

# **Comparing U.S. and European Market Volatility Responses to Interest Rate Policy Announcements\***

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\* We would like to thank Fred Hays, Bill Keeton, and Antonio Millaruelo. We are grateful for helpful comments from seminar participants at Kansas State University, the University of Missouri – Kansas City, University of Tulsa, and University of West Florida and to researchers at the Federal Reserve Bank of Kansas City and the Banco de España.

Kevin Krieger<sup>a</sup>, Nathan Mauck<sup>b\*</sup>, and Joseph Vazquez<sup>b</sup>

<sup>a</sup> University of West Florida, <sup>b</sup> University of Missouri-Kansas City

E-mail addresses: [kevinkrieger@uwf.edu](mailto:kevinkrieger@uwf.edu), [mauckna@umkc.edu](mailto:mauckna@umkc.edu), [jcv4m7@mail.umkc.edu](mailto:jcv4m7@mail.umkc.edu)

## ABSTRACT

We examine the response of U.S. (VIX) and German (VDAX) implied volatility indices to the announcement of interest rate policy decisions by the Federal Open Market Committee (FOMC) and the European Central Bank (ECB). We present new findings that indicate that VDAX declines on FOMC meeting days, a result that holds for nearly all announcement types. VDAX declines on ECB meeting days in which there is a negative rate surprise or no surprise and is unrelated to ECB meeting days otherwise. VIX is unrelated to ECB meeting days. We confirm prior findings that VIX declines on FOMC meetings days regardless of the content of the meeting. Taken collectively, our results indicate a prominent position for the FOMC in determining uncertainty levels both domestically and abroad relative to a conditional domestic relation between uncertainty levels and the ECB.

*JEL classification:* G14, E44

*Keywords:* FOMC, ECB, VIX, VDAX, Monetary policy, Volatility spillover

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\* Corresponding author.

## 1. Introduction

Interest rate decisions by central banks are noteworthy for researchers given their far-reaching effects. While the relation between central bank communication and the equities market has received considerable focus, relatively little is known about the relation of communication to forward-looking volatility. Option implied volatility allows us to infer what the market expects future volatility to be, and implied volatility indices are frequently described as uncertainty or fear indices. VIX has been linked to “fear” by Whaley (2009) and has been used to measure uncertainty in Nikkinen et al. (2007) and Bialkowski et al. (2008). Nikkinen and Sahlstrom (2004), Chen and Clements (2007), Vahamaa and Aijo (2011) and Krieger et al. (2012) document VIX declines on FOMC (Federal Open Market Committee) meeting days in the U.S. market and conclude that FOMC meetings are generally uncertainty resolving, rather than uncertainty creating. However, the impact of other, non-U.S. central bank communications on volatility is unaddressed by the previous literature. Similarly, the literature has not addressed cross-border volatility responses to foreign central bank announcements. We consider these issues in this paper by examining similarly constructed volatility indices in the U.S. and Germany and scheduled rate decisions by the FOMC and ECB (European Central Bank). Additionally, we are the first, to our knowledge, to examine the relation between scheduled central bank meetings and implied volatility decomposed into risk aversion and uncertainty following Bekaert et al. (2013).

As noted in Bekaert et al. (2013), examining the link between monetary policy and implied volatility may be important for three reasons. First, the relation between monetary policy and financial stability remains a topic of debate, particularly following the financial crisis of 2008-09. Implied volatility provides a forward looking, market-based view of stability, and we are able

to identify the link between scheduled meetings and this view. Second, greater economic uncertainty is linked to lower employment (Bloom, 2009 and Bloom et al., 2009). Thus, the link between scheduled central bank meetings and uncertainty measures, such as implied volatility indices, may be relevant. Third, understanding the relation between scheduled central bank meetings and implied volatility may add to our understanding of the relation between monetary policy and the stock market.

Our first results confirm previous work which finds that FOMC meeting days are uncertainty resolving in the U.S. VIX drops on scheduled meeting days regardless of the content of such meetings. Most strikingly, to the best of our knowledge, we are the first to find that ECB meeting days are related to a decline in the German implied volatility index (VDAX), conditional on the meeting containing either no rate surprise or a negative rate surprise, and are unrelated to VDAX when rate increases are announced. In short, both the ECB and FOMC are uncertainty resolving domestically, however the relation for ECB meetings is less robust and economically smaller in magnitude. ECB meeting days are unrelated to VIX, indicating that ECB rate decisions are not related to uncertainty resolution in U.S. markets. Conversely, in our cross-border analysis, we find that FOMC meeting days do, in fact, appear to help resolve uncertainty in German markets as VDAX declines on meeting days. This is indicative of a stronger international effect from scheduled U.S. central bank meetings than scheduled European central bank meetings. When decomposing VIX and VDAX into their respective risk aversion and uncertainty components, we find that FOMC meetings are associated with reductions in VIX (VDAX) risk aversion (uncertainty). The results suggest that the ECB and FOMC differ in terms of the market response to their interest rate decisions.

The paper proceeds as follows: Section 2 reviews the literature and develops hypotheses, Section 3 discusses data and methodology, Section 4 discusses the results and Section 5 concludes.

## 2. Literature Review and Hypotheses

Recent literature has documented the relation between FOMC scheduled meetings and VIX changes. Nikkinen and Sahlstrom (2004), Chen and Clements (2007), Vahamaa and Aijo (2011), and Krieger et al. (2012) find evidence of VIX declines following FOMC announcements. However, the focuses and approaches of these papers differ. Nikkinen and Sahlstrom (2004) and Chen and Clements (2007) consider FOMC announcements and document that FOMC meetings are linked with drops in VIX. They do not, however, consider cross-border impacts or separately consider whether surprises within announcements are particularly meaningful. Vahamaa and Aijo (2011), for instance, conclude that positive rate surprises are uncertainty inducing while negative surprises resolve uncertainty. By contrast, Krieger et al. (2012), focusing only on domestic impacts in the U.S., find that VIX declines on FOMC meeting days regardless of pre-meeting VIX levels or the nature of the FOMC's decision (increase, decrease, or no change to rates); thus, they interpret their findings as evidence that all FOMC meeting dates tend to provide uncertainty resolution. A related line of literature structural has indicated that monetary policy (measured more generally by the interest rate environment) is related to implied volatility. For instance, Bekaert et al. (2013) employ a structural VAR approach to examine the relation between monetary policy and the components of implied volatility, risk aversion, and uncertainty. They find that monetary policy influences both risk aversion and uncertainty;

however, the economic and statistical significance is much greater with respect to risk aversion. Their focus is entirely on domestic effects of U.S. monetary policy. Overall, the literature suggests that on FOMC meeting days VIX will decline.

As a starting point we begin our analysis herein by briefly reexamining the VIX-FOMC scheduled meeting relationship with the following null hypothesis:

Hypothesis 1 – VIX changes are unrelated to scheduled FOMC meeting days.

The literature establishes some relation between ECB announcements and financial markets. Hussain (2011), for example, focuses on the impacts of monetary policy surprises on European and U.S. stock index returns and volatility. Sensitive, intraday data reveals short-term reactions to policy actions, and the author also demonstrates the additional explanatory importance of the press conferences that accompany ECB announcements. Furthermore, the impact of target components and path surprise components of decisions, discussed by Gurkaynak (2005), are separated, and it is revealed that markets are not responsive to path surprises. Additionally, Hussain (2011) is able to decouple effects of potential simultaneous announcements of U.S. economic data, which is an issue in about 40% of the 2000-2008 observations.

However, the literature has not addressed, to the best of our knowledge, the relation between ECB meetings and implied volatility. Jiang et al. (2012) note that, in a single-country setting, the effect of news announcements on implied volatility depends on whether the release is scheduled or unscheduled. Their analysis considers ECB meetings, but they simultaneously consider many other types of announcements and do not isolate ECB meetings for specific study. To the extent that the ECB and FOMC are similar, we may expect to find European implied volatility declines on ECB meeting days. This may be due to the same type of information uncertainty resolution evidenced in the U.S. However, the ECB and FOMC may differ in key ways as well. The

charges of the ECB and FOMC do differ (e.g., the FOMC focuses on U.S. employment, as well as price stability, while the ECB's focus is more strictly tied to price control). Key differences between the ECB and FOMC may be relevant to the response of European implied volatility and ECB meeting days. For instance, a result of interest from Ehrmann and Fratzscher (2007) is related to communication. They note that the Federal Reserve is marked by communication from multiple individuals with varying opinions while the ECB follows an approach in which committee members have a high degree of consistency in their public comments. Moreover, the tone of public statements differs between the two central banks. Specifically, Ehrmann and Fratzscher (2007) find that ECB statements are "neutral" at nearly twice the rate of FOMC meetings (62% vs. 32%) based on a content analysis of rate decision communications.<sup>2</sup> This indicates that ECB meeting communications are less likely to reduce information uncertainty than FOMC meetings. We note that the vote of both the ECB and FOMC is nearly always unanimous, so it is the communication styles that differ between the two. Thus, as the extent of information provided by a meeting might drive the relation between central bank announcements and implied volatility, we would expect ECB meeting days to resolve less uncertainty than FOMC meeting days given their generally more neutral tones.

