.31)	(−3.40)
Contractionary	Pre	3.60	2.95
	Post	3.86	3.13
	Diff	0.26***	0.18***
		(4.02)	(3.11)
Panel C: ECB's announcements			
Expansionary - all	Pre	3.72	2.94
	Post	3.69	2.87
	Diff	−0.03	−0.07
		(−0.42)	(−1.17)
Expansionary - 2009 to 2012	Pre	3.10	2.73
	Post	3.35	2.96
	Diff	0.25***	0.23***
		(3.31)	(4.38)
Expansionary - others	Pre	4.50	3.20
	Post	4.12	2.76
	Diff	−0.38***	−0.44***
		(−5.11)	(−6.98)
Contractionary	Pre	5.31	4.23
	Post	5.34	4.29
	Diff	0.03	0.06
		(0.32)	(0.80)
Panel D: BoJ's announcements			
Expansionary	Pre	3.19	2.45
	Post	3.01	2.70
	Diff	−0.18***	0.25***
		(−3.29)	(6.50)
Panel E: Political announcements			
	Pre	4.94	3.76
	Post	5.11	3.77
	Diff	0.17***	0.01
		(3.15)	(0.32)

Note: This table reports the change in $\widetilde{\text{VRP}}$ and $\widetilde{\text{SRP}}$ within-market relation displayed in the left Panel C in Fig. 2. Panels A, B, C, and D present the impacts of expansionary and contractionary announcements, and Panel E shows the impacts of political announcements. For these spillover effects, the values reported show their change, which is measured as the difference one month after (post) and prior (pre) to the various announcements from the Federal Open Market Committee (FOMC), European Central Bank (ECB), Bank of England (BoE), and the Bank of Japan (BoJ). We calculate the *t*-statistics (i.e., the numbers in parentheses) by dividing the change in spillover by the standard deviations one month after and before the events. ***, **, and * denote significance at 1%, 5%, and 10% levels, respectively.

Table 8
Change in $\widetilde{\text{VRP}}$ and $\widetilde{\text{SRP}}$ between-market relation surrounding events.

		Spillover from $\widetilde{\text{VRP}}$ to $\widetilde{\text{SRP}}$	Spillover from $\widetilde{\text{SRP}}$ to $\widetilde{\text{VRP}}$
Panel A: Expansionary and contractionary announcements			
Expansionary - all	Pre	5.75	4.16
	Post	5.50	3.97
	Diff	−0.25***	−0.19**
		(−2.83)	(−1.99)
Expansionary - 2009 to 2012	Pre	5.90	3.72
	Post	6.09	4.19
	Diff	0.19***	0.47***
		(3.23)	(6.14)
Expansionary - others	Pre	5.63	4.51
	Post	5.03	3.80
	Diff	−0.59***	−0.70***
		(−5.66)	(−6.44)
Contractionary	Pre	4.70	3.81
	Post	4.71	3.90
	Diff	0.01	0.09
		(0.10)	(1.34)
Panel B: FOMC's announcements			
Expansionary - all	Pre	5.56	4.21
	Post	5.29	3.96
	Diff	−0.27***	−0.24**
		(−3.21)	(−1.96)
Expansionary - 2009 to 2012	Pre	5.72	3.81
	Post	5.85	4.44
	Diff	0.13*	0.64***
		(1.82)	(7.12)
Expansionary - others	Pre	5.45	4.47
	Post	4.92	3.64
	Diff	−0.53***	−0.83***
		(−5.85)	(−5.83)
Contractionary	Pre	4.35	3.57
	Post	4.47	3.66
	Diff	0.11	0.10
		(1.22)	(1.47)
Panel C: ECB's announcements			
Expansionary - all	Pre	5.90	4.32
	Post	5.98	4.20
	Diff	0.08	−0.12
		(0.96)	(−1.38)
Expansionary - 2009 to 2012	Pre	5.97	3.68
	Post	6.19	4.08
	Diff	0.22***	0.40***
		(4.00)	(5.70)
Expansionary - others	Pre	5.82	5.11
	Post	5.71	4.35
	Diff	−0.10	−0.76***
		(−1.03)	(−7.53)
Contractionary	Pre	5.21	4.17
	Post	5.07	4.25
	Diff	−0.15*	0.08
		(−1.84)	(1.15)
Panel D: BoJ's announcements			
Expansionary	Pre	5.52	3.34
	Post	3.85	2.96
	Diff	−1.67***	−0.39***
		(−12.90)	(−7.60)
Panel E: Political announcements			
	Pre	4.78	4.26
	Post	4.97	4.69
	Diff	0.19***	0.43***
		(2.35)	(4.47)

