Using intraday data to gauge financial market responses to Fed and ECB monetary policy decisions

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Abstract**

Using intraday data, this paper examines bond and stock market volatility reactions in the euro area and the US following their respective economies' monetary policy decisions, over a uniform sample period (April 1999 to May 2006). A strong upsurge in intraday volatility at the time of the release of the monetary policy decisions, which is more pronounced for the US financial markets following Fed monetary policy decisions. The increase in intraday volatility in the two economies surrounding monetary policy decisions can be explained by both news of the level of monetary policy and revisions in the expected future monetary policy path.

JEL classification: E52, E58, G14

**The paper has benefited from useful discussions and suggestions from Claus Brand, Michael Ehrmann, Marcel Fratzscher, Claus Greiber, Manfred Kremer, Jarkko Turunen, David Vestin and one anonymous referee. The paper is partly based on an internal ECB note which received helpful input from Francesco Drudi, Julian Von Landesberger and Philippe Moutot. The author is also grateful for comments and suggestions received when presenting the paper at the 2007 Southwestern Finance Association 2007 conference in San Diego and at the 2007 meeting of the Swiss Society of Economics and Statistics in St. Gallen. The views expressed in this paper are solely the responsibility of the author and should not be interpreted as reflecting the views of the ECB. Any remaining errors are the author's responsibility.

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1. Introduction

How do financial markets react to the release of monetary policy decisions? The answer to this question is of fundamental interest to monetary policymakers, as it provides them with information as to first, how well decisions are anticipated by market participants, and second, how these agents adjust their views about future monetary policy, output growth and inflation in response to a given decision. Such information enables a central bank to judge the immediate "success" of any decision taken, i.e. whether market participants reacted in accordance with the policymakers' intentions.

The purpose of this paper is to assess bond and stock market reactions in the euro area and the US following monetary policy decisions by the European Central Bank (ECB) and the Federal Reserve over a uniform sample period (April 1999 to May 2006). Intraday data are used, and the asset price reaction is measured in terms of derived realised volatility measures over five-minute intervals. Two different angles are viewed. First, asset price volatility on monetary policy announcement days is compared to the volatility observed on non-announcement days. Second, the volatility pattern when the central bank changes policy rates as opposed to when the monetary policy rates are left unchanged is examined. Conditional on these two events, the extent to which monetary policy target and path surprises can explain the observed volatility is analysed.

The paper contributes to the existing literature in two main aspects. First, a direct comparison of the US and euro area bond and stock market intraday volatility patterns following monetary policy decisions is novel. Second, this paper is the first to examine the influence that monetary policy target and path surprises exert on intraday financial market volatility patterns, conditional on whether monetary policy rates have been altered or not.

The paper reaches three main findings. First, intraday US and euro area stock and bond market volatility strongly increases at the time of the release of monetary policy decisions, and is particularly pronounced for the US financial markets. Second, monetary policy target and path surprises by the ECB both significantly move the euro area financial markets, whereas path surprises by the Fed have on average a larger influence on US bond and stock market volatility compared with the target surprises. Third, the yield response sensitivity for the German bond markets following an ECB monetary policy target surprise is stronger on the occasions when the monetary policy rates have been altered compared with periods when the ECB decided to leave it unchanged.

Although some tentative explanations are given in the paper, the observed discrepancy between asset price reactions in the US and in the euro area following monetary policy decisions still remains a puzzle.

The remainder of this paper is organised as follows. Section 2 presents some background and related literature, while Section 3 discusses the data used. The bond and stock market volatility reactions in the euro area and the US following their respective economies' monetary policy decisions are elaborated upon in Section 4. Section 5 concludes.

2. Background and related literature

Volatility of prices of financial assets such as stocks and bonds surrounding monetary policy decisions can be used to gauge the extent to which they contain "new news" for market participants that would lead them to revise their expectations about the future monetary policy path and/or the macroeconomic outlook. If a monetary policy decision causes market participants to revise their expectations, this should then be reflected in higher volatility of financial market prices compared with a period free of such an event.

Several differences can be noted in both the frequency and magnitude of interest rate settings between the two central banks (see Table 1). First, the ECB conducts monetary policy decisions meetings more frequently compared with the Fed. Second, the Federal Reserve has, on average, changed the interest rate more often and by larger magnitudes than the ECB over recent years.

Table 1. Fed and ECB monetary policy decisions (April 1999 – May 2006)

	Fed	ECB
Total number of events:	54	118
of which the monetary policy stance was changed	32	16
No of increases, 25 bp	21	7
No of increases, 50 bp	1	2
No of reductions, 25 bp	4	3
No of reductions, 50 bp	6	4

Note: In this study, for comparison, the data start in April 1999, as the ECB then began to release its monetary policy decisions at the regular time of 13:45 CET. All statistics exclude the 17 September 2001 observation. Unscheduled monetary policy meetings by the Federal Reserve are also excluded.

Both the degree of predictability of monetary policy decisions and the influence the decisions exert on financial asset prices have been discussed in the literature. As regards the former, many papers have shown that US monetary policy decisions in general have been well anticipated among market participants (see for example Bernanke and Kuttner (2004) and Flemming and

Piazzesi (2005)). The same holds true for the euro area, where financial markets have also been able to foresee the ECB's monetary policy decisions (see for instance Wilhelmsen and Zaghini (2005)). In addition, monetary policy communication plays a key role in enhancing short-term predictability by allowing the public to understand monetary policy decisions, a fact which has been documented in a number of studies by Ehrmann and Fratscher (2005a, 2005b and 2005c).

A number of papers have also examined the impact monetary policy decisions exert on the level of financial asset prices. Applied to US data, Gürkaynak et al. (2005) and Wongswan (2006) find that the US stock and bond markets react significantly to news about the near-term level of monetary policy and to changes in expectations of the path of monetary policy. Similarly, for the euro area, Brand et al. (2006) suggest that revised ECB monetary policy expectations have a significant and sizeable impact on the level of medium to long-term interest rates in the euro area.

Fewer studies have been conducted on volatility reactions surrounding monetary policy communications. Applied to the United States, Andersen et al. (2005) find a significant rise in US long-term bond yield volatility surrounding monetary policy decisions by the Fed. Similarly, Ehrmann and Fratzscher (2002) show that the volatility on euro area money market rates tends to be higher following Governing Council statements by the ECB. This paper fills a gap in the existing literature by conducting a direct comparison between the US and euro area bond and stock market intraday volatility pattern following monetary policy decisions.

3. Description of data used

The data used to measure financial market reactions consist of intraday data on euro area and US bond and stock prices.

Asset	Exchange
German bond futures	EUREX
US bond futures	Chicago Board of Trade
EURO STOXX 50 futures	EUREX
S&P 500 index	Chicago Mercantile Exchange

The data have been provided by TickData Inc. The dates and times of when the Fed's monetary policy decisions have become available to the public are taken from the paper by Fleming and

Piazzesi (2005).[1] The actual and expected outcome of the Fed's interest rate decisions are taken from the Bloomberg survey. The dates and times for the ECB's monetary policy decisions have been collected internally. With regards to market expectations for ECB monetary policy decisions, the expected outcome from the Reuters survey is used.

This paper derives a volatility measure V using regularly spaced five-minute intervals:

$$V_t = abs\left(100 * \log\left(\frac{P_t}{P_{t-1}}\right)\right) \tag{1}$$

where P_t is the five-minute prices of the four assets.[2]

Table 2 summarises the descriptive statistics for the four return series used in the paper. The sample mean of the asset returns are all small and, given the sample standard deviations, not statistically different from zero. The returns are obviously not normally distributed given the large magnitudes of the skewness and kurtosis statistics.