Additionally, there is at least one other important difference between the ECB and FOMC – meeting frequency. The FOMC is scheduled to meet 8 times a year while the ECB is scheduled to meet 12 times a year.<sup>3</sup> The more frequent ECB meetings may be associated with less "build up" of uncertainty following the previous meeting, which may make the relative importance of each individual ECB meeting less meaningful than a given FOMC meeting. This would suggest

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<sup>2</sup> For instance, ECB communication often notes that rates are "appropriate," which is interpreted by Ehrmann and Fratzscher (2007) as neutral.

<sup>3</sup> Technically, the ECB is scheduled to meet twice a month but the rate decision is usually only taken at the first meeting. In the early years of the ECB, rate decisions were made more frequently.

a weaker relation between uncertainty resolution and ECB meetings. We test the following null hypothesis which we interpret based on the discussion of ECB and FOMC similarities and differences:

Hypothesis 2 - VDAX changes are unrelated to scheduled ECB meeting days.

While domestic responses to central bank announcements have received some attention in the literature, very little focus has been given to the potential of a spillover effect into other markets beyond the home country/countries. Specifically, it is unclear what, if any, relation exists between FOMC meetings and European financial markets or between ECB meetings and U.S. markets. We offer predictions and hypotheses for these issues, which to our knowledge have been heretofore unaddressed.

Although the specific literature from central bank announcement effects is silent, Jiang et al. (2012) examine volatility spillover between Europe and the U.S. more generally. They also test if controlling for various announcements eliminates the observed spillover. Their results indicate positive volatility spillover from the U.S. into Germany, but not the reverse (i.e., German volatility does not spillover into the U.S.). Specifically, they find that lagged daily VIX changes are related to present daily VDAX changes. Further, they find that aggregate scheduled (unscheduled) news events do not (do) affect VIX or VDAX, and the spillovers remain after controlling for news.<sup>4</sup> To the extent that central bank rate decisions are typical events from Jiang's (2012) study, we might then expect no relation between scheduled FOMC meetings and German implied volatility or between scheduled ECB meetings and U.S. implied volatility (since these meetings and their announcements are scheduled events).

Conversely, in an earlier paper, Ehrmann and Fratzscher (2005) find that European interest rates react to U.S. macroeconomic and monetary policy news and vice versa. This relation

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<sup>4</sup> Evans and Speight (2010) similarly find EUR-USD exchange rate return and volatility responses to news.

strengthened in the last five years of their sample, ending in 2003. They attribute the strong spillover to “increased real integration of the two economies” and note that the U.S. news is generally released before European news which creates a leading relation for U.S. news releases. Similarly, Kim and Nguyen (2009) find that FOMC and ECB announcements spill over into Asian stock market volatility. Furthermore, Lucca and Moench (2013) find that the return of the DAX equity index is 43 basis points higher on FOMC meeting days than on other days. Thus, it appears possible that FOMC (ECB) meeting days may indeed affect German (U.S.) markets and vice versa. We, for the first time in the literature, specifically investigate the international relationships regarding market volatility and scheduled central bank rate announcements via two null hypotheses:

Hypothesis 3 - VIX changes are unrelated to scheduled ECB meeting days.

Hypothesis 4 - VDAX changes are unrelated to scheduled FOMC meeting days.

### 3. Data and Methodology

Our sample covers the period from 1999 through 2012. The range of this sample is dictated by the fact that the ECB did not issue interest rate decisions prior to January of 1999. We identify FOMC<sup>5</sup> and ECB<sup>6</sup> meeting days and interest rate decisions from the organizations’ respective websites. During the period examined, there are 112 scheduled FOMC meeting dates and 204 scheduled ECB meeting dates. We obtain historical VIX data from the Chicago Board Options Exchange website.<sup>7</sup> Historical VDAX data is from the website of Deutsche Borse.<sup>8,9</sup>

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<sup>5</sup> <http://www.federalreserve.gov/monetarypolicy/fomccalendars.htm>

<sup>6</sup> <http://www.ecb.europa.eu/press/govcdec/mopo/previous/html/index.en.html>

<sup>7</sup> <http://www.cboe.com/micro/vix/historical.aspx>

<sup>8</sup> <http://www.boerse-frankfurt.de/en/equities/indices/vdax+new+DE000A0DMX99>

<sup>9</sup> We focus on German volatility as the data is available from the first ECB meeting through the present period.

Both VIX and VDAX are calculated as the implied 30-day volatility of the underlying index (S&P 500 and DAX), which makes direct comparison possible. Although other European implied volatility indices have been created, the VDAX has been in existence since the start of the ECB in 1999 and has been the focus of prior European research.<sup>10</sup> For robustness, we examine our results using implied Euro STOXX 50 volatility (VSTOXX) instead of VDAX. Linking the FOMC and ECB meeting days to VIX and VDAX requires precision. Specifically, FOMC meetings are nearly always completed after German markets have closed. As such, FOMC meeting days must be linked to the following day VDAX changes. No such adjustment is needed for ECB decisions and VIX as the time lag allows U.S. markets to incorporate ECB decisions on the same day of ECB meetings.

Our initial analysis focuses on changes in VIX and VDAX on FOMC and ECB meeting days. Dickey-Fuller unit root test results are found in Appendix A. In the case of VIX and VDAX, the null hypothesis of a unit root is rejected regardless of the lag used. Our formal test of the relation between scheduled central bank meetings and implied volatility is in the form of a seemingly unrelated VAR(1) regression.<sup>11</sup> Our model is based on that of Jiang et al. (2012) who examine volatility spillover between the U.S. and Europe. However, unlike Jiang et al. (2012), the focus of our paper is on scheduled central bank meetings only, as opposed to many general news releases, and on the differences between scheduled and unscheduled meetings. We first estimate the following equation which establishes the volatility spillover results:

$$\Delta IV_t = C + \varphi \Delta IV_{t-1} + \mu_t, \tag{1}$$

where  $\Delta IV_t = IV_t - IV_{t-1}$  is a (2 x 1) vector of changes in the implied volatility indices for the U.S. and Germany,  $C$  is a vector of constants, and  $\varphi$  is a (2 x 2) matrix of coefficients. We

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<sup>10</sup> See for example, Jiang et al. (2012) and Lucca and Moench (2013).

<sup>11</sup> The lag length is selected in order to be consistent with Jiang et al. (2012) and is based on AIC.

generalize equation (1) to include indicator variables for FOMC and ECB meeting days. This generalized model allows us to test the relation between scheduled FOMC and ECB meeting days and implied volatility in the U.S. and Germany while controlling for volatility spillover.

As part of our analysis, we also consider whether the responses of volatility indices to scheduled announcements of interest rate policy are driven by whether the contents of the announcements are expected or unexpected. In doing so, we seek to better delineate whether the clarity provided by the announcement or the specific policy announced is more meaningful. In order to proceed, we utilize the methodology of Perez-Quiros and Sicilia (2002) and Ehrmann and Fratzscher (2007).<sup>12</sup> Specifically, we use the overnight EONIA rates for the ECB and overnight LIBOR rates for the U.S. The surprise measure is the change in these key interest rates on the day of the policy decision.<sup>13</sup>

In order to provide robustness via an additional methodology common in the monetary policy literature, as well as to focus on decomposed implied volatility, we closely follow Bekaert et al. (2013) in a structural VAR analysis. Our initial model is a five-variable structural VAR. Two of the five variables follow Bekaert et al. (2013) directly. Specifically, we include the U.S. interest rate as a measure of the monetary policy environment and the log-difference of U.S. industrial production to measure the business cycle. While Bekaert et al. (2013) include decomposed VIX, we include changes in VIX and changes in VDAX. Finally, we include an indicator for FOMC meetings. The reason for our departure from Bekaert et al. (2013) on the final three variables is that we are interested in addressing the market response to scheduled FOMC meetings rather than monetary policy shocks more generally. However, we conduct

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<sup>12</sup> FOMC results are robust to modeling surprises following the methodology of Krueger and Kuttner (1996), Kuttner (2001), and Soderstrom (2001) which uses 30-day federal funds futures data (not reported for brevity but available upon request). Such data is not available to us for a European equivalent so results reported in this paper focus on short term interest rates, which yield a surprise measure for both FOMC and ECB meetings.

<sup>13</sup> Results are robust to the use of one-month rates rather than overnight rates.

several robustness checks, including: decomposing VIX and VDAX into their risk aversion and uncertainty components rather than using first-difference measures<sup>14</sup>, measuring monetary policy as the difference between U.S. and European interest rates<sup>15</sup>, and truncating the sample at the end of 2007 to avoid the recent financial crisis observations. Seven restrictions on the VAR are needed to identify the system and we use the standard Cholesky decomposition. The variables are ordered as described above. Results are reported using the usual impulse response functions only in the case in which FOMC is the impulse and implied volatility is the response.