Note: This table reports the change in the $\widetilde{\text{VRP}}$ and $\widetilde{\text{SRP}}$ between-market relations displayed in the right Panel C in Fig. 2. Panels A, B, C, and D present the impacts of the expansionary and contractionary announcements, and Panel E shows the impacts of the political announcements. For these spillover effects, the values reported show the change, which is measured as the difference one month after (post) and prior (pre) to the various announcements from the Federal Open Market Committee (FOMC), European Central Bank (ECB), Bank of England (BoE), and the Bank of Japan (BoJ). We calculate the *t*-statistics (i.e., the numbers in parentheses) by dividing the change in spillover by the standard deviations one month after and before the events. ***, **, and * denote significance at 1%, 5%, and 10% levels, respectively.

discussed for Tables 5 and 6, following the FOMC, ECB, and BoJ's expansionary announcements occurring during crisis and regular periods, we document sharp rises and declines, respectively, in the cross-moment spillovers. Likewise, both cross-moment spillovers, i.e., from $\widetilde{\mathsf{VRP}}$ to $\widetilde{\mathsf{SRP}}$ and from $\widetilde{\mathsf{SRP}}$ to $\widetilde{\mathsf{VRP}}$, substantially increase around the time of political events. In contrast, the overall contractionary events and, in particular, the FOMC's expansionary announcements, generate increases in within-moment effects between $\widetilde{\mathsf{VRP}}$ and $\widetilde{\mathsf{SRP}}$. Concerning expansionary events, we show that FOMC news induces changes in the within-moment effect from $\widetilde{\mathsf{SRP}}$ and $\widetilde{\mathsf{VRP}}$, whereas the ECB announcements significantly influence both within-moment effects.

On the whole, our findings highlight the significant impacts of expansionary announcements on the cross-moment relations between volatility and skewness risk premia, and the importance of contractionary announcements for the within-moment effects. Notably, we show that expansionary news weakens the relationships between $\widetilde{\mathsf{VRP}}$ and $\widetilde{\mathsf{SRP}}$, whereas contractionary news and expansionary announcements occurring during the crisis period strengthen them.

6. Conclusion

In this paper, we examine the risk premium spillovers among the stock markets of four major advanced economies (the U.S., the U.K., Germany, and Japan) from 2008 to 2016. We define the risk premia as the difference between the implied and realized moments (Bollerslev et al., 2009) using the model-free risk-neutral moments (Bakshi et al., 2003) and realized moments from high-frequency data (Andersen et al., 2003; Amaya et al., 2015). By using Diebold and Yilmaz's (2012, 2014) and Greenwood-Nimmo et al.'s (2015) approaches, we provide a better cross-market and cross-moment understanding of the interactions of the volatility and skewness risk premia.

Our investigation reveals several important findings. First, we emphasize the time variation in the pattern of risk premium spillovers. We find that during periods of stress, there is an increase in the cross-border spillovers across markets and risk premia. During these periods, the within-market and within-moment effects decline, indicating that investors are likely more concerned with risk transmission across stock markets. Second, we document strong bidirectional spillovers between volatility and skewness risk premia. In addition, we find that the cross-moment risk premia, namely, volatility and skewness, are higher than the within-moment risk premia. Third, we highlight that various announcements have typically led to a variation in risk premium spillovers among markets and moments, as well as in cross-market and cross-moment spillovers. In particular, our findings reveal that expansionary and contractionary announcements led to declines and rises in the risk premium spillover effects, except for expansionary news occurring during periods of stress. Fourth, extending our investigation to the kurtosis risk premium confirms the robustness of our main findings. Overall, we highlight that risk premium spillovers among stock markets are characterized by (i) increasing attention given to the cross-market and cross-moment effects, especially during periods of stress and following various announcements; (ii) the prominent role played by the volatility risk premium; and (iii) the existence of a relationship between risk premium spillovers and several announcements.

