Financial Crises, Price Discovery, and Information Transmission: A High-Frequency Perspective

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Abstract

This paper examines the price discovery processes before and during the 2007-09 subprime and financial crisis, as well as the subsequent European sovereign crisis, for the stock, bond, and U.S. dollar/euro FX markets in the U.S. and Germany in a high-frequency setting. Based on five-second intervals, we analyze how asset prices interact and incorporate information conditional on macroeconomic announcements and news surprises from the U.S. and Germany. Our results show strong state-dependent return and volatility patterns across assets and markets. Moreover, we document significant co-movement and spillover effects that result from a dynamic network of news-based and trading-based information transmissions. We find that some effects we first identify during the financial and subprime crisis vanish, but others persist.

Keywords: *Financial crises, macroeconomic announcements, price discovery process, information transmission process, high-frequency data.*

JEL Codes: *G*01, *G*12, *G*14, *G*15

1 Introduction

How quickly do bond, stock, and currency markets incorporate new information into prices? Are there systematic information transmission mechanisms among these asset markets? How did the 2007–09 subprime and financial crisis as well as the subsequent European sovereign crisis affect these information transmission processes? Have these financial crises changed the price discovery process?

We provide answers to the above questions by focusing on price adjustment processes around macroeconomic announcements. In addition to standard analyses using (five) minute intervals, we open up the minute after announcements to gain insight into the underlying processes that take place over seconds instead of examining just the results arising from this price discovery process. We analyze news effects on asset returns and volatility with respect to direction, size, and response time, as well as the patterns in trading volume of different assets around macroeconomic announcements. All these effects are interpreted in relation to the type and origin of the news as well as the state of the economy.

To the best of our knowledge, we are the first to analyze – on an (ultra-)high frequency – how quickly and strongly news is directly incorporated in different asset prices and how it is transmitted indirectly by the immediate impact that information has on prices. The resulting structure can be interpreted as a dynamic network of transmissions of news-related and trading-related information. Empirically, we capture co-movement and spillover effects among returns and volatility of the three main asset classes – bonds, stocks, and the USD/EUR exchange rate of the U.S. and Germany – in order to detect systematic transmission channels that are conditional on those countries' news.

Our analyses are based on the definition of information transmissions in terms of co-movements and spillovers in returns and volatility among assets conditional on funda-

mental news. This interpretation follows Franses et al. (1997), who interpret interactions in the first and second moments as alternative measures of information diffusion.

Further, we provide a detailed analysis of reactions to macroeconomic announcements conditional on different states of the economy. Most previous studies have used macroeconomic announcements from one country (mainly the U.S.) only.[1] However, we consider real-time announcement data from the U.S. and Germany, as well as expectations of the announcements, to analyze effects on both U.S. and German assets. Because our sample covers the pre-crisis period from 2006 to 2007, the 2007-09 subprime and financial crisis period, as well as the subsequent European sovereign crisis period, we can distinguish between "normal" and "crisis" times in the economy.[2] Moreover, the consideration of two different crises enables us to disentangle the effects that macroeconomic news has during a global financial crisis compared to those being provoked by a regional crisis, i.e., when only one market is directly affected. This setting of two different successive crises allows us to study changes in size, direction, significance, and duration of effects between a regional and global financial crisis. Finally, moving from pre-crisis to crisis periods provides insights into changes in the price reactions to announcements, and thus, the short-term pricing of risk factors.

Discussing the impact of high-frequency trading on market microstructure, O'Hara (2015) argues that five-minute sampling intervals are nowadays too long. Harnessing the high quality of our tick data to investigate high-frequency characteristics, we confirm this view based on the observation of heavy trading around announcements and the near-

[1]For example, Balduzzi et al. (2001) analyze the U.S. bond market, while Boyd et al. (2005) study U.S. bond and stock markets. Andersen et al. (2007) and Faust et al. (2007) expand their analysis to multi-country cases and Chatrath et al. (2014) focus on four different exchange rates. The fact that the German markets are open when most U.S. news is released makes these two markets ideal for studying co-movement and spillover effects among assets and market places.

[2]This differentiation is related to Andersen et al. (2003b), who report that there are asymmetric market reactions (sign effects) between "good" and "bad" news during "good times" (expansion periods) and "bad times" (contraction periods).

continuous-time reaction of market participants.[3] Similarly, Ederington and Lee (1993) document that most of the price adjustments to major announcements occur within the first minute.

For our kernel-based volatility estimator, we use one minute and five seconds as sampling intervals and also provide evidence on volatility estimates calculated from frequencies between one and 1,500 seconds.[4] This narrow window provides a more natural environment from which we can detect effects that are not observable when using longer intervals. In other words, a higher sampling frequency enables us to study the price discovery process itself rather than just its results. Brogaard et al. (2014) document substantial increases in high-frequency trading within seconds after macroeconononomic announcements, and also significant return effects in both directions depending on "good" or "bad" news in the ten seconds after news surprises. We can thus deepen our understanding of how macroeconomic fundamentals affect linkages among asset markets by simultaneously mitigating the omitted variable bias and dual-causality problems in our estimation strategy.

We further show that the response pattern of asset returns to macroeconomic news is gradual, lasting from one to eight minutes, with the largest movement occurring within the first minute after the announcement release. The findings complement the results of earlier studies that use a five-minute interval.[5] In general, the estimated size of price responses increases from pre-crisis period to subprime and financial crisis period, and bounces back for most of the assets during the European sovereign crisis, but still remains at a higher level compared to the pre-crisis period. This change in the estimates of

[3]See, e.g., Christensen et al. (2011) for a literature overview on sampling intervals over the last four decades.

[4]Chaboud et al. (2010) show that sampling intervals of two to five seconds for a USD/EUR FX dataset (and even higher on announcement days) do not lead to a noticeable bias when using realized kernels.

[5]For example, **?** and citetAndersen2007 record a contemporaneous price jump of five minutes for the Deutsche Mark/USD exchange rate. In contrast, Lucca and Moench (2015) report significant excess returns in pre-announcement periods to monetary policy decisions for U.S. equities. However, we do not find such pre-announcement drifts.

macroeconomic announcement effectscould be explained as a lasting change in risk perception as a result of continuing economic uncertainty. Similar to Füss et al. (2016), we interpret the change in the estimated coefficients as time-varying pricing of risk factors triggered by a fundamental change in the risk-taking of market participants.

Analyzing the first one-minute trading interval after news releases with our approach of five-second intervals enables the identification of transmission patterns, i.e., co-movements and spillovers, in the returns and highly persistent volatility processes among the three asset markets. The information transmission exhibits distinctive inter- and intra-asset features in an international cross-border context depending on the origin of the fundamental news and the state of the economy. The interactions among the markets increase strongly during the first crisis period. We identify different effects for the price discovery process and risk-return transmission mechanisms conditional on news during the pre-crisis period and the phases of crises.

The remainder of this paper is organized as follows. In Section 2, we lay out the economic foundation for market responses to fundamentals. Section 3 describes the data. In Section 4, we specify the estimation models, and Section 5 presents our empirical results. Section 6 concludes.

2 Responses to Economic Fundamentals

This section provides an economic foundation for our empirical analysis by formulating the expected effects of macroeconomic announcements and news surprises on return and volatility co-movements and spillovers. We first turn to the effects that macroeconomic announcements have on each single asset separately. This forms the basis for the two main research questions we have: (i) whether and how the price processes of assets are interconnected conditional on macroeconomic news, and (ii) how the financial market

crisis and the European sovereign crisis affect this interaction.

We classify our macroeconomic variables into five indicators: economic activity (durable goods orders, GDP, industrial production, trade balance), price (consumer price index, producer price index), labor market (initial unemployment claims, non-farm payroll), housing market (housing starts, new home sales), and business climate and consumer confidence (consumer confidence, IFO business climate, ZEW survey, manufacturing ISM, non-manufacturing ISM).

2.1 News Effects on Bond, Stock, and FX Markets

Both returns and return volatility are expected to be affected by macroeconomic announcements. Positive inflationary shocks affect bond returns negatively because they ultimately lead to revisions in expected inflation, while positive real shocks lead to higher inflation and interest rates (according to, e.g., the Phillips curve equation). Thus, procyclical indicators (such as economic activity, housing market, and business climate and consumer confidence-related variables) affect bond returns negatively. The same is true for inflationary pressures, because inflation is positively correlated with economic activity (Balduzzi et al. (2001)). However, countercyclical labor market indicators, such as a higher than expected unemployment rate, lead to expansions in monetary policy, i.e., lower interest rates and thus increasing bond prices (Gürkayanak et al. (2005)).[6]

We expect to find similar effects for the FX market. Note that higher positive real shocks to one economy (relative to another country or monetary area), and consequently higher inflation, will affect the nominal exchange rate positively. According to Lucas (1982), a positive money supply shock due to an unexpectedly high unemployment rate will result in the opposite effect on the nominal exchange rate, with a positive sign for

[6]In line with Remolona (1991), we assume that expected inflation has a stronger effect on bond returns because it directly affects real interest and principal payments.

the USD/EUR spot rate.

Furthermore, positive shocks in the fundamentals lead to decreasing stock prices because of increasing discount rates (assuming a time-invariant risk premium). On the other hand, positive fundamentals imply higher future cash flows, which tend to increase stock prices. Hence, the impact effectively depends on which effect, the discount rate or cash flow, is dominant (Andersen et al. (2007)).

2.2 News Effects during "Normal" and "Crisis" Periods

Boyd et al. (2005) find that the two effects, arising from discount rate and cash flow, are related to the business cycle. For example, a higher unemployment rate is positively correlated with stock prices during economic expansions, but negatively correlated during economic recessions. Andersen et al. (2007) argue further that the discount effect dominates in expansion phases due to lower interest rates, while lower future cash flows during contraction periods lead to decreasing stock returns.

According to Bernanke and Kuttner (2005), the stock market reaction can also be explained by unexpected changes in the federal funds target rate, which directly affects the equity risk premium. Hence, an unexpected positive inflationary shock or unexpected positive real innovation to the economy can lead to a monetary policy surprise, i.e., an unexpected increase in the target rate, where the equity premium goes up and stock prices go down. During "normal" market periods, the risk premium is constantly low and the interest effect plays a dominant role. A positive shock thus leads to increasing discount rates, which lower stock prices, while higher expected cash flows drive stock prices in the opposite direction. During "crisis" periods, however, the interest rate plays a minor role, and a positive announcement surprise will tend to have a significant reducing effect on the equity premium, which leads to increasing stock prices. In general, we expect the

strongest impact of announcement surprises to be on stock market returns, because they represent residual claims with higher volatility.

With regard to return dispersion, long-lasting volatility effects have been well-documented in the literature (see, e.g., Andersen and Bollerslev (1997, 1998), and Andersen et al. (1999, 2001, 2003a)). In highly liquid markets, we expect to see a significant increase in volatility shortly before scheduled announcements.[7] However, the informational shocks diminish only gradually after the announcement release because of the uncertainty about how it will affect price levels, firm earnings, and the overall real economy. Moreover, Foster and Viswanathan (1993) and Pasquariello and Vega (2007) show that price volatility increases after a public signal.

2.3 Information Transmissions Among Asset Markets

In the long run, stock and bond markets exhibit negative correlations (see, e.g., the result of Campbell and Ammer (1993) for monthly data). Similarly, Ranaldo and Söderlind (2010) find that bond, equity, and FX markets are significantly interrelated at sampling intervals of several hours or days. Brenner et al. (2009), who study responses of U.S. stock, Treasury, and bond markets to U.S. macroeconomic surprises, also find fundamentals-driven interrelations on a daily basis. This finding is in line with Bongaerts et al. (2014), who document that jumps and co-jumps in prices are often found in relation to U.S. macroeconomic announcements.

Such systematic (high-frequency) transmission patterns among stock, bond, and FX markets can be traced back to common informational shocks and cross-market hedging effects (Fleming et al. (1998)). The announcement surprises may lead to covariance shifts (see, e.g., Karolyi and Stulz (1996) and Connolly and Wang (2003)), and can increase

[7] In contrast, the emergence of information can also serve to resolve uncertainty and/or create disagreement among market participants, so that markets tend to be more volatile before the news event (see, e.g., Pasquariello (2007)).

portfolio rebalancing activities across asset markets (see, e.g., Fleming et al. (1998) and Kodres and Pritsker (2002)). We examine these dynamics among assets by relating them to macroeconomic fundamentals.

2.4 State-Dependent Return and Volatility Responses

In general, we expect to see more pronounced and longer-lasting return responses after news releases during times of distress than during normal times. In crisis periods, we would also expect to find substantially higher volatility before and after the release of news, particularly due to the higher uncertainty among market participants (and/or the overreactions of market participants). During such periods, investors require compensation for being exposed to liquidity and/or volatility risk (Pastor and Stambaugh (2003), Acharya and Pedersen (2005), and Brunnermeier and Pedersen (2009)).

Investigating yield curves and exchange rates, Goldberg and Grisse (2013) also discover time-variation in responses to macroeconomic announcements. They document that the differences can be explained by economic conditions and risk perceptions. These differences in the size of the return and volatility responses between normal and crisis periods may hold for all asset classes. However, the effects should be more pronounced for the stock market as they represent residual claims. Because the 2007-09 subprime and financial crisis originated with the bursting of the housing bubble in the U.S., we expect U.S. news, particularly housing market related indicators, to be of more significance during this period. An empirical question is whether the sizes of the return and volatility responses go back to their pre-crisis level or remain at a higher level when the European sovereign crisis emerged after the subprime and financial crisis. The latter effect can be explained by a time-varying pricing of risk in terms of changing risk perception during the course of a crisis (see, e.g., Füss et al. (2016)). In particular, because we can assume that the subprime and global financial crisis vanishes after 2009 and the impact of the

underlying U.S. risk factors mitigates, higher remaining price responses of U.S. assets to U.S. news before and after the global financial crisis imply that investors' risk attitudes may have changed and did cause a change in the underlying pricing of risk.

2.5 State-Dependent Information Transmissions

Under different market conditions the relevance of different types of information can change. Adams et al. (2004) and Andersen et al. (2007) report asymmetric news effects for periods of economic expansion and contraction. Thus, when analyzing the subprime and financial crisis and the European sovereign crisis in comparison to the pre-crisis period, we expect a stronger interdependence among asset markets.

There is strong empirical evidence on increasingly positive correlations both within and between asset classes during crisis times.[8] However, to the best of our knowledge a detailed analysis of how informational effects are influencing the interdependence in different states of the economy is missing. By opening up the one-minute interval after announcements and investigating the interconnectedness based on five-second intervals, we close this gap and turn the focus especially on the price mechanism among asset markets. It can be expected that during times of market turmoil uncertainty is higher and participants pay more attention to news in the relevant areas. So we expect them to react more strongly than in calm periods. When news hits the market, this should lead to adjustments in the respective asset markets and also trigger co-movement and spillover effects. Furthermore, the higher uncertainty in crisis periods should amplify the effect of news on market volatility and its transmission across asset markets. We consider the latter as a second, indirect channel that adds to the direct effect of the macroeconomic surprises.

[8]See Ramchand and Susmel (1998), Longin and Solnik (2001), Ang and Bekaert (2002), Ang and Chen (2002), Forbes and Rigobon (2001), and Baele (2005) among others.

