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In 2004 all publications will carry a motif taken from the €100 banknote.

1 Valuable comments by Magnus Andersson, Antonello D'Agostino, Emmanuel Davradakis, Manfred Kremer, Elizaveta Krylova, Jussi Nikkinen, Elias Papaioannou, Seppo Pynnönen, an anonymous referee, and seminar participants at the European Central Bank are gratefully acknowledged. This paper was prepared while the author was visiting the Capital Markets and Financial Structure Division of the ECB. The views expressed in this paper are those of the author and do not necessarily reflect the views of the European Central Bank.

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ABSTRACT

This paper uses data on German government bond futures options to examine the behaviour of market expectations around monetary policy actions of the European Central Bank (ECB). In particular, this paper focuses on the asymmetries in bond market expectations, as measured by the skewness of option-implied probability distributions of future bond yields. The results show that market expectations are systematically asymmetric around monetary policy actions of the ECB. Around monetary policy tightening, option-implied yield distributions are positively skewed, indicating that market participants attach higher probabilities for sharp yield increases than for sharp decreases. Correspondingly, around loosening of the policy, implied yield distributions are negatively skewed, suggesting that markets assign higher probabilities for sharp yield decreases than for increases. Furthermore, the results indicate that market expectations are significantly altered around monetary policy actions, as asymmetries in market expectations tend to increase before changes in the monetary policy stance, and to decrease afterwards.

JEL classification: E44; E52; G10; G13

Keywords: market expectations, asymmetries, implied skewness, monetary policy

NON-TECHNICAL SUMMARY

This paper examines the behaviour of asymmetries in bond market expectations around monetary policy actions of the European Central Bank (ECB). Although not directly observable, these market expectations are implicit in the market prices of options. For instance, the price of a call option depends on the probability of the underlying asset price exceeding the strike price of the option. Consequently, a set of option prices with the same maturity but with different strike prices can be used to infer the entire probability distribution of the underlying asset price. This paper uses data on German government bond futures options to examine the behaviour of asymmetries in market expectations around monetary policy actions of the ECB. The asymmetries in market expectations are assessed by focusing on the skewness of option-implied probability distributions of future bond yields.

A priori, it is expected that market expectations are systematically asymmetric around changes in the monetary policy stance. The reasoning for this is the essentially asymmetric action set of the central bank. During restrictive monetary policy periods, market participants know that the reference interest rates are either increased or kept unchanged in a given monetary policy meeting. Similarly, in an expansive monetary policy environment, market participants know that the central bank will either reduce the interest rates or keep them unchanged. In addition, given that the market participants tend to anticipate the timing of monetary policy actions, but not necessarily the exact impact of the action on asset prices, market expectations are likely to be prominently asymmetrically dispersed.

The results of this paper show that market expectations are systematically asymmetric around monetary policy actions of the ECB. Around monetary policy tightening, option-implied yield distributions are positively skewed, indicating that market participants attach higher probabilities for sharp yield increases than for sharp decreases. Correspondingly, around loosening of the policy, implied yield distributions are negatively skewed, suggesting that markets assign higher probabilities for sharp yield decreases than for increases. These results are reasonable, given the essentially asymmetric action set of the central bank during expansive and restrictive monetary policy periods.

Furthermore, the results of this analysis indicate that market expectations are significantly altered around monetary policy actions of the ECB. The results shows that the asymmetries in market expectations tend to increase before changes in the monetary policy stance, and to decrease afterwards. This suggests that market participants are inclined to anticipate monetary policy shifts. Finally, the results indicate that asymmetries in bond market expectations may be utilised in predicting monetary policy actions of the ECB.

In general, the results of this paper show that option-implied asymmetries can provide useful insight into market expectations. These results may be of interest, for instance, to central banks, as the assessment of possible asymmetries in market expectations may provide useful complementary information for the purposes of formulating monetary policy and, additionally, for assessing the timing of monetary policy actions.