Table 2. Descriptive statistics, five-minute returns

	German bond futures	US bond futures	EURO STOXX 50 futures	S&P 500 index
Mean	0.0001	0.0001	-0.0001	-0.0003
Standard deviation	0.0258	0.0398	0.1252	0.1048
Skewness	-0.24	-0.30	-0.57	0.16
Kurtosis	17.73	55.07	37.82	12.43

Note: April 1999 to May 2006. The overnight returns are omitted when computing the descriptive statistics

Volatility is normally not constant throughout a trading day, but tends to be higher at opening and closing hours than during the middle of a trading day. This feature has to be taken into account when gauging whether policy decisions by central banks induce elevated price fluctuations. Figures 1 A–D below show the average five-minute volatility during the trading days for the US and euro area bond and stock series.[3]

[1] With the exception of the 2005 and 2006 decisions, which are taken from Bloomberg.

[2] As an alternative the squared return could also be used as a measure of realised intraday volatility. This measure does not however change the interpretations.

[3] Over the sample under consideration, the trading hours of the EURO STOXX 50 futures and the German Bond futures have not remained constant. The intraday volatility patterns shown in Figures 1A and 1B are therefore based only on the business hours where trading have occurred throughout the entire sample.

Figure 1A: German intraday bond market volatility (April 1999 – May 2006, 8.00 – 19.00 Central European time zone)

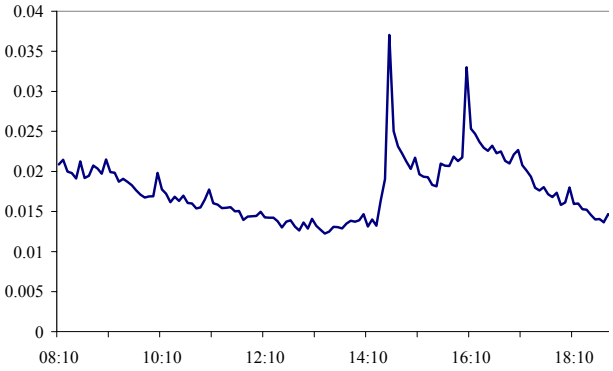
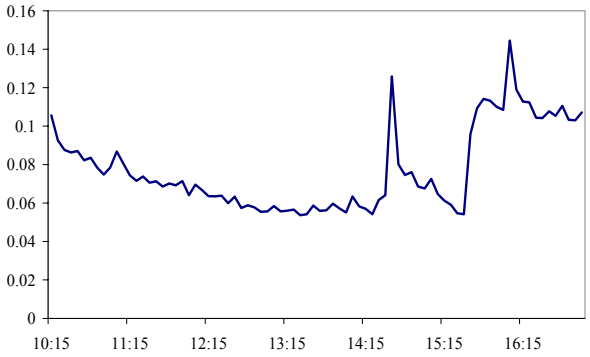


Figure 1B. Euro area intraday stock market volatility (April 1999 – May 2006, 10.15 – 17.00 Central European time zone)



The German bond and euro area STOXX future contracts display a number of interesting intraday features. First, volatility in general tends to be higher at the opening and closing hours of the trading day. At opening hours, prices normally have to adjust to new information, which may induce heightened price fluctuations. Higher volatility close to the end of the trading day is probably linked to some investors closing their trading books to avoid having open positions overnight. Second, the two spikes – occurring at 14:30 and 16:00 (Central European time) - correspond to the release of several important US macro announcements, such as the Non-farm payroll, Producer Price Index, Retail Sales, Consumer Price Index, ISM and Consumer Confidence. In addition, at 14:30 on the first Thursday of each month, the ECB holds a press conference at which information about the considerations concerning the monetary policy decision is conveyed. Third, the level of intraday volatility is higher for the euro area stock markets compared to the German bond future markets, which is something that is also observed for much lower frequencies such as daily data.

Figure 1C: US intraday bond market volatility (April 1999 – May 2006, 07.20 – 14.00 Central time zone)

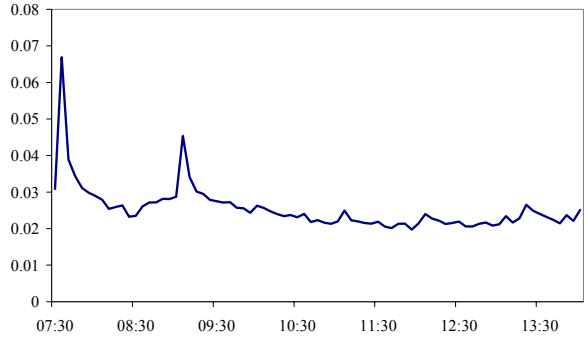
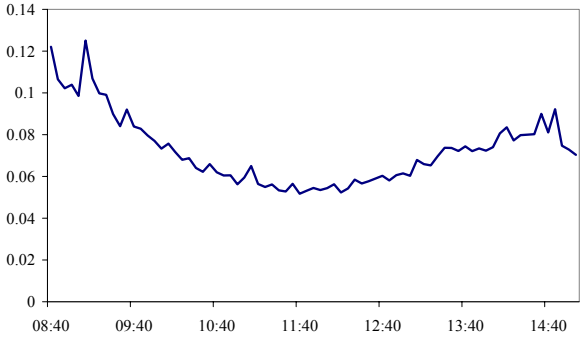


Figure 1D. US intraday stock market volatility (April 1999 – May 2006, 08.30 – 15.00 Central time zone)



The US bond and stock markets show a broadly similar pattern to their European counterparts. These two assets are traded on the Chicago Board of Trade (CBT), and the spikes at 07:30 and 9:00 mainly arise from releases of the above-reported US macro announcements. Overall, bond

and stock markets on both sides of the Atlantic seem to display generally similar levels of volatility.

4. Asset price reactions following monetary policy decisions by the ECB and the Fed

The following three subsections examine financial market intraday volatility patterns surrounding monetary policy decisions by the ECB and the Fed. Target and path surprises implicitly embedded in the monetary policy decisions are computed. These surprises are used as explanatory variables to the observed intraday pattern. In Section 4.1 the general volatility pattern is analysed. Section 4.2 provides some tentative explanations for the observed discrepancy between asset price reaction in the US and in the euro area following monetary policy decisions. Section 4.3 regresses the general intraday volatility pattern on monetary target and path surprises. Section 4.4 evaluates if the volatility pattern in financial markets differs depending on if monetary policy rates have been altered or not.

4.1 General intraday volatility pattern surrounding monetary policy decisions

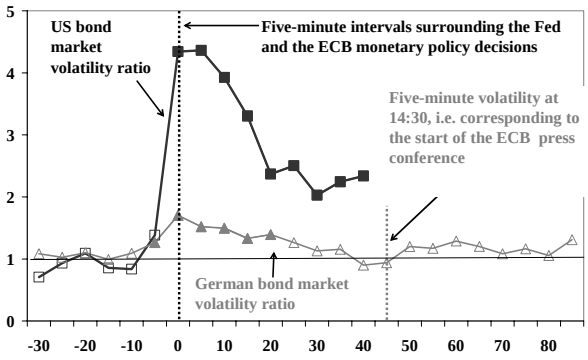
Figures 2 and 3 display the ratio between five-minute bond and stock market volatility surrounding monetary policy decisions by the Fed and the ECB respectively, and the average five-minute volatility on the same weekdays and the same times but on non-announcement days, thereby controlling for both intraday and 'weekday' effects. A ratio above one can be interpreted as the monetary policy decisions inducing "higher than normal" volatility. As regards the timing, the Fed's interest rate decisions are usually released at 13:15, and the ECB's interest rate decisions at 13:45 (both local times).