#### 4. Results

We first identify changes of the VIX, VDAX and VSTOXX volatility indices on scheduled FOMC and ECB meeting days. Panel A of Table 1 presents the mean and median changes in VIX, VDAX and VSTOXX on scheduled FOMC meeting days. We test the two-tailed hypotheses that each index's change on scheduled meeting days is equal to zero over the period of 1999 through 2012. The results suggest that VIX declines on scheduled FOMC meeting days (significant at the 1% level). The mean raw (percentage) change in VIX level is -0.703 (-2.78%), and the median change is -0.540 (-2.57%). Thus, based on these preliminary tests, we reject null Hypothesis 1. These results are consistent with Nikkinen and Sahlstrom (2004), Chen and Clements (2007), Vahamaa and Aijo (2011) and Krieger et al. (2012) who document VIX declines on FOMC meeting days.

[Insert Table 1 Here]

Interestingly, the results in Panel A of Table 1 indicate that VDAX also declines on scheduled FOMC meeting days. The results in Panel A are qualitatively identical for VSTOXX

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<sup>14</sup> The method of decomposing VIX and VDAX follows Bekaert et al. (2013) directly.

<sup>15</sup> We use the Fed Funds rate for the U.S. and the ECB marginal lending facility rate for Germany.

which captures European implied volatility rather than German implied volatility (VDAX). The mean (median) change is significant at the 1% level given a two-sided test. The mean and median raw VDAX changes are -0.404 and -0.430, respectively, while the mean and median changes, in percentage terms, are -1.41% and -2.24%, respectively. Thus, we have evidence to reject null Hypothesis 3. We are the first, to our knowledge, to document the specific decline in foreign market volatility (VDAX) on FOMC meeting days. Lucca and Moench (2013) focus on the German equity market (DAX), rather than on implied volatility, and find that the DAX sees higher returns on FOMC meeting days than non-meeting days. Our results indicate that FOMC meetings are associated with a reduction of German information uncertainty (i.e., lower expected future volatility) as well.

The decline in VDAX on FOMC meeting days in Panel A of Table 1 is not as strong or consistent as the drop in VIX on FOMC meeting days. For instance, the VIX declines about 75% of the time on FOMC meeting days (83 out of 112 observations) whereas the VDAX declines only about 60% of the time on FOMC meeting days (67 out of 112 observations). The economic and statistical significance of the VDAX decline is also not quite as strong as that of VIX. Collectively, this unsurprisingly suggests that FOMC meeting days are more strongly linked with information uncertainty reduction in the U.S. relative to Germany. Yet, the existence of information uncertainty reduction in Germany on FOMC meeting days is still a compelling result. Similar to Ehrmann and Fratzscher (2005), who find that the money markets of the U.S. and Europe are interdependent, our results indicate a strong link between U.S. monetary policy and the German economy.

Panel B of Table 1 presents results for VIX, VDAX and VSTOXX changes on ECB meeting days. For the VIX, VDAX and VSTOXX, implied volatility is statistically unrelated to

ECB meeting days. Thus, the ECB does not appear to reduce information uncertainty in either the European or U.S. market, and our evidence fails to support rejection of null Hypotheses 2 and 4. The difference between implied volatility reactions for the FOMC and ECB may be due to differences in the ways the two groups operate. The results are inconsistent with the predictability findings from Ehrmann and Fratzscher (2007) who find that the FOMC and ECB are similarly predictable. This similarity would suggest no difference in information uncertainty resolution between FOMC and ECB meeting days. Our results are more consistent with the communication result of Ehrmann and Fratzscher (2007). They find that 62% of all ECB statements are “neutral” while only 32% of all FOMC statements are “neutral.” The higher frequency of ECB interest rate, decision-related meetings may also drive volatility’s lack of response to such decisions. Overall, the lack of VIX response to ECB meetings is not surprising given that the literature has found that U.S. news in general drives European markets more than the converse (Ehrmann and Fratzscher, 2005, Jiang et al., 2012, and Dimpfl and Peter, 2014). However, the lack of VDAX or VSTOXX response to ECB is somewhat unexpected. The literature generally finds that ECB communications warrant a response in European markets (e.g., Conrad and Lamla, 2010 who find exchange rate reaction to ECB meetings). Given that our results are qualitatively identical for VDAX and VSTOXX in Table 1 (and elsewhere in unreported results), we only report and focus on VDAX results from this point forward.

Table 2 sorts meeting days based on the VIX and VDAX levels at the time of the scheduled FOMC and ECB meeting days. Relatively higher implied volatility indices are related to higher levels of uncertainty. During periods which experience higher levels of uncertainty, the possibility of greater uncertainty reduction following FOMC and ECB meetings exists. Consistent with Krieger et al. (2012) we find that VIX declines on FOMC meeting days are more

extreme when VIX is higher. ECB meeting influence on VIX is not systematically related to the level of VIX at the time of the meetings. This is consistent with the insignificant relation between VIX and ECB meetings seen in Table 1.

Table 2 also shows that VDAX declines on FOMC meeting days regardless of the pre-FOMC VDAX level. The response, however, is not systematically greater for higher levels of VDAX. Overall, the results are consistent with FOMC meetings reducing information uncertainty in the German market. Finally, the direction and magnitude of VDAX changes on ECB meeting days is not consistent with any trend. This is consistent with the lack of a significant relation in Table 1. Here and throughout Table 2, we do not provide tests of statistical significance given that the sample is split into small sub-samples.

[Insert Table 2 Here]

Table 3 shows the results for the VAR (1) model in equation (1). This model controls for volatility spillover between the U.S. and German market identified in Jiang et al. (2012). Panels A and B of Table 3 recreate the basic volatility spillover result from that paper using levels and percent changes in volatility, respectively. We confirm that lagged VIX is positively related to contemporaneous VDAX, which indicates volatility spillover from the U.S. to Germany. We further confirm the absence of volatility spillover from Germany to the U.S.

In Panels C and D of Table 3 we add indicator variables for FOMC and ECB meeting days. The results indicate that FOMC meeting days are associated with a decline in VIX (significant at the 1% level). This is consistent with Table 1 and the prior literature. FOMC meeting days are also associated with a decline in VDAX (significant at the 10% level). This is consistent in sign with Table 1 as well and indicates that FOMC meeting days reduce German

market information uncertainty. The ECB meeting day indicator is not significantly related to changes in either VIX or VDAX.

[Insert Table 3 Here]

The results above do not consider the content of the central bank meeting, simply its occurrence. In Table 4 we isolate the changes in VIX and VDAX relative to the content of the rate decision of the ECB and FOMC (i.e., increase, decrease, or no change). In Panel A of Table 4 we find that VIX declines on FOMC meeting days regardless of the content of the meeting. Similarly, VDAX declines on FOMC meeting days regardless of the content of the meeting. Further, VDAX declines are economically larger than VIX declines on FOMC meetings days in which the rate declines. In both the rate increase and no change scenarios, the economic importance of VIX declines is greater than that of VDAX declines. While Jiang et al. (2012) do not isolate FOMC meeting announcements, our results are inconsistent with their conclusions, in regard to central bank meetings, as they find that implied volatility declines only on scheduled information release days from the U.S. to Europe. Our results suggest this does not depend on the content of the meeting. We provide tests of statistical significance in Table 4, although we note that the sub-samples created are small in many cases and the tests may therefore lack power.

Panel B of Table 4 presents results for VIX and VDAX changes on ECB meeting days. Consistent with results in Tables 1 and 3, there is no identifiable relation between ECB meeting days and VIX changes. The results for VDAX changes on ECB days indicate that ECB meetings are generally uncertainty reducing when rates decline or are unchanged (declines occur 58% and 59% of the time, respectively) and are uncertainty inducing when rates rise (increases 54% of the time). Thus, unlike the relation between the FOMC and VIX, which is not dependent on the

content of the meeting, the relation between the ECB and VDAX is contingent on the rate decision.

[Insert Table 4 Here]

Jiang et al. (2012) focus on scheduled vs. unscheduled news in their study of volatility spillover between the U.S. and Europe. The motivation for this analysis is that surprise information is more likely to be reflected in volatility indices than non-surprise information. Their results confirm this reasoning. However, in the context of central bank meetings, Krieger et al. (2012) document that VIX declines on FOMC meetings days regardless of whether or not the results of those meetings is a surprise. Additionally, Vahamaa and Aijo (2011) emphasize the surprise component of FOMC meetings in their analysis. In Table 5, we present measures of central bank predictability (i.e., surprise measures) that are based on Ehrmann and Fratzscher (2007).

[Insert Table 5 Here]

In Table 5, we present the mean and variance of LIBOR and EONIA overnight rate changes (i.e., surprise) on the days of FOMC and ECB meetings, respectively. We find that the surprise measure is very similar for FOMC and ECB. The mean absolute surprise for FOMC meetings days is 5.4bp and is 4.7bp for ECB meeting days.<sup>16</sup> These results are qualitatively consistent with the findings of Ehrmann and Fratzshcher (2007) and are quantitatively similar as well. Our absolute surprise measures are slightly larger than Ehrmann and Fratscher (2007), but their sample ended in 2004 and ours extends through 2012.

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<sup>16</sup> LIBOR and EONIA rate changes are Winsorized at the 1% level.