1. INTRODUCTION

Considerable advances in extracting market expectations from financial asset prices have occurred during the last ten years (see Söderlind and Svensson, 1997 for a survey). Traditionally, market expectations of future interest rates, for instance, have been extracted from the term structure of interest rates or from futures contracts on money market instruments and bonds. A severe limitation of these measures is that they reflect only central expectations, and hence provide no indication about the dispersion of market expectations. Consequently, the focus has recently started to shift to information contained in option prices.

Volatility implied by option prices is now widely considered to be a useful forward-looking measure of market uncertainty, and is therefore used extensively among market participants and central banks to assess the uncertainty surrounding central expectations. Option prices, however, may reveal considerable information beyond implied volatility. For instance, a call option has a positive payoff only if the price of the underlying asset at the maturity of the option exceeds the strike price of the option. The call option price should therefore reflect market expectations about the probability of the underlying asset price exceeding the strike price of the option. Hence, a set of option prices with the same maturity but with different strike prices can be used to extract the entire probability distribution of the underlying asset price at the maturity of the option.

Option-implied probability distributions have gained a lot of attention over recent years. Central banks, in particular, are now increasingly using option-implied distributions to evaluate market expectations of future interest rates and exchange rates, and using these expectations as complementary information for the purposes of formulating monetary policy.[1] Several alternative methods for extracting probability distributions from option prices have been proposed in the literature. Reviews of different techniques are provided in Bahra (1997), Jackwerth (1999), and Bliss and

[1] A substantial proportion of the research on option-implied distributions has been conducted in central banks. Recent examples of central bank research include Bahra (1997), Melick and Thomas (1997), Hördahl (2000), Bliss and Panigirtzoglou (2002), Glatzer and Scheicher (2003), Hördahl and Vestin (2003), Bliss and Panigirtzoglou (2004), and Panigirtzoglou and Skiadopoulos (2004).

Panigirtzoglou (2002), while Campa et al. (1998) and Jondeau and Rockinger (2000) provide comparisons of alternative methods. A number of papers have used option-implied probability distributions to examine the behaviour of market expectations around specific events, such as macroeconomic news announcements (e.g., Beber and Brandt, 2003), financial crises (e.g., Melick and Thomas, 1997; Gemmill and Saflekos, 2000; Söderlind, 2000), elections (e.g., Gemmill et al., 2000, Coutant et al., 2001), and central bank interventions (e.g., Cooper and Talbot, 1999; Galati and Melick, 2002). These studies show that option-implied distributions are useful for assessing market expectations around economic events.[2] Moreover, implied distributions can be used to gauge changes in market expectations and, additionally, to reveal possible asymmetries in expectations.

This paper uses data on German government bond futures options to examine the behaviour of market expectations around monetary policy actions of the European Central Bank (ECB). In particular, this paper focuses on the asymmetries in bond market expectations, as measured by the skewness of option-implied probability distributions of future bond yields. By focusing on the behaviour of asymmetries in bond market expectations, this paper provides new evidence on the impact of monetary policy actions on financial markets.

The existing literature on the impact of monetary policy actions on financial markets is extensive. Several papers document that monetary policy actions of central banks systematically affect money market interest rates, bond yields, and stock prices (see e.g., Neumann and Weidmann, 1998; Kuttner, 2001; Lee, 2002; Bomfim, 2003; Gasbarro and Monroe, 2004).[3] In addition, studies such as Jensen et al. (1996), Thorbecke (1997), and Johnson et al. (2003) show that stock and bond returns are significantly different during expansive and restrictive monetary policy periods. Option-implied probability distributions and monetary policy decisions have previously been combined in Bhar and Chiarella (2000) and Mandler (2003). Bhar et al. (2000) investigate the behaviour of option-implied distributions of short-term interest rates

[2] Gemmill et al. (2000), however, conclude that although implied distributions are useful for revealing the market sentiment, they do not have much power for forecasting future events.