It should be noted that the Fed's interest decisions, are also accompanied by a statement in which the outlook for the future monetary policy stance is conveyed.[4] This implies that, particularly for the Federal Reserve, there are two potential sources of new information arising from the interest rate decisions, a target surprise and a path surprise. The target surprise can be defined as the degree to which market participants have been able to anticipate the actual monetary policy decisions. The path surprise instead measures to what degree market participants have revised the future expected monetary policy path following the actual decision and/or monetary policy statements.

[4] The trading of the US 10-year Treasury future note closes at 14:00 Central Time, i.e. 45 minutes after the Fed's interest rate decisions. To enable a consistent comparison between the US bond and stock markets, the volatility window spans between 30 minutes before to 40 minutes after the decisions for these two markets.

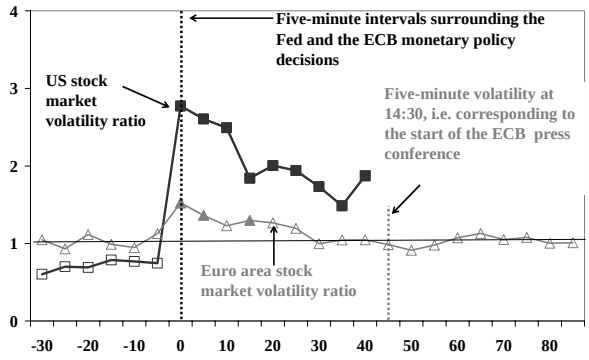
In contrast to the Fed, the ECB's interest decisions and statements are released to the public at separate times. Announcements of the actual outcome of monetary policy decisions are released at 13:45 local time. However, details about the economic and monetary analyses underlying each interest rate decision are instead conveyed in the Introductory Statement read by the ECB President 45 minutes later. In the figures below, the volatility pattern for the euro area bond and stock markets is therefore extended to include any financial market movements that take place surrounding the press conference as well.

Figure 2: US and German bond market volatility ratio surrounding monetary policy decisions by the Fed and the ECB (April 1999 – May 2006)**.**



Note: The volatility measures are calculated as the ratio between i) five-minute intraday volatility on the US and German long-term bond futures markets surrounding interest rate decisions by the Federal Reserve and the ECB, and ii) "normal volatility", the latter computed as the average absolute returns on the same week-days and same times but on non-announcement days. Using one-sided t-test, the filled dots implies that the ratio is significantly higher than 1 and empty dots that the ratio cannot be deemed as exceeding 1.

Figure 3. US and euro area stock market volatility ratio surrounding monetary policy decisions by the Fed and the ECB (April 1999 – May 2006)**.**



Note: The volatility measures are calculated as the ratio between i) five-minute intraday volatility on the US (S&P 500) and euro area (EURO STOXX) stock markets surrounding interest rate decisions by the Federal Reserve and the ECB and ii) "normal volatility", the latter computed as the average absolute returns on the same week-days and same times but on non-announcement days. Using one-sided t-test, the filled dots implies that the ratio is significantly higher than 1 and empty dots that the ratio cannot be deemed as exceeding 1.

Four interesting features can be inferred from the two figures. First, monetary policy decisions on both sides of the Atlantic tend to induce significantly "higher than normal" volatility on their respective economies' bond and stock markets. Second, this feature seems to be particularly pronounced for the US bond and stock markets following interest rate decisions by the Fed. Third, some volatility persistence can be observed, in particular for the US bond and stock markets, where "excess" volatility can be noted up to 40 minutes after the decisions have taken place. Fourth, in the euro area, the Introductory Statement read by the ECB President induces somewhat "higher than normal" volatility on the euro area bond market.

Potentially, any interpretations on the basis of Figures 2 and 3 could be spurious if important macro announcements were systematically released on the same days and at the same times as the monetary policy decisions of the Federal Reserve and the ECB. To examine this in detail, 43 US and euro area macro announcements were collected and tested to establish whether they were made within a 60-minute window of the monetary policy announcements by the two central

banks.[5] The results of this examination suggested that none of the announcements under consideration occurred at the same time as the Federal Reserve decisions. The monetary policy decisions of the ECB coincided with the release of macro statistics on only two occasions, and both concerned the German CPI statistics released on 23 March 2001 and 26 April 2001. These two instances of concurrence should not, however, distort the interpretation, as previous announcement papers have found that the German CPI does not move the euro area financial markets in any significant way – see Andersson et al. (2006) and Ehrmann and Fratzscher (2003).

The small number of macro releases occurring at the time of the monetary policy decisions suggests that the observed upsurge in volatility is prompted by from the actual decisions and does not reflect market reactions to macro news. In stark contrast, the ECB press conference is usually held at times of important US macro announcements – in particular, the weekly initial jobless claims – making the volatility ratio difficult to interpret.[6] An analysis of the ECB press conference is, however, outside the scope of this paper, which purely concentrates on market reaction to the actual decisions.

The average reaction to asset prices shown in Figures 2 and 3 may not be static but rather changing over time. There are several reasons why price reaction can change over time. Andersson et al. (2006) suggest that policymakers can sometimes signal a preference for one or more macroeconomic indicators as input for their policy decisions. In addition, some macroeconomic releases may behave in an unusual manner at a certain point in the business cycle, which can in turn have an impact on monetary policy decisions. To check for potential time variation, yearly averages were computed. Appendix A shows the yearly volatility ratios for the five-minute periods immediately surrounding and 30 minutes ahead of the monetary policy decisions respectively. The yearly averages are broadly similar across the years, suggesting that the pattern shown in Figures 2 and 3 can be deemed a general feature.

4.2 Why intraday asset price movements are stronger in the US than in the euro area - some tentative explanations

The finding that there is a higher intraday asset price reaction in the US than in the euro area following their respective economies' monetary policy decisions is, interesting, but somewhat

[5] See Andersson et al. (2006), Table 1, where the 43 announcements are listed.

[6] Over the sample April 1999 to May 2006, the Initial Jobless Claims was released at 106 times within a 60 minute window surrounding the 14.30 Press Conference. Similarly the release of the Philadelphia Fed Index occurred five times, Durable Goods two times, Business Inventories three times, Retail Sales at four times, CPI at two times, Advanced GDP at three times, GDP Preliminary at two times and GDP final at two times.

puzzling. The three best possible explanations for this discrepancy are as follows. First, potentially "more" information becomes available during the release of Fed interest rate decisions. In this respect, even though the actual decisions by the Fed have been anticipated by the markets, heightened volatility could still arise given an unexpected change in the tone of the accompanying statement. An interesting example of this took place in January 2004 when the Fed, as expected, held the policy rate unchanged (at 1 percent) but at the same time significantly changed its wording in the statement following the decision. As the Wall Street Journal wrote in its market commentary column the day after the decision; "*While investors had expected the Fed's decision to keep short-term interest rates on hold at 1%, the absence of the "considerable period" phrasing, used since August 2003 to describe how long the bank would keep rates low, caught market participants off guard […] Prices plummeted in the immediate aftermath of the Fed's decision and the yield on the 10-year note shot up to 4.26%*".