In Table 6, we examine VIX and VDAX responses to FOMC and ECB meetings based on surprise. Although ECB meetings were unrelated to VIX or VDAX in previous tables, we include ECB meetings in Table 6. In Panel A of Table 6 we confirm the results of Krieger et al. (2012) in that VIX declines for all categories of surprise for FOMC meetings. The mean VIX change is not statistically significant in the negative surprise sample; however, with 23 observations, the power of the test is limited. We reconcile the difference between this lack of significance and the strong significance in Krieger et al. (2012) by noting that Krieger et al. (2012) use a surprise measure based on Fed Funds futures for FOMC meetings only, as discussed in Bernanke and Kuttner (2005), whereas we use changes in LIBOR rates. The economic magnitude of the decline is indeed greater for positive surprise meetings, however. Like the VIX, mean and median VDAX show declines for all categories of surprise for FOMC meetings. However, median and mean declines are only statistically significant for negative surprise meetings. This suggests that the relation between VDAX and FOMC meetings is more sensitive to the content of the meeting than the relation between VIX and FOMC meetings. Nonetheless, the sign of the VDAX changes is negative for all groups, and the surprise groups have relatively small samples (i.e., 21 observations for the non-significant positive surprise group).

[Insert Table 6 Here]

Panel B of Table 6 presents results for ECB meetings by surprise type. In all three groups (i.e., negative surprise, no surprise, and positive surprise) VIX change is unrelated to ECB meeting days. Thus, consistent with earlier tables, U.S. volatility does not appear to respond to ECB meetings regardless of the content of such meetings. Contrary to earlier results, which show no relation between ECB meetings and VDAX, we find evidence that VDAX declines on ECB meeting dates in which there is a negative rate surprise or no surprise (the positive surprise group

is negative, but economically small and statistically insignificant). Thus, once we account for the surprise element of ECB meetings, we find that such meetings are uncertainty reducing in the majority of meeting outcomes (negative surprise and no surprise). While the relation between the ECB and VDAX differs from the relation between the FOMC and VIX, in the sense that FOMC meetings are uncertainty reducing in all situations (i.e., generally unconditional on meeting content), once we account for announcement surprise type, both the FOMC and ECB appear to reduce uncertainty domestically through rate announcements.

Ehrmann and Fratzscher (2005) note that the interdependence between U.S. and European interest rates strengthened very late in their sample, which ended in 2003. They also concluded that one likely source for the interdependence was due to increasingly interdependent economies related to globalization. In Table 7, we generalize this idea to our particular focus. Specifically, we split our sample into three groups based on the period examined (1999-2002, 2003 to 2007, and 2008 to 2012) and examine VIX and VDAX changes on FOMC meeting days in each period. We focus only on FOMC meeting days, given the lack of relation between implied volatility and ECB meeting days observed in earlier tables in which the surprise is not considered.

[Insert Table 7 Here]

The results in Table 7 indicate that VIX declines on FOMC meeting days in all sub-periods examined. The economic significance is roughly 50% larger (in terms of % change) in the most recent period compared to the earliest period. This is likely due to the financial crisis which overlaps the 2008-2012 period.<sup>17</sup> The results for VDAX changes on FOMC meetings days by sub-period reveal two interesting findings. First, during the earliest period examined (1999-

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<sup>17</sup> This is consistent with Krieger et al. (2012) who find that VIX declines are economically larger when VIX levels prior to the meeting are relatively higher.

2002) VDAX actually increases on FOMC meeting days. Although the result is not statistically significant, VDAX increases for 24 of 37 (65%) meetings during this period. Second, VDAX declines on FOMC meeting days in the most recent sub-periods. This result is statistically significant in median (mean) results for both groups (2003-2007 only). In both the 2003-2007 and 2008-2012 period, VDAX declines on 27 of the 40 FOMC meeting days. Overall, the results suggest that as the economies of the U.S. and Germany have become relatively more interdependent, the FOMC has played an increasing role in the dynamics of German implied volatility.

Figure 1 presents the impulse response functions associated with our structural VAR approach. In all panels, we report only the cases in which the impulse is the indicator for an FOMC meeting. Overall, the results confirm our earlier analysis even after controlling for additional variables commonly used in the monetary policy literature. Additionally, the results contain new insights in the dynamics of the relation between FOMC meetings and implied volatility.

[Insert Figure 1 Here]

Panels A-F are based on a five-variable VAR in the spirit of Bekaert et al. (2013). The five-variable VAR includes as factors: monetary policy (Fed Funds rate), business cycle (industrial production), FOMC meeting indicator, change in daily VIX, and change in daily VDAX. Panel A of Figure 1 confirms that VIX declines on FOMC meeting days. The effect remains statistically significant for two days. Panel B confirms that VDAX declines on FOMC meeting days with the effect dissipating after two days. Thus, even after controlling for additional factors, the main results of the paper hold. Further, the results are qualitatively identical in Panels C and D which truncate the sample in 2007 to avoid including the 2008-2009

financial crisis. In Panels E and F the Fed Funds rate is replaced with the difference between the Fed Funds rate and the ECB marginal facility rate with qualitatively identical results.

In Panels G-J, we follow Bekaert et al. (2013) by decomposing implied volatility into uncertainty and risk aversion components. Similar to Bekaert et al. (2013) we find that in the U.S. the FOMC is most related to risk aversion (see Panels G and H). We are the first, to our knowledge, to examine this decomposition in the context of German implied volatility. Our results indicate that the decline in VDAX surrounding FOMC meeting days is mostly driven by a decline in uncertainty (see Panels I and J).

## 5. Conclusion

We consider the similarities and differences between the volatility responses by U.S. and European markets to news of governmental interest rate policy. We determine that market volatility tends to decline when scheduled interest rate policy announcements are made in the U.S. This is the case regardless of whether (and to what degree) the announcement actually releases unexpected information. This effect has remained consistent for a number of years. The relation between the ECB and European volatility is less robust and economically smaller and indicates that uncertainty is only resolved in the case of no rate surprise or a negative rate surprise.

There are significant differences between U.S. and European cross-border effects, however. European market volatility levels decline substantially in response to U.S. interest rate policy announcements (FOMC meetings) but U.S. volatility levels do not respond to ECB meeting announcements. The U.S. market volatility measure, VIX, is more responsive to U.S. interest rate policy announcements, but there is a spillover effect into the German market volatility measure, VDAX, which serves as a European proxy.

Our conjecture is that U.S. FOMC meetings provide more uncertainty resolution than the corresponding European ECB meetings, and thus market volatility is reduced to a greater degree in response. This may be due to the less neutral tone of typical announcements of FOMC meetings or the market's relative attentiveness to U.S. interest rate policy, even in Europe.

The collective results of our paper have important policy implications. First, when seeking to influence domestic uncertainty, central banks must be mindful that the actions of other nations' central banks may in part negate or enhance their own. Specifically, given that FOMC meetings are related to European implied volatility, the actions of the FOMC may need to be considered when setting European monetary policy. Additionally, the actions of the FOMC may need to recognize the international influence of such actions. Second, there is reason to believe that central banks may impact uncertainty as implied volatility tends to decline on domestic central bank meeting days both in Europe and the U.S. Third, the component of implied volatility related to FOMC differs between the U.S. and Europe. In the U.S., FOMC meetings are on average associated with a decline in risk aversion, although the effect is short-lived. In Europe, FOMC meetings are on average associated with a decline in uncertainty, and the effect is short-lived. Thus, it does not appear that U.S. monetary policy is able to influence risk taking in Europe in the short-run.

## Appendix A

### Unit root tests: sample period, 1999:01 to 2012:12 (Observations 188)

Augmented Dickey-Fuller regression

$$\Delta x_t = a_0 + \alpha x_{t-1} + \sum_{i=1}^m \gamma_i \Delta x_{t-i} + v_t$$

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variables ( $x_t$ )	Dickey-Fuller test			
	$\tau_\alpha$			
	1 lag	2 lags	3 lags	4 lags
VIX <sub>t</sub>	-5.549	-4.570	-4.382	-4.145
VDAX <sub>t</sub>	-4.692	-4.584	-4.396	-4.217

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**Table 1 VIX and VDAX changes on schedule FOMC and ECB meeting days**

This table presents changes in the VIX, VDAX and VSTOXX levels on the day of scheduled FOMC and ECB meetings. Changes in the absolute level in VIX, VDAX and VSTOXX, as well as the percentage changes relative to the previous day are reported. The sample period is 1999-2012. T-test results of the mean change and sign-rank tests of the median change are reported. \*\*\*, \*\*, and \* denote statistical significance at the 1%, 5%, and 10%, respectively.