Our findings raise at least two interesting avenues for future research. We show that various announcements drive the time variation in the risk premium spillovers. As a result, future research could explore the cross-market predictive relationship between risk premia and returns during specific announcements. Moreover, the existence of important cross-market and cross-moment risk premium spillovers raises the question of whether the cross-market and cross-moment risk premia have better predictive ability for a market's returns or for a market's own volatility and skewness risk premia. Although these questions are beyond the scope of the current paper, they deserve special attention in future research.

Appendix A.1 The block approach by moment

The Diebold-Yilmaz (2012, 2014) framework can be used either to measure spillovers among individual variables or to summarize aggregate spillover activity among all variables in the system. However, it does not provide a simple way to measure spillovers among groups of variables. As such, it is not straightforward to measure spillovers among multiple markets, each of which is represented by two variables, i.e., $\widetilde{VRP}_{it}$ and $\widetilde{SRP}_{it}$. Consequently, Greenwood-Nimmo et al. (2015) develop a generalized framework that exploits the block aggregation of the connectedness matrix.

To evaluate the connectedness among the two groups of moments for all N markets collectively, we apply the same approach, which consists of ordering the variables in the VAR to obtain $\tilde{\boldsymbol{x}}_{\boldsymbol{t}} = (\widetilde{\boldsymbol{VRP}}_{\boldsymbol{t}}, \widetilde{\boldsymbol{SRP}}_{\boldsymbol{t}})$. In this case, we may write the H-step-ahead connectedness matrix with g = 2 groups of moments composed of $m = N$ variables:

$$\mathbf{C}^{(H)} = \begin{bmatrix} \boldsymbol{B}^{(H)}_{\widetilde{\mathsf{VRP}} \leftarrow \widetilde{\mathsf{VRP}}} & \boldsymbol{B}^{(H)}_{\widetilde{\mathsf{VRP}} \leftarrow \widetilde{\mathsf{SRP}}} \\ \boldsymbol{B}^{(H)}_{\widetilde{\mathsf{SRP}} \leftarrow \widetilde{\mathsf{VRP}}} & \boldsymbol{B}^{(H)}_{\widetilde{\mathsf{SRP}} \leftarrow \widetilde{\mathsf{SRP}}} \end{bmatrix} \tag{A.1}$$

$$\mathbf{B}^{(H)}_{i \leftarrow j} = \begin{bmatrix} \psi^{(H)}_{\widetilde{\mathsf{VRP}}_1 \leftarrow \widetilde{\mathsf{VRP}}_1} & \psi^{(H)}_{\widetilde{\mathsf{VRP}}_1 \leftarrow \widetilde{\mathsf{VRP}}_2} & \cdots & \psi^{(H)}_{\widetilde{\mathsf{VRP}}_1 \leftarrow \widetilde{\mathsf{VRP}}_N} \\ \psi^{(H)}_{\widetilde{\mathsf{VRP}}_2 \leftarrow \widetilde{\mathsf{VRP}}_1} & \psi^{(H)}_{\widetilde{\mathsf{VRP}}_2 \leftarrow \widetilde{\mathsf{VRP}}_2} & \cdots & \psi^{(H)}_{\widetilde{\mathsf{VRP}}_2 \leftarrow \widetilde{\mathsf{VRP}}_N} \\ \vdots & \vdots & \ddots & \vdots \\ \psi^{(H)}_{\widetilde{\mathsf{VRP}}_N \leftarrow \widetilde{\mathsf{VRP}}_1} & \psi^{(H)}_{\widetilde{\mathsf{VRP}}_N \leftarrow \widetilde{\mathsf{VRP}}_2} & \cdots & \psi^{(H)}_{\widetilde{\mathsf{VRP}}_N \leftarrow \widetilde{\mathsf{VRP}}_N} \end{bmatrix}$$