[3] Note that the reverse impact may also occur, as monetary policy makers may respond to asset price developments (see Gilchrist and Leahy, 2002 for a review).

around four interest rate reductions conducted by the Reserve Bank of Australia. They find that the probability of a decline in interest rates increases before the actual central bank rate reductions, suggesting that market participants anticipate the forthcoming interest rate cut. Mandler (2003) focuses on the impact of the ECB's monetary policy meetings on implied distributions of short-term interest rates. He shows that the monetary policy meetings of the ECB tend to decrease the uncertainty in market expectations.[4]

This paper differs from Bhar et al. (2000) and Mandler (2003) in several respects. First, Bhar et al. (2000) conduct case studies around four monetary policy actions, while this paper provides a more systematic investigation by using a longer data period, which includes several monetary policy shifts. Second, while Bhar et al. (2000) use implied distributions to assess the probability of a decline in interest rates before monetary policy actions, this paper focuses on the asymmetries of implied distributions. Third, Mandler (2003) investigates the impact of monetary policy meetings, regardless of whether the monetary policy stance is actually changed or not, on option-implied probability distributions. This paper differs from Mandler (2003) by focusing solely on the impact of monetary policy actions. Finally, Bhar et al. (2000) and Mandler (2003) use nonparametric volatility smile smoothing techniques (à la Shimko, 1993) to estimate the option-implied distributions. In this paper, option-implied probability distributions are extracted based on a parametric approach, which assumes that the distribution of the underlying asset price at the maturity of the option is a mixture of two lognormal distributions. This approach may be considered theoretically more competent as it ensures proper behaviour of the tail probabilities.[5]

This paper contributes to the literature on the impact of monetary policy actions on financial markets by focusing on the asymmetries in bond market expectations as

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[4] Consistently, Nikkinen and Sahlström (2004) find that implied volatility tends to be reduced by the Federal Open Market Committee (FOMC) meetings.

[5] Campa et al. (1998) show that the mixture of lognormals technique and the approach based on volatility smile smoothing produce virtually identical implied distributions while Bliss and Panigirtzoglou (2002) document the nonparametric technique to be more robust. However, the mixture of lognormals approach is theoretically more appealing as it ensures smooth behaviour of the tails, and most importantly, precludes negative tail probabilities.

reflected in option-implied probability distributions of future bond yields. It is hypothesized here that market expectations are systematically asymmetric around changes in the monetary policy stance. The reasoning for this is the essentially asymmetric action set of the central bank. During restrictive monetary policy periods, market participants know that the reference interest rates are either increased or kept unchanged in a given monetary policy meeting. Similarly, in an expansive monetary policy environment, market participants know that the central bank will either reduce the interest rates or keep them unchanged. In addition, given that the market participants tend to anticipate the timing of monetary policy actions (e.g., Perez-Quiros and Sicilia, 2002), but not necessarily the exact impact of the action on asset prices,[6] market expectations are likely to be prominently (asymmetrically) dispersed. Therefore, it is expected that around monetary policy tightening, option-implied yield distributions are positively skewed, indicating that market participants attach higher probabilities for sharp yield increases than for sharp decreases. Similarly, implied yield distributions are expected to be negatively skewed around loosening of the policy, implying that markets assign higher probabilities for sharp yield decreases than for increases.

The remainder of the paper is organized as follows. Section 2 describes the bond futures options data used in the empirical analysis. The methodology used to extract asymmetries in market expectations from option prices is presented in Section 3. In Section 4, the empirical findings on the behaviour of asymmetries in market expectations around monetary policy actions of the ECB are reported. Finally, Section 5 offers concluding remarks.

2. DATA

The empirical analysis in this paper is performed using daily settlement prices of options on short-term German government bond futures traded at Eurex. The bond underlying the futures contract is Bundesschatzanweisungen (Schatz), a notional

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[6] Note that although the impact of a monetary policy action on short-term money market rates may be correctly anticipated, the exact impact of the action on bond yields and stock prices is likely to be unknown.

