Volatility Spillovers and the Effect of News Announcements*

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Abstract

We examine the spillover of implied volatility, both across U.S. and European stock markets and within European markets, as well as the effect of scheduled U.S. and European macroeconomic news announcements on this transmission. To this end, we use a number of synchronously measured international implied volatility indices. Consistent with existing literature, we find significant spillovers of implied volatility between U.S. and European markets as well as within European markets. In particular, there is a spillover effect from U.S. to Europe that remains significant even after controlling for spillovers within the Euro-zone. In addition, we find that only the European releases affect U.S. and European implied volatility. These resolve information uncertainty, leading to a decrease of implied volatility. Nevertheless, news announcements, both at the aggregate and individual level, do not fully explain the reported spillovers. However, they affect the magnitude of volatility spillovers. Our results are robust to extreme market events, such as the recent financial crisis and support the notion of volatility contagion.

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1 Introduction

The Crash of October 1987 in U.S. stock market and its impact on other stock markets around the world has motivated the growth of a vast literature that explores the transmission of volatility across stock markets (see Gagnon and Karolyi, 2006, for an extensive review). Surprisingly, to the best of our knowledge there is no paper that examines whether news announcements affect volatility spillovers.[1] From a theoretical point of view, news releases are expected to affect volatility since they affect expectations about future cash flows (see Schwert, 1989, for a similar rationale on the relationship between volatility and macroeconomic variables); Ross (1989) shows that in the absence of arbitrage, the instantaneous variance of returns equals the variance of information flow. In this paper, we examine the spillover of *implied* volatility, both across U.S. and European markets and within European markets as well as the effect of macroeconomic scheduled news on this transmission. Implied volatility is, by definition, a measure of expected stock market volatility. Hence, it is inherently a forward-looking measure of market volatility and therefore is expected to estimate it more accurately as opposed to historical measures of volatility (see e.g., Granger and Poon, 2003, for a review of the literature on the information content of implied volatility and Kostakis et al., 2011, for a discussion of the use of of the information embedded in option markets in finance).

A number of studies have documented the transmission of implied volatility across international markets (see e.g., Gemmill and Kamiyama, 2000, Skiadopoulos, 2004, Konstantinidi et al., 2008). In addition, the empirical evidence suggests that implied volatility drops as soon as a scheduled news announcement is released (see e.g., Patell and Wolfson, 1979, Donders and Vorst, 1996, Ederington and Lee, 1996, Fornari and Mele, 2001, Kim and Kim, 2003, Fornari, 2004, for an examination of at-the-money implied volatility, Bailie, 1988, for a study of an average of implied volatilities, and Beber and Brandt, 2006, for an examination of the second moment of option implied risk-neutral distributions).[2] This finding is consistent with the models of implied volatility behavior around scheduled news announcements suggested by Patell and Wolfson (1979), and Ederington and

[1] To the best of our knowledge, Connolly and Wang (1998) is the only study that has examined the relation between news announcements and volatility spillovers. They explore whether news announcements account for the reported volatility spillovers between U.S., U.K., and Japan. Their study, however, is based on realized volatility where the volatility measure is constructed from historical data (conditional volatility model).

[2] In the case of scheduled news announcements, the timing but not the content of the release is known a priori by market participants. There is also some literature that considers unscheduled news announcements (i.e. neither the timing nor the content are known a priori by market participants); implied volatility is found to increase on unscheduled announcement days (see e.g., Ederington and Lee, 1996, Fornari and Mele, 2001).

Lee (1996) that predict that implied volatility falls on scheduled news announcement days leading to a resolution of uncertainty.[3] A similar reaction to scheduled news announcements has also been documented in an implied volatility index setting (see e.g., Chen and Clements, 2007). However, none of these studies has investigated the effect of news announcements to the reported volatility spillovers; their analysis is constrained in a single-country setting.

Extending the existing literature, we investigate the *impact of news announcements on volatility spillovers*. In particular, this paper ties together the volatility spillover and news announcement literature by examining (1) how shocks in volatility are transmitted both between U.S. and European stock markets and within European markets, (2) how news announcements account for the reported volatility spillovers, i.e. to what extent volatility linkages across markets are driven by news announcements, and (3) whether news announcements affect the magnitude of volatility spillovers, i.e. whether volatility spillovers are significantly different on announcement days as opposed to non-announcement days. The answer to these questions is of particular importance to both academics and practitioners for at least the following four reasons. First, the results will shed light on whether news releases lead to a resolution of uncertainty. Second, the transmission of volatility shocks from one market to another offers direct evidence of how much markets within and across regions are integrated (see e.g., Bekaert et al., 2005, and references therein). Third, understanding how volatility shocks transmit from one market to another is important for international portfolio management and risk management. For instance, in the case where volatility is transmitted across markets in a systematic way around scheduled news announcements, it may be possible to devise profitable option trading strategies (see e.g., Donders and Vorst, 1996, Ederington and Lee, 1996). Fourth, in the case where volatility spillovers continue to show up even after news announcements about "fundamentals" have been taken into account, this

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[3] Both models predict that implied volatility increases gradually prior to a news release and falls on the announcement date. This prediction does not take into account the content of news announcements. In addition, it is based on the interpretation of implied volatility as the average volatility expected until the expiration of the option (see Hull and White, 1987), a set of further assumptions and a shrinking time to maturity. Thus, this prediction does not hold for implied volatility indices that have a constant time to maturity at every point in time. However, both models can be extended so as to accommodate a constant time to maturity, yet unambiguous predictions cannot be made without making any additional restrictive assumptions. Note also that in the case of conditional volatility, the reverse behavior is anticipated, namely conditional volatility is expected to be low before an important release occurs and then increase on the announcement (see Cenesizoglu, 2009, for a theoretical explanation). This is in line with the empirical evidence reported on the conditional volatility in bond markets, termed the "calm-before-the-storm" effect by Jones et al. (1998).

points to the existence of volatility contagion.[4]

To address our three main questions, we adopt major international implied volatility indices widely followed by academics and practitioners. More specifically, we use seven European and the U.S. VIX implied volatility indices. These are constructed in a model-free way and enable capturing the volatility of the respective stock markets (see Jiang and Tian, 2005, Carr and Wu, 2006 and the CBOE VIX white paper).[5] The value of an implied volatility index represents the implied volatility of a synthetic option that has constant time-to-maturity at every point in time. In addition, they are more informative than the implied volatility of a single option contract, since they take into account the information contained in option prices across the whole spectrum of strike prices. Furthermore, using implied volatility indices is advantageous because they are not subject to the considerable measurement errors that implied volatilities are notorious for since they use information from out-of-the money options (see Hentschel, 2003). In addition, the use of U.S. and European implied volatility indices will also allow us detecting the importance of the two regions in explaining implied volatility spillovers, i.e. whether there is a European (U.S.) regional effect where Euro-zone (U.S.) volatility drives European and U.S. volatility indices. To address the three posed research questions, we employ vector autoregression specifications that allow studying the effect of news releases on volatility transmissions. We consider a number of well followed U.S. and European news announcements and construct aggregate and regional news releases variables.

To the best of our knowledge, the approach taken in this paper is novel and makes four contributions to the existing literature. First, it examines whether there is a U.S. effect that drives the changes in implied volatility after we explicitly control for the European regional effect. This is analogous to the literature that attributes a country's volatility to three separate sources, namely the local (i.e. own-country), the regional (i.e. own-region) and the world (usually the U.S. is used as a proxy of the world) component (see e.g., Baele, 2005, Bekaert et al., 2005, Asgharian and Nossman, 2010). This literature finds mixed results, in the sense that the regional component is more important in some cases (see e.g., Bekaert et al., 2005, Asgharian and Nossman, 2010) and the U.S. component

[4] There is not a unanimous agreement in the literature on the definition of contagion (see Karolyi, 2003, and Pericoli and Sbracia, 2003, for reviews). We define volatility contagion to be the existence of volatility linkages that are not linked to prevailing economic conditions as these are reflected by economic news announcements (see e.g., Bae et al., 2003, and Bekaert et al., 2005, for an analogous definition). This definition allows distinguishing from volatility spillovers that are due to normal interdependence across various economies (see also Dornbusch et al., 2000, Forbes and Rigobbon, 2002). Yet, it should be acknowledged that the question of volatility contagion is inevitably tested jointly with the assumed variables that are used to control for its existence. Hence, all results should be treated cautiously.

[5] The CBOE white paper can be retrieved from http://www.cboe.com/micro/vix/vixwhite.pdf

dominates in some other (see e.g., Baele, 2005). Second, we provide evidence whether volatility spillovers exist even after the effect of economic fundamentals reflected by news announcements has been taken into account. In the case they do, it begs potential alternative explanations for volatility spillovers, e.g. the contagion explanation offered by the model of King and Wadhwani (1990) where rational agents try to infer information from price changes in other markets thereby causing an increase in volatility in their market. Third, the result also provides evidence for whether macroeconomic news releases affect the magnitude of implied volatility spillovers. Fourth, we examine the impact of both U.S. and European news releases; the literature on the effect of news announcements on implied volatility has considered that of either U.S. or European releases, separately.[6] In addition, the use of various U.S. and European release items enables us to detect their respective individual as well as aggregate impact on the dynamics of implied volatility. Previous studies have primarily focused on examining the effect of individual news release on volatility, with the exception of Nofsinger and Prucyk (2003) and de Goeij and Marquering (2006) who employ aggregate news announcements within a single-country setting. We also examine the robustness of the results in the presence of the recent 2007-2009 financial crisis period. To this end, we perform an additional check by applying the method proposed by Bae et al. (2003) that takes into account extreme co-movements in volatilities. This sheds light on whether extreme market events affect the transmission of implied volatilities and the role of news releases.

The rest of the paper is structured as follows. The following section describes the dataset. In Section 3 presents the results pertinent to implied volatility spillovers. Section 4 explores the extent to which implied volatility spillovers are preserved once the surprise effect of aggregate, regional and individual news announcements has been taken into account. Section 5 examines the impact of aggregate and regional news announcements on the magnitude of implied volatility spillovers. Section 6 investigates the robustness of the results reported in the previous sections in the case where the period over the recent sub-prime crisis is considered. The final section concludes and discusses the implications of the findings.

2 The dataset

The data consist of daily levels of seven implied volatility indices and a set of macroeconomic news

[6] Nikkinen and Sahlström (2004) considered the effect of both European and U.S. releases on implied volatility. They find that only the U.S. news announcements exert a significant impact on implied volatility.

announcements. The sample is from July 1, 2003 to December 31, 2010. One U.S. (VIX) and six European (VDAX-NEW, VCAC VAEX, VBEL, VSMI and VSTOXX) implied volatility indices are considered. In the case of the European indices, we employ daily closing prices measured at 11:30am ET. In the case of VIX, opening prices (measured at 9:30am ET), intraday (measured at 11:30am ET so as to match the closing time of the European option markets) and closing prices (measured at 4:15pm ET) are considered. Note that some of the previous studies have examined the reaction of financial market volatility to news announcements by using intra-day data (see e.g., Chen et al., 1999, for an examination of stock market volatility). We focus instead on the closing prices of the European implied volatility indices under consideration. The choice of daily data is not casual. First, high-frequency data are unavailable for most implied volatility indices over the whole sample period. Second, closing prices are less noisy than the intra-day ones that suffer from microstructure frictions (see Brenner et al., 2009, for a discussion and references therein). Third, closing prices are immune to the "leakages" of the announcement information prior to the actual release (see Birru and Figlewski, 2010), and the adjustment of volatility to its equilibrium level after the occurrence of the announcement (see Ehrmann and Fratzscher, 2005, and Birru and Figlewski, 2010).

The construction algorithm of all implied volatility indices is based on the concept of model-free implied variance proposed by Britten-Jones and Neuberger (2000).[7] Every index represents the 30-day variance swap rate once it is squared (see Carr and Wu, 2006, Jiang and Tian, 2007, and the references therein).[8] VIX, VDAX-New, VCAC, VAEX, VBEL, VSMI and VSTOXX are extracted from the market prices of options on the S&P 500 (U.S.), DAX (Germany), CAC 40 (France), AEX (Netherlands), BEL 20 (Belgium), SMI (Switzerland) and DJ EURO STOXX 50 (Eurozone) index, respectively. The closing prices for all implied volatility indices are obtained from Bloomberg. The intra-day data for VIX are obtained from CBOE.

Table 1 shows the summary statistics of the implied volatility indices (in levels and first differences, Panels A and B, respectively). The first order autocorrelation ρ_1, the Jarque-Bera and the Augmented Dickey Fuller (ADF) test values are also reported. We can see that none of the implied volatility indices is normally distributed either in levels or first differences. In addition,

[7] The construction algorithm of all implied volatility indices is based on the concept of the fair value of the variance swap rate suggested by Demeterfi et al. (1999). Jiang and Tian (2007) show that this concept is equivalent to the model-free implied variance.

[8] A variance swap is a forward contract on annualized variance; the buyer (seller) of the contract receives the difference between the realized variance of the returns of a stated index and a fixed variance rate, termed variance swap rate, if the difference is positive (negative).

most indices exhibit strong autocorrelation both in the levels and first differences. Finally, the values of the ADF test show that implied volatility indices are non-stationary in the levels, and stationary in the first differences (see also Dotsis et al., 2007, for a study on the dynamics of various implied volatility indices).

We also employ eleven U.S. and eight European scheduled news announcement items. The exact timing of the releases and their corresponding survey forecasts are obtained from Bloomberg.[9] Every Friday, Bloomberg surveys key market participants for their forecasts regarding the values of economic variables that will be released within the next week. The median of the survey is considered as the forecast for the respective economic variable (see Vähämaa et al., 2005). The U.S. economic variables under consideration are the change in non-farm payrolls (NFP), consumer confidence index (CCI), consumer price index (CPI), durable goods orders (DGO), FOMC rate decision (FOMC), gross domestic product (GDP), initial jobless claims (IJC), leading indicators (LI), new home sales (NHS), producer price index (PPI), and the retail sales less autos (RS). The European news announcements include the ECB interest rate (ECB), Euro-zone consumer confidence index (EU-CCI), Euro-zone consumer price index (EU-CPI), Euro-zone gross domestic product (EU-GDP), Euro-zone producer price index (EU-PPI), Euro-zone retail sales (EU-RS), IFO business climate (IFO), and the ZEW survey (ZEW). The various news announcement items are briefly defined in Table 2.