Second, the announcement literature which examines the impact on financial prices surrounding important macro economic announcements, has in general found stronger asset price sensitivity to US news compared with euro area news, partly owing to the view that the US is currently perceived among investors as the main engine of global growth.[7]

Third, related liquidity and volume issues cannot be excluded as potentially important factors behind the apparent differences in observed asset price volatility across the Atlantic. This in turn can be divided into two subcategories, where the first concerns uncertainty regarding the timing of the decisions, and the second the fact that data on volumes may reveal presence of differences of beliefs among traders. As regards the first subcategory, Flemming and Piazzesi (2005) suggest that some uncertainty exists about the exact release of the US monetary policy announcements, which in turn have an impact on intraday market pricing in the US Treasury markets. In particular, liquidity tends to be low if an announcement is released minutes later than the expected 13:15. This in turn can trigger higher price sensitivity when the actual announcements are released. In contrast, timing uncertainty for the ECB's monetary policy decisions should not exist given the exact 13:45 release.

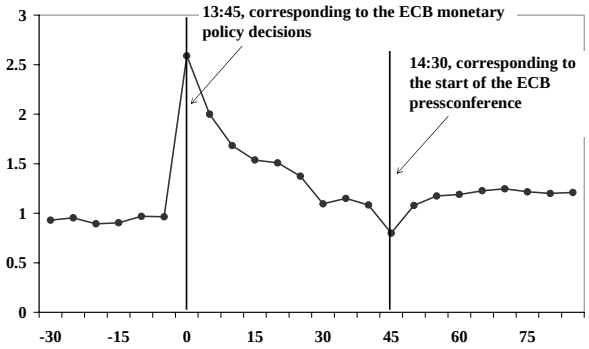
For the second subcategory, a sharp increase in volume may reveal higher levels of differences in opinions among traders which in turn can results in higher financial market volatility, everything else held equal, see Harris and Raviv (1993). Empirical studies have found that trading volume increases at the time of macroeconomic announcements and monetary policy

[7] See for instance Andersson et. al. (2006), Ehrmann and Fratscher (2003) and Goldberg and Leonard (2003).

decisions.[8] Recently, Gropp and Kadareja (2006) test the hypothesis as to whether differences in opinions among traders can induce heightened intraday volatility, applied on European banks stock data. The annual report is used as a measure of the precision of the information available about banks. The authors find, in line with theory, that intraday volatility of the banks' stocks following a monetary policy shock becomes larger the longer the lag is since the annual report was released.

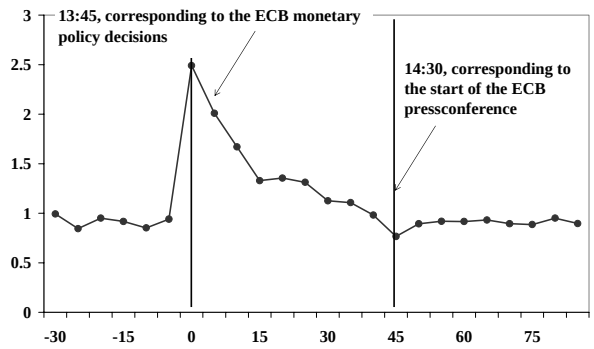
The intraday data used in this study do not unfortunately contain volume information for the sample under consideration. However, the number of transactions within a specified time interval should closely track the volume in the markets, according to the data provider. For the series used in this paper, this data type is available for the German bond markets, the euro area stock markets and the US bond markets. Figures 4 - 6 replicate the volatility ratio calculations above and display the ratio between the amount of transactions within five-minute intervals surrounding monetary policy decisions by the ECB and the Fed respectively, and the average five-minute transactions on the same weekdays and the same times but on non-announcement days.

Figure 4: Volume approximation for the German bond markets surrounding monetary policy decisions by the ECB (April 1999 – May 2006)**.**



Note: The volume approximations are calculated as the ratio between i) the number of transactions in the five-minute intervals for the German long-term bond futures markets surrounding interest rate decisions by the ECB, and ii) the number of transactions on the same days and same times but on non-announcement days. The intervals span 30 minutes before to 85 minutes after the decisions for the ECB.

Figure 5: Volume approximation for the German stock markets surrounding monetary policy decisions by the ECB (April 1999 – May 2006)**.**



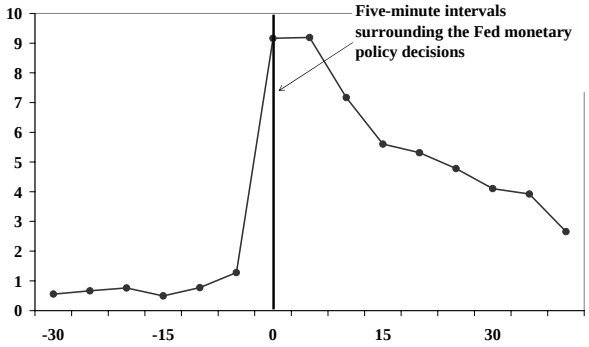
Note: The volume approximations are calculated as the ratio between i) the number of transactions in the five-minute intervals for the euro area (EURO STOXX) stock markets surrounding interest rate decisions by the ECB, and ii) the number of transactions on the same days and same times but on non-announcement days. The intervals span 30 minutes before to 85 minutes after the decisions for the ECB.

The volume approximations for the German bond markets and the euro area stock markets reveal a similar picture and to some extent mimic the observed spikes in volatility shown in Figures 2 and 3. Overall the number of transactions in the two markets on average is more than double at

[8] See for instance Balduzzi et. al. (2001) applied on economic news and Flemming and Piazzesi (2005) applied on Fed's monetary policy decisions.

the time of the ECB's monetary policy decisions compared with the number of transactions during Thursdays where there is no ECB monetary policy meeting.

Figure 6: Volume approximation for the US bond markets surrounding monetary policy decisions by the Fed (July 2003 – May 2006)**.**



Note: The volume approximations are calculated as the ratio between i) the number of transactions in the five-minute intervals for the US bond markets surrounding interest rate decisions by the Fed, and ii) the number of transactions on the same days and same times but on non-announcement days. The intervals span 30 minutes before to 40 minutes after the decisions for the Fed.

A similar calculation was conducted for the US Treasury markets. The sample size is however shorter than for the European assets above. The reason is that up until June 2003, only the number of so-called pit trades is available. From July 2003 and onwards the electronic trades were also included, making a comparison with the EUREX traded assets more accurate for this latter period. As seen in the figure, nearly ten times as many trades were conducted during the time of the Fed monetary policy decisions compared with the number of transactions during the same days but with no Fed monetary policy meeting.

Thus, it cannot be excluded that in the US markets, there are more investors with differences in opinions from the mean investor than in the euro area, which in turn may play a role in explaining the marked differences in intraday volatility.

4.3 Evaluating the impact monetary policy surprises have on intraday financial market volatility

All in all, it is reasonable to assume that the arrival of new information could heighten volatility surrounding monetary policy releases. To assess this in more detail, this and the next subsection will focus on the strong upturn observed at the time "0" in Figures 2 and 3, which corresponds to the realized asset price volatility immediately surrounding the monetary policy decisions by the Fed and the ECB respectively. The idea is to analyse to what extent the upswing in volatility can be explained by monetary policy surprises.

Monetary policy surprises are divided into two types: target surprises and path surprises. A target surprise is defined as the degree to which market participants have been able to anticipate the actual monetary policy decisions, whereas a path surprise measures the degree to which market participants have revised the future expected monetary policy path following the actual decision and/or monetary policy statements.