German government bond with 6 percent coupon and maturity of 1¾ to 2¼ years. The settlement prices for the Schatz futures and futures options are obtained from Eurex. The sample period used in the analysis extends from July 1999 to July 2003. During this period, the minimum bid rate used in the main refinancing operations of the ECB was changed 14 times.

German government bond derivatives are commonly regarded as the benchmark for the euro area yield curve. The options on German government bond futures traded at Eurex are ideal for deriving implied distributions, since a wide range of strike prices is continuously available for trading. Moreover, the high liquidity of the options and the underlying futures contracts ensures that the prices of these derivatives instruments reasonably accurately reflect the information set available to financial markets.[7]

The options on Schatz futures are American-style. However, due to the futures-style margining procedure, these options are actually priced as European options, and hence, the option prices do not include premium for the early exercise possibility (see Chen and Scott, 1993 and Bahra, 1997 for further discussion). The expiration months for the Schatz futures options are the three nearest calendar months as well as the following month within the quarterly expiration cycle of March, June, September, and December. The Schatz futures contracts expire in March, June, September, and December. The underlying contract for the options expiring in the quarterly expiration cycle months is the futures contract expiring in the same month. For other expiration months, the underlying contract is the next maturing futures contract in the quarterly expiration cycle. The Schatz futures options expire six trading days before the first calendar day of the contract month.

Three filtering constraints are imposed to the complete option data set. First, in order to avoid expiration-related unusual price and volume fluctuations, options with less than 5 trading days to maturity are excluded from the sample. Second, only at-the-money (ATM) and out-of-the-money (OTM) options are used in the empirical analysis. In-the-money (ITM) options are discarded because they are less liquid than OTM and

[7] German government bond futures and futures options are the most liquid exchange-traded derivatives in the world. Their daily trading volumes exceed the volumes of the corresponding U.S. Treasury Note derivatives.

ATM options, and because by using both OTM call and put options it can be ensured that the complete strike price spectrum is efficiently utilised in the estimation of implied distributions. Finally, options for which the quoted settlement price equals the minimum possible price quotation are discarded, as their prices are uninformative and unreliable. Altogether 116,186 option price observations satisfy the sampling criteria.

3. EXTRACTING ASYMMETRIES IN MARKET EXPECTATIONS FROM OPTION PRICES

The price of a call option, c, written on a (bond) futures contract F, equals the discounted expected value of the option's payoff function, $\max[F-K,0]$, where K denotes the strike price of the option, and the expectations of the payoff function are taken with respect to the risk-neutral probability measure. Therefore, the price of a European call option at time t, with expiration date T, can be written as

$$c = e^{-r(T-t)} \int_{K}^{\infty} f(F_T)(F_T - K)dF_T \qquad (1)$$

where $f(F_T)$ denotes the risk-neutral probability density function[8] of the underlying asset price at the maturity of the option, and r is the risk-free interest rate. Analogously, the price of a put option equals the discounted expected value of the payoff function, $\max[K-F,0]$, and hence, the price of a European put option, p, can be expressed as

$$p = e^{-r(T-t)} \int_{0}^{K} f(F_T)(K - F_T)dF_T \ . \qquad (2)$$

[8] The risk-neutral probability distribution may differ from the objective distribution. Risk-neutrality, however, should mainly affect the location of the distribution, and influence the distributional shape only negligibly (see e.g., Rubinstein, 1994).

Since the option price is a function of the risk-neutral density function, $f(F_T)$, a set of option prices observable in the market can be used to extract this density. In principle, the density function may take any functional form. In practice, however, finite variance distributions which are stable under addition are the only reasonable candidates. Applying the lognormal distribution to Equations (1) and (2), for instance, leads to the Black-Scholes (1973) model.