Table 3 reports the source, timing, frequency, units of measurement and total number (*N*) of the news announcements in our sample. We can see that all but FOMC announcement items are released before 11:30am ET, i.e. before the closing time of the European option markets. In addition, most news announcement items are reported on a monthly basis. The only exceptions are the initial jobless claims announcement that is released every week, as well as the FOMC rate decision and the ECB interest rate announcements (eight and eleven times per annum, respectively).

[9] In general, the Bloomberg survey forecasts have been found to be rational (see Switzer and Noel, 2001). Similar findings have also been documented for the Money Market Services International (MMS) survey forecasts (see e.g., Cambell and Sharpe, 2009). MMS survey forecasts have been used frequently in previous studies (see e.g., Beber and Brandt, 2006). However, we use the Bloomberg forecasts, since MMS forecasts are not available for Euro-zone news announcements.

3 Implied volatility spillovers

3.1 Do implied volatility spillovers exist? A preliminary analysis

We begin our analysis by investigating whether implied volatility is transmitted across markets. So, hypothesis *H1a* is formulated as:

H1a: *Implied volatility does not spillover across markets.*

We test hypothesis *H1a* by considering a VAR(1) model, i.e.

$$\Delta IV_t = C + \Phi \Delta IV_{t-1} + \varepsilon_t \qquad (1)$$

where $\Delta IV_t = IV_t - IV_{t-1}$ is the (6x1) vector of changes in the implied volatility indices between *t*-1 and *t*, *C* is a (6x1) vector of constants, Φ is a (6x6) matrix of coefficients with φ_{ij} being the coefficient of the *i*-th lagged implied volatility index when the *j*-th implied volatility index serves as the dependent variable (*i* and *j* take the value 1 for VIX, 2 for VDAX, 3 for VCAC, 4 for VAEX, 5 for VBEL, 6 for VSMI), and ε_t is a (6x1) vector of residuals. Then *H1a* translates into a hypothesis for the off-diagonal elements of Φ being equal to zero. Previous studies have also employed a VAR modeling framework to investigate the presence of implied volatility spillovers (see e.g., Gemmill and Kamiyama, 2000, Skiadopoulos, 2004, Konstantinidi et al., 2008).

Table 4 shows the coefficient estimates, *t*-statistics in parentheses, adjusted R^2 and Wald test statistic for H_0: $\varphi_{ij} = 0$ when $i \neq j$ and for the VAR(1) model. One and two asterisks denote rejection of the null hypothesis of a zero coefficient(s) at the 5% and 1% level, respectively. Closing prices for all indices are used as a preliminary check for the existence of volatility spillovers. We can see that the non-diagonal coefficients of Φ are found to be jointly significant. Hence, *H1a* is rejected and therefore, implied volatility is transmitted across markets. More specifically, implied volatility is transmitted from U.S. to Europe, since the lagged changes in the VIX index have a significant impact on all European volatility indices. In addition, implied volatility spillovers from Europe to the U.S., since VIX is affected by the lagged changes in all but VBEL European implied volatility indices. Finally, there are some spillover effects within the European region, as for instance lagged changes in VDAX have a significant impact on all the other European indices.

Motivated by the above findings, we investigate next whether the dynamics of each one of the European implied volatility indices are driven by the U.S. volatility once we explicitly control for the volatility of the Euro-zone (U.S. and regional European effect, respectively). The establishment of such a relationship shall be termed *U.S. effect*. To this end, *H1a* is appropriately modified as:

H1b: *There is no U.S. effect for the individual European indices once we control for the regional European effect.*

To examine the significance of the U.S. and the European effect, two alternative single-equation specifications are considered. First, we test *H1b* by estimating the following specification (PC model):

$$\Delta IV_{i,t} = c_i + \varphi_i \Delta IV_{i,t-1} + \alpha_i \, \Delta VIX_{t-1} + \beta_i \, PC^{EU}_{i,t-1} + \varepsilon_{i,t} \tag{2}$$

where i = 1 (for VDAX), 2 (for VCAC), 3 (for VAEX), 4 (for VBEL), 5 (for VSMI), and $PC^{EU}_{i,t-1}$ is the lagged first principal component (PC) extracted from applying Principal Components Analysis (PCA) to the set of the European implied volatility indices where the i-th European implied volatility index is excluded from this set. The lagged VIX accounts for the spillovers stemming from U.S. to the i-th European implied volatility index and captures the U.S. effect. On the other hand, the $PC^{EU}_{i,t-1}$ takes into account the presence of spillovers stemming from the European region and captures the regional European effect. This implies that the null hypothesis to be tested is *H1b*: $\alpha_i = 0$ for i = 1, 2, …, 5.

Second, we test *H1b* again by estimating the following alternative specification (VSTOXX model):

$$\Delta IV_{i,t} = c_i + \varphi_i \Delta IV_{i,t-1} + \alpha_i \, \Delta VIX_{t-1} + \beta_i \, \Delta VSTOXX_{t-1} + \varepsilon_{i,t} \tag{3}$$

where $VIX_{t\text{-}1}$ captures the U.S. effect, while $VSTOXX_{t\text{-}1}$ (instead of $PC^{EU}_{i,t-1}$) captures now the regional European effect; VSTOXX is often regarded as a pan-European index. Hence, the null hypothesis to be tested is *H1b*: $\alpha_i = 0$ for i = 1, 2, …, 5.

Table 5 shows the coefficient estimates, t-statistics in parentheses and adjusted R^2 for equations (2) and (3) [Panel A and B, respectively]. In the case of the PC model (Table 5, Panel A), we can see that there is a systematic U.S. effect for all European implied volatility indices once we control for the regional European effect and hence *H1b* can be rejected. Only in the case of VSMI both the U.S. and European effects are significant. Similar results are also obtained in the case of the VSTOXX model (Table 5, Panel B). These findings suggest that the U.S. effect dominates for all individual European implied volatility indices, i.e. the dynamics of the volatility of every European index are dictated only by these of the U.S. volatility; the volatility of the Euro-zone does not affect them.

3.2 The issue of non-synchronous measurement of implied volatility indices

All models specification in Section 3.2 are estimated by considering closing prices for both the VIX index and the European implied volatility indices. A non-synchronicity issue arises though since changes in VIX are measured at 4:15pm ET on day *t* and contain more information than the changes in the European volatility indices that are measured at 11:30am ET on day *t*. Hence, we investigate next whether the previously reported finding of a dominant U.S. effect for all individual European volatility indices is robust or whether it is attributed solely to the non-synchronous measurement of implied volatility indices.

To this end, the timing difference between the measurement of U.S. and European implied volatility indices is minimized. More specifically, we consider opening prices for VIX (i.e. prices measured at 9:30pm ET on day *t*) and closing prices for all the European ones (i.e. prices measured at 11:30pm ET on day *t*, see also Albuquerque and Vega, 2009, for a similar approach). Table 6 shows the coefficient estimates, *t*-statistics in parentheses and adjusted R^2 for equations (2) and (3) [Panel A and B, respectively] in the case where opening prices for the VIX index and closing prices for the European indices are used. In the case of the PC model (Table 6, Panel A), we can see that there is no systematic U.S. effect for all European implied volatility indices once we control for the regional European effect. On the other hand, the European effect (i.e. $PC_{i,t-1}^{EU}$) is significant for all but one European implied volatility indices. Analogous results are also obtained in the case of the VSTOXX model (Table 6, Panel B). These findings are in contrast with the results documented in the case were closing prices are used for all implied volatility indices and highlights the necessity to use synchronous prices for both the U.S. and the European implied volatility indices. Hence, in the remaining of the paper we will perform the analysis by using the 11:30am ET intra-day data for VIX and the synchronously measured closing prices for the European indices.

3.3 Implied volatility spillovers revisited

Next, we revisit hypotheses *H1a* and *H1b* by using the *synchronous* prices for the VIX index and the European implied volatility indices measured at 11:30am ET. To this end, we re-estimate specifications (1), (2) and (3) by using the intra-day VIX prices collected at 11:30am ET.

Table 7 shows the results for the VAR(1) model [equation (1), Panel A], PC model [equation (2), Panel B] and VSTOXX model [equation (3), Panel C]. Regarding the VAR(1) model (Table 7, Panel A), we can see that the non-diagonal coefficients of Φ are jointly significant and hence, implied volatility is transmitted across markets. In particular, the lagged VIX index affects all European implied volatility indices suggesting that implied volatility spills over from the U.S. to Europe. Implied volatility is also transmitted from Europe to the U.S., since all but one European implied volatility indices have a significant effect on the VIX index. Furthermore, implied volatility spillovers also exist within the European region, as for example VDAX and VBEL affect all the European indices significantly. Moreover, for most implied volatility indices, the coefficients of their own lagged terms are significant and negative, suggesting that implied volatility index changes are autocorrelated and mean reverting. These findings are in line with Melvin and Melvin (2003) who document the presence of "meteor showers" (i.e. volatility spillovers across markets) and "heat waves" (i.e. autocorrelation in volatility).

In the case of the PC model (Table 7, Panel B) and the VSTOXX model (Table 7, Panel C), we can see that the lagged changes in VIX affect all European implied volatility indices once we control for the regional European effect. The latter is found to be insignificant in most cases. This suggests that both model specifications reject the *H1b* and that the U.S. effect dominates for all individual European implied volatility indices. Finally, this asymmetric implied spillover effect is in line with the findings of Hamao et al. (1989) who document that the U.S. conditional volatility is transmitted to other markets but the reverse does not hold.

4 The effect of news announcements on implied volatility dynamics

4.1 News announcement surprises

To investigate the effect of news announcements on implied volatility spillovers, we construct measures of surprises (i.e. unexpected shocks) of news announcements. Specifically, we use the absolute value of the standardized surprise element, $S_{i,t}$, of a release of item *i* at time *t*. This measure has been commonly used in the literature (see e.g., Balduzzi et al., 2001, Brenner et al., 2009, Jiang et al., 2010, and the references therein) and is defined as follows:

$$S_{i,t} = \frac{A_{i,t} - F_{i,t}}{\sigma_i} \quad (4)$$

where $A_{i,t}\left(F_{i,t}\right)$ is the announced value (Bloomberg forecast) for the *i*-th economic variable before *t*, and σ_i is the standard deviation of the unexpected component (i.e. $A_{i,t} - F_{i,t}$) of the announcements for the *i*-th economic variable for the whole sample period. The standardization helps comparing the effect of different announcements that differ in the units of measurement. Note that the surprise variable takes into account the timing as well as the content of the respective release.[10]

The fact that the absolute value of $S_{i,t}$, is considered assumes implicitly that only the magnitude and not the sign of the surprise matters.[11] This is in line with Christiansen and Ranaldo (2007) who argue that large positive and negative surprises should affect volatility identically, since a larger surprise implies greater uncertainty. Furthermore, taking the absolute value of equation (4) accommodates the construction of an aggregate surprise measure of all news announcements under consideration. This is because our sample includes different news types (e.g., real economic activity releases, inflationary releases etc.) and hence, one cannot aggregate their unexpected component without taking its absolute value. The construction of an aggregate surprise measure is also facilitated by the fact that the unexpected component of news announcements has been standardized [see equation (4)]. This is because the standardization of the surprise element eliminates the units of measurement and hence, allows aggregating the unexpected component across news announcement items. Thus, the aggregate surprise component $|S_t|$ of *all* U.S. and European news announcement that occurs between *t*-1 and *t* is defined as:

$$|S_t| = |S_t^{US}| + |S_t^{EU}| \tag{5}$$

where $|S_t^{US}| = \sum_{i=1}^{12} |S_{i,t}^{US}|$ $\left(|S_t^{EU}| = \sum_{j=1}^{8} |S_{j,t}^{EU}| \right)$ is the aggregate U.S. (European) absolute surprise component of the announcements for *all* of the U.S. (European) economic variables that occur between *t*-1 and *t*.

4.2 The effect of aggregate news releases on implied volatility dynamics

In this section, we examine the effect of *aggregate* releases on the dynamics of implied volatility. Aggregate releases have been used in the past to examine the impact of news announcements on

[10] There is a series of papers that has considered only the timing of the releases (see e.g., Ederington and Lee, 1996, Donders and Vorst, 1996, Fornari and Mele, 2001, Nikkinen and Sahström, 2004, Chen and Clements, 2007).

[11] Beber and Brandt (2009) consider positive and negative surprises separately and interpret these as bad and good news, respectively. This interpretation is valid in their case since they consider only inflationary announcements within a single country setting. However, such an exercise is not possible in our case since different news announcement types are considered within a multi-country setting.

volatility only within a single-country setting (see Nofsinger and Prucyk, 2003, and de Goeij and Marquering, 2006). Hence, we formulate the following hypothesis to examine the aggregate surprise effect on implied volatility spillovers:

H2: *Implied volatility spillovers do not exist once we account for the surprise effect of aggregate releases.*

We test *H2* by augmenting a VAR(1) model with the aggregate surprise variable:

$$\Delta IV_t = C + \Phi \Delta IV_{t-1} + A\left|S_t\right| + \varepsilon_t \tag{6}$$

where $\Delta IV_t = IV_t - IV_{t-1}$ is a (6x1) vector of changes in the implied volatility indices between 11:30am ET on day *t*-1 and 11:30am ET on day *t*, *C* is a (6x1) vector of constants, Φ is a (6x6) matrix of coefficients, *A* is a (6x1) vector of coefficients, $|S_t|$ is the aggregate surprise component of the announcements for *any* economic variable that occur between 11:30am ET on day *t*-1 and 11:30am ET on day *t*, and ε_t is a (6x1) vector of residuals. Note that testing *H2* is equivalent to testing whether the off-diagonal elements of Φ are statistically insignificant.