	Mean Change	Median Change	Mean % Change	Median % Change
Panel A: 112 scheduled FOMC meetings from January 1999 to December 2012				
VIX	-0.703***	-0.540***	-2.78%***	-2.57%***
t-stat	(-4.05)		(-4.85)	
VIX increases	29			
VIX decreases	83			
VDAX	-0.404***	-0.430***	-1.41%***	-2.24%***
t-stat	(-2.76)		(-2.68)	
VDAX increases	45			
VDAX decreases	67			
VSTOXX	-0.265***	-0.340***	-1.56%***	-1.32%***
t-stat	(-2.65)		(-2.83)	
VSTOXX inc.	38			
VSTOXX dec.	74			
Panel B: 204 scheduled ECB meetings from January 1999 to December 2012				
VIX	0.109	-0.145	0.003%	-0.008%
t-stat	(0.84)		(0.62)	
VIX increases	91			
VIX decreases	113			
VDAX	0.017	-0.210	0.001%	-0.010%
t-stat	(0.12)		(0.23)	
VDAX increases	89			
VDAX decreases	115			
VSTOXX	-0.075	-0.140	-0.363%	-0.726%
t-stat	(-0.92)		(-1.09)	
VSTOXX inc.	89			
VSTOXX dec.	115			

**Table 2 Mean VIX and VDAX changes by pre-meeting level**

This table presents statistics for the changes in mean VIX and VDAX levels on the day of scheduled FOMC and ECB meetings. The meeting days are sorted based on the VIX or VDAX level prior to the day of the meeting. Panel A shows results for mean VIX changes on FOMC meeting days. Panel B shows results for mean VIX changes on ECB meeting days. Panel C shows results for mean VDAX changes on FOMC meeting days. Panel D shows results for mean VDAX changes on ECB meeting days. The sample period is 1999-2012.

	Pre-FOMC meeting VIX level				
	Sub 15	15-20	20-25	25-30	over 30
Panel A: VIX changes January 1995 to December 2012					
n	24	24	33	15	16
VIX change	-0.46	-0.55	-0.56	-0.98	-1.33
VIX % change	-3.14%	-2.72%	-2.24%	-3.20%	-3.02%
	Pre-ECB meeting VIX level				
	Sub 15	15-20	20-25	25-30	over 30
Panel B: VIX changes January 1999 to December 2012					
n	35	51	57	32	29
VIX change	0.06	-0.25	-0.3	-0.07	1.94
VIX % change	0.58%	-1.04%	-1.21%	-0.15%	5.83%
	Pre-FOMC meeting VDAX level				
	Sub 15	15-20	20-25	25-30	over 30
Panel C: VDAX changes January 1995 to December 2012					
n	8	23	32	23	26
VDAX change	-0.21	-0.50	-0.52	-0.31	-0.31
VDAX % change	-1.37%	-2.47%	-1.84%	-0.88%	-0.21%
	Pre-ECB meeting VDAX level				
	Sub 15	15-20	20-25	25-30	over 30
Panel D: VDAX changes January 1999 to December 2012					
n	13	43	64	44	40
VDAX change	0.13	-0.42	-0.29	-0.05	1.04
VDAX % change	1.07%	-2.14%	-0.97%	-0.02%	2.88%

**Table 3 Seemingly unrelated regressions**

This table presents results from the VAR(1) model in equation (1).  $\Delta VIX_t$  ( $\Delta VDAX_t$ ) is the change in the implied VIX (VDAX) volatility index between t-1 and t, and C is a constant. Panels A and B (C and D) presents results without (with) FOMC and ECB meeting day indicators. Panels A and C (B and D) use the change in the level (percent) of volatility. FOMC (ECB) indicators are equal to one on the day of a scheduled FOMC (ECB) meeting day and are zero otherwise. T-statistics are reported in parentheses and adjusted  $R^2$  is reported. \*\*\*, \*\*, and \* denote statistical significance at the 1%, 5%, and 10% level, respectively. The model is estimated for 1999-2012.

Panel A: Volatility spillover – Volatility levels

	$\Delta VIX_t$	$\Delta VDAX_t$
$\Delta VIX_{t-1}$	-0.136*** (-6.77)	0.180*** (14.30)
$\Delta VDAX_{t-1}$	0.008 (0.38)	-0.101*** (-7.49)
C	-0.002 (-0.06)	-0.034* (-1.77)
Adj. $R^2$	0.02	0.06

Panel B: Volatility spillover – Volatility changes

	$\Delta VIX_t$	$\Delta VDAX_t$
$\Delta VIX_{t-1}$	-0.104*** (-5.14)	0.247*** (14.96)
$\Delta VDAX_{t-1}$	0.001 (0.02)	-0.154*** (-7.82)
C	0.002* (1.79)	0.001 (0.48)
Adj. $R^2$	0.01	0.06

Panel C: Volatility spillover with FOMC and ECB meeting days – Volatility levels

	$\Delta VIX_t$	$\Delta VDAX_t$
$\Delta VIX_{t-1}$	-0.136*** (-6.77)	0.179*** (14.16)
$\Delta VDAX_{t-1}$	0.011 (0.51)	-0.101*** (-7.48)
FOMC	-0.518*** (-3.60)	-0.72* (-1.90)
ECB	0.074 (0.59)	-0.060 (-0.74)
C	0.011 (0.34)	-0.024 (-1.24)
Adj. R <sup>2</sup>	0.02	0.06

Panel D: Volatility spillover with FOMC and ECB meeting days – Volatility changes

	$\Delta VIX_t$	$\Delta VDAX_t$
$\Delta VIX_{t-1}$	-0.103*** (-5.11)	0.244*** (14.77)
$\Delta VDAX_{t-1}$	0.003 (0.12)	-0.153*** (-7.80)
FOMC	-0.021*** (-4.22)	-0.008* (-1.95)
ECB	-0.001 (-0.22)	-0.002 (-0.71)
C	0.003** (2.38)	0.001 (0.92)
Adj. R <sup>2</sup>	0.02	0.06

**Table 4 Implied volatility changes relative to rate movement**

This table presents frequencies of the occurrence of VIX and VDAX declines and increases, relative to the type of interest rate movements on FOMC (Panel A) or ECB (Panel B) meeting days. Mean and median VIX changes are reported for each category based on both levels and percent changes. Significance levels for statistical tests of VIX and VDAX changes are reported based on two-sided tests (t-test for means, signed-rank test for medians). \*\*\*, \*\*, and \* denote statistical significance at the 1%, 5%, and 10% levels, respectively. The sample period is 1999-2012.

## Panel A: FOMC Meeting Days

	Rate Change < 0	Rate Change = 0	Rate Change > 0
VIX fall count	11	55	17
VIX rise count	7	21	6
Mean VIX change	-0.840	-0.716***	-0.557***
Median VIX change	-0.410	-0.620***	-0.470***
Mean VIX % change	-2.674%	-2.732%***	-3.003%***
Median VIX % change	-1.555%	-2.748%***	-3.076%***
VDAX fall count	12	45	13
VDAX rise count	6	31	10
Mean VDAX change	-1.217**	-0.221	-0.367
Median VDAX change	-1.260**	-0.440	-0.170
Mean VDAX % change	-3.701%**	-0.841%	-1.457%
Median VDAX % change	-4.801%**	-2.240%*	-1.001%

## Panel B: ECB Meeting Days

	Rate Change < 0	Rate Change = 0	Rate Change > 0
VIX fall count	10	88	15
VIX rise count	9	69	13
Mean VIX change	-0.193	0.1002	0.383
Median VIX change	-0.010	-0.160	-0.230
Mean VIX % change	-0.805%	0.540%	-0.352%
Median VIX % change	-0.050%	-0.952%	-1.040%
VDAX fall count	11	93	13
VDAX rise count	8	64	15
Mean VDAX change	-0.253	-0.059	0.6485
Median VDAX change	-0.300	-0.240*	0.140
Mean VDAX % change	-0.768%	-0.223%	1.058%
Median VDAX % change	-1.060%	-1.115%*	0.339%

**Table 5 Predictability of policy decisions**

This table presents summary statistics regarding the degree of surprise announcement content on FOMC and ECB meeting days. The frequencies surprise types of FOMC meetings and ECB meetings are also noted. Per Ehrmann and Fratzscher (2007), "surprise" is defined as the interest-rate change from the relevant previous day in the LIBOR (for FOMC meetings) or the EONIA (for ECB meetings). Positive (negative) surprises occur when the relevant interest rate increases (decreases) by more than one basis point. The sample period is 1999-2012.

	FOMC	ECB
Number of Meetings	112	204
Mean absolute surprise	0.054	0.047
Variance of absolute change	0.014	0.008
Positive Surprise	23	66
No Surprise	68	108
Negative Surprise	21	30

**Table 6 Implied volatility changes relative to surprise**

This table presents frequencies of the occurrence of VIX and VDAX declines and increases on the trading day following a meeting, relative to the surprise of an FOMC meeting (in Panel A) or an ECB meeting (in Panel B). Mean and median VIX and VDAX changes are reported for each category. Per Ehrmann and Fratzscher (2007), "surprise" is defined as the interest-rate change from the previous day in the LIBOR (for FOMC meetings) or the EONIA (for ECB meetings). Significance levels for statistical tests of VIX and VDAX changes are reported based on two-sided tests (t-test for means, signed-rank test for medians). \*\*\*, \*\*, and \* denote statistical significance at the 1%, 5%, and 10% levels, respectively. The sample period is 1999-2012.