Given that financial asset price distributions are in the neighbourhood of the lognormal distribution, Ritchey (1990), Melick and Thomas (1997), Bahra (1997), Campa et al. (1998), Gemmill and Saflekos (2000), and Söderlind (2000), among others, assume that the risk-neutral density function of the underlying asset price is a mixture of lognormal densities. This approach is relatively flexible in the sense that a wide variety of distributional shapes can be approximated by a mixture of lognormal distributions.[9]

Assume the density function of the underlying asset price at the maturity of the option to be a linear combination of two lognormal density functions

$$f(F_T) = \omega\, L(\alpha_1, \beta_1, F_T) + (1-\omega)\, L(\alpha_2, \beta_2, F_T) \tag{3}$$

where $L(\cdot)$ denotes the lognormal density function, α_i and β_i are the location and dispersion parameters for the lognormal density i, respectively, and ω is a weighting parameter. Under the mixture of lognormals assumption, Equations (1) and (2) can be rewritten as

$$c = e^{-r(T-t)} \int_K^{\infty} \left[\omega\, L(\alpha_1, \beta_1, F_T) + (1-\omega)\, L(\alpha_2, \beta_2, F_T)\right](F_T - K)\, dF_T \tag{4}$$

$$p = e^{-r(T-t)} \int_0^{K} \left[\omega\, L(\alpha_1, \beta_1, F_T) + (1-\omega)\, L(\alpha_2, \beta_2, F_T)\right](K - F_T)\, dF_T\ . \tag{5}$$

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[9] The approach based on a mixture of lognormals allows for arbitrary asymmetries and multimodality in the option-implied distribution.

Bahra (1997) derives closed-form solutions to Equations (4) and (5). The closed-form option pricing formulas for European call and put options on (bond) futures are given by[10]

$$c = \omega\left[e^{\alpha_1+\frac{1}{2}\beta_1^2}\Phi(d_1) - K\Phi(d_1-\beta_1)\right] + (1-\omega)\left[e^{\alpha_2+\frac{1}{2}\beta_2^2}\Phi(d_2) - K\Phi(d_2-\beta_2)\right] \tag{6}$$

$$p = \omega\left[-e^{\alpha_1+\frac{1}{2}\beta_1^2}\Phi(-d_1) + K\Phi(\beta_1-d_1)\right] + (1-\omega)\left[-e^{\alpha_2+\frac{1}{2}\beta_2^2}\Phi(-d_2) + K\Phi(\beta_2-d_2)\right] \tag{7}$$

where

$$d_1 = \frac{-\ln K + \alpha_1 + \beta_1^2}{\beta_1}, \quad d_2 = \frac{-\ln K + \alpha_2 + \beta_2^2}{\beta_2}$$

and $\Phi(\cdot)$ denotes the cumulative standard normal distribution function. The existence of closed-form option pricing formulas obviates the need for numerical integration, and thus, ensures greater accuracy in the estimation of option-implied risk-neutral density functions.

In this paper, Equations (6) and (7) are applied to estimate the unobserved distributional parameters, $\theta = \{\alpha_1, \alpha_2, \beta_1, \beta_2, \omega\}$, for the mixture density from a set of option prices. The distributional parameters are estimated by minimizing the sum of squared deviations between the observed market prices, $\hat{c}$ and $\hat{p}$, and theoretical option prices, c and p, given by Equations (6) and (7)

$$\min_{\theta} \sum_{i=1}^{m}[\hat{c}_i - c_i(\theta)]^2 + \sum_{i=1}^{n}[\hat{p}_i - p_i(\theta)]^2 \tag{8}$$

---

[10] Black's (1976) version of the Black-Scholes (1973) formula is the corresponding single lognormal model.

where m and n denote the number of call and put price observations on a given day for a given maturity class, respectively. Once the distributional parameters have been estimated, the option-implied risk-neutral probability distribution of the underlying asset price at the maturity of the option can be constructed. Initially, option-implied distribution of the bond futures price is obtained. Since results in terms of yield to maturity may be more informative and intuitive, the estimated bond futures price distribution, $f(F_T)$, is subsequently transformed into a bond yield distribution, $f(y_T)$, using an approximation based on modified duration and convexity.