Equation (6) can be viewed as an encompassing regression. In the case where the matrix *A* turns out to be statistically insignificant and the off-diagonal elements of Φ significant, this would favor a volatility contagion story (see e.g., King and Wadhwani, 1990), i.e. news announcements do not account for the observed volatility spillovers. On the other hand, if the elements of *A* turn out to be statistically significant and the off-diagonal elements of Φ statistically insignificant, then news announcements are the sole drivers of volatility changes since they subsume all information available in volatility spillovers. Finally, in the case where both *A* and the off-diagonal elements of Φ turn out to be statistically significant, this would suggest that news announcements would account only for a part of the documented volatility spillovers.

Table 8 shows the results for the VAR(1) model that allows for the vector of constants to be affected by the aggregate surprise variable [*H2*, equation (6)]. The coefficient estimates, *t*-statistics, Wald test statistic for testing the H_0: $\varphi_{ij} = 0$ when $i \neq j$ and adjusted R^2 are reported. We can see that aggregate releases have a significant effect on the dynamics of most European implied volatility indices but VDAX and VCAC. On the other hand, the dynamics of VIX are not affected by aggregate news announcements. In addition, the coefficients of the aggregate surprise variable are negative in all cases. This finding supports the resolution of uncertainty hypothesis of Ederington and Lee (1996) according to which the occurrence of a scheduled announcement reduces the information uncertainty of market participants. The reduction in implied volatility on the scheduled announcement days is also in line with the findings of the literature on the effect of news announcements on implied volatility (see e.g., Patell and Wolfson, 1979, Donders and Vorst, 1996, Ederington and Lee, 1996, Fornari and Mele, 2001, Kim and Kim, 2003, Fornari, 2004, Steeley, 2004, Beber and Brandt, 2006) and implied volatility indices within a single-country setting (see e.g., Chen and Clements, 2007). On the other hand, it is in contrast with the findings on the reaction of volatility measures other than implied volatility to news releases (see e.g., Jones et al., 1998, who document that the conditional volatility in bond markets increases on the announcement day). Furthermore, we can see that implied volatility spillovers remain significant despite the fact that we take into account economic fundamentals as measured by the release of macroeconomic news. In particular, there is evidence of "meteor showers" and "heat waves"; this is analogous to the results of Melvin and Melvin (2003). The findings imply the presence of volatility contagion across countries.

4.3 The effect of regional news releases on implied volatility dynamics

Next, we focus on the respective effects of European and U.S. announcements. In particular, we examine whether implied volatility spillovers remain significant after the effect of *regional* aggregate announcements is taken into account. Thus, the following hypothesis is formulated:

H3: *Implied volatility spillovers do not exist once we account for the surprise effect of the U.S. and European releases.*

We test *H3* by considering a VAR(1) model that allows for the vector of constants to be affected by regional aggregate surprise variables:

$$\Delta IV_t = C + \Phi \Delta IV_{t-1} + A\left|S_t^{US}\right| + B\left|S_t^{EU}\right| + \varepsilon_t \qquad (7)$$

where A and B are (6x1) vectors of coefficients, $|S_t^r|$ is the aggregate surprise component of the announcements for *any* economic variables of region r (r = 1, 2 for U.S. and Europe, respectively) that occur between 11:30am ET on day t-1 and 11:30am ET on day t, and ε_t is a (6x1) vector of residuals. Equation (7) is estimated by using the SUR methodology. Note that *H3* is translated into a test of the statistical insignificance of the off-diagonal elements of Φ.

Table 9 shows the results for the VAR(1) model that allows for the vector of constants to be affected by the regional surprise variables [*H3*, equation (7)]. Results are similar to these obtained in the case where aggregate news were considered. In particular, three remarks are in order. First, we can see that only the European news announcements affect the dynamics of the VIX index and all but the VDAX European implied volatility indices. This suggests that European news announcements have an impact within the European region, but also cross over the Atlantic. On the other hand, the U.S. surprise element is insignificant for all implied volatility indices. The fact that only the European news announcements have a significant effect on the dynamics of implied volatility contradicts the findings of Nikkinen and Sahström (2004) who find that only the U.S. news announcements affect the VDAX and a Finish implied volatility index within a single-country setting. This discrepancy in results might be explained by the fact that the latter study considers only the timing and not the content of news announcements. Second, we can see that regional news announcements have a negative effect on implied volatility which is consistent with the resolution of uncertainty hypothesis of Ederington and Lee (1996). Finally, implied volatility spillovers continue driving the dynamics of implied volatilities when the effect of news announcements is taken into account. This suggests that *H3* is rejected and hence, volatility contagion effects exist.

4.4 The effect of individual news releases on implied volatility dynamics

So far, we have investigated whether implied volatility spillovers drive the dynamics of implied volatilities after taking into account the surprise effect of aggregate releases, as well as that of the regional ones. Next, we turn our attention to the effect of *individual* news announcements on the presence of implied volatility spillovers as a driver of volatility dynamics. Thus, we test the following hypothesis:

H4: *Implied volatility spillovers do not exist once we account for the surprise effect of the individual releases.*

To test this hypothesis, the impact of scheduled news announcements on each one of the six implied volatility indices is incorporated in the VAR model. Given that any news surprise may have an asymmetric effect on implied volatility dynamics depending on its sign, we also employ a dummy sign variable (see e.g., Beber and Brandt, 2006, for a similar approach). This will help in studying further the resolution of the uncertainty finding documented in the previous sections (e.g., a positive surprise in GDP is expected to decrease uncertainty while a negative one to increase it). Note that in the specifications used in the previous sections, absolute surprises had to be used in order to enable the construction of aggregate variables. In addition, in these cases a dummy sign variable could not be defined because we aggregate across different news announcement items. In particular, we test *H4* by estimating the following specification using the SUR methodology:

$$\begin{aligned}\Delta IV_t = C + \Phi \Delta IV_{t-1} &+ \left[\left(A_1 + B_1 D_{1t}^{US} \right) | S_{1t}^{US} | + \ldots + \left(A_{11} + B_{11} D_{11t}^{US} \right) | S_{11t}^{US} | \right] \\ &+ \left[\left(\Gamma_1 + Z_1 D_{1t}^{EU} \right) | S_{1t}^{EU} | + \ldots + \left(\Gamma_8 + Z_8 D_{8t}^{EU} \right) | S_{8t}^{EU} | \right] + \varepsilon_t\end{aligned} \quad (8)$$

where A_i, B_i, Γ_j, and Z_j are (6x1) vectors of coefficients (*i* = 1 for NFP, 2 for CCI, …, 11 for RS and *j* = 1 for ECB, 2 for EU-CCI,…, 8 for ZEW; the ordering of the news items corresponds to this shown in Table 2), $|S_{it}^{US}|$ $\left(|S_{jt}^{EU}|\right)$ is the absolute surprise component of the *i*-th individual U.S. (*j*-th individual European) announcement item that occurs between 11:30am ET on day *t*-1 and 11:30am ET on day *t*, D_{it}^{US} $\left(D_{jt}^{EU}\right)$ is a sign dummy variable for the *i*-th individual U.S. (*j*-th individual European) announcement item that takes the value 1 when the $S_{it}^{US} < 0$ $\left(S_{jt}^{EU} < 0\right)$ and zero otherwise, and ε_t is a (6x1) vector of residuals.

Testing *H4* is analogous to testing the hypothesis that the off-diagonal elements of Φ are equal to zero. In addition, in the case where both A_i (Γ_j) and B_i (Z_j) turn out to be significant, this would mean that the announcements of the *i*-th U.S. (*j*-th European) release item have a significant asymmetric effect on implied volatility, i.e. the effect of positive and negative surprises on implied volatility is different. Furthermore, in the case were only B_i (Z_j) turns out to be significant then only the negative surprises of the *i*-th U.S. (*j*-th European) news announcement item have a systematic effect on implied volatility. On the other hand, if only A_i (Γ_j) is found to be significant then the *i*-th U.S. (*j*-th European) release item has a symmetric impact on implied volatility, i.e. positive and negative surprises affect volatility in the same way.

Table 10 shows the results for the VAR(1) model augmented by the surprise variables for the individual news announcement items [*H4*, equation (8)]. We can see that the vast majority of individual news announcement items does not affect the dynamics of implied volatility indices. Regarding the asymmetric effect, only two U.S. and one European release items (leading indicators, retail sales less autos and IFO business climate) have an asymmetric effect on volatility; in this case, only the negative surprises affect volatility dynamics. These findings are analogous to those of Connolly and Wang (1998) who report that news announcements show up less evidently when they are considered at an individual rather than a regional level. Finally, we can see that volatility contagion is present, since implied volatility spillovers are preserved even after we take into account the effect of individual news announcement items. This is in line with the findings documented in the case of aggregate and regional releases.

5 The surprise effect of news announcements on the magnitude of implied volatility spillovers

The results reported in the previous sections document that implied volatility spillovers are significant even after we control for the effect of news announcements. Motivated by this finding, we investigate directly whether macroeconomic releases affect the transmission of volatility across markets. More specifically, we examine the impact of news announcements on the magnitude of implied volatility spillovers.[12] To this end, we explore the surprise effect of aggregate and regional releases, separately.

5.1 The effect of aggregate news releases on the magnitude of implied volatility spillovers

First, we examine whether the magnitude of implied volatility spillovers is the same on announcement and non-announcement dates when the content of *aggregate* news announcements is considered. Thus, we test the following hypothesis:

H5: *Aggregate news announcement surprises do not have any effect on the magnitude of implied volatility spillovers.*

To test this hypothesis, we allow the matrix of the coefficients of the lagged implied volatility indices to be affected by the aggregate surprise component of news announcements within a VAR modeling framework. Hence, we estimate the following specification by using the SUR methodology:

$$\Delta IV_t = C + \left(A + B\,|\,S_t\,|\right)\Delta IV_{t-1} + \varepsilon_t \tag{9}$$

where C is a (6x1) vector of constants, A and B are (6x6) matrices of coefficients, $|S_t|$ is the aggregate surprise component of the announcements for *any* economic variable that occur between

[12] The magnitude of implied volatility spillovers may also depend on other variables that measure the degree of integration of the countries under consideration. The external trade would have been a natural choice to use as a control variable (see e.g., Dornbusch et al., 2000). We do not investigate this because trade data are not available at a daily frequency.

11:30am ET on day t-1 and 11:30pm ET on day t, and ε_t is a (6x1) vector of residuals. This hypothesis translates into testing the elements of B being equal to zero. Note that in the case were A is found to be significant and B insignificant, this would suggest that news announcements do not have an impact on the magnitude of volatility spillovers. On the other hand, if B also turns out to be significant, then the magnitude of implied volatility spillovers differs between announcement and non-announcement days. Note that the magnitude of implied volatility spillovers increases on announcement days in the case where both A and B are significant and have the same sign.

Table 11 shows the results for the surprise effect of aggregate releases on the magnitude of implied volatility spillovers [*H5*, equation (9)]. We can see that the aggregate releases affect the magnitude of the autoregressive coefficients in all indices but the Dutch and Belgian one. In addition, we can see that news announcements have a significant effect on the magnitude of implied volatility spillovers in most of the cases. In particular, news releases affect the magnitude of volatility spillovers between the European countries. They also affect the magnitude of the transmission of implied volatility stemming from most European implied volatility indices to the U.S. (i.e. VIX). Interestingly, aggregate news announcements increase significantly the magnitude of implied volatility spillovers in most cases. On the other hand, aggregate releases do not affect the magnitude of the transmission of implied volatility stemming from the U.S. (i.e. VIX) to most European indices.

5.2 The effect of regional news releases on the magnitude of implied volatility spillovers

Next, we distinguish between releases of U.S. and European economic variables and investigate whether the magnitude of implied volatility spillovers is the same between announcement and non-announcement days when the surprise component of *regional* news announcements is considered:

H6: *The U.S. and European announcement surprises do not have any effect on the magnitude of implied volatility spillovers.*

We test *H6* by allowing the matrix of the coefficients of the autoregressive terms to be affected by the regional aggregate surprise component of news announcements within a VAR setting. In particular, we estimate the following specification by using the SUR methodology:

$$\Delta IV_{1,t} = c_1 + \Delta IV_t = C + \left(A + B \,|\, S_t^{US} \,| + \Gamma \,|\, S_t^{EU} \,|\right) \Delta IV_{t-1} + \varepsilon_t \qquad (10)$$

where C is a (6x1) vector of constants, A, B and Γ are (6x6) matrices of coefficients, $|S_t^r|$ is the aggregate surprise component of the announcements for *any* economic variables of region r (r = 1, 2 for U.S. and Europe, respectively) that occur between 11:30am ET on day t-1 and 11:30am ET on day t, and ε_t is a (6x1) vector of residuals. This hypothesis translates into a test for the elements of B and Γ being zero. In the case where A is found to be significant while B and Γ are not, this would suggest that news announcements do not affect the magnitude of volatility spillovers. On the other hand, if B (Γ) also turns out to be significant then this would suggest that the magnitude of implied volatility spillovers differs between announcement and non-announcement days of U.S. (European) releases. Note that the magnitude of implied volatility spillovers increases on announcement days of U.S. (European) news items in the case where both A and B (A and Γ) turn out to be significant and have the same sign.

Table 12 shows the results for the surprise effect of regional releases on the magnitude of implied volatility spillovers [*H6*, equation (10)]. We can see that the magnitude of implied volatility spillovers is affected by the regional news announcements. Three remarks are in order. First, in the case where we examine the magnitude of implied volatility spillovers stemming from U.S. (i.e. VIX) to the European indices, we can see that this is affected by both U.S. and European news announcements in most cases. Notice that U.S. releases increase the size of the transmission (i.e. A and B have the same sign), while European releases decrease it (i.e. A and Γ have opposite signs). This opposite effect of news announcements explains the fact that aggregate releases have been found not to affect the magnitude of the spillovers stemming from VIX to the European markets. Second, in the case where we examine the size of implied volatility transmission from the European indices to VIX, we can see that that this is affected mostly by the European news announcements. Interestingly, the magnitude of the transmission of volatility stemming from VDAX is affected by U.S. and European news announcements in all cases; releases decrease the size of spillovers to VIX and increase it for the remaining European implied volatility indices. Finally, U.S. and EU releases affect the magnitude of spillovers within the European region, in most cases.