Panel A: FOMC Meetings	Surprise < 0	Surprise = 0	Surprise > 0
VIX Fall Count	17	50	15
VIX Rise/Same Count	6	18	6
Mean VIX Change	-0.428	-0.596***	-1.300***
Median VIX Change	-0.525*	-0.510***	-1.120***
Mean VIX % Change	-1.80	-2.23***	-5.48***
Median VIX % Change	-2.35*	-2.10***	-4.93***
VDAX Fall Count	17	39	14
VDAX Rise/Same Count	6	29	7
Mean VDAX Change	-1.100***	-0.199	-1.268
Median VDAX Change	-1.250***	-0.220	-0.420
Mean VDAX % Change	-3.74***	-0.67	-6.09
Median VDAX % Change	-4.87***	-1.17	-2.24
Panel B: ECB Meetings	Surprise < 0	Surprise = 0	Surprise > 0
VIX Fall Count	39	60	16
VIX Rise/Same Count	27	48	14
Mean VIX Change	0.226	0.078	-0.039
Median VIX Change	-0.200	-0.150	-0.080
Mean VIX % Change	-0.38	0.37	-0.14
Median VIX % Change	-0.99	-0.87	-0.41
VDAX Fall Count	60	62	18
VDAX Rise/Same Count	16	36	12
Mean VDAX Change	-0.727**	-0.855**	-0.151
Median VDAX Change	-0.635***	-0.345***	-0.415
Mean VDAX % Change	-3.45**	-4.35**	-1.01
Median VDAX % Change	-2.86***	-1.54***	-2.03

**Table 7 Implied volatility changes by period on FOMC meeting days**

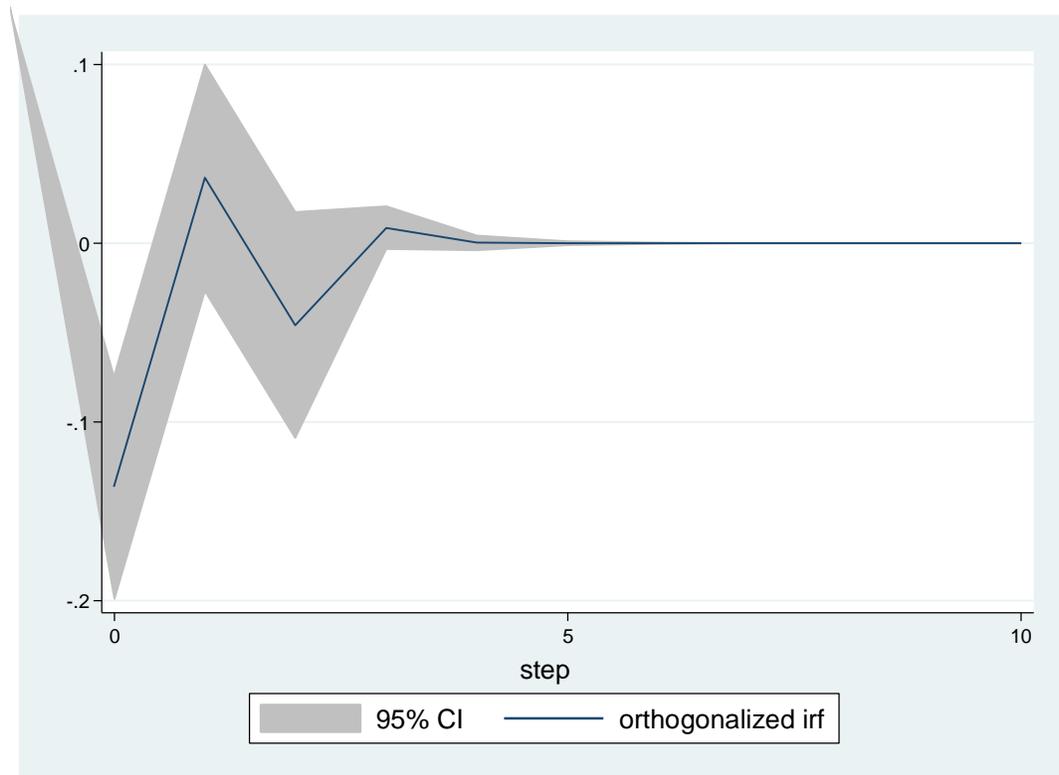
This table presents frequencies of the occurrence of VIX and VDAX declines and increases on FOMC meeting days, for three different sub-periods of our sample. Mean and median VIX and VDAX changes are reported for each category based on both levels and percent changes. The full sample period is 1999-2012. T-test results of the mean change and sign-rank tests of the median change are reported. \*\*\*, \*\*, and \* denote statistical significance at the 1%, 5%, and 10%, respectively.

	1999-2002	2003-2007	2008-2012
VIX Fall Count	25	28	29
VIX Rise Count	7	12	11
Mean VIX Change	-0.525***	-0.544**	-1.006**
Median VIX Change	-0.540***	-0.420***	-0.790***
Mean VIX % Change	-2.102%***	-2.783%**	-3.031%**
Median VIX % Change	-2.179%***	-3.072%***	-3.478%***
VDAX Fall Count	13	27	27
VDAX Rise Count	24	13	13
Mean VDAX Change	0.153	-0.384***	-0.369
Median VDAX Change	0.175	-0.345***	-0.455*
Mean VDAX % Change	0.600%	-1.587%***	-0.917%
Median VDAX % Change	0.614%	-1.806%***	-1.737%

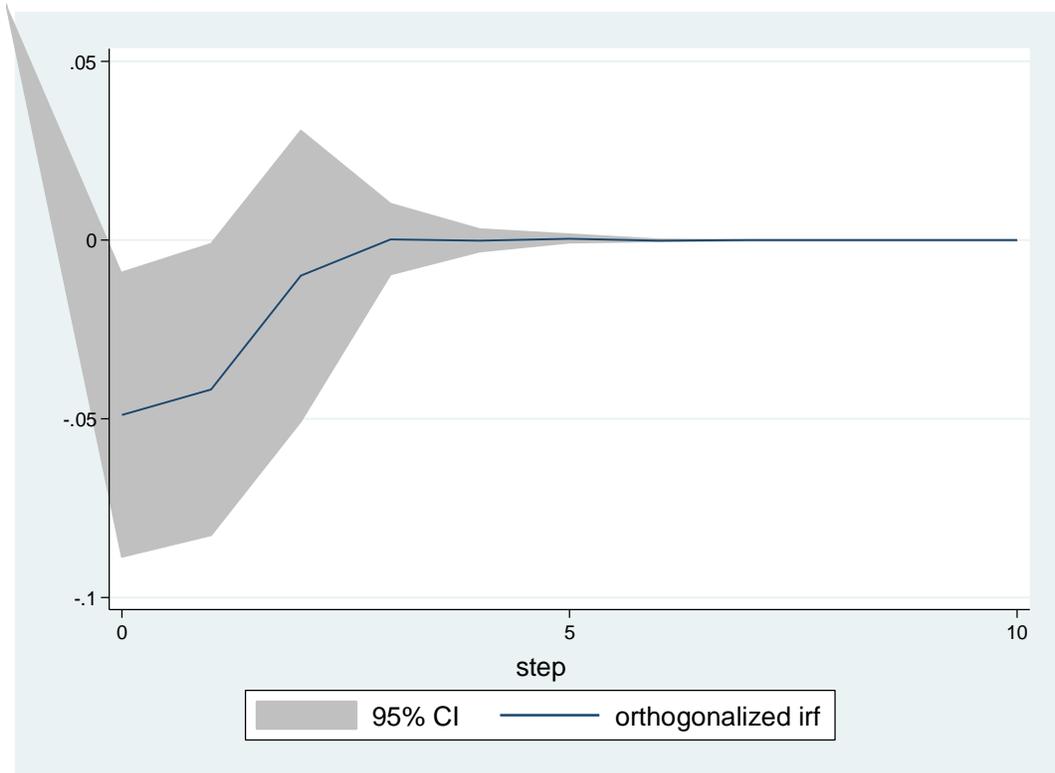
### Figure 1 Impulse Response Functions

This figure presents impulse response functions for our structural VAR. Panels A-F are based on a five variable VAR and Panels G-J are based on a seven variable VAR. The five variable VAR includes: monetary policy (Fed Funds rate in all except Panels E and F which use the difference between Fed Funds rate and ECB marginal facility rate), business cycle, FOMC meeting indicator, change in daily VIX and change in daily VDAX. The seven variable VAR replaces changes in VIX and VDAX with decomposed volatility indices (risk aversion and uncertainty). The sample period (unless otherwise indicated) is 1999-2012.