Asymmetries in market expectations are quantified as the skewness of option-implied probability distribution of future bond yields. Option-implied skewness, ξ, is defined as the standardized third central moment of the option-implied yield distribution

$$\xi = \frac{\mathrm{E}\left[\left[y_T - \mathrm{E}(y_T)\right]^3\right]}{\mathrm{E}\left[\left[y_T - \mathrm{E}(y_T)\right]^2\right]^{\frac{3}{2}}} \quad . \tag{9}$$

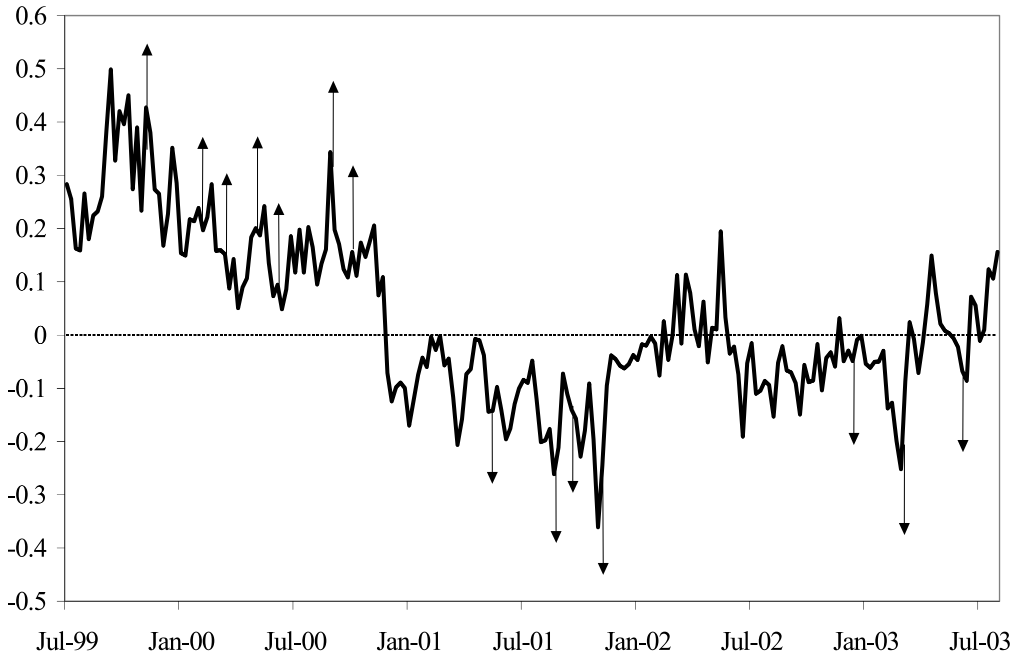
Option-implied skewness is estimated from the bond futures options data for each trading day in the data set, and for each maturity of option contracts on a given day. In order to avoid spurious inference due to time-to-maturity effects of options, a time-series of implied skewness with a constant maturity of 30 days is constructed. The constant maturity time-series is obtained by linear interpolation between two adjacent maturity skewness estimates. The three shortest maturity option contracts are used as follows. The shortest and the second shortest option contracts are used until the second shortest has 30 days to maturity. Thereafter, the second and the third shortest option contracts are used until the expiry of the shortest contract. The changes in the constant maturity implied skewness over time should purely reflect changes in market expectations. Finally, in order to minimize the unavoidable estimation errors in the skewness series, the daily data on constant maturity implied skewness are averaged into a weekly data set. The resulting data set is comprised of 213 time-series observations of option-implied skewness.