6 Further analysis

6.1 Implied volatility spillovers during the financial crisis

During periods of crises, stock market volatility has been found to increase (see e.g., Schwert, 1989) and volatility spillovers have been found to be more pronounced (Diebold and Yilmaz, 2009). Hence, investigating the role of news announcements during the recent financial crisis period is of particular importance. To this end, we examine whether the effect of news announcements on volatility spillovers reported in the previous sections are robust over the recent financial crisis period. In line with Gorton (2009), we consider August 2007 as the beginning of the recent financial crisis. Hence, the sample to be analyzed spans the period from August 1, 2007 to December 31, 2010.

Table 13 shows the results for the effect of aggregate [equation (6), Panel A], regional [equation (7), Panel B] and individual [equation (8), Panel C] news announcements on the dynamics of implied volatility spillovers. We can see that the results are similar to the ones obtained from the previous analysis over the whole sample period 2001-2010 in all cases. More specifically, volatility spillovers are found to be significant, even after the effect of news announcements is taken into account. Furthermore, aggregate releases affect the dynamics of only some European volatility indices while they do not affect these of VIX. In addition, European regional releases exert a significant effect on the volatility dynamics. This is not the case for the individual news announcement items, which do not affect the implied volatility indices in most cases. Interestingly, the adjusted R^2 increases over the crisis period in all cases, which suggests that volatility contagion is more pronounced over the crisis period.

Table 14 shows the results for the effect of aggregate [equation (9), Panel A] and regional [equation (10), Panel B] news announcements on the magnitude of implied volatility spillovers. We can see that most of the results are similar to those reported over the whole sample period with only one exception. More specifically, U.S. and European news announcements continue to affect the magnitude of spillovers stemming from VDAX to all implied volatility indices. However, regional news announcements increase the size of the spillover stemming from VDAX to VIX over the crisis period.

6.2 Contagion during the financial crisis: An alternative test

Given the evidence on contagion reported in the previous sections, we perform an alternative test of contagion over the recent financial crisis by using the methodology of Bae et al. (2003). In particular, we explore whether aggregate and regional news announcements over the recent financial crisis period explain (a) the occurrence of extreme positive changes in the VIX index, (b) the *joint* occurrence of extreme positive changes in the set of European implied volatility indices and (c) the *joint* occurrence of extreme positive changes in the set of all volatility indices. To this end, in line with Bae et al. (2003), we consider a multinomial logistic regression model for the conditional probability of joint occurrence of large *positive* changes in implied volatility. Following Bae et al. (2003), large positive changes or 'exceedances' in implied volatility are defined as those that lie above the 95th percentage point of the empirical marginal distribution of each implied volatility index over the period of the crisis. Let a random variable Y that counts the number of (co)-exceedances and takes the value i when there are large positive changes (i.e. exceedances) in i implied volatility indices jointly on day t. We define this variable for the U.S. and European implied volatility indices, separately, as well as for all the implied volatility indices jointly. Then, the multinomial logistic regression model is given by the following equation:

$$P(Y=i|x)=\frac{e^{g_i(x)}}{\sum_{j=0}^{k}e^{g_j(x)}} \tag{11}$$

where $Y = 0, 1, 2, \ldots k$ is the (co)-exceedance variable defined for either the U.S., European or all implied volatility indices (k = 1 for the U.S., 3 for the European and 3 for all implied volatility indices), $g_i(x)=\ln\frac{P(Y=i|x)}{P(Y=0|x)}=c+\beta_i'x$ is the logit function in the case of i co-exceedances with $g_0(x)=0$, β_i is a vector of coefficients and x is a vector of covariates (i.e. explanatory variables).

We consider two different sets of covariates. First, the lagged U.S. exceedances, lagged European co-exceedances, and surprise element of aggregate news announcements are used as covariates, i.e.

$$g_i(x_t)=\ln\left[P(Y_t=i|x_t)/P(Y_t=0|x_t)\right]=c_i+\beta_{i1}Y_{t-1}^{US}+\beta_{i2}Y_{t-1}^{EU}+\beta_{i3}\,|\,S_t\,| \tag{12}$$

where $Y_{t-1}^{US}\left(Y_{t-1}^{EU}\right)$ is the lagged U.S. (European) co-exceedance variable. Second, the lagged U.S. exceedances, lagged European co-exceedances, and surprise element of regional news announcements serve as covariates:

$$g_i(x)=\ln\left[P(Y_t=i|x_t)/P(Y_t=0|x_t)\right]=c_i+\beta_{i1}Y_{t-1}^{US}+\beta_{i2}Y_{t-1}^{EU}+\beta_{i3}\,|\,S_t^{US}\,|+\beta_{i4}\,|\,S_t^{EU}\,| \tag{13}$$

In both cases, if the coefficients of the lagged (co)-exceedances turn out to be significant [i.e. β_{i1} and β_{i2} in equations (12) and (13)], then this suggests that there are spillovers in the (co)-exceedances in the sense that lagged (co)-exceedances affect the probability of extreme movements. At the same time, if the coefficients of the news announcement variables are insignificant [i.e. β_{i3} in equation (12), and β_{i3} and β_{i4} in equation (13)], then this suggests that fundamentals do not explain (co)-exceedances and there is room to consider contagion as an alternative explanation for volatility spillovers. We estimate the multinomial logistic regression model by maximum likelihood estimation. The log-likelihood is given by:

$$\ln L = \sum_{t=1}^{n} \sum_{i=0}^{k} I_{ti} P\left(Y_t = i \middle| x_t\right) \qquad (14)$$

where n is the number of observations and I_{ti} is an indicator variable that takes the value 1 when there are i co-exceedances on day t and 0 otherwise.

Table 15 shows the estimated coefficients, pseudo R^2, and likelihood ratio test statistics (LRT) for the multinomial regression model where the probability of (a) exceedances for the U.S., (b) co-exceedances for the European and (c) co-exceedances for all implied volatility indices is considered separately as the dependent variable. Entries report results across the various levels of (co)-exceedances Y in the case where aggregate (Panel A) and regional (Panel B) news announcements are considered as explanatory variables. One and two asterisks denote rejection of the null hypothesis of a zero coefficient at the 5% and 1% level, respectively. In the case of the LRTs, one and two crosses denote rejection of the null hypothesis that the coefficients of any given covariate across the various levels of Y are jointly significant at the 5% and 1% level, respectively. We can see that in the case where *aggregate* news announcements are used as explanatory variables (Table 15, Panel A), the LRTs show that releases do not affect the probability of any (co)-exceedance variable. However, the lagged (co)-exceedances are significant and hence there are spillovers of (co)-exceedances. These findings suggest that there is contagion of volatility shocks between European and U.S. volatility indices. Interestingly, the statistically significant coefficients are positive; this implies that the conditional probability of co-exceedances moves to the same direction with each one of the covariates. Analogous results are also documented in the case where *regional* news announcements are considered as covariates (Table 15, Panel B); U.S. and European news announcements are not significant in any case which supports further the contagion story.

7 Conclusions

We investigate for the first time the effect of scheduled U.S. and European news announcements to the international transmission of market volatility. To this end, we employ an extensive dataset of major European and U.S. implied volatility indices and various news announcements items. We eliminate the issue of non-synchronous measurement of the implied volatility indices by using intra-day prices for the VIX index measured at 11:30am ET so as to match the closing time of the European option markets. Furthermore, we examine both the timing and content of the respective releases within a VAR setting by employing news surprises. First, we explore whether volatility spillovers exist. Next, we address the question whether implied volatility spillovers continue to show up once we take into account the effect of aggregate, regional, and individual releases. Finally, we investigate the impact of aggregate and regional news announcements on the magnitude of implied volatility spillovers.

Five are the main findings of our study. First, in the case where no-news announcements are considered, we find that there are implied volatility spillovers between and within regions. More specifically, U.S. volatility is found to drive the European implied volatility indices. Second, in the case where news announcements are also incorporated in the analysis, we find that aggregate releases drive the dynamics of most European implied volatility indices while they do not affect those of VIX. In the case where the effect of regional announcements is considered, we find that only the European regional releases affect the dynamics of U.S. and European volatilities. Furthermore, most individual news announcement items do not contain additional information over the documented implied volatility spillovers. Third, implied volatility drops in the cases where the aggregate and regional releases have a significant impact. Fourth, regarding the effect of aggregate and regional news announcements on the magnitude of implied volatility spillovers, we find that this is significant. Interestingly though, aggregate releases do not affect the size of the transmission stemming from the U.S. to the European implied volatility indices. This is because regional U.S. and European news announcements have an opposite effect on the magnitude of volatility spillovers. Finally, our findings are robust over the 2007-2009 financial crisis period.

The results have two main implications. First, volatility contagion is present since news about economic fundamentals do not account entirely for the implied volatility interrelations. Second, the greater the surprise element of scheduled releases, the greater is the resolution of uncertainty within an implied volatility spillover setting. This is consistent with the findings of the previous literature on the effect of news announcements to implied volatility within a single-country setting.

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	VIX	VDAX	VCAC	VAEX	VBEL	VSMI
	Panel A: Summary statistics for the levels of the implied volatility indices					
# Observations	1,891	1,914	1,923	1,925	1,926	1,897
Mean	20.71	23.03	22.14	23.23	19.17	19.19
Std. Deviation	10.68	9.52	9.23	10.66	8.88	8.95
Skewness	2.28	2.35	2.07	2.04	1.87	2.61
Kurtosis	9.50	10.88	9.27	8.30	7.75	12.41
Jarque-Bera	**4968.9****	**6716.0****	**4524.4****	**3583.3****	**2933.4****	**9153.6****
ρ_1	**0.956****	**0.975****	**0.969****	**0.978****	**0.975****	**0.976****
ADF	-1.09	-2.68	**-4.20****	-2.75	-2.57	-2.51
	Panel B: Summary statistics for the daily changes in the implied volatility indices					
# Observations	1,823	1,887	1,897	1,901	1,903	1,856
Mean	-0.03	-0.01	0.00	-0.01	0.00	-0.01
Std. Deviation	1.77	1.61	1.96	1.61	1.52	1.30
Skewness	1.16	1.81	0.91	0.93	0.16	0.37
Kurtosis	25.89	34.02	41.87	12.82	31.40	42.65
Jarque-Bera	**40210.3****	**76683.3****	**119701.7****	**7909.8****	**63982.5****	**121609.3****
ρ_1	**-0.05***	**0.06****	**-0.11****	-0.05	**-0.13****	**0.16****
ADF	**-13.50****	**-16.85****	**-35.55****	**-28.53****	**-29.66****	**-21.69****

Table 1: Summary Statistics. Entries report the summary statistics for the closing prices of each of the implied volatility indices in the levels and the daily first differences. The first order autocorrelation ρ_1, the Jarque-Bera and the Augmented Dickey Fuller (ADF, a trend and an intercept have been included in the test equation) test values are also reported. One and two asterisks denote rejection of the null hypothesis at the 1% and 5% level, respectively. The null hypothesis for the first order autocorrelation, Jarque-Bera and the ADF tests is that the first order autocorrelation is zero, that the series is normally distributed and that the series has a unit root, respectively. The sample spans the period from July1, 2003 to December 31, 2010.

Panel A: U.S. Economic Variables	
Non-Farm Payroll (NFP)	Change in the number of people employed over the last month, not including jobs relating to the farming industry.
Consumer Confidence Index (CCI)	Degree of optimism that consumers feel about the overall state of the economy and their personal financial situation. It is calculated as the average of responses to five questions: current business conditions, expectations for business conditions in six months, current employment conditions, expectations for employment conditions in six months and expectations for the total family income in six months.
Consumer Price Index (CPI)	Change in prices of all goods and services purchased for consumption by urban households over the last month.
Durable Goods Orders (DGO)	Measures the new orders placed with domestic manufacturers for immediate and future delivery of factory hard goods.
FOMC rate announcement (FOMC)	Federal funds target rate (annualized based on a 360 day)
Gross Domestic Product (GDP)	Market value of all final goods and services made within the borders of the U.S.
Initial Jobless Claims (IJC)	Number of people that filed for unemployment benefits over the last week.
Leading Indicators (LI)	A composite index of ten economic indicators that should lead overall economic activity
New Home Sales (NHS)	Number of newly constructed homes with a committed sale during the month
Producer Price Index (PPI)	Average changes in prices received by U.S. producers of commodities in all stages of processing.
Retail Sales Less Autos (RS)	Total receipts at stores that sell durable and nondurable goods.
Panel B: European Economic Variables	
ECB Rate Announcement (ECB)	ECB's decision to increase, decrease, or maintain interest rates
Euro-zone Consumer Confidence (EU-CCI)	Arithmetic average of the balances of four questions: the financial situation of households, the general economic situation, unemployment expectations (with inverted sign) and savings, all computed over the next 12 months.
Euro-zone CPI (EU-CPI)	Euro-zone consumer price index. Euro-zone is treated as a separate entity by Eurostat. The Euro-zone consists of 12 members as of January 1, 2001.
Euro-zone GDP (EU-GDP)	Measure of the total value of goods and services produced by Euro-zone nations.
Euro-zone PPI (EU-PPI)	Average changes in prices received by producers of commodities in all stages of processing within the Euro-zone.
Euro-zone Retail Sales (EU-RS)	Monthly activity in volume of Retail Trade, except of motor vehicles and motorcycles.
IFO Business Climate (IFO-BC)	A survey is conducted monthly, querying German firms on their expectations for the next six months. Firms rate the future outlook as better, same, or worse.
ZEW Survey (ZEW)	A survey is conducted monthly, querying about 350 institutional investors and analysts on their expectations of future economic growth in Germany within the next 6 months. It represents the difference between positive and negative responses in a survey of about.