The target surprise can be derived from either available surveys or financial market prices. Both measures have their pros and cons. The main advantage of the former is that they in principle should contain the "true" mean expectations about upcoming future monetary policy decisions. On the other hand, financial market expectations benefit from the fact that they are available at a much higher frequency compared with survey-based measures. But, as shown by Piazzesi and Swanson (2004) and applied to US data, expectations derived from the financial markets could contain risk premia and market noise, which may blur the interpretation.

This paper will make uses a survey-based measure for the target surprise which represents the difference between the actual outcomes and the mean of analysts' expectations concerning the outcomes of the monetary policy decisions. This measure is chosen as the methodology used is identical for both the euro area and the US. As a cross-check, Appendix B shows the target surprise used in this paper compared with market-based measures employed in some earlier studies. Overall the two measures exhibit very similar patterns which are also confirmed by the estimated correlation coefficients of 0.75 for the ECB target surprises, and 0.8 for the Fed target surprises. Thus, the survey-based measure should therefore be a good indicator of the target surprise as perceived among investors.

The path surprise component employed in this study is derived in line with Gürkaynak et. al. (2005):

$$\Delta f_{t-30,t} = \alpha + \beta * TS_t + PS_t \tag{2}$$

where $\Delta f_{t-30,t}$ represents the 30-minute intraday changes in the expected three-month interest rate in six months' time surrounding the monetary policy decisions (Euribor and Eurodollar future contracts for the euro area and the US respectively). The *TS* represents the target surprise component as described above. The innovation from the regression in Equation (2) is defined as the path surprise (*PS*). Given that the purpose of this exercise is to examine the effects on financial markets surrounding the actual monetary policy decisions, potential information about future ECB monetary policy conveyed in the Introductory Statement at the ECB press conference is not included in the derived ECB path surprises.

To evaluate how the changes in the volatility ratios surrounding the monetary policy decisions by the Fed and the ECB as shown in Figures 2 and 3 can be explained by the target and/or path surprises, the following regression set-up is used:

$$\Delta Volratio_{t-30,t} = \alpha + \beta_1 * Abs(TS) + \beta_2 Abs(PS) + \varepsilon_t \tag{3}$$

The *Abs(TS)* and *Abs(PS)* variables in eq. (3) correspond to the absolute values of the target and the path surprises respectively. The $\Delta Volratio_{t-30,t}$ represents the difference between the observed volatility ratio in the period immediately surrounding the monetary policy decisions and the volatility ratio 30 minutes ahead of the decisions.[9] The choice of the intraday impact relative to that of non-announcement days as a dependent variable is in line with the procedure by Ederington and Lee (1993), see Appendix C. Table 3 below outlines the results of the regression.

Table 3

Dependent variable $\Delta Volratio_{t-30,t}$	Constant	Abs(TS)	Abs(PS)	R^2	Corr(Abs(TS), Abs(PS))
(i) German bond markets	-0.34* (0.18)	0.22*** (0.09)	0.29 (0.24)	0.38	0.56
(ii) Euro area stock markets	-0.64*** (0.13)	0.06* (0.04)	0.90*** (0.12)	0.38	0.56
(i) US bond markets	1.25* (0.70)	-0.10 (0.09)	0.77*** (0.20)	0.40	0.10
(ii) US stock markets	0.82 (0.68)	-0.05 (0.06)	0.43** (0.21)	0.20	0.10

Note: The regression specifications are: $\Delta Volratio_{-30,\,t} = \alpha_{1,t} + \beta_1 * Abs(TS) + \beta_2 * Abs(PS) + \varepsilon_t$ *for the four asset classes respectively. The Volratio is defined as the ratio between volatility on monetary policy days and volatility on the same weekdays and hours but when no monetary policy decision are taking place.* $\Delta Volratiot_{-30,t}$ *represents the 30-minute changes in this volatility ratio surrounding the decisions. Abs(TS) and Abs(PS) correspond to the absolute values of the target and the path surprises respectively. Newey-West heteroskedasticity-consistent standard errors are in parentheses. One, two and three asterisks denote significance at the 10 percent, 5 percent, and 1 percent levels, respectively.*

Three notable features can be inferred. First, a monetary policy target surprise induces significantly higher than normal volatility in the euro area bond and stock markets. Second, the ECB path surprises exert a significant impact on the euro area stock markets. Third, in the US the results suggest that path surprises on average have a larger influence on the US bond and stock market volatility compared with target surprises.

One potential problem with the Equation (3) regression specification could be presence of multicollinearity between the explanatory variables. However, the classic symptoms of multicollinearity, such as i) high R^2 and few significant t-ratios and ii) high pair-wise correlations

[9] As Appendix C shows, the changes in the volatility ratios mostly hover in positive territory across the four markets. However, on a few occasions the observed volatility ratio is slightly lower at the time of the monetary policy decisions compared with the volatility ratio observed 30 minutes ahead of the announcements. A closer inspection of the data suggests that this can occur on occasions when the surprise components are small in magnitude.

between the regressors, cannot be detected. This suggests that it should be possible to isolate the individual impact that the target and the path surprises have on financial market prices.

4.4 Impact of monetary policy surprises on intraday financial market volatility, conditional on whether policy rates have been altered or not

One possible source for the different reaction patterns between the two economies could be that the markets react differently depending on whether monetary policy rates are changed or not. In this regard, monetary policy moves usually take place when market uncertainty can be expected to be higher than normal, such as risks of very low inflation or outright deflation,[10] or when there is uncertainty regarding an expected future strengthening of economic activity.[11] Furthermore, some interest rate moves take place during extreme market conditions. One example was the joint interest rate reduction of 50 basis points by the ECB and the Fed in the aftermath of the September 11 terrorist attack. Using daily data, Wilhelmsen and Zaghini (2005) find less predictability – the latter measured as the standard deviation in money market rates – when a modification in the official policy rate is decided on, compared with days when the monetary policy authority does not change the official rate. This pattern holds true for all 14 economies included in their study.

Appendix D decomposes the volatility pattern between monetary policy events when policy rates are adjusted, and when they remained unchanged. As seen in Figures D1 and D2, the elevated volatility, in euro area bond and stock markets during monetary policy announcements seems to be related to the periods when the ECB decided to change rates. In contrast, monetary policy decisions by the Fed induce elevated bond and stock market volatility independent of the outcome (see Figures D3 and D4).

One possible explanation for the different pattern of behaviour across the two markets can be related to an asymmetry in the monetary policy surprises, i.e. that they are higher in magnitude when the ECB changes rates compared with no change events. Table 4 summarises the mean and the standard deviation of the surprises conditional on whether rates have been altered or not. Overall, the mean of the (absolute) surprises is somewhat higher in both economies (and for both

[10] An example of this was the 25 basis point rate reduction by the Fed in June 2003. The accompanying statement justified the decision stating: "*The Committee perceives that the upside and downside risks to the attainment of sustainable growth for the next few quarters are roughly equal. In contrast, the probability, though minor, of an unwelcome substantial fall in inflation exceeds that of a pickup in inflation from its already low level.*"

[11] An example of this was the increase of 25 basis points by the ECB in December 2005. The accompanying introductory statement explained why: "*On the basis of our regular economic and monetary analyses, we have decided to increase the key ECB interest rates by 25 basis points, after two and a half years of maintaining rates at historically low levels. Looking ahead, on the external side, ongoing growth in global demand should support euro area exports, while on the domestic side, investment should benefit from continued favourable financing conditions and the robust growth of corporate earnings.*"

categories of surprises) when rates were changed compared with those meetings when they remained unchanged. However, the difference is particularly pronounced for the computed target surprise of the ECB, which could partly explain why asset price volatility in the euro area is higher when policy rates are adjusted compared with periods when policy rates are left unchanged.