4. MONETARY POLICY ACTIONS AND ASYMMETRIES IN BOND MARKET EXPECTATIONS

Figure 1 plots the developments in the option-implied skewness of short-term bond yields over the period from July 1999 until July 2003. During this period, the monetary policy stance of the ECB was changed 14 times. The upward arrows in Figure 1 denote the weeks when the minimum bid rate used on the main refinancing operations of the ECB was raised and downward arrows the weeks when the minimum bid rate was reduced. Several interesting features can be noted from Figure 1. On average, the implied yield distribution is almost symmetric, with a mean skewness estimate of 0.03. However, it is apparent from Figure 1 that there are considerable asymmetries in market expectations. In addition, Figure 1 indicates that these asymmetries are varying heavily over time, with long periods of positive skewness during the first part of the sample period followed by long periods of considerable negative skewness during the latter part.

Interestingly, the major trends in the economic outlook can be easily identified from the implied skewness series, suggesting that the asymmetries in market expectations are closely related to developments in the economic fundamentals. During the exceptionally optimistic growth period from July 1999 until the end of 2000, implied skewness was constantly positive, and then dropped to levels below zero, implying a sudden change in market participants' expectations from attaching higher probabilities for sharp yield increases to instead attaching higher probabilities for declines in bond yields. This sudden drop in skewness at the end of 2000 is concurrent with the increased uncertainty regarding global, and especially U.S. economic growth prospects. As the euro area economic growth also started to slow down in the second quarter of 2001, skewness declined even further, and reached the bottom in the aftermath of the September 11th terrorist attack. The most negative spike in the skewness series occurred in the beginning of November 2001, about two months after the September 11th events and one week before the ECB loosened the stance of the monetary policy.

Figure 1. Option-implied skewness and monetary policy actions of the ECB.



As the expectations of economic recovery increased in the spring of 2002, also skewness increased, and started to wander around zero. However, already during the second half of 2002 skewness again became more negative, perhaps in response to the downward revised economic forecasts at that time. The decline in skewness in the spring of 2003 is contemporaneous with the subdued economic activity and the Iraq crisis. Overall, Figure 1 suggests that implied skewness tends to be positive when there is a positive outlook for economic growth while during periods of sluggish growth prospects skewness appears to be negative.

Turning the focus onto the impact of monetary policy actions on the asymmetries in bond market expectations, Figure 1 shows a striking feature. Implied skewness has always been positive when the ECB has tightened the stance of the monetary policy, and negative when the monetary policy has been loosened. Table 1 reports descriptive statistics of implied skewness for the complete sample, for the weeks in which the monetary policy stance was loosened, and for the weeks in which the monetary policy stance was tightened. The descriptive statistics in Table 1 confirm that skewness has been high and positive, with an average skewness estimate of 0.20, in the weeks when

Table 1. Option-implied skewness and changes in the monetary policy stance.

The table reports summary statistics of option-implied skewness for the complete sample and for the weeks when the stance of the monetary policy was loosened or tightened. The confidence bounds for the mean estimates (reported in parentheses) are obtained via bootstrapping.

	All Weeks	Loosening	Tightening
Mean	0.031	-0.132	0.200
95% Conf. Bound	[0.010. 0.053]	[-0.186. -0.081]	[0.148. 0.258]
Median	-0.010	-0.141	0.184
Standard Deviation	0.157	0.078	0.081
Minimum	-0.361	-0.245	0.094
Maximum	0.499	-0.029	0.343

the minimum bid rate used on the main refinancing operations of the ECB was raised, and low and negative, with an average skewness estimate of –0.14, in the weeks when the minimum bid rate was reduced. The bootstrapped confidence bounds for the mean estimates (reported in parentheses) indicate that the observed differences in implied skewness are statistically highly significant. To illustrate these findings, Figure 2 plots two implied yield distributions with different levels of skewness.[11] The other distribution corresponds to an average implied distribution in the weeks in which the monetary policy stance was tightened (skewness of 0.20), and the other to an average distribution in the weeks in which the policy stance was loosened (skewness of –0.14).

Overall, Figure 1 together with Table 1 clearly demonstrate that the level of implied skewness is significantly different during expansive and restrictive monetary policy periods. During expansive monetary policy periods, market participants seem to assign higher probabilities for sharp yield decreases than for sharp increases. Analogously, market participants appear to attach higher probabilities for sharp yield increases than for sharp decreases during restrictive monetary policy periods.