3 Data

3.1 Asset Markets

We choose E-mini S&P500, 10-year Treasury note, DAX, and Bund futures, as well as the USD/EUR spot rate, which constitute major internationally traded and integrated assets. The data for the DAX and Bund futures is obtained from Deutsche Börse (tick-by-tick transaction data). Both futures markets are highly liquid, and are already open by 8:00 Central European Time (CET), when important German macroeconomic news such as GDP, PPI, and retail sales numbers are released. The E-mini S&P500 and 10-year Treasury note futures tick-by-tick transaction data are obtained from Tickdatamarket.com. The USD/EUR spot exchange rates (second-by-second transaction data) come from the Electronic Broking System (EBS) of ICAP, London, a twenty-four-hour liquid electronic FX trading platform for USD/EUR, which is used by virtually all FX dealers worldwide who trade in major currency pairs.[9]

Our full sample spans 1,528 trading days from January 2006 through December 2011. The trading hours of DAX and Bund futures on most days are from 7:50 to 22:00 and 8:00 to 22:00, respectively. E-mini S&P500 futures and 10-year Treasury note futures start to trade at 18:00 EST (00:00 CET), and their trading ends at 17:00 EST (23:00 CET). To avoid contamination from overnight news or from hedging activities at the end of the trading day, we remove opening and closing prices and only use the overlapping trading hours of 8:00 to 22:00.[10]

We split our sample to cover the pre-crisis period (January 2006 through July

[9]The USD/EUR futures market at the CME only trades from 8:20 to 15:00 Eastern Standard Time (EST), and thus the marketplace is closed when many European announcements are released. Chen and Gau (2010) find that the FX market on ICAP is leading the FX futures market.

[10]All five markets are open between 8:00 to 22:00. The FX market is open on a 24-hour basis. E-mini S&P500 futures and the 10-year Treasury note futures are traded almost 24 hours, except a one-hour daily maintenance and 15-minute trading halt.

2007), the subprime and financial crisis period (August 2007 through August 2009), and the period thereafter (September 2009 through December 2011), which includes the European sovereign crisis.

3.2 Basic Facts of One-Minute Series

We start our study with the examination of price reactions conditional on macroeconomic surprises based on one-minute time series. We then refine our sampling interval to five seconds to analyze how macroeconomic surprises trigger spillover effects among markets.[11] These short sampling intervals allow us to study the processes themselves and not just their outcomes.

Figure 1 plots the average one-minute absolute returns over the entire trading day. For all five assets, we find a first spike at 9:00 CET, when the German and London stock markets open.[12] The DAX futures show the largest jump as the underlying starts to trade. At 14:30 CET (8:30 U.S. EST), major U.S. macroeconomic announcements are released, such as CPI, GDP, and PPI. The volatilities of the five markets sharply increase. At 15:30 CET (9:30 EST), the U.S. stock market begins to trade, and not surprisingly, the E-mini S&P500 futures strike the most. At 16:00 CET (10:00 EST), many U.S. macroeconomic announcements, such as the manufacturing ISM (Institute of Supply Management) index and the composite index of leading indicators, arrive at the market. Again, we find that the volatilities of all markets jump instantly. The German stock market closes at 17:30 CET (11:30 EST) when the volatilities slightly increase.[13]

[11] To convert the irregularly spaced tick-by-tick prices into time series with fixed time intervals, we take the last transaction price within the interval [t,t+1] as the price, P_t.

[12] We remove the opening and closing prices resulting from the respective auctions at 8:00 and 22:00 when the German futures markets open and close. When the underlying markets open at 9:00, we find a spike in the futures markets, showing that there is a daily volatility pattern associated with stock market opening and closing.

[13] We also find significant negative first-order autocorrelations in asset returns with higher-order autocorrelations around or within the 95% confidence band. The volatilities of all five markets follow a long-memory process.

« Insert Figure 1 about here »

Figure 2 plots the average (calculated over all macroeconomic announcements) one-minute trading volume of each asset market, beginning thirty minutes prior to and ending one hour after the announcements. Trading volume immediately jumps after news releases for all five markets and decreases gradually afterwards, which confirms the reliability of our announcement stamps. Compared with DAX futures, Bund futures, and USD/EUR, the surge in trading volume of the two U.S. assets, E-mini S&P500 futures and 10-year Treasury note futures, is much larger after U.S. news than after German news. This indicates that domestic information triggers larger turmoil in the U.S. than in foreign asset markets.

« Insert Figure 2 about here »

3.3 Macroeconomic Announcement Data

We obtain macroeconomic announcement data for the U.S. and Germany from the Market News International (MNI) database.[14] Table A1 in the Internet Appendix summarizes the announcements.[15] We further control for overlapping subprime and financial crisis and European sovereign crisis events by adding dummy variables for respective news from mid-2007 through the end of 2011. We identify 39 relevant news releases within the sample. They are collected from Bloomberg, the Federal Reserve Bank of St. Louis and the European Central Bank, and are summarized in Table A2 in the Internet Appendix.[16]

[14]We also use announcement data from the European Monetary Union (EMU). With the exception of a minor impact on the USD/EUR exchange rate, we find that aggregate EMU news is generally insignificant. One explanation for the insignificant effect of macroeconomic data from the EMU lies in the non-revision of forecasts. Only some survey participants revise their reported forecasts for the EMU after announcements from single countries, but most do not, which leads to a biased measurement of surprises.

[15]Some forecasting data in the MNI database is missing, particularly for EMU and German announcements. We only include announcements for which sufficient observations are available.

[16]It is important to note that only those events that coincide with announcements are listed. For example, the Lehman Brothers collapse took place when no macroeconomic news was released.

Following Balduzzi et al. (2001) and Andersen et al. (2003b, 2007), we construct standardized news to control for market expectations and different measurement units. The surprise, defined as actual value minus forecasted value, is divided by the sample standard deviation of the surprise, as follows:

$$S_{kt} = \frac{R_{kt} - F_{kt}}{\hat{\sigma}_k}, \tag{1}$$

where R_{kt} and F_{kt} are the actual value and the market expectation of announcement k measured by the median MNI forecast, respectively, and $\hat{\sigma}_k$ is the sample standard deviation of the surprise, $R_{kt} - F_{kt}$.[17]

4 Model Specifications

4.1 Modeling Average Intraday Volatility

We follow Zhou (1996) and Hansen and Lunde (2003, 2005, 2006), who develop a kernel-based volatility estimator that remains consistent and unbiased even at very high frequencies. We define the realized kernel as:

$$K(X) = \gamma_0(X) + \sum_{h=1}^{H} k\left(\frac{h-1}{H}\right)\{\gamma_{-h}(X) + \gamma_h(X)\}, \tag{2}$$

with the price process, $X = P + U$, consisting of the efficient price P plus the market friction U, the realized autocovariances $\gamma_h(X) \equiv \sum_{i=1}^{n} R_i R_{i-h}$ for $h = 0, 1, ..., H$, and a kernel function (weight) of $k(\frac{h-1}{H})$. We use the modified Tukey-Hanning kernel, $sin^2\left\{\frac{\pi^2}{2}(1-x)^2\right\}$, which has been tested by Barndorff-Nielsen et al. (2008), and offers a

[17] We do not apply a minimum threshold as a deviation from the expectation (as, e.g., in Hanousek and Kocenda (2011)), as this would only eliminate very few observations.

balance between computational efficiency and accuracy with respect to power.

Bandi and Russel (2006) and Chaboud et al. (2010) show that, in highly liquid markets, sampling intervals of less than one minute do not lead to biases for the realized variance. And for simple realized kernel estimators, this window can be as short as two to five seconds without causing a noticeable bias.[18]

For our time-varying volatility estimation approach, where average daily volatility is treated merely as a control variable, we follow Andersen et al. (1999) and use signature plots to detect the optimal frequency for calculating intraday volatility.[19] Based on the signature plots in Figure B1 of the Internet Appendix, we find that a one-minute interval is a good balance between noise and sampling errors. We therefore construct one-minute return and trading volume time series.

4.2 Modeling News Effects

We construct time series for a window of ten minutes before and one hour after macroeconomic announcements.[20] To detect the macroeconomic news effects on the markets, we follow Andersen et al. (2003b, 2007), and use a two-step regression model. In the first step, we apply the following dynamic regression model for each return series:

[18] Chaboud et al. (2010) use a USD/EUR dataset from ICAP and demonstrate that fifteen- to twenty-second intervals can be used without contaminating the realized variance with market microstructure noise. For a simple realized kernel estimator, they find no noticeable bias, even for two- to five-second intervals. They show that sampling intervals may be even shorter for days when U.S. macroeconomic data are released.

[19] We compare the realized variance with the realized kernel for DAX and Bund futures and for the USD/EUR exchange rate for different sampling frequencies. The realized kernels converge to a stable level at a frequency of roughly one minute, while realized volatility approaches true volatility at a twenty-minute frequency. The volatilities of E-mini S&P500 and 10-year Treasury note futures tend to be underestimated using realized kernels at lower frequencies. Realized kernels based on five-second to one-minute intervals are closer to the true volatilities. We also use Bandi and Russel's (2005) MSE approach to calculate the optimal time interval for realized volatility, which confirms the results from the signature plot (i.e., an optimal interval of about twenty minutes).

[20] We also extend the time window to one and a half hours after the announcements. However, the results do not change materially. Furthermore, a one-hour time window is sufficient to capture the volatility response.

$$R_t = \beta_0 + \sum_{i=1}^{I} \beta_i R_{t-i} + \sum_{k=1}^{K} \sum_{j=0}^{J} \beta_{kj} S_{k,t-j} + \sum_{l=0}^{L} \beta_l C_{t-l} + \varepsilon_t \qquad \text{for } t = 1, \dots T, \tag{3}$$

where R_t are log returns, $K = 19$ is the total number of macroeconomic announcements, S_{kt} denotes news surprises, and C_t is the crisis dummy. We choose $I = 15$, $J = 8$, and $L = 6$, according to the Akaike information criterion.

The autoregressive terms play a role similar to that in Stoll and Whaley (1990), who propose an ARMA(p,q) filter with infinite order to mitigate the bid-ask bounce and discreteness effects. We estimate the conditional mean of Equation (3) by using ordinary least squares regressions, and then extract the heteroskedastic residuals to model the time-varying volatility $|\varepsilon_t|$ as follows:

$$\begin{aligned} |\varepsilon_t| = c + \Psi \frac{\hat{\sigma}_{d(t)}}{\sqrt{840}} + \sum_{k=1}^{K} \sum_{j'=-10}^{J'} \delta_{kj'} |SD_{k,t-j'}| + \sum_{m=1}^{M} \sum_{j''=0}^{J''} \varphi_{mj} D_{m,t-j''} \\ + \sum_{l'=0}^{L'} \beta_{l'} C_{t-l'} + \sum_{n=1}^{N} \theta_n W_n + u_t. \end{aligned} \tag{4}$$

The first part of Equation (4), $\hat{\sigma}_{d(t)}$, is the daily volatility measured by realized kernels, standardized with the square root of the number of one-minute intervals from 08.00 CET (02:00 EST) to 22.00 CET (16:00 EST). D_m are calendar event dummies, including the opening and closing of German and U.S. bond and stock markets, while W is the trading day dummy with $N = 4$ to capture a day-of-the-week effect on volatility. SD_k are the macroeconomic news dummies, which have much longer effects on volatilities, where $J' = 60$.[21] The residuals of the conditional mean in Equation (3) exhibit clear heteroskedasticity. In order to obtain robust coefficients, we apply a weighted least squares (WLS) procedure to the conditional mean equation. Thus, we use the fitted time-varying

[21] In line with Andersen et al. (2007) we use macroeconomic dummies instead of absolute values, which make it also easier to compare the effects.

volatility from Equation (4) to estimate a WLS regression of Equation (3).

To get an overview of the volatility response pattern while maintaining flexibility, we next impose two third-order polynomial response functions to capture the pre- and post-news effects, as follows:

$$p(j') = a_1(1 - (j'/60^3)) + a_2(1 - (j'/60)^2)j' + a_3(1 - (j'/60))j'^2, \tag{5a}$$

$$p(j'') = b_1(1 - (j''/10^3)) + b_2(1 - (j''/10)^2)j' + b_3(1 - (j''/10))j''^2, \tag{5b}$$

where $j' = 0, ..., 60$ and $j'' = 0, ..., 10$. The impact after one hour, $p(60)$, and before ten minutes prior to the announcement, $p(10)$, is assumed to be zero. The coefficients of macroeconomic news dummies in Equation (4) are replaced by the polynomial response functions. This considerably reduces the number of coefficients to be estimated.

5 Empirical Results

5.1 News Effects on Single Assets

Before we refer to our main research questions on information transmission and its pattern during normal and distressed market periods, we first take a look at the impact that news has on returns and volatility of individual assets. Figure 3 presents return responses to selected macroeconomic U.S. and German news for the whole sample period, together with 95% confidence intervals and average trading volumes from three minutes before until eight minutes after the news releases.[22]

[22]We also tried to include first and second leads in the model, but we found no pre-announcement impact on returns. The choice of minutes around the news releases shown in Figure 3 was done on the basis of significant price changes in the data, with effects mainly observed in the -3 to +8 minute window around announcements.

« Insert Figure 3 about here »

We observe return jumps lasting from one to eight minutes for most economic announcements.[23] For almost all of the indicators, the largest impact on all five assets occurs within the first minute after the announcement (denoted as contemporaneous response), which is in line with the results reported by Ederington and Lee (1993). All contemporaneous responses are significant at least at the 95% level. The impact generally decreases during the following minutes. Trading volumes also surge as macroeconomic news is released, and decrease gradually thereafter.[24] Before the news release, trading volumes appear to be stable with no distinctive pattern.

Table C2 in the Internet Appendix reports the contemporaneous and cumulative return responses to macroeconomic news for the three time periods and the five asset classes based on the different types of macroeconomic indicators from the U.S. and Germany. In general, the significant response length ranges from one to three minutes, with the cumulative response being larger than the contemporaneous response.[25] Most announcements show only a contemporaneous impact on the USD/EUR exchange rate, whereas the price discovery for the stock and bond markets takes longer, with one to two minutes for the U.S. assets and one to three minutes for the German assets.[26] The impact of German news is generally lower than that of U.S. macroeconomic news.

The return volatility is influenced by most of the macroeconomic news in all five

[23] Table C1 in the Internet Appendix shows the results for the whole sample and for all macroeconomic news.

[24] We also added a variable for standardized trading volume in our return equation in order to capture liquidity effects on the volatility. However, the coefficients are economically small.

[25] We define the cumulative impact on return as the sum of continuous significant coefficients (as long as they do not involve a sign change). The accumulation of return responses begins from the first significant coefficient, and ceases when a coefficient becomes insignificant or changes its sign. We impose this relatively conservative measure to avoid overestimation or amplification of the cumulative responses.

[26] The effects are also economically significant. For instance, one standard deviation unexpected increase in non-farm payroll leads to a 0.6% increase of the DAX futures price during the post-crisis period.

markets.[27] Figure 4 shows the average polynomial response of volatilities to selected U.S. and German macroeconomic news, respectively, for one hour after the release.[28] We note an immediate surge in volatility, followed by a sharp decrease within the first twenty minutes and finally a complete phase-out. Thus, the volatility response patterns are much longer than those of returns. Our estimated response coefficients are in line with Andersen and Bollerslev (1998) and Andersen et al. (2003b), who report similar results for a longer-lasting volatility impact.

« Insert Figure 4 about here »

To address the question of whether differences in the information transmission process arise from various states in recent business cycles, we split the sample into pre-crisis (from January 2006 through July 2007), subprime and financial crisis (from August 2007 through August 2009), and European sovereign crisis period (from September 2009 to December 2011). In the sections below, we show a noticeable shift in the impact of different macroeconomic news over the different states of the economy.