Table 4. Summary statistics of the monetary policy surprises, in basis points

	ECB		Fed	
	Target surprise	Path surprise	Target surprise	Path surprise
Mean of the absolute surprises				
Total sample	3.0	1.0	2.5	3.4
When rates were left unchanged	1.5	0.6	0.6	2.8
When rates were changed	13.0	1.4	4.0	4.0
Standard deviation of the absolute surprises				
Total sample	5.6	1.4	5.6	3.2
When rates were left unchanged	3.2	0.5	1.0	2.6
When rates were changed	7.7	1.9	7.1	3.5

To examine the asymmetric issue further, a slight modification of the regression set-up in Equation (3) is used:

$$\Delta Volratio_{t-30,t} = \alpha_1 + \alpha_2 D + \beta_{1,t} X + \beta_{2,t} DX + \varepsilon_t \quad (4)$$

where D is a dummy variable which takes on a value of 1 when interest rates are changed, and a value of 0 if they are unchanged. The matrix X corresponds to the independent variables (i.e. the absolute values of the target and path surprises). Equation (4) has the following implications:

Mean volatility when $D = 0$ (i.e. monetary policy rates unchanged)

$$E(\Delta Volratio | D = 0, X) = \alpha_1 + \beta_1 X \quad (5)$$

Mean volatility when $D = 1$ (i.e. monetary policy rates altered)

$$E(\Delta Volratio | D = 1, X) = (\alpha_1 + \alpha_2) + (\beta_1 + \beta_2) X \quad (6)$$

Four different possibilities can be tested using this set-up:

1) $\alpha_1 = \alpha_2$ and or $\beta_1 = \beta_2$; the two regressions are the same.

2) $\alpha_1 \neq \alpha_2$ and or $\beta_1 = \beta_2$; the two regressions differ in the intercept.

3) $\alpha_1 = \alpha_2$ and or $\beta_1 \neq \beta_2$; the two regressions have the same intercept but different slopes.

4) $\alpha_1 \neq \alpha_2$ and or $\beta_1 \neq \beta_2$; the two regressions have different intercepts and different slopes.

Thus, a significantly positive α_2 coefficient suggests that volatility on average is higher when monetary policy rates are altered compared with periods when rates are left unchanged. In the same vein, a significant positive coefficient of β_2 implies stronger asset price sensitivity when monetary policy rates are altered compared with periods when rates are left unchanged. Of particular interest is to test the significance of α_2 and/or β_2 for the German bond markets and the euro area stock markets. This could shed further light on the factors driving the elevated volatility following alterations of the ECB's monetary policy rates, as shown in Appendix D. Table 5 outlines the results of the regressions after dropping the non-significant variables from Equation (3).

The table reveals that asset price sensitivity is not linear for the German bond markets and the euro area stock markets. Instead, the volatility pattern is different depending on if policy rates have been altered or not. For the German bond market, the null-hypothesis of equal slope coefficient can be rejected at the five percent level. For the euro area stock markets the null-hypothesis of equal slope coefficient can be also be rejected, but only at the ten percent level. As regards the US, no differences in the asset price reaction following either scenario can be detected.

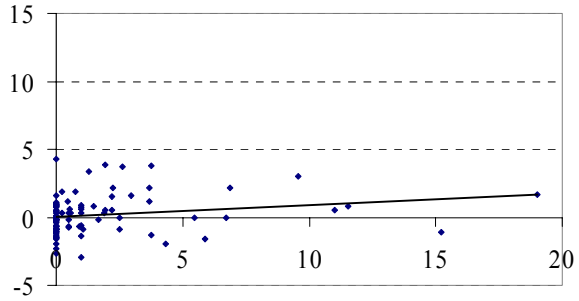
Table 5

Dependent variable $\Delta Volratio_{t-30,t}$	Constant	Constant | D=1	Abs(TS)	Abs(TS) | D=1	Abs(PS)	Abs(PS) | D=1
(i) German bond markets	0.00 (0.15)	-0.36 (1.58)	0.09* (0.05)	**0.25**** **(0.11)**		
(ii) Euro area stock markets	-0.39** (0.19)	0.29 (1.00)	0.03 (0.06)	0.00 (0.08)	0.56*** (0.20)	**0.43*** **(0.26)**
(i) US bond markets	1.83 (1.14)	-1.40 (1.35)			0.60*** (0.22)	0.24 (0.34)
(ii) US stock markets	0.81 (0.88)	-0.40 (0.99)			0.59*** (0.19)	-0.20 (0.19)

Note: The regression specification follows the one specified in Equation (4) to test whether price sensitivity differs during periods when the central banks change policy rates. Newey-West heteroskedasticity-consistent standard errors are in parentheses. One, two and three asterisks denote significance at the 10 percent, 5 percent and 1 percent levels, respectively.

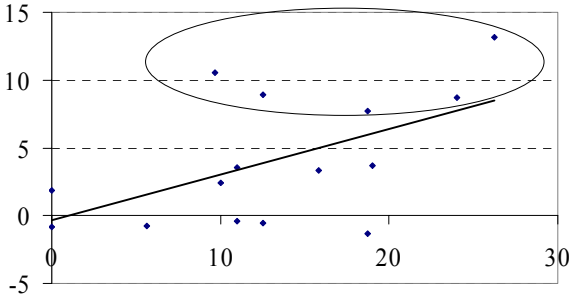
Figures 7 and 8 visualise the differences in asset price pattern for the German bond market volatility ratio by scatter-plotting the volatility ratios against the target surprises.

Figure 7: Changes in German bond volatility ratio *(y-axis)* **and the ECB monetary policy target surprise** *(x-axis)***. Sample includes only observations when the ECB left monetary policy rates unchanged** *(April 1999 – May 2006)*



Note: Details of how the bond volatility ratio ($\Delta Volratio_{t-30,t}$) is calculated are shown in Appendix C.

Figure 8. Changes in German bond volatility ratio *(y-axis)* **and the ECB monetary policy target surprise** *(x-axis)***. Sample includes only observations when the ECB altered monetary policy rates** *(April 1999 – May 2006)*



Note: Details of how the bond volatility ratio ($\Delta Volratio_{t-30,t}$) is calculated are shown in Appendix C.

The figures clearly show that intraday volatility tend to be of larger magnitude (see Figure 8) when interest rates are changed than when they are not changed (see Figure 7), even when the surprise are of the same magnitudes. Comments from the financial press after the interest rate decisions highlighted in Figure 8 seem to suggest that the interest rate decisions took the markets by surprise during these occasions (see Appendix E).

5. Concluding remarks

Monetary policy decisions and the expected path of future policy rates strongly influence asset prices. Among the worlds' leading central banks, monetary policy actions by the Federal Reserve and the ECB are particularly monitored among investors as they control short-term interest rates in the two major economies. This paper tries to shed some light on the link between monetary policy decisions and asset price reactions. Using long time series of intraday data, US and euro area bond and stock market intraday volatility patterns surrounding monetary policy decisions by the two central banks are derived. Overall both the ECB and the Fed decisions induce an upsurge in intraday volatility on their respective bond and stock markets. The reaction on US financial markets following the Fed's decisions are more pronounced compared with the reaction the ECB exerts on the German bond markets and the euro area stock markets. Although this paper provides some tentative explanations that partly explain this discrepancy between the two markets, their decoupling patterns still remain a puzzle.