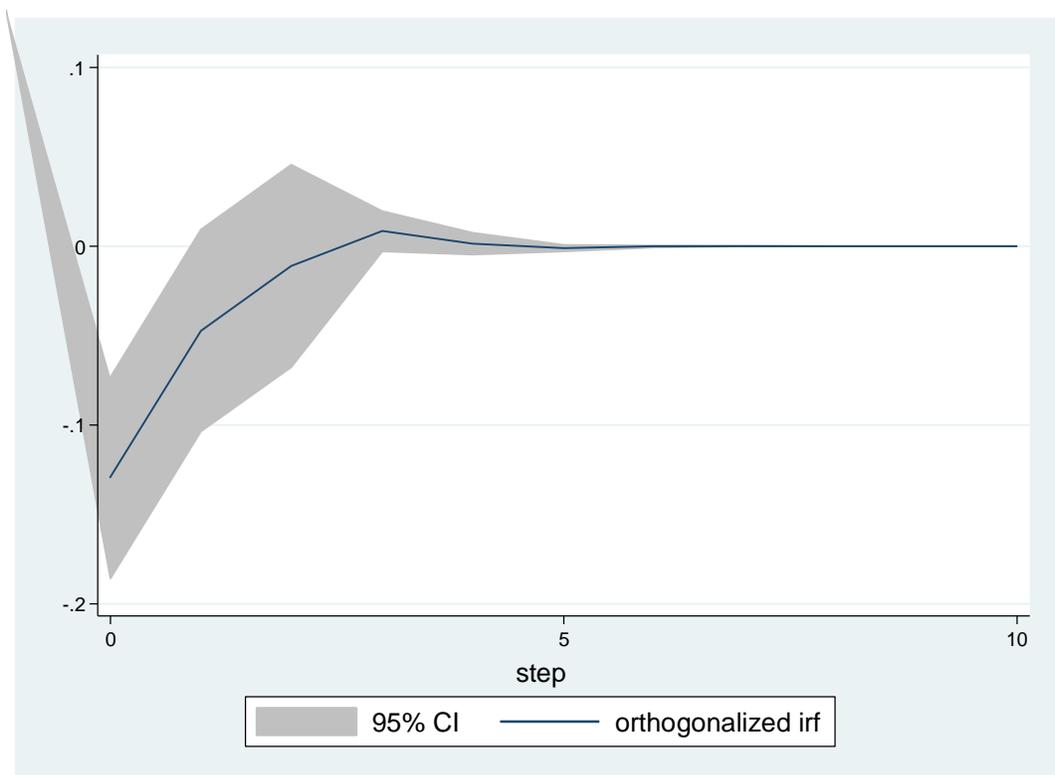
Panel A - Impulse FOMC, response VIX



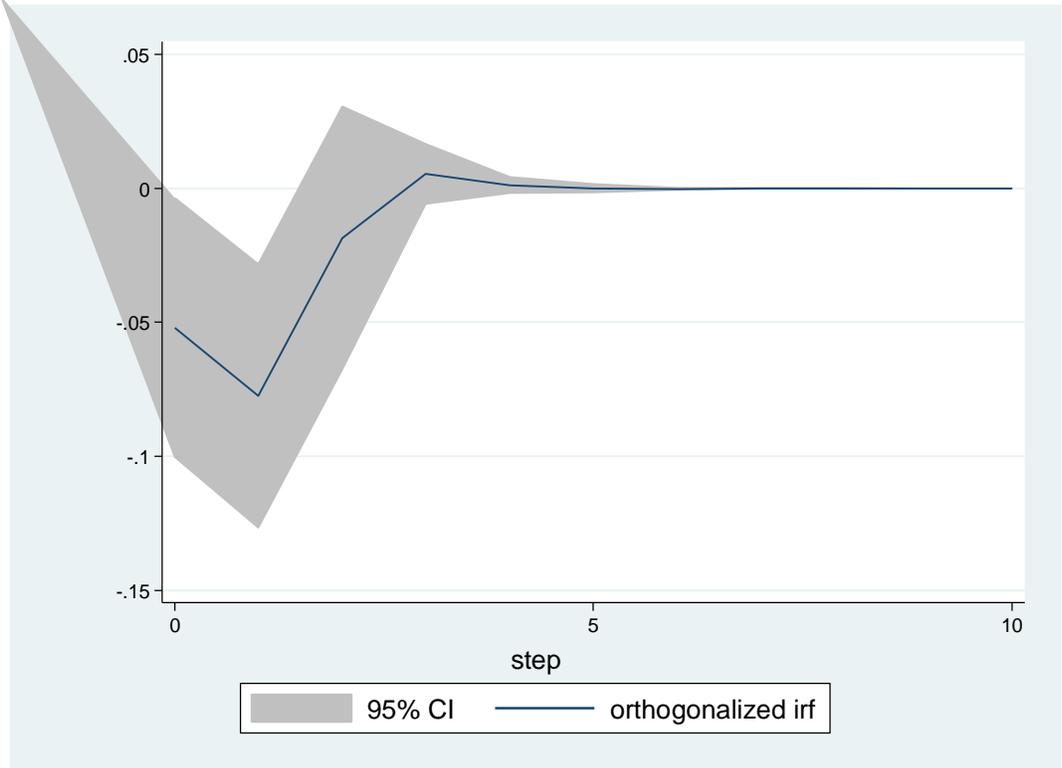
Panel B - Impulse FOMC, response VDAX



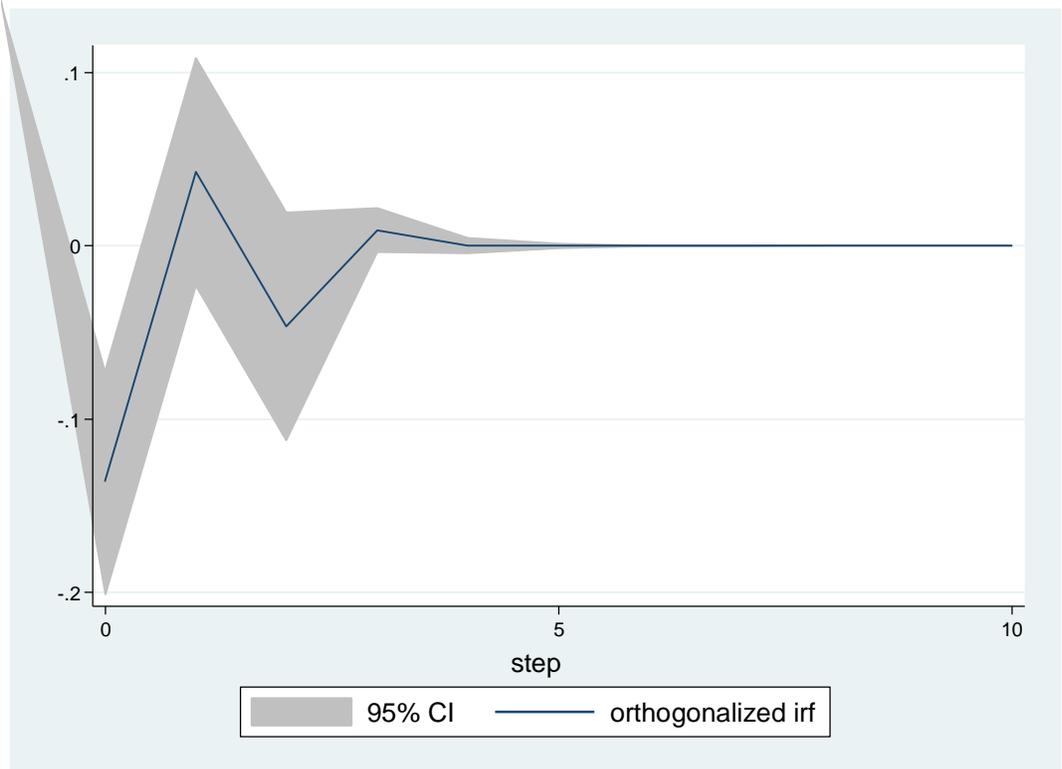
Panel C - Impulse FOMC, response VIX (sample ending in 2007)



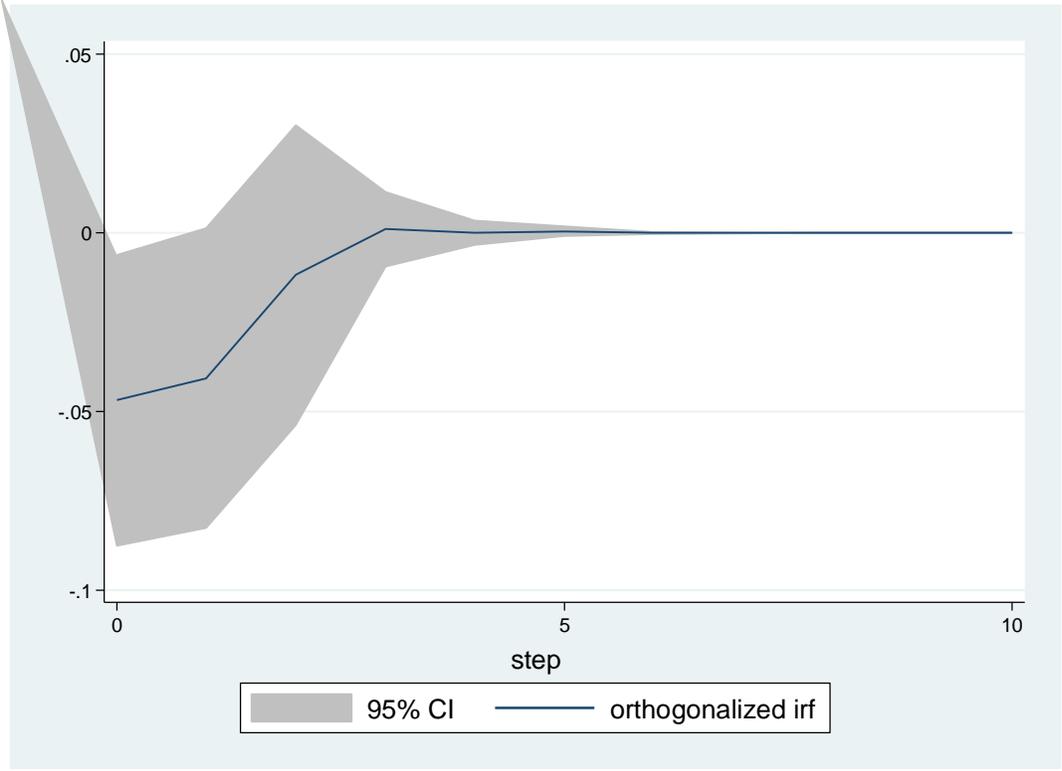
Panel D - Impulse FOMC, response VDAX (sample ending in 2007)