5.2 Conditional Information Transmission Among Asset Markets

With the single asset estimations pointing at significant and economically relevant announcement effects, we are interested in the price mechanism within the first minute after the announcement. By examining the five second-wise responses of returns and volatility

[27] We also examine the volatility response for ten minutes before the news release. We find slight increases in volatility for some important economic indicators. However, the magnitude is very small, and there is no distinctive pattern.

[28] The polynomial response functions of Equations (5a) and (5b) replace the coefficients of news dummies in Equation (4). The average intraday volatility accounts for most of the variation. Other factors (news dummies and average intraday volatility, as well as calendar, event, crisis, and day-of-the-week dummies) that influence volatilities are also incorporated into the volatility equation as discussed in the previous section. Thus, the polynomial responses capture only the macroeconomic news effects.

in multivariate setups, we gain insight into the transmission of information across the asset markets.

We test for return and volatility co-movements and spillover effects by using correlation structure and Granger causality, as well as VAR processes and HAC-robust OLS estimates for macroeconomic announcements, which are identified as significant for at least two asset markets in the single asset estimations of Sub-section 5.1. We define information transmissions as return and volatility co-movements and spillovers across assets conditional on fundamental news. Thus, in line with Franses et al. (1997), we interpret interactions in the first and second moments as alternative measures of information transmission. In other words, we analyze how macroeconomic news surprises influence the joint behaviour of returns (i.e., the information transmission channels and the contemporaneous and lagged price discovery processes) among the three asset categories.[29]

The largest price movements occur within the first minute after announcements, and most of the announcements influence asset markets only in this very minute. This finding confirms that the one-minute time window has to be opened up to determine the information transmission process conditional on macroeconomic news. Hence, we consider this as strong evidence to capture conditional return and volatility co-movements and spillovers by using five-second sampling intervals. The results on the information transmission among asset returns and volatility are discussed in the following sub-sections.

[29] We also conducted a placebo test by choosing days without announcements. Note that the results are reported only for day spans where the number of zero returns was below 60%. Unsurprisingly, the robustness checks for selected days reported in Table D1 in the Internet Appendix show substantially lower estimates. This finding supports the assumption that information transmissions predominantly occur at the time of a news release.

5.2.1 Information Transmission in Returns

Return Comovements We use a realized kernel-corrected correlation coefficient to measure return co-movements.[30] The signs of conditional correlation coefficients, i.e., conditional on macroeconomic announcements, are as expected and reported in Table 1.[31] The bond and USD/EUR exchange markets move in opposite direction to the stock markets in response to unexpected U.S. news. We find that the correlations between each pair of stock and bond markets increase substantially from pre-crisis to the subprime and financial crisis period. The co-movements are further strengthened in the third period, when the European sovereign crisis emerged. The opposite holds true for the correlation between the USD/EUR exchange rate and the bond markets, which can be traced back to lower responses of the USD/EUR exchange rate to unexpected U.S. news in the latter two subsamples. The co-movements between the two bond markets remain at a high level all the time, while the positive correlation between the two stock markets increases from the subprime and financial crisis onward. This indicates that German and U.S. bond and stock markets become very sensitive to U.S. macroeconomic news due to long-lasting market uncertainty.

« Insert Table 1 about here »

Correlation coefficients conditional on German news as compared to U.S. news are generally smaller in magnitude, and this is largely because of a lower response of U.S.

[30] We calculate the correlation coefficient based on the realized kernel as $\rho_{12}^{RK} \frac{\sum_{n=1}^{N} R_{1,n} R_{2,n}}{\sqrt{RK_1}\sqrt{RK_2}}$, where the means of returns R_1 and R_2 are approximately zero. In the denominator, the variances of R_1 and R_2 are replaced by the realized kernels RK_1 and RK_2, calculated throughout the aggregated one-minute time windows. We also calculated the Bravais-Pearson correlation coefficient – as well as a realized volatility-based coefficient. Both qualitatively confirm our realized kernel-based results.

[31] By definition, positive U.S. news has a negative impact on the USD/EUR exchange rate, while positive German news affects FX positively. Therefore, we observe opposite signs of conditional correlation coefficients between USD/EUR exchange rate and any other market in response to U.S. and German news, e.g. $\rho^{US;\ Pre-crisis}_{USD/EUR,Bund\ Futures} = 0.4788$ and $\rho^{German;\ Pre-crisis}_{USD/EUR,Bund\ Futures} = -0.3030$.

asset markets to German news. Stock and bond markets are negatively correlated, and the strength of negative correlation is amplified in crisis times. This is an interesting finding, as Longin and Solnik (2001) and Forbes and Rigobon (2001) among others report increased correlations during market turmoil. However, most related studies use lower frequencies such as daily, weekly or monthly data, whereas we focus on the five-second frequency, and apparently the standard negative correlation is preserved. This result could be explained by a significant proportion of market participants trading these assets against each other (at a very high frequency).

The changes in magnitudes of correlations conditional on German news are quite similar to those on U.S. news. The only exception is the correlation structure among the FX and the other markets, which tend to decline during the global financial crisis and increase afterwards. Interestingly, the general increase in the size of coefficients when going from pre-crisis to the global financial crisis period persists during the European sovereign debt crisis period. The time-varying co-movements, if any, are mainly reflected in increasing magnitude rather than in a change of the direction of the coefficients. This result points to a higher sensitivity to news during crises. Following Franses et al. (1997) in interpreting the interactions of the assets as a measure of information transmission, we consider these findings not only as evidence of increased attention to news, but also of increased information transmission during market turmoil.

There are also commonalities across all periods, with short-term co-movements being lowest among stock and FX as well as bond and FX markets. Furthermore, intra-asset co-movements are stronger than inter-asset ones, even in an international context, and the co-movement in the stock market is higher since the subprime and financial crisis. Our results for the dependence structure between FX and the other markets confirm those of Ranaldo and Söderlind (2010) for futures contracts of S&P500 and ten-year Treasury notes on an hourly sampling interval (up to twelve hours). As we find evidence for a

stronger interconnectedness among assets based on an increase in return co-movements, which we interpret as an increase in information transmission, we further study the price dynamics, i.e., spillover effects, among national and international asset markets.

Return Spillovers To examine the conditional spillover effects among asset returns, we specify the following vector autoregressive (VAR) model:

$$\begin{bmatrix} R_t^{\text{E-mini S\&P}} \\ R_t^{\text{10YR T-Note}} \\ R_t^{\text{USD/EUR}} \\ R_t^{\text{DAX}} \\ R_t^{\text{Bund}} \end{bmatrix} = \begin{bmatrix} c^{\text{E-mini S\&P}} \\ c^{\text{10YR T-Note}} \\ c^{\text{USD/EUR}} \\ c^{\text{DAX}} \\ c^{\text{Bund}} \end{bmatrix} + \begin{bmatrix} a_{t-1}^{11} & a_{t-1}^{12} & a_{t-1}^{13} & a_{t-1}^{14} & a_{t-1}^{15} \\ a_{t-1}^{21} & a_{t-1}^{22} & a_{t-1}^{23} & a_{t-1}^{24} & a_{t-1}^{25} \\ a_{t-1}^{31} & a_{t-1}^{32} & a_{t-1}^{33} & a_{t-1}^{34} & a_{t-1}^{35} \\ a_{t-1}^{41} & a_{t-1}^{42} & a_{t-1}^{43} & a_{t-1}^{44} & a_{t-1}^{45} \\ a_{t-1}^{51} & a_{t-1}^{52} & a_{t-1}^{53} & a_{t-1}^{54} & a_{t-1}^{55} \end{bmatrix} \cdot \begin{bmatrix} R_t^{\text{E-mini S\&P}} \\ R_t^{\text{10YR T-Note}} \\ R_t^{\text{USD/EUR}} \\ R_t^{\text{DAX}} \\ R_t^{\text{Bund}} \end{bmatrix} + \dots$$
$$+ \begin{bmatrix} a_{t-p}^{11} & a_{t-p}^{12} & a_{t-p}^{13} & a_{t-p}^{14} & a_{t-p}^{15} \\ a_{t-p}^{21} & a_{t-p}^{22} & a_{t-p}^{23} & a_{t-p}^{24} & a_{t-p}^{25} \\ a_{t-p}^{31} & a_{t-p}^{32} & a_{t-p}^{33} & a_{t-p}^{34} & a_{t-p}^{35} \\ a_{t-p}^{41} & a_{t-p}^{42} & a_{t-p}^{43} & a_{t-p}^{44} & a_{t-p}^{45} \\ a_{t-p}^{51} & a_{t-p}^{52} & a_{t-p}^{53} & a_{t-p}^{54} & a_{t-p}^{55} \end{bmatrix} \cdot \begin{bmatrix} R_t^{\text{E-mini S\&P}} \\ R_t^{\text{10YR T-Note}} \\ R_t^{\text{USD/EUR}} \\ R_t^{\text{DAX}} \\ R_t^{\text{Bund}} \end{bmatrix} \tag{6}$$

We select lag length p according to the Hannan-Quinn and Schwarz information criteria. Table 2 shows the significant coefficients for return spillovers at the 5% significance level.[32]

« Insert Table 2 about here »

The sign of return spillover coefficients are generally in line with our expectations based on economic considerations and the results derived from the correlation analysis. We see

[32]To conserve space we do not report the full tables with the estimated coefficients here; however, they are shown in Table E1 in the Internet Appendix.

negative coefficients between bond and stock markets as well as between FX and stock markets. Intra-asset (i.e., DAX-E-mini S&P500 and Bund-T-Note) return spillovers have positive coefficients with the sole exception of inconsistent signs for the coefficients between FX and bond markets conditional on U.S. news from the beginning of the subprime and financial crisis onwards. The negative coefficients between FX and the Bund futures can be explained by the interest rate channel; if Bund futures prices increase, the interest rate declines, and thus the Euro depreciates in the short run, which leads the USD/EUR exchange rate to decrease.

For U.S. news we observe intra-asset lagged return spillover and feedback effects between markets of the same asset class before the crisis, i.e., between DAX and E-mini S&P500 futures, as well as Bund and 10-year Treasury note futures, but no inter-asset return spillovers. We further find return spillovers uni-directionally from the German and U.S. bond markets to the USD/EUR exchange market. During the subprime and financial crisis, the return spillover effects become intensified. Feedback effects do not exist only within the same asset markets across countries, but also across different asset markets, which implies that all markets become more sensitive to new information revealed in other markets.

During the European sovereign crisis, inter-asset spillovers and feedback effects are mitigated. Information flows from the USD/EUR to the two stock markets. Returns of all other markets spill over to E-mini S&P500. Generally the USD/EUR impacts the other markets only in the second crisis period. This is straightforward on economic grounds, as during the financial crisis the currency market was only affected indirectly on the basis of the general economic outlook and the approaching recession, whereas the European sovereign crisis posed a threat to the European Monetary Union and, ultimately, to the Euro.

During the pre-crisis period we mainly see spillovers and feedbacks between German

assets and some interactions with the USD/EUR market. In the subprime and financial crisis, we find additional feedback effects between DAX and E-mini S&P500 futures, and from the Bund to the Treasury note futures. However, during the European sovereign crisis and in line with the related economic reasoning, the increased significance of German news spurs information spillovers from DAX futures to E-mini S&P500 futures, and feedback effects between Bund and 10-year Treasury note futures.

Overall, German asset markets lead other markets when information regarding the German economy is revealed. Thus, we can observe that market participants do act only partially on the news itself, but also on the effect this news has in the closely related assets. This result can only be uncovered by slicing the one-minute interval into shorter (i.e., five-second) observation periods after the release of announcements. It yields the following insight on the information transmission across markets conditional on macroeconomic news: trading is sensitive to both new information and the immediate impact of it, with the resulting structure being a dynamic network of transmissions from news-related and (observed) trading-related information.

The results above confirm our economic hypothesis that asset prices react more sensitively to news released in the market where a crisis originated. Therefore, in a further step we test whether and how information is transmitted among asset prices and markets. We apply bivariate Granger-causality tests for each pair of markets:

$$\begin{aligned} R_{1,t} &= a_0 + \sum_{p}^{P} a_p R_{1,t-p} + \sum_{p}^{P} b_p R_{2,t-p} + \varepsilon_{1,t} \\ R_{2,t} &= a_0 + \sum_{p}^{P} a_p R_{2,t-p} + \sum_{p}^{P} b_p R_{1,t-p} + \varepsilon_{2,t}, \end{aligned} \tag{7}$$

where we hypothesize for the null that $H_0 : b_1 = ... = b_p = 0$, and we estimate a heteroskedasticity-consistent covariance matrix of coefficients.

Figure 5 illustrates the results of the Granger causality tests. The interaction among the assets in response to U.S. news increases during the global financial crisis. Afterwards, it returns to a level similar to the pre-crisis period, i.e., the information sensitivity is temporary. This might be explained by a temporarily increased attention to the U.S. economy, where the crisis originated. For German macroeconomic news, where the interaction also intensifies during the first crisis, we cannot see a decline afterwards. In detail, there is no increase in the number of causal relationships regarding German assets, but of pairs including the USD/EUR exchange rate. This further strengthens our notion of the influence of the European crisis and the Euro currency risk associated with Bund and DAX Futures, as well as FX spot markets.

« Insert Figure 5 about here »

Like the implications derived from the correlation structure uncovered by the five-second interval, this change in the pricing of several assets has strong consequences for trading. Market participants can expect that the reactions of assets to macroeconomic news are strongly dependent on the state of the market where the news is released. Given these insights regarding the interconnectedness of asset returns, we also need to consider the transmissions in the second statistical moment. The discussion on volatility transmission follows in the next sub-section.

5.2.2 Information Transmission in Volatility

We construct time series of five-second volatility processes, approximated by five-second absolute returns $|R_t|$, in order to detect conditional volatility co-movements and spillovers. We again select news that significantly impacts at least two markets during the first hour after the release of the announcement. As the volatility series exhibit long-memory process properties, we first filter the volatility series of all three markets by using an

ARFIMA(1,d,1) model, $(1-\rho L)(1-L)^d|R_t| = (1-\theta L)\xi_t$.[33]

We model the filtered volatility series separately using OLS regressions for the following equation for each asset market:

$$\xi_t^i = c^i + \sum_{q=1}^{Q} \rho_q^i \xi_{t-q}^i + \sum_{j=1}^{4} \sum_{q=0}^{Q} \varphi_q^j \xi_{t-q}^j + \varepsilon_t^i, \tag{8}$$

where i represents the response market, and j is the impact market. We choose lag length Q according to the Hannan-Quinn and Schwarz information criterion.[34] The independent variables are comprised of lagged volatilities from their markets to account for persistence in the filtered volatility process, and the contemporaneous and lagged volatilities from the other four markets to capture volatility co-movements and spillovers among assets.

The ARFIMA filter cannot completely eliminate the long-memory autoregressive structure of the volatility on our very high-frequency basis, but it does substantially reduce its magnitude and persistence.[35] We use HAC-robust standard errors when we study the short-term co-movements and spillovers in the filtered volatility processes among the five markets. We report the significant parameters in Table 3.

« Insert Table 3 about here »

[33]Because of its periodic patterns (see Figure 1), we further filter the USD/EUR exchange rate volatility by using a flexible Fourier form (FFF), $\sum_{q=1}^{Q}(\varphi_q\ cos(\frac{q2\pi t}{720}) + \eta_q\ sin(\frac{q2\pi t}{720}))$ as in Andersen et al. (2003b). We also tested other ARFIMA(p,d,q) model specifications. However, we found that the selected filter is most suitable for whitening the volatility process.