As a next step, monetary policy target and path surprises are used as explanatory variables when explaining these upsurges in volatility. Monetary policy surprises are suitable candidates for this purpose, as only new news should in theory affect asset prices. The paper finds that monetary

policy target surprises by the ECB significantly induce higher than normal volatility in the euro area financial markets. In addition, path surprises by the Fed have on average a larger influence on US bond and stock market volatility compared with target surprises.

When decomposing the asset price reaction based on whether monetary policy rates have been altered or not, the level of intraday volatility of the German bond markets and the euro area stock markets is found to be higher when interest rates are changed. This can probably be linked to two factors. First, monetary policy surprises are on average of a larger magnitude when the ECB decides to change rates compared with meetings which resulted in no change. Second, there is a non-linear asset volatility price sensitivity – which is particularly pronounced for the German bond markets - in that bond markets react significantly stronger to a given target surprise by the ECB when there has been a change in the official rate compared with periods when the policy rates have not been altered.

Building on this study, a key direction for future research would be to find further evidence of factors that could explain the pronounced asset price reaction in the US financial markets following interest rate decisions by the Federal Reserve, compared with the more muted feedback on euro area asset prices surrounding the ECB's monetary policy decisions.

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Appendix A

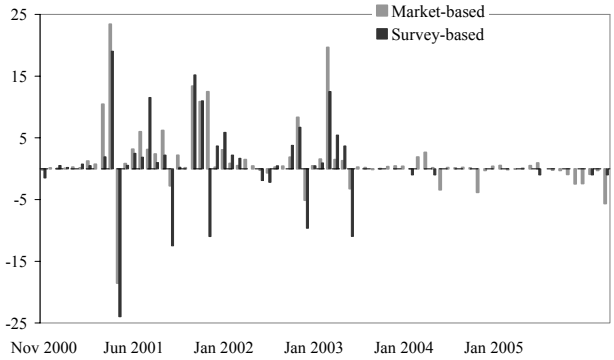
Yearly average volatility ratios surrounding monetary policy decisions

		1999	2000	2001	2002	2003	2004	2005	2006
German bond markets	MPD - 30	1.10	1.10	0.92	1.12	1.31	0.97	1.09	1.40
	MPD	1.01	1.80	1.55	2.00	1.91	1.34	1.15	1.11
US bond markets	MPD - 30	0.84	1.05	0.46	0.45	0.69	0.73	1.11	0.49
	MPD	7.53	2.22	3.45	2.51	4.00	5.64	5.57	6.05
Euro area stock markets	MPD - 30	1.20	1.16	0.86	0.71	0.87	1.19	2.03	1.36
	MPD	1.66	1.45	0.82	1.16	1.66	2.62	2.75	3.28
US stock markets	MPD - 30	0.74	0.69	0.50	0.52	0.83	0.45	0.36	0.76
	MPD	7.22	3.13	3.51	1.56	0.90	2.21	1.75	2.29

Note: The volatility measures are calculated as yearly averages of the ratio between i) five-minute intraday volatility on the US and euro area bond and stock markets surrounding interest rate decisions by the Federal Reserve and the ECB and ii) "normal volatility", the latter computed as the average absolute returns on the same weekdays and same times but on non-announcement days. MPD corresponds to the volatility ratio immediately surrounding the decisions, whereas MPD - 30 represents the volatility ratio 30 minutes prior to the decisions.

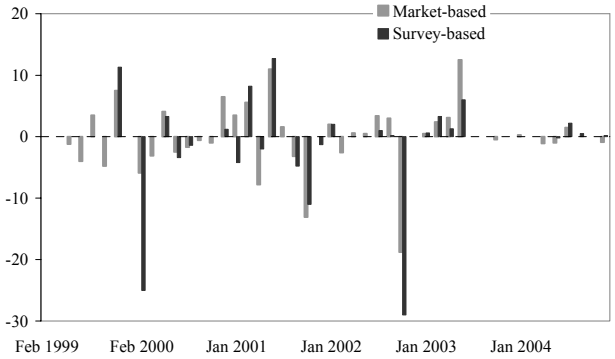
Appendix B

Figure B1. Market and survey-based target surprises in the monetary policy decisions by the ECB *(November 2000 – April 2006)*



Note: The market-based measure comes from Brand, Buncic and Turunen (2006) and represents the 30-minute changes in the 30 day maturity euro area interest rates surrounding the ECB monetary policy decisions (interest rates are filtered using 64 instruments; deposit rates, EONIA and EURIBOR swap rates). The survey-based measure represents the difference between the actual outcome of the monetary policy decisions and analysts' mean expectations taken from the Reuters survey.

Figure B2. Market and survey-based target surprises in the monetary policy decisions by the Fed *(February 1999 – December 2004)*



Note: The market-based measure comes from Flemming and Piazzesi (2005) and represents the one-hour changes in fed fund futures contracts surrounding the Fed monetary policy decisions. The survey-based measure represents the difference between the actual outcome of the monetary policy decisions and analysts' mean expectations taken from the Bloomberg survey.

Appendix C

The volatility measure used as the dependent variable in regressions (3) and (4) is defined as the ratio between volatility on monetary policy days and volatility on the same weekdays and hours but when no monetary policy decision are taking place. More specifically, let k = 1,2 … K be the days of monetary policy decisions and d = 1, 2 ….D be the same weekdays, but when no monetary policy decisions are taking place. The intraday change in the volatility ratio for asset i on a monetary policy decision day k is then calculated as:

$$\Delta Volratio_{t-30,t}^{i,k} = \left(\frac{abs(R_{t=0}^{i,k})}{\frac{1}{D}\sum_{d=1}^{D} abs(R_{t=0}^{i,d})} - \frac{abs(R_{t=-30}^{i,k})}{\frac{1}{D}\sum_{d=1}^{D} abs(R_{t=-30}^{i,d})} \right)$$

R represents the five-minute log-return.

Figure C1. German bond markets. Changes in volatility ratio *(April 1999 – May 2006)*

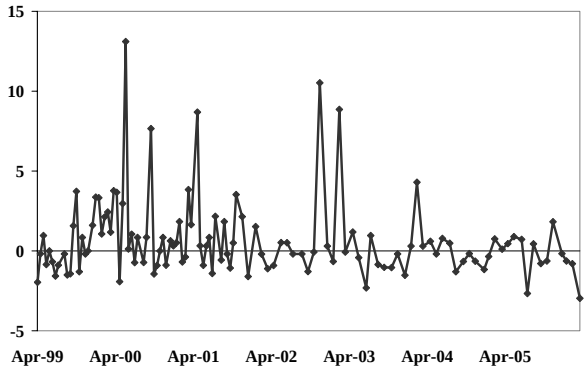


Figure C2. Euro area stock markets. Changes in volatility ratio *(April 1999 – May 2006)*

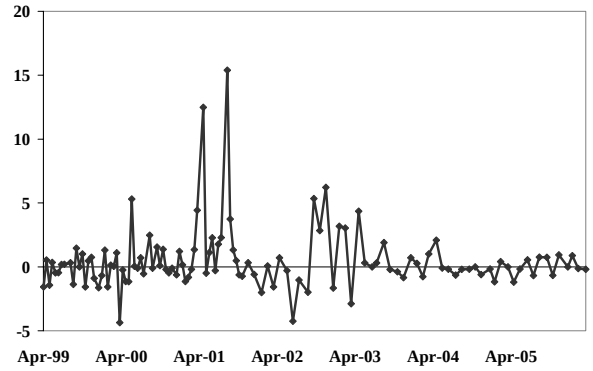


Figure C3. US bond markets. Changes in volatility ratio *(April 1999 – May 2006)*