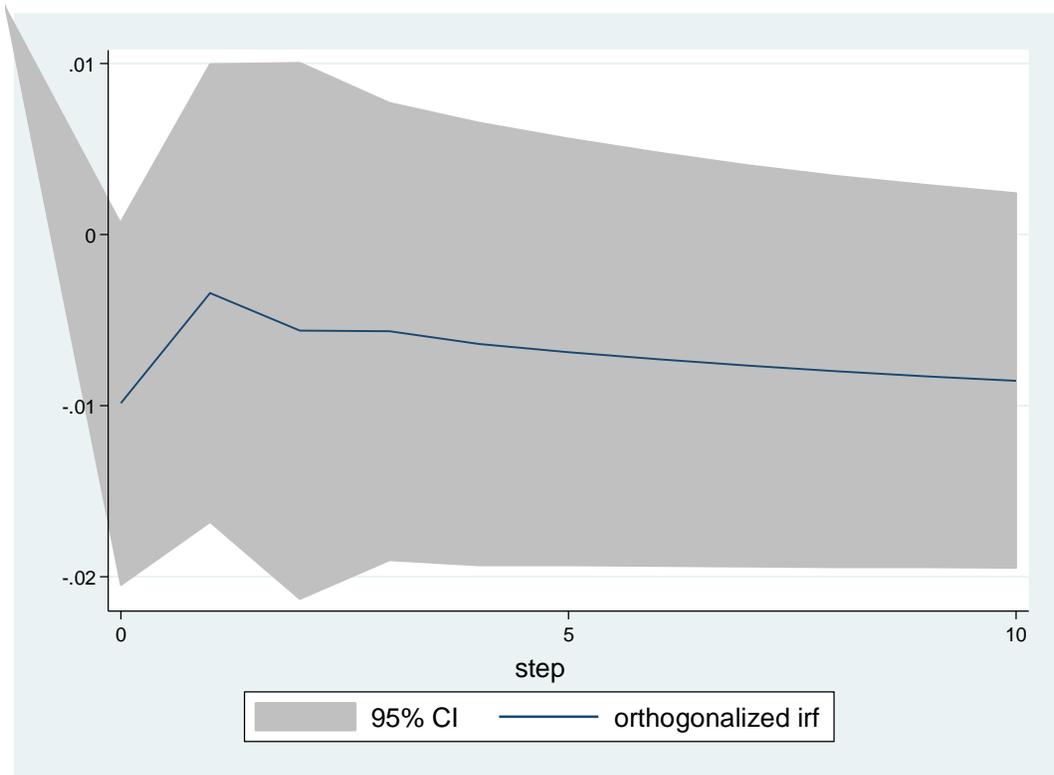
Panel E - Impulse FOMC, response VIX



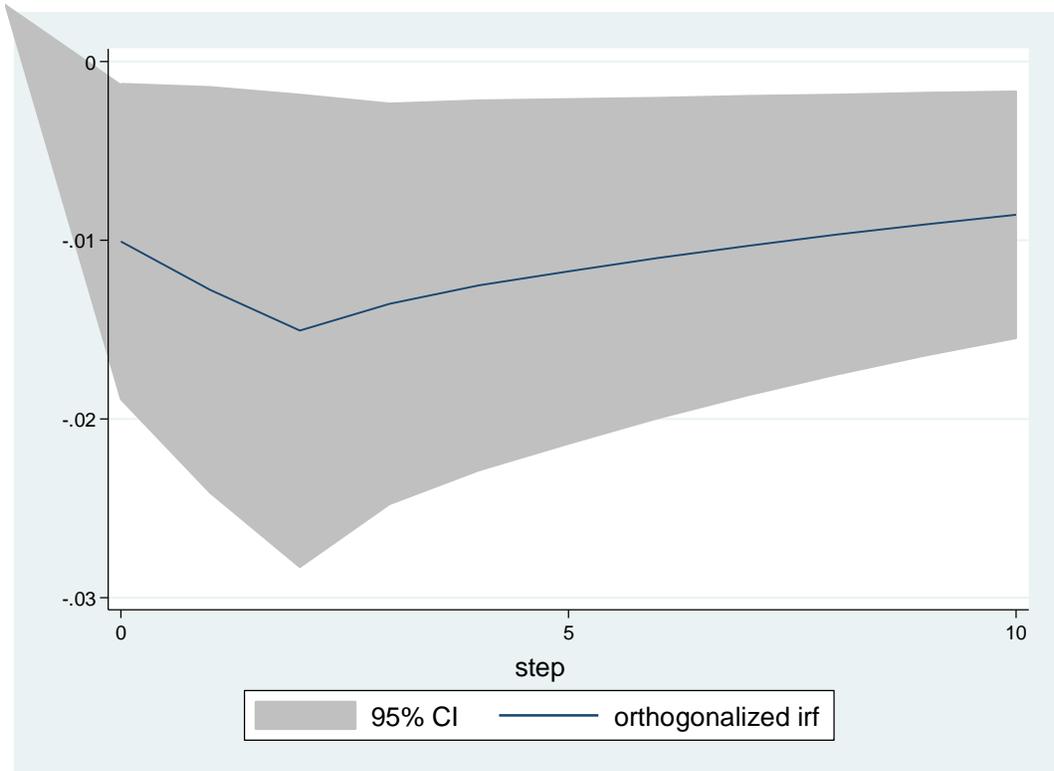
Panel F - Impulse FOMC, response VDAX



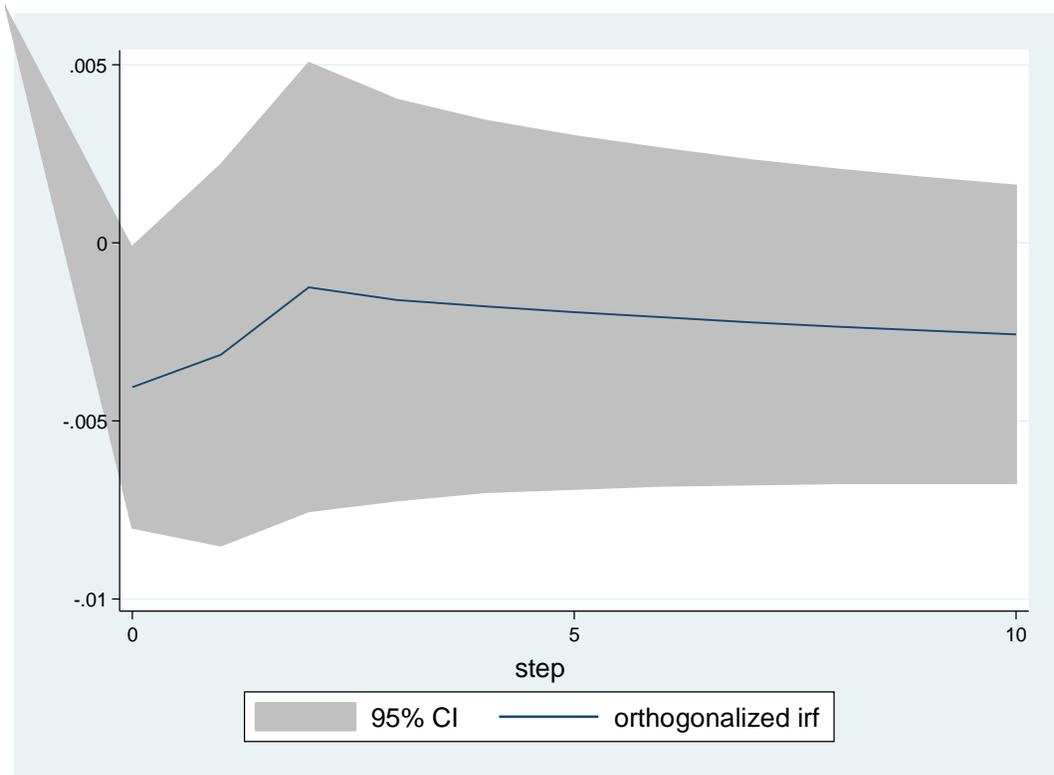
Panel G - Impulse FOMC, response U.S. uncertainty



Panel H - Impulse FOMC, response U.S. risk aversion



Panel I - Impulse FOMC, response Germany uncertainty



Panel J - Impulse FOMC, response Germany risk aversion