Table 2: Definition of scheduled news announcement items. Entries provide a brief definition of the scheduled announcements for the U.S. (Panel A) and the European (Panel B) economic variables under consideration.

	Source of Report	Time of Release	Frequency	Units	N
Panel A: U.S. Economic Variables					
NFP	Bureau of Labor Statistics	8:30am ET	Monthly	Thousands	90
CCI	Conference Board	10:00am ET	Monthly	Base year 1985	90
CPI	Bureau of Labor Statistics	8:30am ET	Monthly	Percentage (%)	90
DGO	U.S. Census Bureau	8:30am ET	Monthly	Percentage (%)	90
FOMC	Federal Reserve	2:15pm ET[(1)]	Fed meets 8 times per year	Percentage (%)	62
GDP	Bureau of Economic Analysis	8:30am ET	Monthly	Percentage (%)	90
IJC	Department of Labor	8:30am ET	Weekly	Thousands	392
LI	Conference Board	10:00am ET	Monthly	Percentage (%)	90
NHS	U.S. Census Bureau	10:00am ET	Monthly	Thousands	89
PPI	Bureau of Labor Statistics	8:30am ET	Monthly	Percentage (%)	90
RS	U.S. Census Bureau	8:30am ET	Monthly	Percentage (%)	90
Panel B: European Economic Variables					
ECB	European Central Bank	From 6:45am to 8:45am ET	ECB meets 11 times per year	Percentage (%)	91
EU-CCI	European Commission	From 4:00am to 11:00am ET	Monthly	Value	97
EU-CPI	Eurostat	From 5:00am to 6:00am ET	Monthly	Percentage (%)	90
EU-GDP	Eurostat	From 5:00am to 6:00am ET	Monthly	Percentage (%)	90
EU-PPI	Eurostat	From 4:00am to 6:00am ET	Monthly	Percentage (%)	90
EU-RS	Eurostat	From 5:00am to 6:00am ET	Monthly	Percentage (%)	90
IFO-BC	IFO Institute	From 3:00am to 5:00am ET	Monthly	Base year 2000	90
ZEW	Center for European Economic Research	From 5:00am to 6:00am ET	Monthly	Value	90

(1) There are two exceptions: 1/22/2008 (8:30am ET) and 10/8/2008 (7:00am ET).
(2) There is one exception: 12/28/2001 (10:30pm ET).

Table 3: Summary of scheduled news announcements. Entries summarize the scheduled announcements for the U.S. (Panel A) and the European (Panel B) economic variables under consideration. The source, timing, frequency, units of measurement and the total number (N) of the news announcements in our sample are reported. The sample spans the period from July 1, 2003 to December 31, 2010.

	ΔVIX_t	$\Delta VDAX_t$	$\Delta VCAC_t$	$\Delta VAEX_t$	$\Delta VBEL_t$	$\Delta VSMI_t$
	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
	(t-stat.)	*(t-stat.)*	*(t-stat.)*	*(t-stat.)*	*(t-stat.)*	*(t-stat.)*
C	-0.013	-0.029	-0.017	-0.032	0.006	-0.014
	(-0.296)	*(-0.839)*	*(-0.398)*	*(-0.910)*	*(0.171)*	*(-0.508)*
ΔVIX_{t-1}	**-0.100****	**0.390****	**0.391****	**0.320****	**0.326****	**0.225****
	(-3.650)	*(17.220)*	*(14.066)*	*(13.952)*	*(15.405)*	*(12.824)*
$\Delta VDAX_{t-1}$	**0.413****	**0.097***	**0.365****	**0.292****	**0.348****	**0.411****
	(7.621)	*(2.148)*	*(6.622)*	*(6.388)*	*(8.301)*	*(11.842)*
$\Delta VCAC_{t-1}$	**-0.130****	0.018	**-0.353****	**-0.085****	-0.044	**0.046***
	(-3.952)	*(0.656)*	*(-10.698)*	*(-3.106)*	*(-1.752)*	*(2.210)*
$\Delta VAEX_{t-1}$	**-0.113***	**-0.309****	-0.008	**-0.435****	**-0.118****	**-0.355****
	(-2.217)	*(-7.320)*	*(-0.149)*	*(-10.181)*	*(-2.998)*	*(-10.913)*
$\Delta VBEL_{t-1}$	0.068	**0.098****	**-0.147****	0.058	**-0.358****	**0.195****
	(1.640)	*(2.862)*	*(-3.525)*	*(1.670)*	*(-11.258)*	*(7.401)*
$\Delta VSMI_{t-1}$	**-0.346****	**-0.111***	**-0.119***	-0.009	**-0.114****	**-0.208****
	(-6.421)	*(-2.486)*	*(-2.178)*	*(-0.208)*	*(-2.738)*	*(-6.048)*
Adj. R^2	**0.055**	**0.156**	**0.158**	**0.129**	**0.180**	**0.254**
H_0: $\varphi_{ij} = 0$ for $i \neq j$	**1175.82****					

Table 4: Implied volatility spillovers across markets. Entries report results from the following VAR(1) model: $\Delta IV_t = C + \Phi \Delta IV_{t-1} + \varepsilon$, where $\Delta IV_t = IV_t - IV_{t-1}$ is the (6x1) vector of changes in the implied volatility indices between t-1 and t, C is a (6x1) vector of constants, Φ is a (6x6) matrix of coefficients with φ_{ij} being the coefficient of the i-th lagged implied volatility index when the j-th implied volatility index serves as the dependent variable (i and j take the value 1 for VIX, 2 for VDAX, 3 for VCAC, 4 for VAEX, 5 for VBEL, 6 for VSMI) and ε_t is a (6x1) vector of residuals. Closing prices for both the U.S. and European implied volatility indices are used. The coefficient estimates, t-statistics in parentheses, adjusted R^2 and Wald test statistic for H_0: $\varphi_{ij} = 0$ when $i \neq j$ are reported. One and two asterisks denote rejection of the null hypothesis of a zero coefficient(s) at the 5% and 1% level, respectively. The model is estimated for the period July 1, 2003 to December 31, 2010.

	$\Delta VDAX_t$	$\Delta VCAC_t$	$\Delta VAEX_t$	$\Delta VBEL_t$	$\Delta VSMI_t$
	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*
Panel A: PC model					
C	-0.027	-0.027	-0.039	0.000	-0.017
	(-0.934)	*(-0.783)*	*(-1.197)*	*(0.003)*	*(-0.727)*
ΔIV_{t-1}	0.016	**-0.338****	**-0.389****	**-0.375****	**-0.167***
	(0.109)	*(-4.185)*	*(-3.443)*	*(-4.473)*	*(-2.356)*
ΔVIX_{t-1}	**0.366****	**0.382****	**0.312****	**0.315****	**0.188****
	(6.199)	*(3.795)*	*(7.909)*	*(8.118)*	*(4.212)*
PC^{EU}_{t-1}	-0.163	0.110	0.170	0.099	**0.229****
	(-1.241)	*(0.879)*	*(1.632)*	*(1.289)*	*(2.984)*
Adj-R^2	**0.131**	**0.135**	**0.110**	**0.153**	**0.164**
Panel B: VSTOXX model					
C	-0.031	-0.021	-0.036	0.001	-0.016
	(-1.066)	*(-0.643)*	*(-1.074)*	*(0.053)*	*(-0.674)*
ΔIV_{t-1}	-0.105	**-0.425****	**-0.413****	**-0.429****	-0.123
	(-0.741)	*(-6.281)*	*(-3.890)*	*(-5.240)*	*(-1.288)*
ΔVIX_{t-1}	**0.351****	**0.336****	**0.306****	**0.280****	**0.191****
	(6.462)	*(3.607)*	*(6.386)*	*(8.220)*	*(4.987)*
$\Delta VSTOXX_{t-1}$	-0.026	**0.254***	0.181	**0.195***	0.183
	(-0.182)	*(2.525)*	*(1.487)*	*(2.019)*	*(1.453)*
Adj-R^2	**0.124**	**0.161**	**0.118**	**0.181**	**0.158**

Table 5: The U.S. effect versus the European effect in implied volatility spillovers. Panel A: Entries report results from the following regression model for each one of the European implied volatility indices: $\Delta IV_{i,t} = c_i + \varphi_i \Delta IV_{i,t-1} + \alpha_i \Delta VIX_{t-1} + \beta_i PC^{EU}_{i,t-1} + \varepsilon_{i,t}$ where i = 1 (for VDAX), 2 (for VCAC), 3 (for VAEX), 4 (for VBEL), 5 (for VSMI) and $PC^{EU}_{i,t-1}$ is the lagged first principal component extracted from applying PCA to the set of the European implied volatility indices where the *i*-th European implied volatility index is excluded from this set. **Panel B:** Entries report results from the following regression model for each one of the European implied volatility indices: $\Delta IV_{i,t} = c_i + \varphi_i \Delta IV_{i,t-1} + \alpha_i \Delta VIX_{t-1} + \beta_i \Delta VSTOXX_{t-1} + \varepsilon_{i,t}$ where i = 1 (for VDAX), 2 (for VCAC), 3 (for VAEX), 4 (for VBEL), 5 (for VSMI), 6 (for VSTOXX). Closing prices for both the U.S. and European implied volatility indices are used. The coefficient estimates, *t*-statistics in parentheses and adjusted R^2 are reported. One and two asterisks denote rejection of the null hypothesis of a zero coefficient at the 5% and 1% level, respectively. The models are estimated for the period July 1, 2003 to December 31, 2010.

	$\Delta VDAX_t$	$\Delta VCAC_t$	$\Delta VAEX_t$	$\Delta VBEL_t$	$\Delta VSMI_t$
	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*
			Panel A: PC model		
C	-0.033	-0.034	-0.042	-0.007	-0.019
	(-1.042)	*(-0.943)*	*(-1.214)*	*(-0.216)*	*(-0.754)*
ΔIV_{t-1}	0.055	**-0.297****	**-0.257****	**-0.295****	**-0.185****
	(0.479)	*(-3.270)*	*(-2.701)*	*(-4.054)*	*(-2.737)*
ΔVIX_{t-1}	0.007	-0.069	-0.017	-0.090	0.041
	(0.112)	*(-1.055)*	*(-0.302)*	*(-1.630)*	*(1.139)*
PC^{EU}_{t-1}	0.014	**0.327****	**0.250***	**0.271****	**0.326****
	(0.131)	*(3.598)*	*(2.547)*	*(3.495)*	*(4.727)*
Adj-R^2	**0.003**	**0.045**	**0.020**	**0.055**	**0.117**
			Panel B: VSTOXX model		
C	-0.036	-0.027	-0.039	-0.005	-0.017
	(-1.106)	*(-0.745)*	*(-1.091)*	*(-0.154)*	*(-0.674)*
ΔIV_{t-1}	-0.137	**-0.379****	**-0.325****	**-0.332****	-0.139
	(-0.972)	*(-5.170)*	*(-3.805)*	*(-6.206)*	*(-1.619)*
ΔVIX_{t-1}	-0.005	-0.095	-0.012	-0.127	0.054
	(-0.086)	*(-1.301)*	*(-0.198)*	*(-1.792)*	*(1.035)*
$\Delta VSTOXX_{t-1}$	0.194	**0.450****	**0.292****	**0.359****	**0.272***
	(1.236)	*(5.346)*	*(2.708)*	*(4.012)*	*(2.159)*
Adj-R^2	**0.012**	**0.098**	**0.036**	**0.119**	**0.111**

Table 6: Robustness of the U.S. effect versus the European effect in implied volatility spillovers to the non-synchronous measurement of implied volatility indices. Panel A: Entries report results from the following regression model for each one of the European implied volatility indices: $\Delta IV_{i,t} = c_i + \varphi_i \Delta IV_{i,t-1} + \alpha_i \Delta VIX_{t-1} + \beta_i PC^{EU}_{i,t-1} + \varepsilon_{i,t}$ where i = 1 (for VDAX), 2 (for VCAC), 3 (for VAEX), 4 (for VBEL), 5 (for VSMI) and $PC^{EU}_{i,t-1}$ is the lagged first principal component extracted from applying PCA to the set of the European implied volatility indices where the *i*-th European implied volatility index is excluded from this set. **Panel B:** Entries report results from the following regression model for each one of the European implied volatility indices: $\Delta IV_{i,t} = c_i + \varphi_i \Delta IV_{i,t-1} + \alpha_i \Delta VIX_{t-1} + \beta_i \Delta VSTOXX_{t-1} + \varepsilon_{i,t}$ where i = 1 (for VDAX), 2 (for VCAC), 3 (for VAEX), 4 (for VBEL), 5 (for VSMI), 6 (for VSTOXX). Opening prices for the VIX index and closing prices for the European implied volatility indices are used. The coefficient estimates, *t*-statistics in parentheses and adjusted R^2 are reported. One and two asterisks denote rejection of the null hypothesis of a zero coefficient at the 5% and 1% level, respectively. The models are estimated for the period July 1, 2003 to December 31, 2010.