[34]Note that in order to keep the number of lags consistent for all five OLS regressions, we choose the lag length based on a VAR model. We also test specific lag lengths for each single OLS regression model. However, the lag lengths vary only slightly and the results are qualitatively the same.

[35]Note that we use ξ_t from the ARFIMA process as the filtered volatility, and not the absolute values. This is because the absolute returns, $|R_t|$, already represent the volatility process. Thus, taking the absolute values of the residuals derived from the ARFIMA process would reflect the filtered volatility of the return volatility process. From the filtering process, we necessarily obtain positive and negative values; however, the negative deviations are not significantly different from zero.

We observe volatility co-movements and spillovers conditional on U.S. macroeconomic news across all five assets. Their (significant) occurrence and magnitude increases in the global financial crisis and remains above the pre-crisis level during the European sovereign crisis period. International volatility spillovers conditional on German news are rather rare in the pre-crisis period, but both inter- and intra-asset co-movements and spillovers intensify during the first crisis and further increase thereafter. This is in line with our findings from above and the related economic reasoning. We again see strong increases in the spillovers related to the USD/EUR exchange rate, expectedly triggered by the Euro currency crisis.[36]

In addition to the state-dependent reactions of returns to news, we conclude that the price dispersion is also affected by macroeconomic announcements, in particular by those where the crises originated. This can be attributed to the increased uncertainty in the markets and the increased sensitivity to surprises in phases of turmoil. The different origins of the crisis can again be clearly seen as drivers for changes in the way assets are affecting each other, which is a crucial insight in addition to what we can learn from single-asset analyses. Thus, studying the data in five-second intervals again enables insight into the mechanisms across asset markets in the presence of crises and conditional on macroeconomic news.

6 Conclusion

In this paper we analyze the asset price processes around macroeconomic announcements from Germany and the U.S. by distinguishing between "normal" and "crisis" times as well as local and global crises prevailing in the markets. We study the interactions among

[36] We used the same days without announcements that were used for the placebo test for the return spillovers (see Footnote 29). The indicative robustness checks reported in Table D2 show again much smaller interaction coefficients.

markets conditional on the release of macroeconomic announcements based on very high-frequency sampling intervals. Such intervals can mitigate the omitted variable bias and dual-causality problems.

The macroeconomic news impact on stock, bond, and foreign exchange markets varies over time, depending on the state of the economy. We document pronounced state-dependence in the way assets react to news from the respective locations: U.S. asset markets mainly pay attention to their domestic indicators, but during the European sovereign crisis they respond strongly to German news, too. In addition, the impacts of U.S. news are also larger in this period as economic uncertainty continues.

While in general the cumulative responses are greater than the instantaneous impact, pointing at gradual price discovery processes that differ in efficiency and structure, there are distinctive features that we can only discover by increasing the frequency to five-second intervals. That allows us to analyze the data in detail for interconnectedness and transmissions across assets. We find that some effects that we first observe in the subprime and financial crisis vanish, while others endure. This is related to the finding of effects arising with the European sovereign crisis that can be directly attributed to the economic condition of the region and shows up in the way information is transmitted between the assets in a dynamic way.

Most strikingly, we find that the significant spillover effects are a dynamic network of news-based and trading-based information transmissions. Details like a prevailing negative correlation between bonds and stocks in crisis times on very high frequency are in line with theory but in contradiction to lower frequency findings in the literature. The results have strong trading implications and lay the ground for further work on (ultra)-high frequency analysis of dynamic interactions of assets right after announcements, as apparently the pricing-in is both information-driven and regime-dependent.

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Table 1: Realized-Kernels Corrected Conditional Correlation Coefficients

	Pre-Crisis					**Subprime and Financial Crisis**					**European Sovereign Crisis**				
	E-mini S&P500 F.	10Y T-Note F.	USD/EUR	DAX F.	Bund F.	E-mini S&P500 F.	10Y T-Note F.	USD/EUR	DAX F.	Bund F.	E-mini S&P500 F.	10Y T-Note F.	USD/EUR	DAX F.	Bund F.
U.S. Announcements															
E-mini S&P500 F.	1					1					1				
10Y T-Note Futures	-0.064	1				-0.463	1				-0.537	1			
USD/EUR	0.017	0.491	1			-0.087	0.198	1			0.068	0.149	1		
DAX Futures	0.560	-0.107	-0.035	1		0.862	-0.453	-0.113	1		0.830	-0.593	0.066	1	
Bund Futures	-0.020	0.699	0.479	-0.073	1	-0.497	0.605	0.221	-0.542	1	-0.576	0.6706	0.097	-0.645	1
German Announcements															
E-mini S&P500 F.	1					1					1				
10Y T-Note Futures	-0.132	1				-0.328	1				-0.258	1			
USD/EUR	0.148	-0.250	1			0.197	-0.187	1			0.416	-0.231	1		
DAX Futures	0.164	-0.206	0.391	1		0.792	-0.239	0.232	1		0.611	-0.242	0.348	1	
Bund Futures	0.006	0.163	-0.303	-0.226	1	-0.220	0.348	-0.149	-0.290	1	-0.350	0.335	-0.363	-0.370	1

This table shows the realized-kernel corrected correlation coefficients conditional on macroeconomic announcements in the three subsamples: pre-crisis (January 2006 through July 2007), subprime and financial crisis (August 2007 through August 2009), and European sovereign crisis period (September 2009 through December 2011). The correlation coefficients are calculated using five-second returns within one minute after the release of U.S. and German announcements, respectively.

Table 2: VAR Model Results of Conditional Return Spillovers

			U.S. News			**German News**		
			Pre-Crisis	Subpr. and Fin. Crisis	Europ. Crisis	Pre-Crisis	Subpr. and Fin. Crisis	Europ. Crisis
E-mini S&P500 F.	→	10Y T-Note F.					-0.025	
10Y T-Note F.	→	E-mini S&P500 F.			-0.321	-0.119		
E-mini S&P500 F.	→	DAX Futures	0.159	0.236			0.230	
DAX Futures	→	E-mini S&P500 F.	0.194	0.122	0.204	0.089	0.168	0.124
E-mini S&P500 F.	→	Bund Futures						
Bund Futures	→	E-mini S&P500 F.		-0.263	-0.191	-0.060	-0.284	-0.150
E-mini S&P500 F.	→	USD/EUR		0.016	0.017	-0.121		
USD/EUR	→	E-mini S&P500 F.	0.059		0.211			0.160
10Y T-Note F.	→	DAX Futures			-0.316			
DAX Futures	→	10Y T-Note F.		-0.023				
10Y T-Note F.	→	Bund Futures				0.261		0.085
Bund Futures	→	10Y T-Note F.	0.079	0.053	0.065	0.122	0.176	0.092
10Y T-Note F.	→	USD/EUR	0.087		0.046			
USD/EUR	→	10Y T-Note F.		0.096	-0.052		-0.034	
DAX Futures	→	Bund Futures		-0.018				-0.039
Bund Futures	→	DAX Futures		-0.253		-0.695	-0.452	
DAX Futures	→	USD/EUR					0.058	0.058
USD/EUR	→	DAX Futures			0.107			
Bund Futures	→	USD/EUR	0.326	0.119	-0.142	-0.737	-0.529	-0.397
USD/EUR	→	Bund Futures					-0.069	-0.039

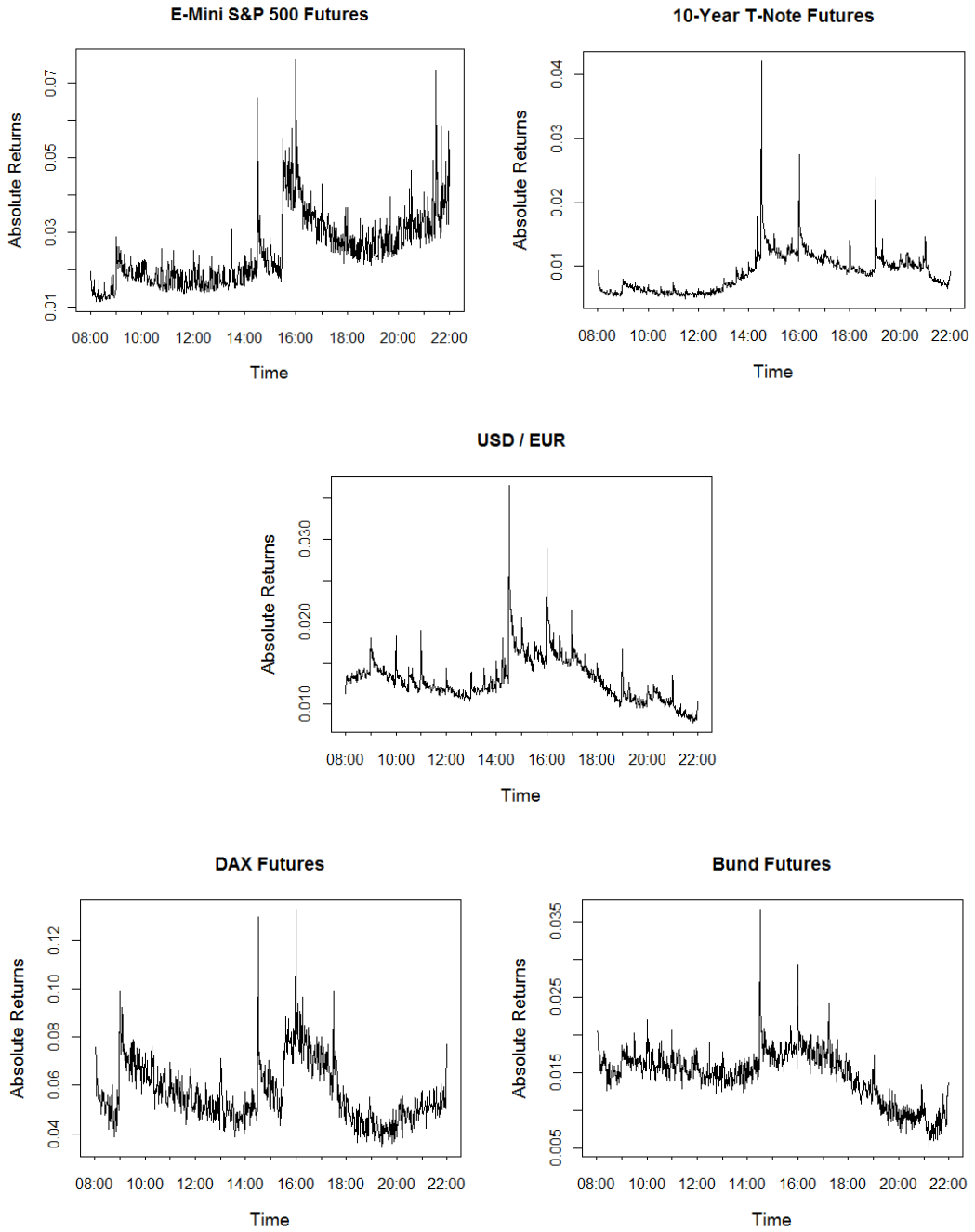
This table shows the VAR model estimation results for five-second returns of E-mini S&P500 futures, 10-year treasury note futures, USD/EUR exchange rate, DAX futures, and Bund futures, falling into the one-minute window after all U.S. news with a significant impact on at least two of the three markets, in the three subsamples: pre-crisis (January 2006 through July 2007), subprime and financial crisis period (August 2007 through August 2009), and European sovereign crisis period (September 2009 through December 2011). The lag length, selected according to the Hannan-Quinn and Schwarz criteria, is two. The coefficient from one market is the sum of coefficients significant at 95% confidence level.

Table 3: Conditional Five-Second Volatility Co-movements and Spillovers

	Pre-Crisis					Subprime and Financial Crisis					European Sovereign Crisis				
	E-mini S&P500 F.	10Y T-Note F.	USD/EUR	DAX F.	Bund F.	E-mini S&P500 F.	10Y T-Note F.	USD/EUR	DAX F.	Bund F.	E-mini S&P500 F.	10Y T-Note F.	USD/EUR	DAX F.	Bund F.
U.S. Announcements															
E-mini S&P500 F. (0)		0.036	0.041	0.006	0.001		0.042	0.031	0.138	0.004		0.035	0.032	0.399	0.022
10Y T-Note F. (0)	0.090		0.130		0.002	0.229		0.054	0.058	0.041	0.143		0.057	0.238	0.139
USD/EUR (0)	0.130	0.165				0.204	0.066		0.061	0.014	0.136	0.058		0.203	0.056
DAX Futures (0)	0.135				0.019	0.404	0.031	0.027		0.045	0.428	0.062	0.052		0.065
Bund Futures (0)	0.373	0.243		0.319		0.129	0.250	0.077	0.511		0.160	0.244	0.096	0.437	
E-mini S&P500 F. (L)		0.009	0.007	0.011	0.002		0.024	0.019	0.006	-0.002		0.008	0.018	0.095	-0.006
10Y T-Note F. (L)	0.070		0.046			0.085		0.019	-0.016	0.007			0.043	-0.090	0.022
USD/EUR (L)	0.046	0.045		-0.011	-0.003	0.043	0.057				0.010	0.025		0.032	0.046
DAX Futures (L)	0.169		-0.033		0.056	0.022		0.011		0.040	0.163		0.013		0.040
Bund Futures (L)	0.527		-0.203	0.863		-0.126	0.184	0.095	0.238		-0.028	0.091	0.107	0.169	
German Announcements															
E-mini S&P500 F. (0)		0.010					0.014	0.010	0.116	0.004		0.013	0.031	0.238	0.018
10Y T-Note F. (0)	0.032		0.027			0.087			0.019	0.023	0.072		0.040	0.086	0.088
USD/EUR (0)		0.021		0.005		0.048			0.035	0.006	0.101	0.023		0.195	0.047
DAX Futures (0)			0.026		0.003	0.261	0.007	0.016		0.014	0.221	0.014	0.055		0.038
Bund Futures (0)				0.024		0.056	0.060		0.100		0.029	0.024	0.023	0.065	
E-mini S&P500 F. (L)		0.020			0.001		0.006	0.007	0.007				0.011	0.018	
10Y T-Note F. (L)	0.026		0.014			0.030		0.016		0.010			0.014	0.028	0.018
USD/EUR (L)		0.008			-0.001	0.030	0.015		0.015	0.007	0.020			0.028	0.024
DAX Futures (L)	0.075				0.017	0.040	0.006	0.015		0.015	0.016	0.007	0.024		0.007
Bund Futures (L)			0.062	0.122			0.032		0.102			0.005	0.009	0.008	