$$\mathbf{B}^{(H)}_{i\leftarrow j}=\begin{bmatrix}\psi^{(H)}_{\widetilde{\mathrm{VRP}}_1\leftarrow\widetilde{\mathrm{SRP}}_1} & \psi^{(H)}_{\widetilde{\mathrm{VRP}}_1\leftarrow\widetilde{\mathrm{SRP}}_2} & \cdots & \psi^{(H)}_{\widetilde{\mathrm{VRP}}_1\leftarrow\widetilde{\mathrm{SRP}}_N}\\ \psi^{(H)}_{\widetilde{\mathrm{VRP}}_2\leftarrow\widetilde{\mathrm{SRP}}_1} & \psi^{(H)}_{\widetilde{\mathrm{VRP}}_2\leftarrow\widetilde{\mathrm{SRP}}_2} & \cdots & \psi^{(H)}_{\widetilde{\mathrm{VRP}}_2\leftarrow\widetilde{\mathrm{SRP}}_N}\\ \vdots & \vdots & \ddots & \vdots\\ \psi^{(H)}_{\widetilde{\mathrm{VRP}}_N\leftarrow\widetilde{\mathrm{SRP}}_1} & \psi^{(H)}_{\widetilde{\mathrm{VRP}}_N\leftarrow\widetilde{\mathrm{SRP}}_2} & \cdots & \psi^{(H)}_{\widetilde{\mathrm{VRP}}_N\leftarrow\widetilde{\mathrm{SRP}}_N}\end{bmatrix}$$

The remaining blocks are defined analogously. In addition to Section 2, where we define the total within-market effects and between-market spillovers, in this section, we decompose each of the total within-moment and between-moment effects into own-moment $O^{(H)}$ and cross-moment $A^{(H)}$ effects. For instance, the total within-$\widetilde{\mathrm{VRP}}$, $M^{(H)}_{\widetilde{\mathrm{VRP}}\leftarrow\widetilde{\mathrm{VRP}}}$ can be decomposed into forecast error variance contributions within-$\widetilde{\mathrm{VRP}}$, $O^{(H)}_{\widetilde{\mathrm{VRP}}\leftarrow\widetilde{\mathrm{VRP}}}$ and between-$\widetilde{\mathrm{VRP}}$, $A^{(H)}_{\widetilde{\mathrm{VRP}}\leftarrow\widetilde{\mathrm{VRP}}}$ as follows:

$$O^{(H)}_{\widetilde{\mathrm{VRP}}\leftarrow\widetilde{\mathrm{VRP}}}=\frac{1}{m}trace\left(\mathbf{B}^{(H)}_{\widetilde{\mathrm{VRP}}\leftarrow\widetilde{\mathrm{VRP}}}\right);A^{(H)}_{\widetilde{\mathrm{VRP}}\leftarrow\widetilde{\mathrm{VRP}}}=M^{(H)}_{\widetilde{\mathrm{VRP}}\leftarrow\widetilde{\mathrm{VRP}}}-O^{(H)}_{\widetilde{\mathrm{VRP}}\leftarrow\widetilde{\mathrm{VRP}}} \tag{A.2}$$

where $M^{(H)}_{\widetilde{\mathrm{VRP}}\leftarrow\widetilde{\mathrm{VRP}}}=\frac{1}{m}\boldsymbol{u}'_{\boldsymbol{m}}\mathbf{B}^{(H)}_{\widetilde{VRP}\leftarrow\widetilde{VRP}}\boldsymbol{u}_{\boldsymbol{m}}$. Note that $O^{(H)}_{\widetilde{\mathrm{VRP}}\leftarrow\widetilde{\mathrm{VRP}}}$ measures the proportion of the H-step-ahead forecast error variance of VRP that is attributable to VRP effects within markets. By contrast, $A^{(H)}_{\widetilde{\mathrm{VRP}}\leftarrow\widetilde{\mathrm{VRP}}}$ records the total H-step-ahead $\widetilde{\mathrm{VRP}}$ spillovers between markets, e.g., $\widetilde{\mathrm{VRP}}$ spillover from one market to another. In line with previous definitions, the within- and between-moment effects from skewness risk premium to volatility risk premium are defined as:

$$O^{(H)}_{\widetilde{VRP}\leftarrow\widetilde{SRP}}=\frac{1}{m}trace(\mathbf{B}^{(H)}_{\widetilde{VRP}\leftarrow\widetilde{SRP}});A^{(H)}_{\widetilde{VRP}\leftarrow\widetilde{SRP}}=\frac{1}{m}\boldsymbol{u}'_{\boldsymbol{m}}\mathbf{B}^{(H)}_{\widetilde{VRP}\leftarrow\widetilde{SRP}}\boldsymbol{u}_{\boldsymbol{m}}-O^{(H)}_{\widetilde{VRP}\leftarrow\widetilde{SRP}}. \tag{A.3}$$

The remaining blocks are defined similarly.

Appendix A.2 Option data and implied moments

Appendix A.2.1 Option data details

To compute the daily implied moments, as proxies for the U.S., U.K., German and Japanese stock markets, we use out-of-money calls and puts written on the S&P 500, FTSE 100, DAX 30, and NIKKEI 225 indices, respectively. These European option data are taken from Thomson Reuters Tick History, cover the period from January 2008 to December 2016, and consist of the option ticker, strike, maturity date, type, and the daily last, bid-ask option quotes. As a proxy for the risk-free rate, we use the LIBOR (London Interbank Offered Rate) interest rates being closest to the expiration dates of the near- and next-term options from Bloomberg. Specifically, we rely on the USD, GBP, EURO, and JPY LIBOR rates for the implied moments' estimation in the U.S., U.K., Germany, and Japan. To clean our options data, we follow the literature on the computation of implied moments (e.g., Bakshi et al., 2003; Jiang and Tian, 2005; Chang et al., 2012; Harris et al., 2019). Specifically, we discard various contracts such as the following: (i) bid-ask option contracts pairs with missing quotes or zero bids, (ii) contracts with zero trading volume, (iii) contracts with option prices that violate arbitrage restrictions to respect the boundary conditions, (iv) contracts with fewer than two out-of-money calls and puts, and (v) contracts that do not correspond to OTM calls and puts.

Appendix A.2.2 Pricing characterization

To compute the risk-neutral moments (i.e., implied variance, skewness, and kurtosis), the studies of Breedon and Litzenberger (1978) and Bakshi and Madan (2000) show that risk-neutral distributions can be recovered from a set of option prices and that any payoff function can be spanned by a continuum of out-the-money calls and puts. The replication of any twice-differentiable payoff $F(S)$ function of any underlying price process S_t at period t and maturity T is given by (Carr and Madan, 2001; Bakshi et al., 2003):

$$\begin{aligned}F(S)&=F(S_0)+\left(S-S_0\right)F_S(S_0)\\&+\int_{S_0}^{\infty}F_{SS}(K)Max\left(S-K,0\right)dK+\int_0^{S_0}F_{SS}(K)Max\left(K-S,0\right)dK.\end{aligned} \tag{A.4}$$

Apply the expectation operator $E^Q\left\{.\right\}$ to $F(S)$, under the risk-neutral probability Q such as:

$$\begin{aligned}E^Q\left\{e^{-r(T-t)}F(S)\right\}&=\left(F(S_0)-F_S(S_0)S_0\right)e^{-r(T-t)}+F_S(S_0)S_t\\&+\int_{S_0}^{\infty}F_{SS}(K)C(T,t,K)dK+\int_0^{S_0}F_{SS}(K)P(T,t,K)dK,\end{aligned} \tag{A.5}$$

where F_S and F_{SS} are the first and second derivatives of the contingent claim payoff function; $C(T,t,K)$ and $P(T,t,K)$ are the call and put options with strike price K and a time to maturity $T-t$. Setting the square, cubic, and quartic contract payoffs to $F(S) = log(S_T/S_t)^2$, $F(S) = log(S_T/S_t)^3$ and $F(S) = log(S_T/S_t)^4$, respectively, allows us to derive risk-neutral moments using the previous equation. Performing standard differentiation steps and setting $S_0 = S_t$, Bakshi et al. (2003) derive the fair payoff values by computing the discounted risk-neutral expectation $E^Q\left\{e^{-r(T-t)}F(S)\right\}$ for the square payoff $V(T,t) = E^Q\left\{e^{-r(T-t)}log(S_T/S_t)^2\right\}$, cubic payoff $W(T,t) = E^Q\left\{e^{-r(T-t)}log(S_T/S_t)^3\right\}$, and quartic payoff $X(T,t) = E^Q\left\{e^{-r(T-t)}log(S_T/S_t)^4\right\}$ as:

$$V(T,t) = \int_{S_t}^{\infty} \frac{2\left(1 - log(\frac{K}{S_t})\right)}{K^2} C(T,t,K)dK + \int_0^{S_t} \frac{2\left(1 + log(\frac{S_t}{K})\right)}{K^2} P(T,t,K)dK \tag{A.6}$$

$$\begin{aligned} W(T,t) = &\int_{S_t}^{\infty} \frac{6\left(log(\frac{K}{S_t})\right) - 3\left(log(\frac{K}{S_t})\right)^2}{K^2} C(T,t,K)dK \\ &- \int_0^{S_t} \frac{6\left(log(\frac{S_t}{K})\right) + 3\left(log(\frac{S_t}{K})\right)^2}{K^2} P(T,t,K)dK \end{aligned} \tag{A.7}$$

$$\begin{aligned} X(T,t) = &\int_{S_t}^{\infty} \frac{12\left(log(\frac{K}{S_t})\right)^2 - 4\left(log(\frac{K}{S_t})\right)^3}{K^2} C(T,t,K)dK \\ &+ \int_0^{S_t} \frac{12\left(log(\frac{S_t}{K})\right)^2 + 4\left(log(\frac{S_t}{K})\right)^3}{K^2} P(T,t,K)dK \end{aligned} \tag{A.8}$$

Appendix A.2.3 Risk-neutral moments

The model-free risk-neutral volatility $v(T,t)$, risk-neutral skewness $s(T,t)$, and risk-neutral kurtosis $k(T,t)$ can then be extracted from a collection of out-the-money option contracts at period t with maturity T. These risk-neutral moments are defined as follows:

$$v(T,t) = \left[e^{r(T-t)}V(T-t) - \mu(T,t)^2\right]^{\frac{1}{2}} \tag{A.9}$$

$$s(T,t) = \frac{e^{r(T-t)}W(T-t) - 3\mu(T,t)e^{r(T-t)}V(T-t) + 2\mu(T,t)^3}{\left[e^{r(T-t)}V(T-t) - \mu(T,t)^2\right]^{\frac{3}{2}}} \tag{A.10}$$

$$\begin{aligned} k(T,t) = &\frac{e^{r(T-t)}X(T-t) - 4\mu(T,t)e^{r(T-t)}W(T-t) + 6\mu(T,t)^2e^{r(T-t)}V(T-t)}{\left[e^{r(T-t)}V(T-t) - \mu(T,t)^2\right]^2} \\ &- \frac{3\mu(T,t)^4}{\left[e^{r(T-t)}V(T-t) - \mu(T,t)^2\right]^2} \end{aligned} \tag{A.11}$$

Using the martingale property, the mean μ of the risk-neutral distribution is computed from a Taylor expansion as follows:

$$\mu(t,T) = e^{r(T-t)} - 1 - e^{r(T-t)}\left(\frac{V(T-t)}{2!} + \frac{W(T-t)}{3!} + \frac{X(T-t)}{4!}\right) \tag{A.12}$$

To evaluate the integration, we use the discretization, which leads to the following implied moments [23]:

$$E^Q\left\{log(S_T/S_t)^2\right\} = -e^{r(T-t)}\sum_i \frac{1}{K_i^2}Q(K_i)\Delta K_i + \left(log(\frac{K_0}{F_t^T}) + \frac{F_t^T}{K_0} - 1\right) \tag{A.13}$$

$$\begin{aligned} E^Q\left\{log\left(S_T/S_t\right)^2\right\} = &e^{r(T-t)}\sum_i \frac{2 - 2log(\frac{K_i}{F_t^T})}{K_i^2}Q(K_i)\Delta K_i \\ &+ \left(log^2(\frac{K_0}{F_t^T}) + 2log(\frac{K_0}{F_t^T})\left(\frac{F_t^T}{K_0} - 1\right)\right) \end{aligned} \tag{A.14}$$