	ΔVIX_t	$\Delta VDAX_t$	$\Delta VCAC_t$	$\Delta VAEX_t$	$\Delta VBEL_t$	$\Delta VSMI_t$
	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*
Panel A: VAR(1) model						
C	-0.022	-0.031	-0.019	-0.034	0.004	-0.015
	(-0.546)	*(-0.869)*	*(-0.441)*	*(-0.943)*	*(0.119)*	*(-0.551)*
ΔVIX_{t-1}	0.046	**0.352****	**0.443****	**0.306****	**0.421****	**0.228****
	(1.396)	*(12.064)*	*(12.685)*	*(10.479)*	*(16.066)*	*(10.332)*
$\Delta VDAX_{t-1}$	0.047	-0.074	**0.136***	**0.141****	**0.124****	**0.296****
	(0.845)	*(-1.487)*	*(2.277)*	*(2.821)*	*(2.772)*	*(7.846)*
$\Delta VCAC_{t-1}$	**-0.063***	0.052	**-0.317****	**-0.057***	-0.013	**0.066****
	(-2.026)	*(1.879)*	*(-9.592)*	*(-2.052)*	*(-0.532)*	*(3.154)*
$\Delta VAEX_{t-1}$	**-0.146****	**-0.259****	0.014	**-0.400****	**-0.117****	**-0.334****
	(-2.990)	*(-5.970)*	*(0.261)*	*(-9.213)*	*(-2.997)*	*(-10.202)*
$\Delta VBEL_{t-1}$	**0.333****	**0.156****	**-0.088***	**0.106****	**-0.307****	**0.229****
	(8.465)	*(4.449)*	*(-2.092)*	*(3.019)*	*(-9.792)*	*(8.652)*
$\Delta VSMI_{t-1}$	**-0.335****	-0.088	-0.082	0.012	-0.075	**-0.191****
	(-6.451)	*(-1.886)*	*(-1.480)*	*(0.262)*	*(-1.801)*	*(-5.458)*
Adj-R^2	**0.067**	**0.092**	**0.143**	**0.092**	**0.189**	**0.234**
H_0: $\varphi_{ij} = 0$ for $i \neq j$	**1245.62****					
Panel B: PC model						
C	-0.025	-0.032	-0.024	-0.038	0.002	-0.016
	(-0.686)	*(-1.040)*	*(-0.690)*	*(-1.151)*	*(0.080)*	*(-0.666)*
ΔIV_{t-1}	-	-0.149	**-0.314****	**-0.386****	**-0.309****	**-0.188****
	-	*(-1.244)*	*(-4.940)*	*(-4.160)*	*(-5.583)*	*(-2.909)*
ΔVIX_{t-1}	0.022	**0.316****	**0.469****	**0.317****	**0.431****	**0.209***
	(0.185)	*(3.205)*	*(5.052)*	*(3.501)*	*(5.273)*	*(2.142)*
PC^{EU}_{t-1}	-0.086	-0.025	-0.010	0.133	-0.057	**0.209****
	(-1.061)	*(-0.216)*	*(-0.101)*	*(1.266)*	*(-0.850)*	*(2.759)*
Adj-R^2	**0.005**	**0.065**	**0.141**	**0.086**	**0.184**	**0.159**
Panel C: VSTOXX model						
C	-0.030	-0.034	-0.022	-0.036	0.001	-0.015
	(-0.837)	*(-1.088)*	*(-0.651)*	*(-1.061)*	*(0.021)*	*(-0.637)*
ΔIV_{t-1}	-	-0.164	**-0.384****	**-0.352****	**-0.383****	-0.110
	-	*(-1.125)*	*(-6.266)*	*(-4.325)*	*(-6.926)*	*(-1.170)*
ΔVIX_{t-1}	0.073	**0.314****	**0.377****	**0.298****	**0.359****	**0.214****
	(0.665)	*(3.748)*	*(4.045)*	*(4.042)*	*(5.289)*	*(3.698)*
$\Delta VSTOXX_{t-1}$	-0.150	-0.016	0.134	0.089	0.064	0.127
	(-1.453)	*(-0.128)*	*(1.564)*	*(1.135)*	*(1.058)*	*(1.288)*
Adj-R^2	**0.011**	**0.062**	**0.141**	**0.081**	**0.176**	**0.143**

Table 7: Implied volatility spillovers revisited. Entries report results from the following VAR(1) model [equation (1), Panel A], the PC model [equation (2), Panel B] and the VSTOXX model [equation (3), Panel C]. Synchronous prices for both the U.S. and European implied volatility indices measured at 11:30am ET are used. The coefficient estimates, *t*-statistics in parentheses, adjusted R^2 and Wald test statistic for H_0: $\varphi_{ij} = 0$ when $i \neq j$ are reported. One and two asterisks denote rejection of the null hypothesis of a zero coefficient(s) at the 5% and 1% level, respectively. The models are estimated for the period July 1, 2003 to December 31, 2010.

	ΔVIX_t	$\Delta VDAX_t$	$\Delta VCAC_t$	$\Delta VAEX_t$	$\Delta VBEL_t$	$\Delta VSMI_t$
	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
	(t-stat.)	*(t-stat.)*	*(t-stat.)*	*(t-stat.)*	*(t-stat.)*	*(t-stat.)*
C	0.026	0.001	0.024	0.027	0.052	0.028
	(0.531)	*(0.015)*	*(0.469)*	*(0.630)*	*(1.326)*	*(0.857)*
ΔVIX_{t-1}	0.056	**0.370****	**0.466****	**0.333****	**0.422****	**0.239****
	(1.684)	*(12.738)*	*(13.402)*	*(11.648)*	*(16.012)*	*(10.860)*
$\Delta VDAX_{t-1}$	0.049	-0.072	**0.138***	**0.144****	**0.125****	**0.297****
	(0.872)	*(-1.464)*	*(2.347)*	*(2.954)*	*(2.799)*	*(7.951)*
$\Delta VCAC_{t-1}$	**-0.071***	0.038	**-0.334****	**-0.077****	-0.014	**0.057****
	(-2.260)	*(1.405)*	*(-10.211)*	*(-2.874)*	*(-0.570)*	*(2.731)*
$\Delta VAEX_{t-1}$	**-0.152****	**-0.267****	0.005	**-0.411****	**-0.121****	**-0.340****
	(-3.135)	*(-6.213)*	*(0.088)*	*(-9.749)*	*(-3.123)*	*(-10.463)*
$\Delta VBEL_{t-1}$	**0.337****	**0.163****	-0.078	**0.117****	**-0.305****	**0.234****
	(8.606)	*(4.714)*	*(-1.887)*	*(3.453)*	*(-9.733)*	*(8.933)*
$\Delta VSMI_{t-1}$	**-0.332****	-0.088	-0.082	0.013	-0.071	**-0.189****
	(-6.413)	*(-1.915)*	*(-1.495)*	*(0.285)*	*(-1.719)*	*(-5.448)*
$\lvert S_t \rvert$	-0.072	-0.051	-0.070	**-0.095****	**-0.066***	**-0.065***
	(-1.827)	*(-1.479)*	*(-1.694)*	*(-2.786)*	*(-2.097)*	*(-2.476)*
Adj-R^2	**0.070**	**0.102**	**0.158**	**0.113**	**0.191**	**0.244**
H_0: $\varphi_{ij} = 0$ for $i \neq j$	**1252.01****					

Table 8: Surprise effect of the aggregate releases on implied volatility spillovers. Entries report results from a VAR(1) model augmented by the aggregate surprise variable for all the news announcements under consideration [equation (6)]. $\lvert S_t \rvert$ is the aggregate surprise variable of all releases. Equation (6) is estimated by the SUR method. Synchronous prices for both the U.S. and European implied volatility indices measured at 11:30am ET are used. The coefficient estimates, *t*-statistics in parentheses, adjusted R^2 and Wald test statistic for H_0: $\varphi_{ij} = 0$ for all $i \neq j$ are reported. One and two asterisks denote rejection of the null hypothesis of a zero coefficient(s) at the 5% and 1% level, respectively. The model is estimated for the period July 1, 2003 to December 31, 2010.

	ΔVIX$_t$	ΔVDAX$_t$	ΔVCAC$_t$	ΔVAEX$_t$	ΔVBEL$_t$	ΔVSMI$_t$
	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*
C	0.023	-0.001	0.019	0.024	0.048	0.027
	(0.473)	*(-0.030)*	*(0.357)*	*(0.571)*	*(1.211)*	*(0.807)*
ΔVIX$_{t-1}$	0.055	**0.370****	**0.464****	**0.332****	**0.421****	**0.239****
	(1.671)	*(12.736)*	*(13.387)*	*(11.643)*	*(16.001)*	*(10.852)*
ΔVDAX$_{t-1}$	0.046	-0.074	**0.135***	**0.142****	**0.122****	**0.296****
	(0.832)	*(-1.503)*	*(2.286)*	*(2.911)*	*(2.737)*	*(7.916)*
ΔVCAC$_{t-1}$	**-0.071***	0.038	**-0.334****	**-0.077****	-0.014	**0.056****
	(-2.271)	*(1.394)*	*(-10.236)*	*(-2.888)*	*(-0.576)*	*(2.722)*
ΔVAEX$_{t-1}$	**-0.148****	**-0.263****	0.012	**-0.408****	**-0.116****	**-0.337****
	(-3.049)	*(-6.128)*	*(0.229)*	*(-9.649)*	*(-2.978)*	*(-10.374)*
ΔVBEL$_{t-1}$	**0.337****	**0.163****	-0.079	**0.117****	**-0.306****	**0.234****
	(8.596)	*(4.704)*	*(-1.920)*	*(3.440)*	*(-9.782)*	*(8.924)*
ΔVSMI$_{t-1}$	**-0.333****	-0.088	-0.083	0.013	-0.072	**-0.189****
	(-6.424)	*(-1.923)*	*(-1.509)*	*(0.278)*	*(-1.734)*	*(-5.457)*
$\|S^{US}_t\|$	-0.032	-0.020	0.005	-0.058	-0.008	-0.041
	(-0.649)	*(-0.457)*	*(0.090)*	*(-1.349)*	*(-0.188)*	*(-1.223)*
$\|S^{EU}_t\|$	**-0.145***	-0.112	**-0.205****	**-0.164****	**-0.171****	**-0.111***
	(-2.143)	*(-1.853)*	*(-2.862)*	*(-2.773)*	*(-3.143)*	*(-2.442)*
Adj-R^2	**0.071**	**0.103**	**0.161**	**0.114**	**0.194**	**0.245**
H_0: $\varphi_{ij} = 0$ for $i \neq j$	**1253.52****					

Table 9: Surprise effect of regional releases (i.e. releases of U.S. and European economic variables separately) on implied volatility spillovers. Entries report results from a VAR(1) model augmented by the aggregate abslute surprise variable for the U.S. and European news announcements, separately [equation (7)]. $|S_t^{US}|\left(|S_t^{EU}|\right)$ is the regional aggregate surprise variable of the U.S. (European) releases. Equation (7) is estimated by the SUR method. Synchronous prices for both the U.S. and European implied volatility indices measured at 11:30am ET are used. The coefficient estimates, *t*-statistics in parentheses, adjusted R^2 and Wald test statistic for H_0: $\varphi_{ij} = 0$ for all $i \neq j$ are reported. One and two asterisks denote rejection of the null hypothesis of a zero coefficient(s) at the 5% and 1% level, respectively. The model is estimated for the period July 1, 2003 to December 31, 2010.

	ΔVIX_t	$\Delta VDAX_t$	$\Delta VCAC_t$	$\Delta VAEX_t$	$\Delta VBEL_t$	$\Delta VSMI_t$
C	0.018	-0.010	0.028	0.024	0.040	0.022
ΔVIX_{t-1}	0.049	**0.367****	**0.464****	**0.333****	**0.409****	**0.233****
$\Delta VDAX_{t-1}$	0.033	-0.091	0.101	**0.131****	**0.102***	**0.275****
$\Delta VCAC_{t-1}$	-0.047	0.051	**-0.328****	**-0.061***	-0.001	**0.064****
$\Delta VAEX_{t-1}$	**-0.146****	**-0.254****	0.021	**-0.407****	**-0.105****	**-0.336****
$\Delta VBEL_{t-1}$	**0.344****	**0.187****	-0.072	**0.127****	**-0.301****	**0.243****
$\Delta VSMI_{t-1}$	**-0.354****	**-0.119***	-0.061	-0.010	-0.064	**-0.176****
$\lvert S_{1t}^{US} \rvert$	0.014	-0.192	-0.239	-0.286	0.064	-0.183
$\lvert S_{2t}^{US} \rvert$	0.116	0.174	0.323	0.325	-0.084	0.075
$\lvert S_{3t}^{US} \rvert$	-0.262	-0.297	0.248	-0.316	-0.122	**-0.431***
$\lvert S_{4t}^{US} \rvert$	-0.172	-0.255	-0.397	-0.308	-0.222	-0.274
$\lvert S_{5t}^{US} \rvert$	0.325	-0.200	-0.054	-0.289	-0.105	0.014
$\lvert S_{6t}^{US} \rvert$	-0.165	-0.175	-0.437	-0.319	-0.223	-0.233
$\lvert S_{7t}^{US} \rvert$	-0.019	-0.061	0.117	-0.036	0.032	0.055
$\lvert S_{8t}^{US} \rvert$	0.281	-0.116	-0.336	-0.004	**-0.624****	**-0.471****
$\lvert S_{9t}^{US} \rvert$	0.115	0.117	0.136	0.048	0.090	0.056
$\lvert S_{10t}^{US} \rvert$	-0.033	0.080	-0.012	-0.017	0.111	0.120
$\lvert S_{11t}^{US} \rvert$	-0.292	-0.065	-0.038	-0.265	0.070	-0.078
$\lvert S_{1t}^{EU} \rvert$	-0.153	-0.019	0.124	-0.075	-0.253	0.009
$\lvert S_{2t}^{EU} \rvert$	-0.158	-0.081	-0.018	-0.126	-0.328	-0.097
$\lvert S_{3t}^{EU} \rvert$	**0.654***	0.180	-0.180	0.106	-0.014	0.028
$\lvert S_{4t}^{EU} \rvert$	-0.225	-0.296	-0.012	-0.433	-0.312	-0.296
$\lvert S_{5t}^{EU} \rvert$	-0.234	-0.075	-0.212	-0.121	0.008	-0.203
$\lvert S_{6t}^{EU} \rvert$	-0.376	-0.576	-0.673	-0.681	-0.301	-0.412
$\lvert S_{7t}^{EU} \rvert$	-0.175	-0.179	-0.104	-0.123	-0.047	-0.152
$\lvert S_{8t}^{EU} \rvert$	0.042	0.209	-0.519	0.194	0.169	-0.110

Table 10: Surprise effect of the absolute surprise element of individual news announcement items on implied volatility spillovers. Entries report results from a VAR(1) model augmented by absolute surprise variables and their interaction with a sign dummy for the individual news announcement items under consideration. The sign dummy takes the value 1 when the surprise component of an individual release is negative and zero otherwise. Results are obtained by using the SUR method. Synchronous prices for both the U.S. and European implied volatility indices measured at 11:30am ET are used. The coefficient estimates, adjusted R^2 and Wald test statistics for H_0: $\varphi_{ij} = 0$ for all $i \neq j$ are reported. One and two asterisks denote rejection of the null hypothesis of a zero coefficient at the 5% and 1% level, respectively. The *t*-statistics are not reported due to space limitation but are available from the authors upon request. The model is estimated for the period July 1, 2003 to December 31, 2010.