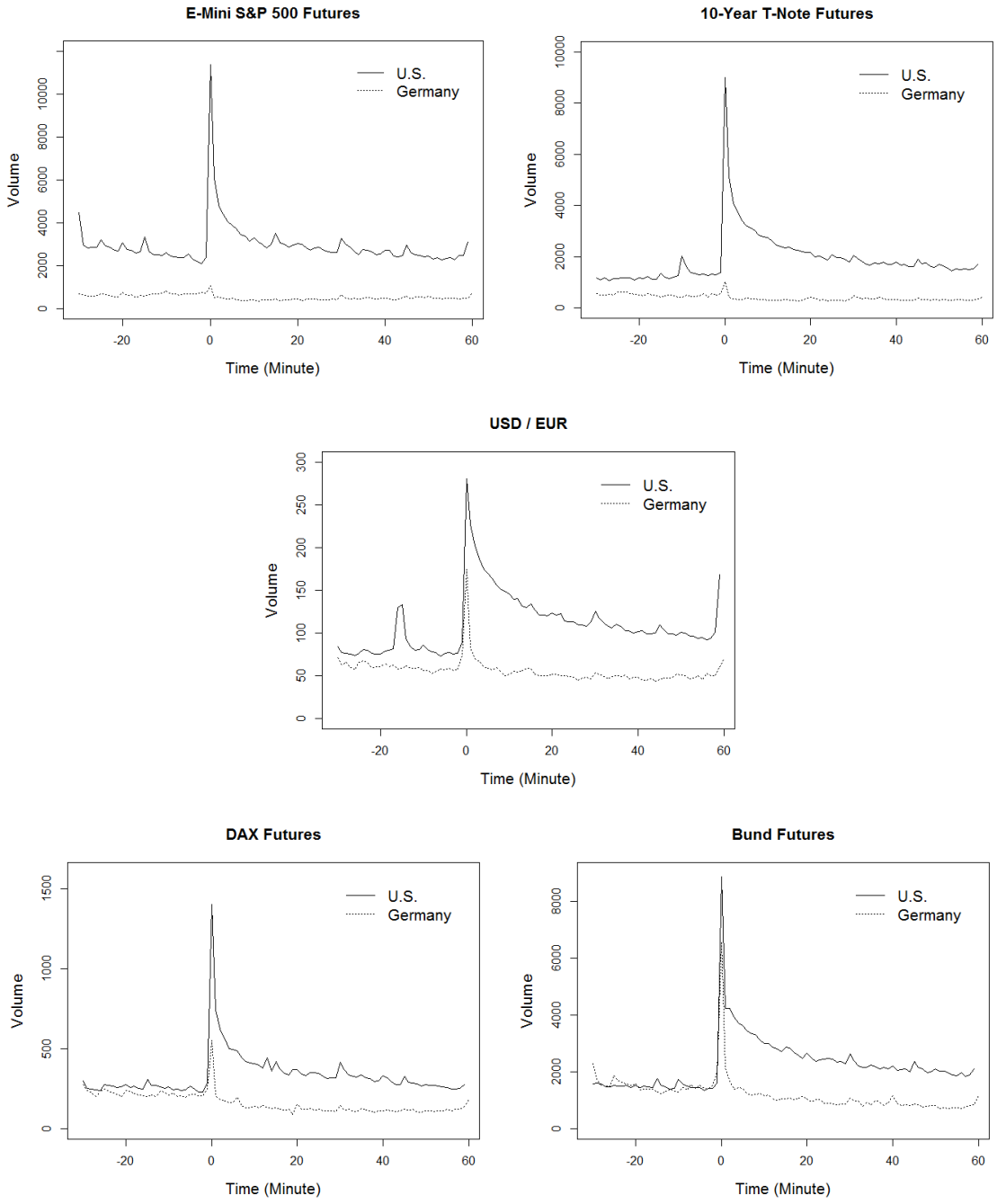
This table shows the volatility co-movements and spillovers among the E-mini S&P500 futures, 10-year Treasury note futures, USD/EUR exchange rate, DAX futures, and Bund futures markets within one hour after macroeconomic announcement releases for five-second sampling intervals. The volatility processes are first filtered using an ARFIMA(1,d,1) model, $(1-\rho L)(1-L)^d|R_t| = (1-\theta L)\xi_t$, while the USD/EUR volatility is additionally filtered by means of a flexible Fourier form to capture the periodic patterns. We then derive the co-movement and spillover estimates from OLS estimates with HAC-robust standard errors. We estimate the following model specifications for five-second filtered volatility processes within one hour after the announcements: $\xi_t^i = c^i + \sum_{q=1}^{Q} \varphi_q^i \xi_{t-q}^i + \sum_{j=1}^{4} \sum_{q=0}^{Q} \varphi_q^j \xi_{t-q}^j + \varepsilon_t^i$. The independent variables are comprised of lagged volatilities (L) from their own markets, and the contemporaneous (0) and lagged volatilities (L) from the other four markets. Given space constraints, the coefficient of lagged variables from one market is the sum of coefficients significant at the 95% confidence level. The coefficients of contemporaneous effects are also significant at the 95% confidence level.

Figure 1: Average Intraday One-Minute Absolute Asset Returns



This figure plots the average intraday one-minute absolute returns from 8:00 CET (2:00 EST) to 22:00 CET (16:00 EST). The spikes on the figures represent the following important daily events: 9:00am CET (1:00 EST): German and London stock markets open; 14:30 CET (8:30 EST): U.S. macroeconomic announcements are released; 15:30 CET (9:30 EST): U.S. stock market opens; 16:00 CET (10:00 EST), U.S. macroeconomic announcements are released; and 17:30 CET (11:30 EST): German stock market closes.

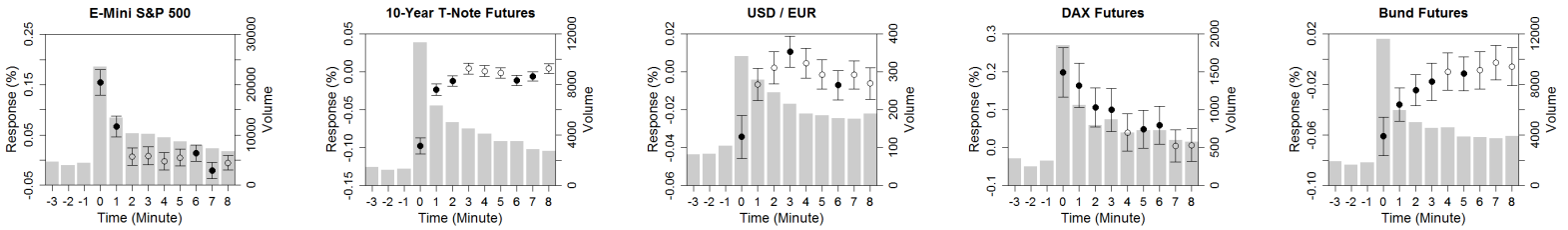
Figure 2: Asset Average One-Minute Trading Volumes around Announcements



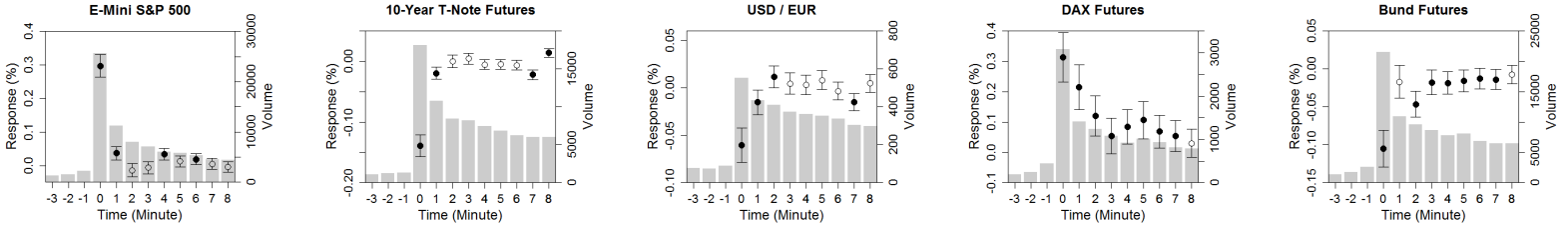
The figures show one-minute trading volume (in contracts for E-mini S&P500, 10-Year T-Note, DAX and Bund futures, in millions of Euro for the USD/EUR exchange rate) half an hour before and one hour after macroeconomic announcements (averaged through announcements from the U.S. and Germany, respectively).

Figure 3: Asset Return and Trading Volume Responses to Macroeconomic News (Full Sample)

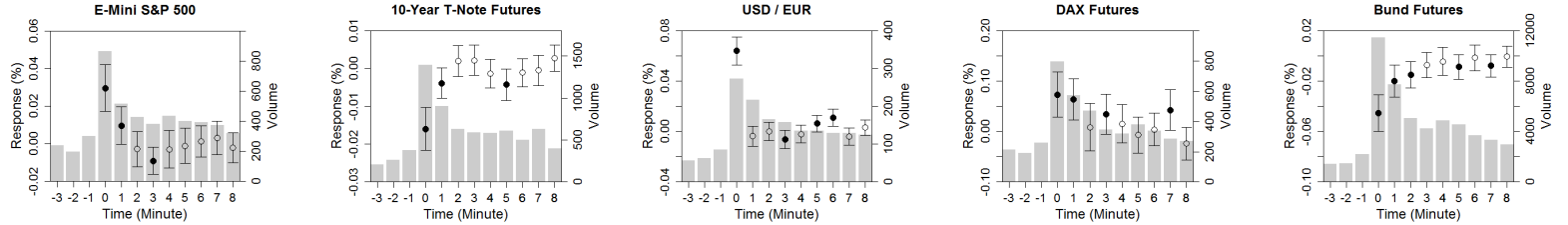
U.S. Manufacturing ISM



U.S. Non-Farm Payroll



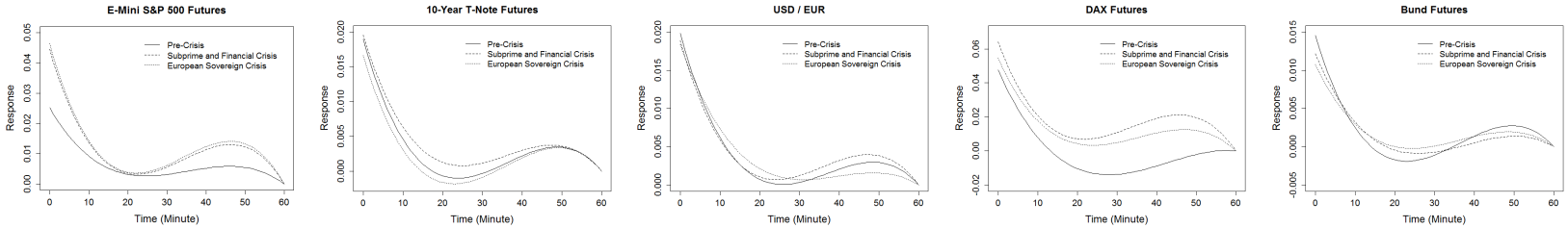
German IFO Business Climate



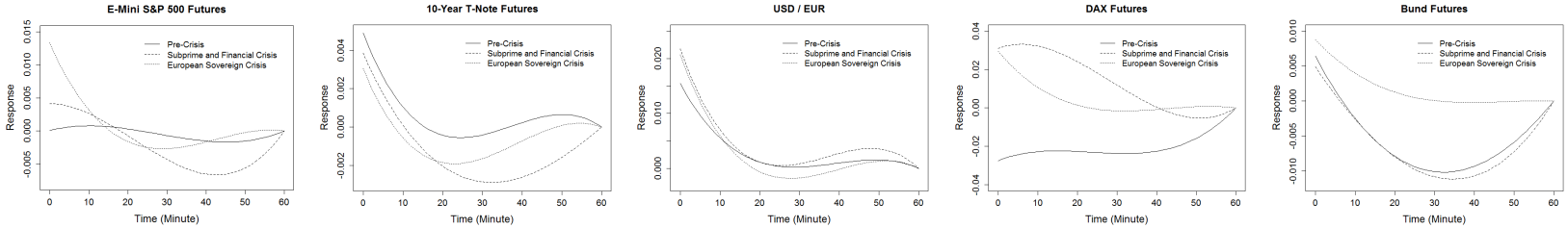
The figures plot the return response with a 95% confidence interval to selected U.S. and German macroeconomic news within eight minutes after release, and the average trading volumes within three minutes before and eight minutes after release. The solid circles represent significant responses at the 95% confidence level.

Figure 4: One-Hour Average Polynomial Response of Volatility)

Panel A: U.S. Macroeconomic Announcements

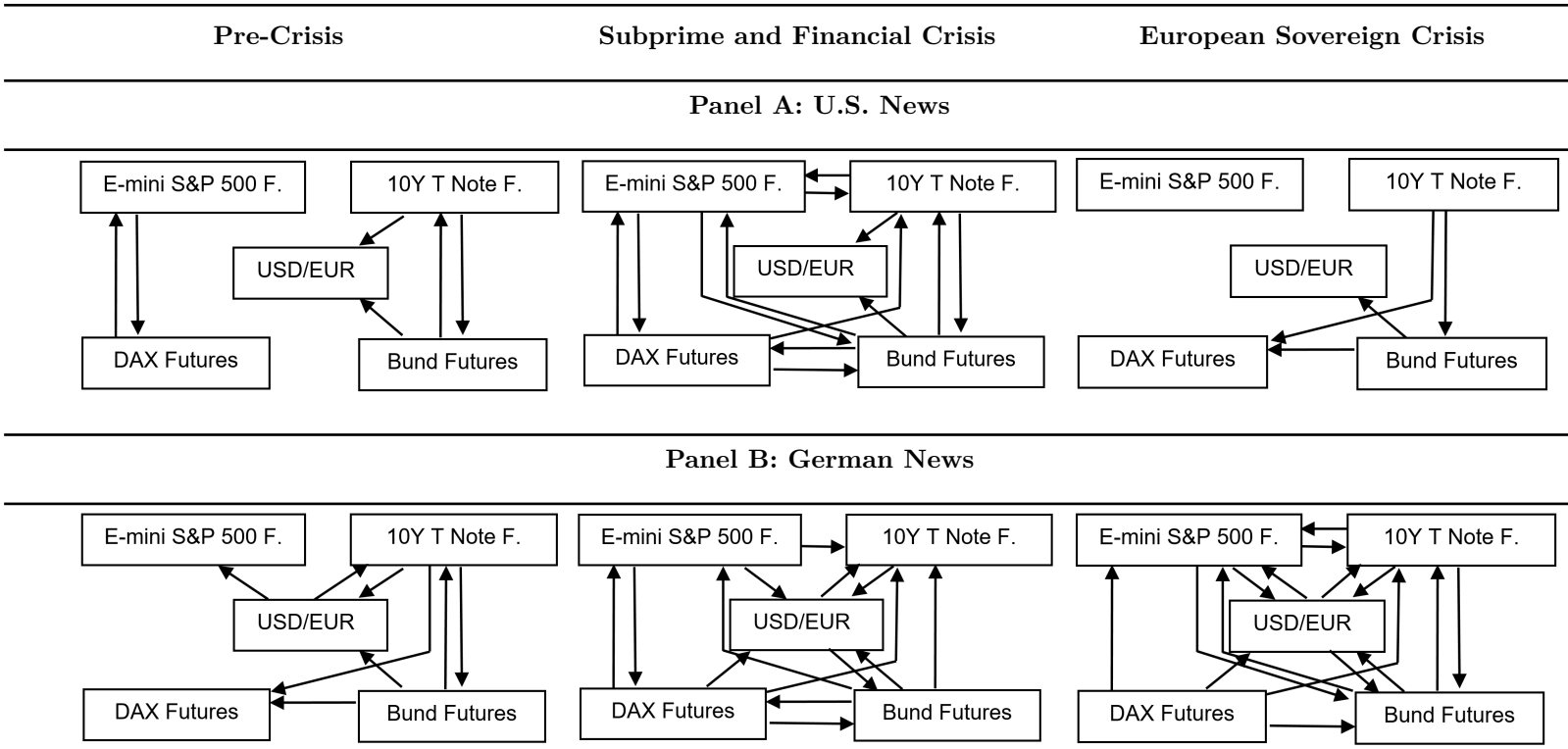


Panel B: German Macroeconomic Announcements



Panels A and B show the polynomial response of volatilities averaged through important macroeconomic announcements in the three subsamples: pre-crisis (January 2006 through July 2007), subprime and financial crisis period (August 2007 through August 2009), and European sovereign crisis period (September 2009 through December 2011).