[23] See the CBOE's (Chicago Board Options Exchange's) white paper at http://www.cboe.com/micro/skew/documents/skewwhitepaperjan2011.pdf.

$$E^{Q}\left\{log(S_T/S_t)^3\right\} = e^{r(T-t)}\sum_i \frac{6log(\frac{K_i}{F_t^T}) - 3log^2(\frac{K_i}{F_t^T})}{K_i^2} Q(K_i)\Delta K_i \tag{A.15}$$
$$+\left(log^3(\frac{K_0}{F_t^T}) + 3log^2(\frac{K_0}{F_t^T})\left(\frac{F_t^T}{K_0} - 1\right)\right),$$

where F_t^T is the forward index level derived from option prices; K_0 is the first listed strike below F_0; K_i is the strike price of the ith out-of-the-money option contract; ΔK_i is the half the difference between the strike on either side of K_i, with $\Delta K_i = \frac{1}{2}\left(K_{i+1} - K_{i-1}\right)$; and $Q(K_i)$ is the midpoint of the bid-ask spread for each option with strike K_i.

To compute the implied moments, we first select the option contracts with more than one week and less than sixty days to expiration (i.e., the near and next-term options that are generally the first and second contract months). Second, we derive the 30-day implied moments by linear interpolation or extrapolation from the implied moments at option expiration dates adjacent to 30 calendar days, which are the near- and next-term prices of the variance and skewness payoffs, respectively.[24] We then scale them to obtain our daily implied moments. Our spillover findings are also robust to using the 30-day implied moments.

Appendix A.2.4 Realized moments

The daily realized variance (RV_t), realized skewness (RS_t), and realized kurtosis (RK_t) are computed using the 5 min intraday returns as follows (Andersen et al., 2003; Amaya et al., 2015):

$$RV_t = \sum_{i=1}^{N} r_{t,i}^2 \tag{A.16}$$

$$RS_t = \frac{\sqrt{N}\sum_{i=1}^{N} r_{t,i}^3}{RV_t^{3/2}} \tag{A.17}$$

$$RK_t = \frac{N\sum_{i=1}^{N} r_{t,i}^4}{RV_t^{4/2}}, \tag{A.18}$$

where $r_{t,i}$ is the ith intraday return on day t and is defined as $r_{t,i} = \log(P_{t,i/N}) - \log(P_{t,(i-1)/N})$; P is the price; and N is the number of intraday return observations in a trading day.

Knowing the risk-neutral and realized moments, we can now estimate the risk premia as the difference between them (Bollerslev et al., 2009).

Appendix A.3 Aggregate connectedness among stock markets

To\From	U.S.	U.K.	Germany	Japan
U.S.	88.80	7.64	2.80	0.76
U.K.	4.42	89.17	5.81	0.60
Germany	3.53	11.46	84.53	0.48
Japan	2.87	8.85	2.94	85.33

Note: This table reports the full sample connectedness among the U.S., U.K., German, and Japanese stock markets. Note that it presents the connectedness considering the volatility risk premium ($\widetilde{VRP}$), skewness risk premium ($\widetilde{SRP}$), and kurtosis risk premium ($\widetilde{KRP}$) innovations. The connectedness matrix is estimated following Diebold and Yilmaz (2012, 2014) under the block aggregation routine of Greenwood-Nimmo et al. (2015) and captures the share of the variance of each market that is explained by shocks occurring in its own market and other markets. The variance decompositions are computed using a forecast horizon of ten trading days.

[24] For instance, we use interpolation when the near- and next-term options have less and more than 30 days to expiration, respectively. The implied moment values reflect the extrapolation of near- and next-term moments when the near-term options have less than one week to expiration, and thus, we use the second and third contract months.