	ΔVIX_t	$\Delta VDAX_t$	$\Delta VCAC_t$	$\Delta VAEX_t$	$\Delta VBEL_t$	$\Delta VSMI_t$
$D_{1t}^{US} \mid S_{1t}^{US} \mid$	0.310	0.488	0.631	0.550	0.317	0.379
$D_{2t}^{US} \mid S_{2t}^{US} \mid$	0.306	**1.024****	0.278	0.095	0.190	0.197
$D_{3t}^{US} \mid S_{3t}^{US} \mid$	0.641	**1.025****	-0.033	0.536	0.471	**0.731****
$D_{4t}^{US} \mid S_{4t}^{US} \mid$	0.065	-0.014	0.267	0.104	0.264	0.047
$D_{5t}^{US} \mid S_{5t}^{US} \mid$	-1.162	-0.380	-0.519	-0.063	-0.354	-0.605
$D_{6t}^{US} \mid S_{6t}^{US} \mid$	-0.015	0.091	0.320	0.160	0.038	0.154
$D_{7t}^{US} \mid S_{7t}^{US} \mid$	-0.205	-0.114	-0.137	-0.237	-0.079	-0.135
$D_{8t}^{US} \mid S_{8t}^{US} \mid$	0.147	0.371	**0.849***	0.386	**0.916****	**0.960****
$D_{9t}^{US} \mid S_{9t}^{US} \mid$	-0.001	-0.055	0.179	0.181	0.136	0.097
$D_{10t}^{US} \mid S_{10t}^{US} \mid$	0.088	-0.297	0.034	-0.235	-0.384	-0.231
$D_{11t}^{US} \mid S_{11t}^{US} \mid$	**0.904***	0.601	-0.022	**0.940****	**0.683***	0.390
$D_{1t}^{EU} \mid S_{1t}^{EU} \mid$	0.050	0.082	0.237	0.173	0.219	0.047
$D_{2t}^{EU} \mid S_{2t}^{EU} \mid$	0.038	-0.185	**-1.060****	-0.112	-0.133	-0.271
$D_{3t}^{EU} \mid S_{3t}^{EU} \mid$	**-0.880***	-0.394	-0.215	-0.352	-0.249	-0.274
$D_{4t}^{EU} \mid S_{4t}^{EU} \mid$	0.039	-0.105	0.152	0.152	0.061	0.080
$D_{5t}^{EU} \mid S_{5t}^{EU} \mid$	0.418	0.139	0.297	-0.051	0.033	0.274
$D_{6t}^{EU} \mid S_{6t}^{EU} \mid$	0.019	0.343	0.313	0.311	0.044	0.202
$D_{7t}^{EU} \mid S_{7t}^{EU} \mid$	**-1.024****	-0.546	**-0.914***	-0.499	**-0.754***	-0.270
$D_{8t}^{EU} \mid S_{8t}^{EU} \mid$	-0.527	-0.186	-0.018	-0.276	-0.381	0.232
Adj. R^2	**0.081**	**0.119**	**0.171**	**0.117**	**0.204**	**0.258**
H_0: $\varphi_{ij} = 0$ for all $i \neq j$	**1219.83****					

Table 10 (Cont'd): Surprise effect of the absolute surprise element of individual news announcement items on implied volatility spillovers. Entries report results from a VAR(1) model augmented by absolute surprise variables and their interaction with a sign dummy for the individual news announcement items under consideration. The sign dummy takes the value 1 when the surprise component of an individual release is negative and zero otherwise. Results are obtained by using the SUR method. Synchronous prices for both the U.S. and European implied volatility indices measured at 11:30am ET are used. The coefficient estimates, adjusted R^2 and Wald test statistics for H_0: $\varphi_{ij} = 0$ for all $i \neq j$ are reported. One and two asterisks denote rejection of the null hypothesis of a zero coefficient at the 5% and 1% level, respectively. The *t*-statistics are not reported due to space limitation but are available from the authors upon request. The model is estimated for the period July 1, 2003 to December 31, 2010.

	ΔVIX$_t$	ΔVDAX$_t$	ΔVCAC$_t$	ΔVAEX$_t$	ΔVBEL$_t$	ΔVSMI$_t$
	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*
C	-0.024	-0.035	-0.019	-0.037	0.011	-0.011
	(-0.595)	*(-0.984)*	*(-0.457)*	*(-1.062)*	*(0.339)*	*(-0.400)*
ΔVIX$_{t-1}$	0.017	**0.355****	**0.414****	**0.367****	**0.380****	**0.220****
	(0.425)	*(10.060)*	*(9.769)*	*(10.503)*	*(11.796)*	*(8.156)*
ΔVDAX$_{t-1}$	-0.134	**-0.225****	-0.085	-0.022	-0.060	**0.156****
	(-1.841)	*(-3.466)*	*(-1.097)*	*(-0.340)*	*(-1.025)*	*(3.165)*
ΔVCAC$_{t-1}$	0.032	0.048	**-0.400****	-0.007	0.022	0.043
	(0.842)	*(1.438)*	*(-9.918)*	*(-0.225)*	*(0.733)*	*(1.691)*
ΔVAEX$_{t-1}$	-0.105	**-0.151****	**0.150***	**-0.445****	-0.042	**-0.284****
	(-1.770)	*(-2.856)*	*(2.374)*	*(-8.516)*	*(-0.872)*	*(-7.049)*
ΔVBEL$_{t-1}$	**0.435****	**0.284****	-0.079	**0.172****	**-0.304****	**0.254****
	(9.044)	*(6.655)*	*(-1.555)*	*(4.084)*	*(-7.831)*	*(7.807)*
ΔVSMI$_{t-1}$	**-0.408****	**-0.138***	0.115	0.074	0.061	-0.033
	(-5.827)	*(-2.201)*	*(1.538)*	*(1.201)*	*(1.083)*	*(-0.690)*
|S$_t$|*ΔVIX$_{t-1}$	**0.089****	0.029	0.058	-0.031	**0.056***	0.009
	(3.138)	*(1.144)*	*(1.941)*	*(-1.267)*	*(2.463)*	*(0.461)*
|S$_t$|*ΔVDAX$_{t-}$	**0.205****	**0.164****	**0.205****	**0.171****	**0.172****	**0.123****
	(4.409)	*(3.930)*	*(4.124)*	*(4.140)*	*(4.560)*	*(3.873)*
|S$_t$|*ΔVCAC$_{t-}$	**-0.112****	0.000	**0.065***	**-0.079****	**-0.053***	0.008
	(-4.236)	*(0.018)*	*(2.311)*	*(-3.403)*	*(-2.474)*	*(0.471)*
|S$_t$|*ΔVAEX$_{t-}$	-0.058	**-0.124****	**-0.174****	0.079	**-0.077***	-0.033
	(-1.202)	*(-2.880)*	*(-3.391)*	*(1.865)*	*(-1.976)*	*(-0.995)*
|S$_t$|*ΔVBEL$_{t-}$	**-0.103****	**-0.136****	-0.009	**-0.085***	-0.006	-0.043
	(-2.709)	*(-3.996)*	*(-0.209)*	*(-2.520)*	*(-0.199)*	*(-1.675)*
|S$_t$|*ΔVSMI$_{t-1}$	**0.099***	0.059	**-0.093***	**-0.083***	**-0.091***	**-0.137****
	(2.258)	*(1.500)*	*(-2.004)*	*(-2.155)*	*(-2.574)*	*(-4.635)*
Adj. R^2	**0.109**	**0.124**	**0.178**	**0.124**	**0.206**	**0.255**

Table 11: Surprise effect of the aggregate releases on the magnitude of implied volatility spillovers. Entries report results from a VAR(1) model that allows for the matrix of coefficients of the lagged implied volatility indices to be affected by the aggregate surprise component of the news announcements for all the economic variables [equation (9)]. Equation (9) is estimated by the SUR method. Synchronous prices for both the U.S. and European implied volatility indices measured at 11:30am ET are used. The coefficient estimates, *t*-statistics, adjusted R^2 and Wald test statistics for H_0: $\beta_{ij} = 0$ for all $i \neq j$ are reported. One and two asterisks denote rejection of the null hypothesis of a zero coefficient at the 5% and 1% level, respectively. The model is estimated for the period July 1, 2003 to December 31, 2010.

	ΔVIX_t	$\Delta VDAX_t$	$\Delta VCAC_t$	$\Delta VAEX_t$	$\Delta VBEL_t$	$\Delta VSMI_t$
	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*	Coeff. *(t-stat.)*
C	-0.014	-0.034	-0.003	-0.034	0.015	-0.008
	(-0.354)	*(-0.973)*	*(-0.073)*	*(-0.987)*	*(0.470)*	*(-0.292)*
ΔVIX_{t-1}	0.018	**0.360****	**0.433****	**0.367****	**0.384****	**0.224****
	(0.448)	*(10.232)*	*(10.276)*	*(10.497)*	*(11.922)*	*(8.499)*
$\Delta VDAX_{t-1}$	**-0.144***	**-0.228****	-0.085	-0.029	-0.067	**0.142****
	(-2.000)	*(-3.534)*	*(-1.109)*	*(-0.457)*	*(-1.149)*	*(2.963)*
$\Delta VCAC_{t-1}$	0.032	0.045	**-0.398****	-0.009	0.018	0.038
	(0.846)	*(1.350)*	*(-9.963)*	*(-0.279)*	*(0.603)*	*(1.512)*
$\Delta VAEX_{t-1}$	-0.097	**-0.138****	**0.163****	**-0.439****	-0.031	**-0.262****
	(-1.649)	*(-2.621)*	*(2.606)*	*(-8.419)*	*(-0.651)*	*(-6.693)*
$\Delta VBEL_{t-1}$	**0.436****	**0.286****	-0.073	**0.169****	**-0.311****	**0.245****
	(9.126)	*(6.748)*	*(-1.446)*	*(4.013)*	*(-8.028)*	*(7.720)*
$\Delta VSMI_{t-1}$	**-0.409****	**-0.153***	0.081	0.080	0.067	-0.027
	(-5.858)	*(-2.449)*	*(1.085)*	*(1.293)*	*(1.188)*	*(-0.574)*
$\|S^{US}_t\|*\Delta VIX_{t-1}$	**0.103****	**0.105****	0.055	0.003	**0.073****	**0.093****
	(2.973)	*(3.377)*	*(1.484)*	*(0.105)*	*(2.594)*	*(3.930)*
$\|S^{US}_t\|*\Delta VDAX_{t-1}$	**0.122***	**0.122****	**0.138****	**0.150****	**0.162***	**0.083***
	(2.450)	*(2.737)*	*(2.599)*	*(3.390)*	*(3.984)*	*(2.484)*
$\|S^{US}_t\|*\Delta VCAC_{t-1}$	**-0.077***	-0.027	0.051	**-0.101****	-0.046	-0.017
	(-2.266)	*(-0.896)*	*(1.414)*	*(-3.399)*	*(-1.679)*	*(-0.746)*
$\|S^{US}_t\|*\Delta VAEX_{t-1}$	-0.022	-0.094	-0.021	0.100	-0.002	**0.078***
	(-0.381)	*(-1.810)*	*(-0.344)*	*(1.946)*	*(-0.039)*	*(2.027)*
$\|S^{US}_t\|*\Delta VBEL_{t-1}$	-0.060	**-0.219****	**-0.129***	-0.068	-0.056	**-0.138****
	(-1.248)	*(-5.122)*	*(-2.534)*	*(-1.593)*	*(-1.440)*	*(-4.309)*
$\|S^{US}_t\|*\Delta VSMI_{t-1}$	0.080	**0.109***	-0.089	**-0.098***	**-0.163****	**-0.219****
	(1.448)	*(2.184)*	*(-1.505)*	*(-1.978)*	*(-3.600)*	*(-5.899)*
$\|S^{EU}_t\|*\Delta VIX_{t-1}$	-0.033	**-0.141****	0.041	**-0.120***	-0.007	**-0.196****
	(-0.559)	*(-2.672)*	*(0.646)*	*(-2.295)*	*(-0.136)*	*(-4.979)*
$\|S^{EU}_t\|*\Delta VDAX_{t-1}$	**0.724****	**0.417****	**0.636****	**0.335****	**0.227***	**0.341****
	(6.419)	*(4.101)*	*(5.274)*	*(3.320)*	*(2.467)*	*(4.524)*
$\|S^{EU}_t\|*\Delta VCAC_{t-1}$	**-0.131****	-0.061	0.025	-0.028	**-0.082***	-0.038
	(-2.753)	*(-1.420)*	*(0.487)*	*(-0.657)*	*(-2.103)*	*(-1.199)*
$\|S^{EU}_t\|*\Delta VAEX_{t-1}$	**-0.294****	-0.141	**-0.560****	0.005	**-0.173***	**-0.146***
	(-3.333)	*(-1.778)*	*(-5.941)*	*(0.059)*	*(-2.405)*	*(-2.465)*
$\|S^{EU}_t\|*\Delta VBEL_{t-1}$	**-0.260****	-0.030	0.121	**-0.185****	0.075	0.077
	(-3.607)	*(-0.464)*	*(1.572)*	*(-2.875)*	*(1.282)*	*(1.602)*
$\|S^{EU}_t\|*\Delta VSMI_{t-1}$	-0.010	-0.055	**-0.195***	-0.087	0.006	-0.048
	(-0.139)	*(-0.853)*	*(-2.577)*	*(-1.376)*	*(0.110)*	*(-1.014)*
Adj. R^2	**0.122**	**0.133**	**0.192**	**0.126**	**0.210**	**0.291**

Table 12: Surprise effect of regional announcements (i.e. releases of U.S. and European economic variables, separately) on the magnitude of implied volatility spillovers. Entries report results from a VAR(1) model that allows for the matrix of coefficients of the lagged implied volatility indices to be affected by the regional U.S. and European absolute surprise variables of the news announcements for the U.S. and European economic variables, respectively [equation (10)]. $|S_t^{US}|\,(|S_t^{EU}|)$ is the regional surprise variable of the U.S. (European) releases. Equation (10) is estimated by the SUR method. Synchronous prices for both the U.S. and European implied volatility indices measured at 11:30am ET are used. The coefficient estimates, *t*-statistics and adjusted R^2 are reported. One and two asterisks denote rejection of the null hypothesis of a zero coefficient at the 5% and 1% level, respectively. The model is estimated for the period July 1, 2003 to December 31, 2010.