Figure 5: Heteroskedasticity-Consistent Granger Causality between Each Pair of Asset Markets



These figures show the heteroskedasticity-consistent (HC) bivariate Granger causality of five-second returns falling into one-minute windows after all news that significantly impacts at least two of the five markets. Based on the F-statistic, the arrow means the Granger causality exists at the 95% confidence level.

Internet Appendix for:

Financial Crises, Price Discovery, and Information Transmission:

A High-Frequency Perspective

Roland Füss* Ferdinand Mager† Michael Stein‡ Lu Zhao§

Abstract

This paper examines the price discovery processes before and during the 2007-09 subprime and financial crisis, as well as the subsequent European sovereign crisis, for the stock, bond, and U.S. dollar/euro FX markets in the U.S. and Germany in a high-frequency setting. Based on five-second intervals, we analyze how asset prices interact and incorporate information conditional on macroeconomic announcements and news surprises from the U.S. and Germany. Our results show strong state-dependent return and volatility patterns across assets and markets. Moreover, we document significant co-movement and spillover effects that result from a dynamic network of news-based and trading-based information transmissions. We find that some effects we first identify during the financial and subprime crisis vanish, but others persist.

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Content

Appendix A

Table A1: Macroeconomic Announcements

Announcement	# of Observations	Announcement Time	Frequency
U.S. Announcements			
Economic Activity			
Durable Goods Orders	72	14:30	Monthly
GDP	72	14:30	Quarterly
Non-Farm Payroll	72	14:30	Monthly
Trade Balance	72	14:30	Monthly
Price			
Consumer Price Index	72	14:30	Monthly
Producer Price Index	72	14:30	Monthly
Labor Market			
Initial Unemployment Claim	313	14:30	Weekly
Housing Market			
Housing Starts	72	14:30	Monthly
New Home Sales	72	16:00	Monthly
Business Climate			
Consumer Confidence Index	72	16:00	Monthly
Manufacturing ISM	72	16:00	Monthly
Non-Manufacturing ISM	72	16:00	Monthly
German Announcements			
Economic Activity			
GDP	23	08:00	Quarterly
Industrial Production	61	12:00	Monthly
Price			
Consumer Price Index	65	Varies	Monthly
Producer Price Index	63	08:00	Monthly
Business Climate			
IFO Business Climate	72	10:00	Monthly
ZEW Survey	71	11:00	Monthly

All timestamps are Central European Time (CET); U.S. GDP includes advanced, preliminary, and final GDP announcements, each is announced quarterly. We pool them into one variable with thirty-six observations. Note that some forecasting data for Germany is missing.

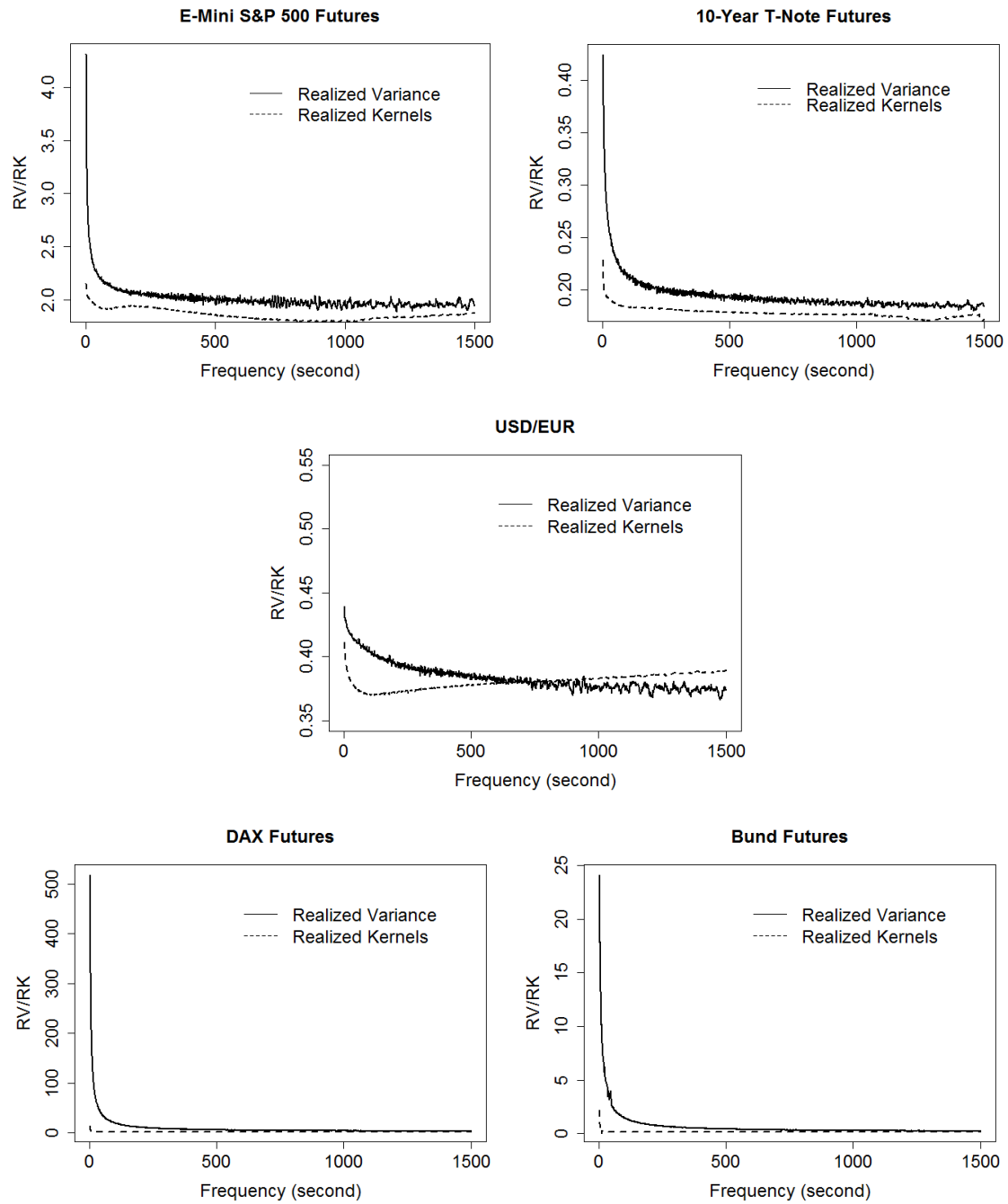
Table A2: Crisis Events from August 2007 through December 2011

Time		**Crisis Events**
August 13, 2007	16:36	Goldman and investors to put $3 billion into fund after 30% loss in one week.
August 15, 2007	15:46	Countrywide Financial "risks bankruptcy".
November 08, 2007	08:20	Morgan Stanley takes $3.7 billion hit.
December 12, 2007	15:00	The Fed announces the creation of a Term Auction Facility (TAF).
December 14, 2007	11:17	Citigroup rescues SIVs with $58 billion debt bailout.
December 27, 2007	15:00	Subprime bank losses reach $97 billion, led by Citigroup.
February 26, 2008	16:30	Banks cut more than 28,000 jobs as subprime losses mount .
May 14, 2008	10:56	Fitch: Subprime losses by global banks total U.S. $400 billion.
June 12, 2008	14:41	KeyCorp to raise $1.5 billion, cut dividend by 50%.
June 25, 2008	15:14	Countrywide Financial faces Illinois suit over mortgage loans.
October 03, 2008	16:06	Dutch part of Fortis is nationalized.
October 15, 2008	11:43	Iceland cuts key interest rate to 0.12 from 15.5%.
October 15, 2008	15:04	European central banks pump $250 billion in liquidity.
October 20, 2008	16:40	Sweden launches financial rescue package.
November 13, 2008	15:29	Ranieri's Franklin Bank files for Chapter 7 bankruptcy.
December 16, 2008	15:08	AIG sells $39.3 billion in assets to NY Fed's fund.
January 14, 2009	14:46	European debt crisis evident in Greek mire.
January 16, 2009	14:30	Treasury Dep., FED and FDIC finalize their guarantee agreement with Citigroup.
February 5, 2009	13:00	The Bank of England reduced interest rates to a record low of 1% from 1.5%.
March 25, 2009	10:28	The IMF and other lenders agreed in principle to provide Romania €20bn in aid.
May 7, 2009	13:00	The Bank of England announced that it will inject £50bn into the UK economy.
May 8, 2009	15:19	Wells Fargo plans to raise $7.5bn from selling new shares.
August 6, 2009	13:00	The Bank of England decided to pump another £50bn into the economy.
July 13, 2010	11:17	Greece returns to bond markets for the first time since bailout.
July 28, 2010	15:06	ECB announces stricter rules on bank collateral.
November 24, 2010	15:02	Ireland's government outlines €15bn in spending cuts and tax hikes.
January 12, 2011	11:48	Portugal will sell 4- and 10-year bonds for up to €1.25bn.
February 22, 2011	15:00	EC, ECB, and IMF made statement on Greece.
March 3, 2011	14:31	ECB announces details of refinancing operations.
June 9, 2011	14:33	ECB announces details of refinancing operations.
August 4, 2011	14:30	ECB announces details of refinancing operations.
August 12, 2011	10:52	EC, ECB, and IMF made statements on Portugal.
September 15, 2011	15:00	ECB announces additional US dollar liquidity-providing operations.
September 29, 2011	15:09	The Bundestag approved expanded EU bailout fund.
October 6, 2011	14:37	ECB announces details of refinancing operations.
October 6, 2011	14:46	ECB announces second covered bond purchase program.
November 3, 2011	13:46	ECB lowers interest rates by 25 basis points.
December 8, 2011	14:33	ECB announces measures to support bank lending and money market activity.

This table shows overlapping crisis events within the time windows we constructed. All events are from the Federal Reserve Bank of St. Louis, Bloomberg, and the European Central Bank. The timestamps of the events are matched from the MNI database. It is important to note that only those events that coincide with announcements are listed. For example, the Lehman Brothers collapse took place when no macroeconomic news is released.

Appendix B

Figure B1: Signature Plots of Realized Variance and Realized Kernels



The signature plots show daily average realized kernels and realized variances of E-mini S&P500 futures, 10-year Treasury note futures, USD/EUR exchange rates, DAX futures, and Bund futures, calculated at various frequencies from one second to 1,500 seconds. The solid lines are realized variances, and the dashed lines are realized kernels.

Appendix C

Table C1: Full Sample Response of Asset Returns

Panel 1: Response of Asset Returns to U.S. News

	E-mini S&P500 F.		10-Year T-Note F.		USD/EUR		DAX Futures		Bund Futures	
	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response
Economic Activity										
Durable Goods Orders	0.0736***		-0.0350***	-0.0438**	-0.0194***		0.1088***	0.2329*	-0.0259***	-0.0482*
	(0.0104)		(0.0050)	(0-1)	(0.0051)		(0.0264)	(0-3)	(0.0057)	(0-2)
GDP	0.1080***		-0.0373***	-0.0499***	-0.0348***	-0.0470***	0.1485***	0.3454*	-0.0368***	-0.0762***
	(0.0108)		(0.0045)	(0-1)	(0.0060)	(0-1)	(0.0294)	(0-3)	(0.0072)	(0-2)
Non-Farm Payroll	0.2970***	0.3337***	-0.1388***	-0.1581***	-0.0604***	-0.0756*	0.3130***	1.0162*	-0.1047***	
	(0.0172)	(0-1)	(0.0092)	(0-1)	(0.0093)	(0-1)	(0.0414)	(0-7)	(0.0123)	
Trade Balance	0.0294***		-0.0125***	-0.0225***	-0.0129***		0.0344		-0.0065	
	(0.0077)		(0.0034)	(0-1)	(0.0049)		(0.0215)		(0.0045)	
Price										
Consumer Price Index	-0.1069***		-0.0432***	-0.0533***	-0.0264***		-0.1242***		-0.0294***	-0.0578***
	(0.0114)		(0.0059)	(0-1)	(0.0053)		(0.0359)		(0.0073)	(0-1)
Producer Price Index	-0.0434***		-0.0223		-0.0230***		-0.0337		-0.0196***	-0.0383*
	(0.0117)		(0.0050)		(0.0052)		(0.0301)		(0.0071)	(0-2)
Labor Market										
Initial Unemployment Claims	-0.0800***	-0.0875**	0.0305***	0.0424***	0.0068***		-0.0981***	-0.2434*	0.0234***	0.0555**
	(0.0049)	(0-1)	(0.0020)	(0-2)	(0.0021)		(0.0136)	(0-4)	(0.0028)	(0-3)
Housing Market										
Housing Starts	0.0448***	0.0554*	-0.0340***		-0.0155***		0.0862***	0.1858*	-0.0292***	-0.0399*
	(0.0103)	(0-1)	(0.0043)		(0.0051)		(0.0305)	(0-2)	(0.0055)	(0-1)
New Home Sales	0.0878***		-0.0409***	-0.0478**	-0.0215***	-0.0296**	0.1026***	0.2491***	-0.0290***	-0.0440***
	(0.0099)		(0.0038)	(0-1)	(0.0047)	(0-1)	(0.0263)	(0-2)	(0.0054)	(0-1)
Business Climate										
Consumer Confidence Index	0.1548***	0.1873*	-0.0409***	-0.0528***	0.0113**	0.0185*	0.2082***	0.5163**	-0.0400***	-0.0724*
	(0.0109)	(0-2)	(0.0039)	(0-1)	(0.0054)	(0-1)	(0.0310)	(0-3)	(0.0062)	(0-2)
Manufacturing ISM	0.1545***	0.2211***	-0.0974***	-0.1323***	-0.0342***		0.1994***	0.5715***	-0.0608***	-0.1385**
	(0.0127)	(0-1)	(0.0054)	(0-2)	(0.0058)		(0.0333)	(0-3)	(0.0077)	(0-3)
Non-Manufacturing ISM	0.0975***		-0.0557***		-0.0248***		0.1571***	0.2061*	-0.0403***	-0.0863**
	(0.0097)		(0.0041)		(0.0049)		(0.0284)	(0-1)	(0.0082)	(0-2)

Table C1 continues on the next page.

Table C1: Full Sample Response of Asset Returns

Table C1 continued.