Appendix A.4 Aggregate connectedness among risk premia

To\From	$\widetilde{\text{VRP}}$	$\widetilde{\text{SRP}}$	$\widetilde{\text{KRP}}$
$\widetilde{\text{VRP}}$	95.58	3.06	1.36
$\widetilde{\text{SRP}}$	3.71	89.20	7.09
$\widetilde{\text{KRP}}$	1.82	8.50	89.68

Note: This table reports the full sample connectedness among the aggregated volatility risk premium ($\widetilde{\text{VRP}}$), the skewness risk premium ($\widetilde{\text{SRP}}$), and the kurtosis risk premium ($\widetilde{\text{KRP}}$) innovations of the U.S., U.K., German, and Japanese stock markets. The connectedness matrix is estimated following Diebold and Yilmaz (2012, 2014) under the block aggregation routine of Greenwood-Nimmo et al. (2015) and captures the share of the variance of each risk premium moment that is explained by shocks occurring in its own moment and other risk premia. The variance decompositions are computed using a forecast horizon of ten trading days.

Appendix A.5 Change in the spillovers surrounding pooled events

		Spillover among markets	Spillover among moments
Panel A: Expansionary and contractionary announcements			
Expansionary - all	Pre	21.71	8.27
	Post	21.67	7.98
	Diff	−0.04	−0.28**
		(−0.24)	(−2.30)
Expansionary - 2009 to 2012	Pre	21.33	8.04
	Post	22.02	8.58
	Diff	0.69***	0.53***
		(5.59)	(5.08)
Expansionary - others	Pre	22.00	8.44
	Post	21.39	7.52
	Diff	−0.61***	−0.92***
		(−3.08)	(−6.83)
Contractionary	Pre	19.42	8.13
	Post	20.01	8.33
	Diff	0.58***	0.20*
		(3.53)	(1.86)
Panel B: FOMC's announcements			
Expansionary - all	Pre	21.15	8.36
	Post	20.74	7.98
	Diff	−0.41**	−0.38***
		(−2.02)	(−2.50)
Expansionary - 2009 to 2012	Pre	22.03	8.79
	Post	22.6	9.29
	Diff	0.57***	0.49***
		(5.33)	(4.11)
Expansionary - others	Pre	20.56	8.06
	Post	19.51	7.11
	Diff	−1.06***	−0.96***
		(−4.33)	(−5.72)
Contractionary	Pre	19.37	7.24
	Post	19.98	7.56
	Diff	0.61***	0.32***
		(3.63)	(3.52)
Panel C: ECB's announcements			
Expansionary - all	Pre	22.08	8.44
	Post	22.41	8.37
	Diff	0.33**	−0.07
		(1.99)	(−0.65)

(*continued on next page*)

		Spillover among markets	Spillover among moments
Expansionary - 2009 to 2012	Pre	21.05	7.74
	Post	21.79	8.29
	Diff	0.74***	0.55***
		(5.70)	(5.59)
Expansionary - others	Pre	23.38	9.31
	Post	23.19	8.47
	Diff	−0.18	−0.85***
		(−0.91)	(−6.98)
Contractionary	Pre	19.51	9.46
	Post	20.04	9.47
	Diff	0.54***	0.01
		(3.38)	(0.07)
Panel D: BoJ's announcements			
Expansionary	Pre	21.41	7.25
	Post	20.61	6.26
	Diff	−0.80***	−0.99***
		(−10.22)	(−10.19)
Panel E: Political announcements			
	Pre	23.48	8.87
	Post	25.04	9.27
	Diff	1.56***	0.40***
		(8.31)	(3.57)

Note: This table reports the change in aggregate spillover among markets and moments from Panel A in Fig. 3. Panel A presents the overall impacts of expansionary and contractionary announcements without accounting for their origin. Panels B, C, and D show the effects of these announcements when taking into account their source, and Panel E presents the political events. For these spillover effects, the values reported show their change, which is measured as the difference one month after (post) and prior (pre) to the various announcements from the Federal Open Market Committee (FOMC), European Central Bank (ECB), Bank of England (BoE), and the Bank of Japan (BoJ). We calculate the *t*-statistics (i.e., the numbers in parentheses) by dividing the change in spillover by the standard deviations one month after and before the events. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

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