	ΔVIX_t	$\Delta VDAX_t$	$\Delta VCAC_t$	$\Delta VAEX_t$	$\Delta VBEL_t$	$\Delta VSMI_t$
Panel A: Aggregate news announcements						
$\lvert S_t \rvert$	-0.117	-0.072	-0.139	**-0.143***	-0.116	**-0.132***
Adj-R^2	**0.083**	**0.123**	**0.176**	**0.128**	**0.224**	**0.274**
H_0: $\varphi_{ij} = 0$ for all $i \neq j$	**708.64****					
Panel B: Regional news announcements						
$\lvert S_t^{US} \rvert$	-0.039	0.002	0.030	-0.069	-0.018	-0.108
$\lvert S_t^{EU} \rvert$	-0.263	-0.210	**-0.439****	**-0.281***	**-0.292****	**-0.183***
Adj-R^2	**0.084**	**0.124**	**0.182**	**0.129**	**0.227**	**0.274**
H_0: $\varphi_{ij} = 0$ for all $i \neq j$	**711.16****					
Panel C: Individual news announcements						
$\lvert S_{3t}^{US} \rvert$	-0.531	-0.497	0.422	-0.543	-0.220	**-0.729***
$\lvert S_{8t}^{US} \rvert$	0.338	-0.338	-0.630	-0.163	**-0.839***	**-0.862****
$\lvert S_{3t}^{EU} \rvert$	**1.636****	0.290	-0.259	0.273	-0.012	0.054
$D_{3t}^{US} \lvert S_{3t}^{US} \rvert$	1.411	**2.282****	0.115	0.960	1.035	**1.440****
$D_{8t}^{US} \lvert S_{8t}^{US} \rvert$	0.618	0.866	**1.906***	0.985	**1.653****	**1.613****
$D_{11t}^{US} \lvert S_{11t}^{US} \rvert$	**1.599***	0.773	-0.321	1.239	0.784	0.580
$D_{2t}^{EU} \lvert S_{2t}^{EU} \rvert$	0.066	-0.186	**-1.582***	-0.060	-0.158	-0.327
$D_{3t}^{EU} \lvert S_{3t}^{EU} \rvert$	**-2.225****	-0.642	-0.477	-0.648	-0.463	-0.547
$D_{7t}^{EU} \lvert S_{7t}^{EU} \rvert$	**-1.765***	-1.047	**-1.626***	-1.030	-1.222	-0.466
Adj-R^2	**0.102**	**0.155**	**0.197**	**0.129**	**0.234**	**0.294**
H_0: $\varphi_{ij} = 0$ for all $i \neq j$	**698.49****					

Table 13: The effect of news announcements on implied volatility dynamics over the recent financial crisis. Entries report results from a VAR(1) model augmented by the surprise variable for the aggregate [equation (6), Panel A], regional [equation (7), Panel B] and individual [equation (8), Panel C] news announcements. $\lvert S_t \rvert$ is the aggregate surprise variable, $\lvert S_t^{US} \rvert$ is the regional U.S. surprise variable, $\lvert S_t^{EU} \rvert$ is the regional European surprise variable, $\lvert S_{it}^{US} \rvert$ is the surprise variable of the *i*-th U.S. announcement item and $\lvert S_{jt}^{EU} \rvert$ is the surprise variable of the *j*-th European announcement item (i = 1 for NFP, 2 for CCI, …, 12 for RS and j = 1 for ECB, 2 for EU-CCI,…, 8 for ZEW). Equations (6), (7) and (8) are estimated by the SUR method. Synchronous prices for both the U.S. and European implied volatility indices measured at 11:30am ET are used. The coefficient estimates and the Wald test statistic for H_0: $\varphi_{ij} = 0$ for all $i \neq j$ are reported. One and two asterisks denote rejection of the null hypothesis of a zero coefficient(s) at the 5% and 1% level, respectively. The *t*-statistics and coefficient estimates for the lagged implied volatility indices and the individual news announcement items that were insignificant for all volatility indices are not reported due to space limitation but are available from the authors upon request. The model is estimated for the period August 1, 2007 to December 31, 2010.

	ΔVIX$_t$	**ΔVDAX$_t$**	**ΔVCAC$_t$**	**ΔVAEX$_t$**	**ΔVBEL$_t$**	**ΔVSMI$_t$**
			Panel A: Aggregate news announcements			
$\|S_t\|$*ΔVIX$_{t-1}$	**0.109***	0.033	0.081	-0.036	0.058	0.010
$\|S_t\|$*ΔVDAX$_{t-1}$	**0.240****	**0.206****	**0.293****	**0.223****	**0.219****	**0.170****
$\|S_t\|$*ΔVCAC$_{t-1}$	**-0.149****	0.001	0.069	**-0.112****	**-0.082***	0.002
$\|S_t\|$*ΔVAEX$_{t-1}$	-0.049	**-0.174***	**-0.247****	0.126	-0.080	-0.069
$\|S_t\|$*ΔVBEL$_{t-1}$	**-0.141***	**-0.137****	0.001	-0.097	0.010	-0.023
$\|S_t\|$*ΔVSMI$_{t-1}$	**0.170***	0.083	-0.113	**-0.130***	-0.103	**-0.173****
Adj. R^2	**0.140**	**0.148**	**0.197**	**0.144**	**0.236**	**0.282**
			Panel B: Regional news announcements			
$\|S_t^{US}\|$*ΔVIX$_{t-1}$	**0.134***	**0.141****	0.070	0.010	0.082	**0.112****
$\|S_t^{US}\|$*ΔVDAX$_{t-1}$	0.138	**0.162***	**0.203***	**0.200****	**0.198****	**0.121***
$\|S_t^{US}\|$*ΔVCAC$_{t-1}$	-0.102	-0.046	0.066	**-0.132****	-0.077	-0.026
$\|S_t^{US}\|$*ΔVAEX$_{t-1}$	-0.037	-0.167	-0.080	0.129	0.011	0.088
$\|S_t^{US}\|$*ΔVBEL$_{t-1}$	-0.067	**-0.220****	-0.103	-0.076	-0.047	**-0.139****
$\|S_t^{US}\|$*ΔVSMI$_{t-1}$	0.146	**0.177***	-0.109	-0.128	**-0.180***	**-0.291****
$\|S_t^{EU}\|$*ΔVIX$_{t-1}$	-0.122	**-0.193***	0.054	-0.171	-0.023	**-0.240****
$\|S_t^{EU}\|$*ΔVDAX$_{t-1}$	**1.148****	**0.590****	**1.044****	**0.484****	0.316	**0.428****
$\|S_t^{EU}\|$*ΔVCAC$_{t-1}$	-0.153	-0.067	0.019	-0.055	-0.105	-0.031
$\|S_t^{EU}\|$*ΔVAEX$_{t-1}$	-0.280	-0.139	**-0.738****	0.086	-0.174	-0.171
$\|S_t^{EU}\|$*ΔVBEL$_{t-1}$	**-0.474****	-0.084	0.036	**-0.250***	0.082	0.084
$\|S_t^{EU}\|$*ΔVSMI$_{t-1}$	-0.130	-0.154	**-0.372****	-0.201	-0.039	-0.095
Adj. R^2	**0.160**	**0.159**	**0.216**	**0.144**	**0.238**	**0.327**

Table 14: The effect of news announcements on the magnitude of implied volatility spillovers over the recent financial crisis. Entries report results from a VAR(1) model that allows for the matrix of coefficients of the lagged implied volatility indices to be affected by the aggregate [equation (9), Panel A] and regional U.S. and European [equation (10), Panel B] surprise variables. $|S_t|$ is the aggregate surprise variable, $|S_t^{US}|$ is the regional U.S. surprise variable and $|S_t^{EU}|$ is the regional European surprise variable. Equations (9) and (10) are estimated by the SUR method. Synchronous prices for both the U.S. and European implied volatility indices measured at 11:30am ET are used. The coefficient estimates and the Wald test statistic for H_0: $\varphi_{ij} = 0$ for all $i \neq j$ are reported. One and two asterisks denote rejection of the null hypothesis of a zero coefficient(s) at the 5% and 1% level, respectively. The t-statistics and coefficient estimates for the lagged implied volatility indices are not reported due to space limitation but are available from the authors upon request. The model is estimated for the period August 1, 2007 to December 31, 2010.

		Panel A: Aggregate news announcements			Panel B: Regional news announcements		
		VIX	**EU indices**	**All indices**	**VIX**	**EU indices**	**All indices**
***i* = 1**	c_1	**-3.393****	**-3.566****	**-3.526****	**-3.413****	**-3.597****	**-3.553****
	b_{11}	0.514	0.169	1.082	0.461	0.087	1.033
	b_{12}	**0.562****	**0.707****	**0.526****	**0.590****	**0.752****	**0.563****
	b_{13}	0.204	0.223	**0.281***	-0.009	-0.085	0.002
	b_{14}	-	-	-	0.322	**0.390***	**0.436***
***i* = 2**	c_2	-	**-4.774****	**-4.609****	-	**-4.805****	**-4.642****
	b_{21}	-	**2.869****	1.494	-	**2.869****	1.436
	b_{22}	-	0.224	**0.681***	-	0.240	**0.719****
	b_{23}	-	0.019	0.177	-	-0.475	-0.167
	b_{24}	-	-	-	-	0.249	0.361
***i* = 3**	c_3	-	**-3.092****	**-3.086****	-	**-3.101****	**-3.096****
	b_{31}	-	**2.142****	**2.060****	-	**2.122****	**2.038****
	b_{32}	-	0.107	0.240	-	0.125	0.258
	b_{33}	-	-0.226	-0.145	-	-0.673	-0.411
	b_{34}	-	-	-	-	-0.041	-0.014
	Pseudo R^2	**0.061**	**0.082**	**0.081**	**0.064**	**0.088**	**0.085**
LRT	**Constant**	**655.426**$^{++}$	**1237.570**$^{++}$	**1268.340**$^{++}$	**655.143**$^{++}$	**1233.815**$^{++}$	**1266.555**$^{++}$
	Y^{US}_{t-1}	187.375	**371.629**$^{++}$	**412.560**$^{++}$	186.088	**367.043**$^{++}$	**408.688**$^{++}$
	Y^{EU}_{t-1}	**194.344**$^{++}$	**363.393**$^{++}$	**407.661**$^{+}$	**193.692**$^{++}$	**360.342**$^{++}$	**405.379**$^{+}$
	$\lvert S_t \rvert$	188.730	356.137	403.076	-	-	-
	$\lvert S_t^{US} \rvert$	-	-	-	185.524	351.663	396.232
	$\lvert S_t^{EU} \rvert$	-	-	-	188.722	352.864	401.416

Table 15: Implied volatility co-exceedances and the effect of news announcements. The entries report results for the multinomial logistic regression model for the implied volatility co-exceedances. **Panel A:** Entries report the estimated coefficients in the case that the lagged U.S. co-exceedances, lagged European co-exceedandes and the surprise element of the aggregate news announcements are used as covariates, namely: $g_i(x_t) = \ln\left[P(Y_t = i|x_t)/P(Y_t = 0|x_t)\right] = c_i + \beta_i' x = c_i + \beta_{i1}Y_{t-1}^{US} + \beta_{i2}Y_{t-1}^{EU} + \beta_{i3}\,|S_t|$, where $Y_{t-1}^{US}\left(Y_{t-1}^{EU}\right)$ is the lagged U.S. (European) co-exceedance variable and $|S_t|$ is the aggregate surprise variable**.** **Panel B:** Entries report results from the estimation of the multinomial logistic regression model in the case that the lagged U.S. co-exceedances, the lagged European co-exceedances and the surprise element of the regional news announcements are used as covariates, namely: $g_i(x) = \ln\left[P(Y_t = i|x_t)/P(Y_t = 0|x_t)\right] = c_i + \beta_i' x = c_i + \beta_{i1}Y_{t-1}^{US} + \beta_{i2}Y_{t-1}^{EU} + \beta_{i3}\,|S_t^{US}| + \beta_{i4}\,|S_t^{EU}|$, where $Y_{t-1}^{US}\left(Y_{t-1}^{EU}\right)$ is the lagged U.S. (European) co-exceedance variable and $|S_t^{US}|\left(|S_t^{EU}|\right)$ is the regional U.S. (European) surprise variable. The coefficient estimates, pseudo R^2 and likelihood ratio test statistics (LRT) are reported. The pseudo R^2 of McFadden (1974) is defined as: pseudo $R^2 = 1 - \left(\ln L_{\text{full}} / \ln L_{\text{constants}}\right)$ where $L_{\text{full}}\left(L_{\text{constants}}\right)$ is the likelihood of the full (constants only) model. One and two asterisks denote rejection of the null hypothesis of a zero coefficient at the 5% and 1% level, respectively. In the case of the LRTs, one and two crosses denote rejection of the null hypothesis that the coefficients of any given covariate across the various levels of *Y* are jointly significant at the 5% and 1% level, respectively. The model is estimated for the period from August 1, 2007 to December 31, 2010.