Panel 2: Response of Asset Returns to German News

	E-mini S&P500 F.		10-Year T-Note F.		USD/EUR		DAX Futures		Bund Futures	
	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response
Economic Activity										
GDP	NA	-0.0098**	NA		NA	0.0120***	NA		NA	
		-1				-1				
Industrial Production	0.0009		-0.0034*		0.0168***		0.0349***	0.0642**	-0.0084	-0.0102**
	(0.0031)		(0.0018)		(0.0032)		(0.0144)	(0-1)	(0.0055)	-2
Price										
Consumer Price Index	-0.0029***		0.0007		-0.0017		0.0189	0.0274**	-0.0031	
	(0.0044)		(0.0026)		(0.0031)		(0.0199)	-1	(0.0043)	
Producer Price Index	NA	0.0085*	NA		NA		NA		NA	0.0140**
		-1								-2
Business Climate										
IFO Business Climate	0.0297***	0.0395*	-0.0160***	-0.0198*	0.0642***		0.0733***	0.1376***	-0.0453***	-0.0799***
	(0.0064)	(0-1)	(0.0029)	(0-1)	(0.0057)		(0.0229)	(0-1)	(0.0074)	(0-2)
ZEW Survey	0.0389		-0.0103*		0.0685***		0.0937***	0.1498***	-0.0389***	-0.0780***
	(0.0068)		(0.0028)		(0.0054)		(0.0214)	(0-1)	(0.0056)	(0-2)

This table shows the return responses of the E-mini S&P500 and 10-Year T-Note futures, the USD/EUR exchange rate, as well as the DAX and Bund futures to the selected macroeconomic news in the full sample. The returns are in percentages. ***, **, and * denote significance at the 99%, 95%, and 90% confidence levels, respectively. Standard errors are in parentheses below the corresponding *contemporaneous* response coefficients. The numbers in brackets below the *cumulative* response coefficients are the lag lengths used to calculate the *cumulative* response. NA denotes missing values for returns at the time of news releases according to Table A1, so that we only report *cumulative* coefficients.

Table C2: Response of Asset Returns to Macroeconomic News

	Pre-Crisis Period		Subprime and Financial Crisis Period		European Sovereign Crisis Period	
Panel 1: Response of E-mini S&P500 Futures Returns						
	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response
U.S. News						
Economic Activity						
Durable Goods Orders	0.0206**		0.1192***		0.1495***	
	(0.0103)		(0.0204)		(0.0235)	
GDP	0.0531***		0.1154***	0.1405*	0.1561***	
	(0.0112)		(0.0191)	[0-1]	(0.0184)	
Non-Farm Payroll	-0.0575***	-0.0878*	0.2817***		0.4744***	0.5726***
	(0.0204)	[0-1]	(0.0266)		(0.0283)	[0-1]
Trade Balance	0.1410*		0.0241***		0.1524***	
	(0.0736)		(0.0076)		(0.0403)	
Price						
Consumer Price Index	-0.1242***	-0.1436*	-0.1079***		-0.0982***	
	(0.0187)	[0-1]	(0.0184)		(0.0204)	
Producer Price Index	-0.0364***		-0.0447**		-0.0137	
	(0.0096)		(0.0206)		(0.0218)	
Labor Market						
Initial Unemployment Claims	-0.0041		-0.0698***	-0.1052*	-0.1381***	
	(0.0059)		(0.0088)	[0-2]	(0.0075)	
Housing Market						
Housing Starts	0.0038		0.1094***	0.1453**	0.1140***	
	(0.0076)		(0.0252)	[0-1]	(0.0275)	
New Home Sales	0.0449***		0.2083***		0.1226***	
	(0.0085)		(0.0343)		(0.0137)	
Business Climate						
Consumer Confidence Index	0.0867***		0.1240***		0.2203***	0.2513**
	(0.0143)		(0.0177)		(0.0190)	[0-1]
Manufacturing ISM	0.1271***	0.1844***	0.1482***	0.2016**	0.1802***	0.2509***
	(0.0183)	[0-1]	(0.0229)	[0-1]	(0.0195)	[0-1]
Non-Manufacturing ISM	0.0416***		0.1380***		0.1221***	0.1609**
	(0.0092)		(0.0153)		(0.0230)	[0-1]
German News						
Economic Activity						
GDP	NA		NA		NA	
Industrial Production	0.0080		0.0200		0.0215***	0.0386***
	(0.0060)		(0.0071)		(0.0064)	[0-1]
Price						
Consumer Price Index	-0.0051		-0.0031		0.0035	
	(0.0034)		(0.0107)		(0.0070)	
Producer Price Index	NA		NA		NA	0.0122*
						[1]
Business Climate						
IFO Business Climate	0.0066		0.0342***		0.0446***	0.0572*
	(0.0057)		(0.0130)		(0.0102)	[0-1]
ZEW Survey	0.0123**		0.0318***		0.0939***	
	(0.0048)		(0.0110)		(0.0151)	

Table C2 continues on the next page.

Table C2: Response of Asset Returns to Macroeconomic News

Table C2 continued.

Panel 2: Response of 10-Y T-Note Futures Returns						
	Pre-Crisis Period		Subprime and Financial Crisis Period		European Sovereign Crisis Period	
	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response
U.S. News						
Economic Activity						
Durable Goods Orders	-0.0291***	-0.0443*	-0.0362***		-0.0603***	
	(0.0074)	[0-2]	(0.0096)		(0.0085)	
GDP	-0.0471***	-0.0639***	-0.0151**		-0.0567***	
	(0.0061)	[0-1]	(0.0076)		(0.0072)	
Non-Farm Payroll	-0.0827***		-0.0681***		-0.2608***	-0.2808***
	(0.0172)		(0.0139)		(0.0130)	[0-1]
Trade Balance	-0.0974***	-0.1745***	-0.0116***	-0.0189**	-0.0713***	
	(0.0368)	[0-1]	(0.0038)	[0-1]	(0.0168)	
Price						
Consumer Price Index	-0.0666***		-0.0327***		-0.0537***	
	(0.0136)		(0.0081)		(0.0102)	
Producer Price Index	-0.0067		-0.0258***		-0.0487***	
	(0.0065)		(0.0081)		(0.0095)	
Labor Market						
Initial Unemployment Claims	0.0224***	0.0375*	0.0260***		0.0442***	0.0570*
	(0.0039)	[0-2]	(0.0032)		(0.0029)	[0-2]
Housing Market						
Housing Starts	-0.0292***	-0.0341*	-0.0279***		-0.0531***	
	(0.0055)	[0-1]	(0.0071)		(0.0115)	
New Home Sales	-0.0403***	-0.0468*	-0.0637***		-0.0259***	
	(0.0038)	[0-1]	(0.0103)		(0.0063)	
Business Climate						
Consumer Confidence Index	-0.0770***	-0.1029***	-0.0286***		-0.0496***	-0.0602**
	(0.0101)	[0-1]	(0.0055)		(0.0058)	[0-1]
Manufacturing ISM	-0.1053***		-0.0903***	-0.1142***	-0.1026***	
	(0.0096)		(0.0107)	[0-1]	(0.0071)	
Non-Manufacturing ISM	-0.0603***		-0.0583***		-0.0441***	
	(0.0058)		(0.0073)		(0.0069)	
German News						
Economic Activity						
GDP	NA		NA		NA	
Industrial Production	-0.0031		-0.0022		-0.0088***	
	(0.0027)		(0.0024)		(0.0030)	
Price						
Consumer Price Index	0.0006		-0.0055		0.0092	
	(0.0032)		(0.0047)		(0.0039)	
Producer Price Index	NA		NA		NA	
Business Climate						
IFO Business Climate	-0.0184***		-0.0121**		-0.0175***	
	(0.0050)		(0.0056)		(0.0036)	
ZEW Survey	-0.0131***		-0.0041	-0.0048*	-0.0158***	
	(0.0033)		(0.0045)	[1]	(0.0061)	

Table C2 continues on the next page.

Table C2: Response of Asset Returns to Macroeconomic News

Table C2 continued.

	Pre-Crisis Period		Subprime and Financial Crisis Period		European Sovereign Crisis Period	
	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response
Panel 3: Response of USD/EUR Returns						
U.S. News						
Economic Activity						
Durable Goods Orders	-0.0403***		-0.0082		0.0176*	
	(0.0076)		(0.0094)		(0.0106)	
GDP	-0.0948***		-0.0128	-0.0133*	0.0028	
	(0.0087)		(0.0087)	[1]	(0.0102)	
Non-Farm Payroll	-0.2062***		-0.0219	-0.0489***	-0.0502***	
	(0.0178)		(0.0137)	[1]	(0.0150)	
Trade Balance	-0.4591***		-0.0091**		-0.0186	
	(0.0604)		(0.0043)		(0.0260)	
Price						
Consumer Price Index	-0.0725***		-0.0108		-0.0457***	
	(0.0126)		(0.0067)		(0.0113)	
Producer Price Index	-0.0189***		-0.0185**		-0.0096	
	(0.0066)		(0.0075)		(0.0106)	
Labor Market						
Initial Unemployment Claims	0.0273***		0.0067**		-0.0093**	
	(0.0042)		(0.0027)		(0.0039)	
Housing Market						
Housing Starts	-0.0224***		-0.0066		-0.0065	
	(0.0069)		(0.0102)		(0.0124)	
New Home Sales	-0.0297***	-0.0404***	-0.0120		-0.0071	
	(0.0048)	[0-1]	(0.0143)		(0.0082)	
Business Climate						
Consumer Confidence Index	-0.0829***		0.0214***	0.0398***	0.0298***	
	(0.0121)		(0.0075)	[0-1]	(0.0082)	
Manufacturing ISM	-0.0905***	-0.1062**	-0.0248**		-0.0052	
	(0.0076)	[0-1]	(0.0110)		(0.0083)	
Non-Manufacturing ISM	-0.0635***		-0.0049	-0.0141**	-0.0034	
	(0.0075)		(0.0081)	[3]	(0.0093)	
German News						
Economic Activity						
GDP	NA	0.0184*	NA	0.0099**	NA	
		[1]		[1]		
Industrial Production	0.0082***		0.0151***		0.0280***	
	(0.0027)		(0.0045)		(0.0064)	
Price						
Consumer Price Index	-0.0028		-0.0008		-0.0041	
	(0.0038)		(0.0047)		(0.0063)	
Producer Price Index	NA		NA		NA	
Business Climate						
IFO Business Climate	0.0412***		0.0838***		0.0611***	
	(0.0086)		(0.0109)		(0.0085)	
ZEW Survey	0.0534***		0.0621***		0.1090***	
	(0.0068)		(0.0078)		(0.0124)	

Table C2 continues on the next page.

Table C2: Response of Asset Returns to Macroeconomic News

Table C2 continued.

Panel 4: Response of DAX Futures Returns						
	Pre-Crisis Period		Subprime and Financial Crisis Period		European Sovereign Crisis Period	
	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response
U.S. News						
Economic Activity						
Durable Goods Orders	0.0439		0.1749***	0.3510**	0.1964***	
	(0.0472)		(0.0441)	[0-2]	(0.0264)	
GDP	0.0816*		0.1682***	0.2643**	0.2107***	
	(0.0484)		(0.0498)	[0-1]	(0.0223)	
Non-Farm Payroll	-0.1179		0.3093***	0.4535**	0.5344***	0.6034***
	(0.0852)		(0.0562)	[0-1]	(0.0329)	[0-1]
Trade Balance	0.2896		0.0277		0.1267***	
	(0.2776)		(0.0217)		(0.0284)	
Price						
Consumer Price Index	-0.1723*		-0.1226**		-0.0864***	
	(0.0921)		(0.0513)		(0.0222)	
Producer Price Index	-0.0657		-0.0018		-0.0372	
	(0.0656)		(0.0421)		(0.0245)	
Labor Market						
Initial Unemployment Claims	-0.0594*		-0.0876***	-0.2002***	-0.1315***	
	(0.0331)		(0.0218)	[0-2]	(0.0086)	
Housing Market						
Housing Starts	0.0359		0.2233***	0.3694***	0.1494***	
	(0.0355)		(0.0744)	[0-1]	(0.0302)	
New Home Sales	0.0413	0.0912**	0.1756**	0.4702*	0.1513***	
	(0.0309)	[2]	(0.0862)	[0-2]	(0.0193)	
Business Climate						
Consumer Confidence Index	0.1044		0.1864***	0.4564*	0.2763***	
	(0.0765)		(0.0453)	[0-3]	(0.0232)	
Manufacturing ISM	0.1167***	0.2206**	0.1805***	0.4832**	0.2100***	0.2534***
	(0.0324)	[0-1]	(0.0523)	[0-3]	(0.0239)	[0-1]
Non-Manufacturing ISM	0.0918		0.1725***	0.2588**	0.1807***	
	(0.0585)		(0.0392)	[0-1]	(0.0239)	
German News						
Economic Activity						
GDP	NA		NA		NA	0.0306**
						[1]
Industrial Production	0.0369*		0.0410*		0.0532***	0.0794**
	(0.0216)		(0.0246)		(0.0132)	[0-1]
Price						
Consumer Price Index	0.1026*		-0.0141		0.0068	
	(0.0525)		(0.0254)		(0.0091)	
Producer Price Index	NA	-0.3331**	NA		NA	
		[1]				
Business Climate						
IFO Business Climate	0.0514	0.1789*	0.0835**	0.1534*	0.0819***	
	(0.0400)	[1-2]	(0.0411)	[0-1]	(0.0162)	
ZEW Survey	0.0851**	0.1681**	0.0493*		0.1749***	
	(0.0345)	[0-1]	(0.0285)		(0.0232)	

Table C2 continues on the next page.

Table C2: Response of Asset Returns to Macroeconomic News

Table C2 continued.

	Pre-Crisis Period		Subprime and Financial Crisis Period		European Sovereign Crisis Period	
Panel 5: Response of Bund Futures Returns						
	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response	Contemp. Response	Cumulative Response
U.S. News						
Economic Activity						
Durable Goods Orders	-0.0115		-0.0424***		-0.0495***	
	(0.0115)		(0.0102)		(0.0082)	
GDP	-0.0294	-0.0656*	-0.0319***		-0.0539***	
	(0.0202)	[1-2]	(0.0115)		(0.0061)	
Non-Farm Payroll	-0.0664	-0.0843**	-0.0678***		-0.1740***	-0.1989*
	(0.0473)	[1]	(0.0145)		(0.0110)	[0-2]
Trade Balance	0.0180	-0.1224**	-0.0047		-0.0365**	
	(0.0485)	[1]	(0.0037)		(0.0164)	
Price						
Consumer Price Index	-0.0539*	-0.0988*	-0.0259***	-0.0577***	-0.0115	
	(0.0282)	[0-1]	(0.0081)	[0-1]	(0.0085)	
Producer Price Index	-0.0330		-0.0116		-0.0359***	
	(0.0204)		(0.0093)		(0.0075)	
Labor Market						
Initial Unemployment Claims	0.0334***	0.0817*	0.0140***		0.0336***	0.0457**
	(0.0073)	[0-3]	(0.0039)		(0.0025)	[0-2]
Housing Market						
Housing Starts	-0.0189*		-0.0509***		-0.0620***	
	(0.0103)		(0.0104)		(0.0095)	
New Home Sales	-0.0251***	-0.0740***	-0.0299**		-0.0240***	
	(0.0036)	[0-2]	(0.0141)		(0.0062)	
Business Climate						
Consumer Confidence Index	-0.0627**	-0.1659*	-0.0271***	-0.0392**	-0.0551***	-0.0759*
	(0.0272)	[0-2]	(0.0078)	[0-1]	(0.0050)	[0-2]
Manufacturing ISM	-0.0501**	-0.1058**	-0.0665***	-0.1508**	-0.0655***	
	(0.0237)	[0-1]	(0.0133)	[0-3]	(0.0058)	
Non-Manufacturing ISM	-0.0302	-0.1001*	-0.0434***	-0.0797***	-0.0399***	
	(0.0247)	[1-3]	(0.0120)	[0-1]	(0.0068)	
German News						
Economic Activity						
GDP	NA		NA		NA	
Industrial Production	-0.0033		-0.0056		-0.0194***	
	(0.0241)		(0.0057)		(0.0039)	
Price						
Consumer Price Index	-0.0090		-0.0018		0.0077*	0.0221*
	(0.0123)		(0.0052)		(0.0042)	[0-2]
Producer Price Index	NA	0.2660	NA		NA	
		[2-4]				
Business Climate						
IFO Business Climate	-0.0771***	-0.2058**	-0.0327***		-0.0319***	
	(0.0221)	[0-3]	(0.0115)		(0.0049)	
ZEW Survey	-0.0517***	-0.1550**	-0.0282***	-0.0482***	-0.0459***	
	(0.0145)	[0-3]	(0.0067)	[0-1]	(0.0071)	

This table shows the return responses of the E-mini S&P500 futures, 10-year Treasury note futures, USD/EUR exchange rates, DAX futures, and Bund futures to the selected macroeconomic news in the full sample. The returns are in percentages. ***, **, and * denote significance at the 99%, 95%, and 90% confidence levels, respectively. Standard errors are in parentheses below the corresponding *contemporaneous* response coefficients. The numbers in brackets below the *cumulative* response coefficients are the lag lengths used to calculate the *cumulative* response. NA denotes missing values for returns at the time of news releases according to Table A1, so that we only report *cumulative* coefficients.