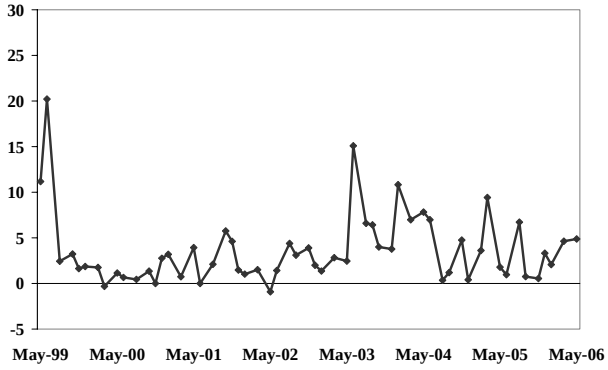
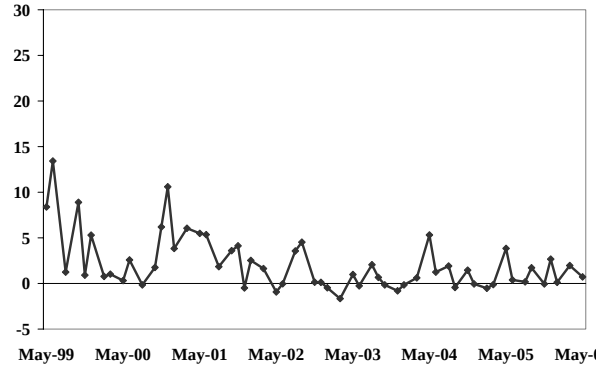


Figure C4. US stock markets. Changes in volatility ratio *(April 1999 – May 2006)*



Appendix D

Figure D1. Volatility ratio on the German long-term bond futures markets surrounding interest rate changes and no interest rate changes by the ECB *(30 minutes before to 85 minutes after the decisions)*

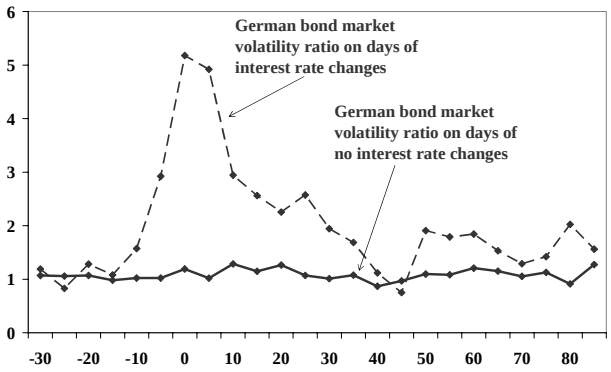


Figure D2. Volatility ratio on the Euro area stock markets surrounding interest rate changes and no interest rate changes by the ECB *(30 minutes before to 85 minutes after the decisions)*

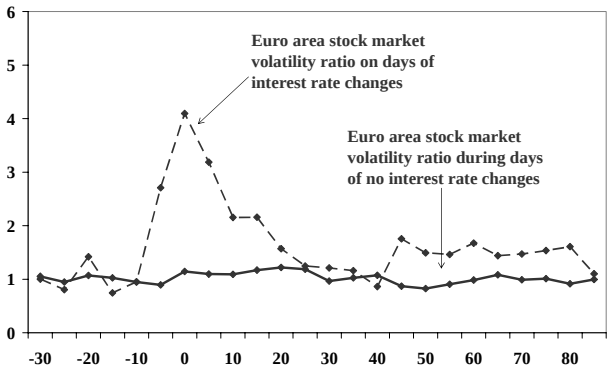


Figure D3. Volatility ratio on the US long-term bond futures markets surrounding interest rate changes and no interest rate changes by the Fed *(30 minutes before to 40 minutes after the decisions)*

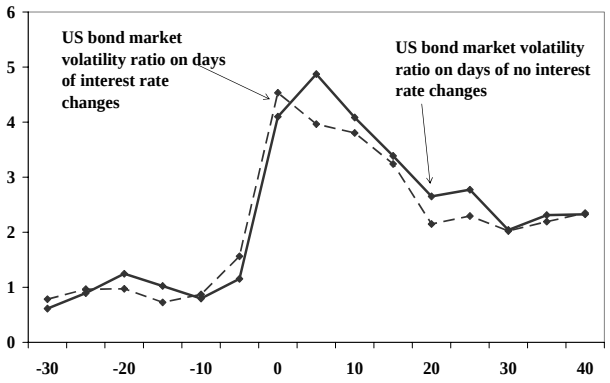
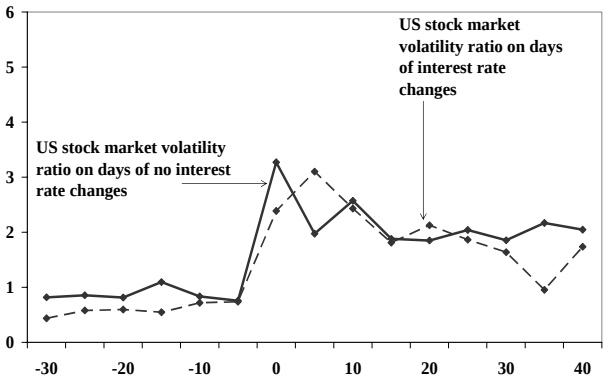


Figure D4. Volatility ratio on the US stock markets surrounding interest rate changes and no interest rate changes by the Fed *(30 minutes before to 40 minutes after the decisions)*



Appendix E

Financial market comments after ECB monetary policy decisions

Date	Interest rate move	Target Surprise	Comment
8 June 2000	+ 50 bp	26.25	Financial Times 9 June 2000: "*The ECB rate rise demonstrated the bank is not afraid of making decisions that surprise the markets … Most investors expected rates to go up by 25 basis points and did not price in a 50 basis points rise…German 10-year bund prices advanced despite the surprisingly aggressive rise in interest rates while the short-dated bonds sold off*".
10 May 2001	- 25 bp	-24	Financial Times 11 May 2001: "*Interest rates fall across Europe… Markets were stunned by the ECB's 0.25 percentage point reduction in its main interest rate to 4.5 per cent. It was the ECB's first cut for more than two years and caught investors unprepared".*
5 October 2000	+ 25 bp	18.75	Financial Times 6 October 2000: "*The biggest surprise in the government bond markets yesterday was the European Central Bank's decision to raise interest rates by 25 basis points to 4.75 per cent, with prices on government bonds falling in response... After the initial shock wore off, bond prices recovered".*
6 March 2003	- 25 bp	12.5	Financial Times 7 March 2003: "*Short-dated eurozone government bond prices recovered their early losses yesterday, despite the European Central Bank's decision to lower interest rates by a quarter rather than a half point. The ECB cut rates to 2.5 per cent, but comments by Wim Duisenberg, ECB president, suggested further easing was on the cards*".
5 Dec 2002	- 50 bp	-9.6	Financial Times 6 December 2002: "*European government bond trading was dominated yesterday by interest rate decisions, notably the European Central Bank's half-point cut to 2.75 per cent ... Eurozone bonds initially rose on the ECB's announcement of its first reduction in rates for more than a year".*