Appendix D

Table D1: Placebo Test for VAR Model Results of Return Spillovers

			2008-10-06 to to 2008-10-08	2011-08-08 to to 2011-08-09
E-mini S&P500 F.	→	10-Y T-Note Futures	-0.0283	-0.0343
10-Y T-Note Futures	→	E-mini S&P500 F.	-0.2224	
E-mini S&P500 F.	→	DAX Futures	1.5357	0.3430
DAX Futures	→	E-mini S&P500 F.	0.0717	0.1661
E-mini S&P500 F.	→	Bund Futures	-0.0490	-0.0122
Bund Futures	→	E-mini S&P500 F.		
E-mini S&P500 F.	→	USD/EUR	0.0525	0.0477
USD/EUR	→	E-mini S&P500 F.		0.0770
10-Y T-Note Futures	→	DAX Futures	-0.1612	
DAX Futures	→	10-Y T-Note Futures		
10-Y T-Note Futures	→	Bund Futures	0.4802	0.1425
Bund Futures	→	10-Y T-Note Futures		0.1274
10-Y T-Note Futures	→	USD/EUR	-0.0221	-0.0244
USD/EUR	→	10-Y T-Note Futures	-0.0226	
DAX Futures	→	Bund Futures	-0.0100	-0.0140
Bund Futures	→	DAX Futures		
DAX Futures	→	USD/EUR		0.0019
USD/EUR	→	DAX Futures		
Bund Futures	→	USD/EUR		-0.0659
USD/EUR	→	Bund Futures	-0.0554	-0.0189

This table shows the results for five-second returns of E-mini S&P500 futures, 10-year treasury note futures, USD/EUR exchange rates, DAX futures, and Bund futures in two sample periods (October 6 to 8, 2008, and August 8 to 9 August, 2011), when none of our selected macroeconomic announcements is released. The lag lengths, selected according to the Hannan-Quinn and Schwarz criteria, are six and three for the two samples, respectively. The coefficient from one market is the sum of coefficients significant at 95% confidence level.

Table D2: Placebo Test for Volatility Co-Movements and Spillovers

	2008-10-06 to 2008-10-08					**2011-08-08 to 2011-08-09**				
	E-mini S&P500 F.	10-Y T-Note F.	USD/ EUR	DAX F.	Bund F.	E-mini S&P500 F.	10-Y T-Note F.	USD/ EUR	DAX F.	Bund F.
E-mini S&P500 Futures (0)		0.042		0.464	0.015		0.019	0.024	0.622	0.016
10-Year T-Note Futures (0)	0.808		0.017		0.052	0.178		0.028	0.268	0.114
USD/EUR (0)		0.016				0.220	0.027		0.237	0.063
DAX Futures (0)	0.062				0.004	0.513	0.024	0.021		0.018
Bund Futures (0)	0.041	0.008		0.091		0.214	0.164	0.092	0.286	
E-mini S&P500 Futures (L)		0.008	0.009	-0.195						
10-Year T-Note Futures (L)	0.075									
USD/EUR (L)										
DAX Futures (L)								0.010		
Bund Futures (L)								0.041		

This table shows the volatility co-movements and spillovers among the E-mini S&P500 futures, 10-year Treasury note futures, USD/EUR exchange rate, DAX futures, and Bund futures markets in two sample periods (October 6 to 8, 2008 and August 8 to 9, 2011), when none of our selected macroeconomic announcements is released. The volatility processes are first filtered using an ARFIMA(1,d,1) model, $(1-\rho L)(1-L)^d|R_t| = (1-\theta L)\xi_t$, and additionally filtered by means of a flexible Fourier form to capture the periodic patterns. We then derive the co-movement and spillover estimates from OLS estimates with HAC-robust standard errors. We estimate the following model specifications for five-second filtered volatility processes within one hour after the announcements: $\xi_t^i = c^i + \sum_{q=1}^{Q} \varphi_q^i \xi_{t-q}^i + \sum_{j=1}^{4} \sum_{q=0}^{Q} \varphi_q^j \xi_{t-q}^j + \varepsilon_t^i$. The independent variables are comprised of lagged volatilities (L) from their own markets, and the contemporaneous (0) and lagged volatilities (L) from the other four markets. The coefficient of lagged variables from one market is the sum of coefficients significant at 95% confidence level. The coefficients of contemporaneous effects are also significant at 95% confidence level.

Appendix E

Table E1: VAR Model Results of Asset Returns

Panel 1: Responses to U.S. News

	Pre-Crisis					Subprime and Financial Crisis Period					European Sovereign Crisis Period				
	E-mini S&P500 F.	10Y T-Note F.	USD/ EUR	DAX F.	Bund F.	E-mini S&P500 F.	10Y T-Note F.	USD/ EUR	DAX F.	Bund F.	E-mini S&P500 F.	10Y T-Note F.	USD/ EUR	DAX F.	Bund F.
E-mini S&P500 F. (-1)	-0.128***	-0.017	0.025	0.104***	-0.006	-0.177***	-0.015*	0.019**	0.146***	0.001	-0.308***	0.002	0.017**	0.040	-0.009
	(0.018)	(0.016)	(0.017)	(0.024)	(0.011)	(0.022)	(0.009)	(0.007)	(0.024)	(0.006)	(0.023)	(0.011)	(0.008)	(0.027)	(0.007)
E-mini S&P500 F. (-2)	-0.073***	-0.028*	0.001	0.055**	-0.008	-0.071***	-0.003	0.002	0.090***	-0.004	-0.081***	-0.004	0.008	0.027	-0.009
	(0.018)	(0.016)	(0.017)	(0.024)	(0.011)	(0.022)	(0.009)	(0.007)	(0.024)	(0.006)	(0.023)	(0.011)	(0.008)	(0.026)	(0.007)
10-Y T-Note F. (-1)	0.039*	-0.134***	0.087***	0.049	0.053***	-0.008	-0.093***	0.0243*	0.030	0.053***	-0.191***	-0.038**	0.046***	-0.185***	0.065***
	(0.023)	(0.020)	(0.022)	(0.031)	(0.014)	(0.041)	(0.017)	(0.014)	(0.046)	(0.011)	(0.042)	(0.019)	(0.014)	(0.048)	(0.012)
10-Y T-Note F. (-2)	-0.001	-0.021	0.011	-0.024	0.027**	-0.025	-0.067***	-0.009	0.027	0.017	-0.131***	0.006	0.035**	-0.131***	0.044
	(0.023)	(0.020)	(0.022)	(0.031)	(0.014)	(0.041)	(0.017)	(0.014)	(0.045)	(0.011)	(0.042)	(0.019)	(0.014)	(0.048)	(0.012)
USD/EUR (-1)	0.059***	0.011	-0.093***	0.023	0.017	0.039	0.096***	0.038***	0.043	-0.013	0.132***	-0.052***	0.010	0.107**	-0.019
	(0.019)	(0.017)	(0.018)	(0.025)	(0.011)	(0.043)	(0.017)	(0.014)	(0.047)	(0.012)	(0.039)	(0.018)	(0.013)	(0.045)	(0.012)
USD/EUR (-2)	-0.020	0.015	-0.130***	-0.007	0.013	-0.058	0.021	-0.092***	-0.041	0.012	0.079**	0.013	-0.026**	0.073	0.001
	(0.019)	(0.017)	(0.018)	(0.025)	(0.011)	(0.043)	(0.017)	(0.014)	(0.047)	(0.012)	(0.039)	(0.018)	(0.013)	(0.045)	(0.012)
DAX Futures (-1)	0.136***	0.002	-0.022*	-0.079***	0.007	0.122***	-0.023***	-0.005	-0.206***	-0.018***	0.204***	0.004	0.001	-0.094***	-0.004
	(0.014)	(0.012)	(0.013)	(0.018)	(0.008)	(0.020)	(0.008)	(0.007)	(0.022)	(0.005)	(0.021)	(0.010)	(0.007)	(0.024)	(0.006)
DAX Futures (-2)	0.059***	0.019	-0.003	0.021	-0.003	0.036*	-0.010	0.007	-0.115***	-0.001	0.020	0.014	-0.007	-0.101***	0.006
	(0.014)	(0.012)	(0.013)	(0.019)	(0.008)	(0.020)	(0.008)	(0.007)	(0.022)	(0.005)	(0.021)	(0.010)	(0.007)	(0.024)	(0.006)
Bund Futures (-1)	-0.067*	0.183***	0.196***	-0.033	-0.134***	-0.263***	0.126***	0.067***	-0.253***	-0.142***	-0.191***	0.120***	-0.068***	-0.117	-0.080***
	(0.035)	(0.031)	(0.032)	(0.046)	(0.021)	(0.063)	(0.026)	(0.021)	(0.070)	(0.017)	(0.071)	(0.033)	(0.023)	(0.082)	(0.021)
Bund Futures (-2)	0.014	0.106***	0.130***	-0.042	-0.017	-0.074	0.133***	0.052**	-0.121*	-0.054***	-0.022	0.019	-0.074***	0.031	-0.066***
	(0.035)	(0.031)	(0.033)	(0.046)	(0.021)	(0.063)	(0.026)	(0.021)	(0.070)	(0.017)	(0.071)	(0.033)	(0.023)	(0.082)	(0.021)

Table E1 continues on the next page.

Table E1: VAR Model Results of Asset Returns

Table E1 continued.

Panel 1: Responses to German News

	Pre-Crisis					Subprime and Financial Crisis Period					European Sovereign Crisis Period				
	E-mini S&P500 F.	10Y T-Note F.	USD/ EUR	DAX F.	Bund F.	E-mini S&P500 F.	10Y T-Note F.	USD/ EUR	DAX F.	Bund F.	E-mini S&P500 F.	10Y T-Note F.	USD/ EUR	DAX F.	Bund F.
E-mini F. (-1)	-0.136***	-0.023	-0.002	0.187*	-0.014	-0.174***	-0.012	0.046*	0.230***	-0.009	-0.318***	0.003	0.062*	0.118*	-0.027
	(0.032)	(0.019)	(0.049)	(0.098)	(0.049)	(0.033)	(0.011)	(0.025)	(0.053)	(0.019)	(0.034)	(0.011)	(0.035)	(0.061)	(0.017)
E-mini F. (-2)	-0.042	-0.008	-0.121**	0.143	0.022	-0.132***	-0.025**	-0.013	-0.022	0.019	-0.107***	-0.009	0.028	0.029	-0.017
	(0.031)	(0.019)	(0.048)	(0.096)	(0.048)	(0.032)	(0.011)	(0.025)	(0.053)	(0.019)	(0.034)	(0.011)	(0.035)	(0.061)	(0.017)
10-Y T-Note F. (-1)	-0.119**	-0.168***	-0.146*	-0.275*	0.261***	0.102	-0.214***	-0.018	0.003	0.055	-0.134	-0.139***	-0.056	-0.267*	0.085**
	(0.053)	(0.032)	(0.082)	(0.162)	(0.081)	(0.086)	(0.030)	(0.067)	(0.140)	(0.049)	(0.083)	(0.026)	(0.086)	(0.150)	(0.042)
10-Y T-Note F. (-2)	-0.088*	-0.057*	-0.007	-0.033	-0.093	0.140	-0.082***	0.052	-0.006	0.086*	0.136*	-0.083***	0.025	-0.011	-0.003
	(0.052)	(0.032)	(0.081)	(0.160)	(0.080)	(0.086)	(0.029)	(0.067)	(0.139)	(0.049)	(0.082)	(0.026)	(0.085)	(0.149)	(0.042)
USD/EUR (-1)	-0.011	-0.002	-0.117***	0.003	-0.003	0.015	-0.034***	0.088***	0.016	-0.069***	0.098***	-0.014	-0.108***	0.057	-0.039***
	(0.022)	(0.013)	(0.033)	(0.066)	(0.033)	(0.037)	(0.013)	(0.029)	(0.060)	(0.021)	(0.027)	(0.009)	(0.028)	(0.049)	(0.014)
USD/EUR (-2)	-0.026	-0.023*	-0.103***	-0.055	-0.012	-0.025	0.015	-0.078***	-0.029	-0.008	0.062**	-0.013	-0.090***	0.089*	-0.010
	(0.020)	(0.012)	(0.030)	(0.060)	(0.030)	(0.035)	(0.012)	(0.027)	(0.056)	(0.020)	(0.027)	(0.009)	(0.028)	(0.048)	(0.014)
DAX Futures (-1)	0.050***	0.003	0.007	-0.454***	0.004	0.098***	-0.004	0.058***	-0.230***	-0.015	0.124***	-0.006	0.058***	-0.076**	-0.020**
	(0.010)	(0.006)	(0.016)	(0.032)	(0.016)	(0.021)	(0.007)	(0.016)	(0.034)	(0.012)	(0.019)	(0.006)	(0.019)	(0.034)	(0.010)
DAX Futures (-2)	0.039***	-0.003	0.004	-0.199***	-0.005	0.070***	-0.008	0.007	-0.063***	-0.005	0.014	-0.005	-0.014	-0.107***	-0.019**
	(0.010)	(0.006)	(0.016)	(0.032)	(0.016)	(0.021)	(0.007)	(0.016)	(0.034)	(0.012)	(0.019)	(0.006)	(0.020)	(0.034)	(0.010)
Bund Futures (-1)	-0.060***	0.122***	-0.553***	-0.480***	0.069**	-0.284***	0.134***	-0.393***	-0.452***	-0.059**	-0.150***	0.092***	-0.397***	-0.107	-0.099***
	(0.022)	(0.013)	(0.034)	(0.068)	(0.034)	(0.053)	(0.018)	(0.041)	(0.086)	(0.030)	(0.057)	(0.018)	(0.059)	(0.103)	(0.029)
Bund Futures (-2)	-0.032	0.029*	-0.183***	-0.215***	-0.002	-0.086	0.042**	-0.146***	-0.060	-0.004	-0.063	0.019	-0.099*	0.069	-0.062**
	(0.025)	(0.015)	(0.039)	(0.077)	(0.038)	(0.055)	(0.019)	(0.043)	(0.090)	(0.032)	(0.058)	(0.018)	(0.060)	(0.105)	(0.029)

This table shows the VAR model estimation results for five-second returns of E-mini S&P500 futures, 10-year treasury note futures, USD/EUR exchange rate, DAX futures and Bund futures falling into the one-minute window after all U.S. and German news with a significant impact on at least two of the three markets. The lag lengths are selected according to the Hannan-Quinn and Schwarz criteria. The bold numbers denote significant coefficients. ***, **, and * denote significance at the 99%, 95%, and 90% confidence levels, respectively.