[11] Mean, volatility, and kurtosis of the plotted distributions are set equal in order to facilitate comparison.

Figure 2. Option-implied bond yield distributions.

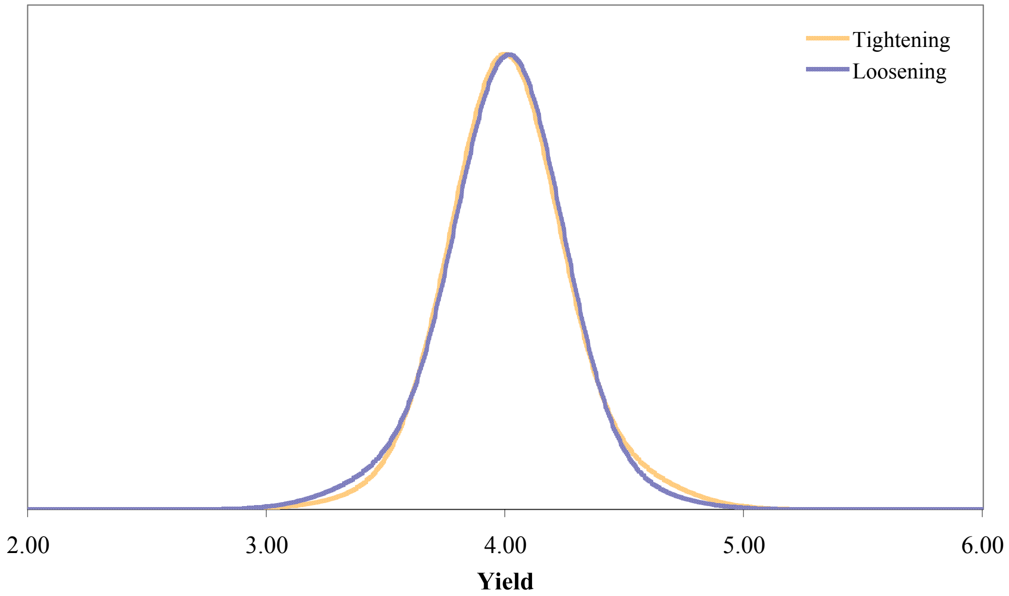


Figure 1 also reveals that most of the changes in the minimum bid rate have coincided with a spike in implied skewness, suggesting that the asymmetries in market expectations are significantly altered around monetary policy actions. To investigate whether there are systematic changes in implied skewness around changes in the monetary policy stance, changes in skewness are regressed on a set of dummy variables which identify the weeks before and after monetary policy actions. Figure 1 would suggest that implied skewness decreases before the stance of the monetary policy is loosened and increases afterwards, and correspondingly, increases before monetary policy is tightened and decreases afterwards. To ascertain the behaviour of asymmetries in market expectations around monetary policy actions, the following regression model is estimated

$$\Delta SKEW_t = \alpha + \beta_1 DEC_t^- + \beta_2 DEC_t^+ + \beta_3 INC_t^- + \beta_4 INC_t^+ + \varepsilon_t \qquad (10)$$

where $SKEW_t$ denotes option-implied skewness at time t, and DEC^-, DEC^+, INC^-, and INC^+ are dummy variables identifying the weeks before and after the monetary policy stance is loosened and tightened, respectively, and Δ is the first difference operator.

The Breusch-Godfrey LM test indicates significant serial correlation in the residuals of this regression specification. In order to kill the residual serial correlation, an AR(2) error structure is specified. Model diagnostics suggest that this specification is adequate.

The estimation results of Equation (10) are reported in Table 2. The signs of the estimated regression coefficients are as expected, being negative for the DEC^{-} and INC^{+} dummies and positive for the DEC^{+} and INC^{-} dummies. This suggests that implied skewness decreases (i.e., becomes more negative) on the week before the stance of the monetary policy is loosened, and returns to a more normal level on the week after the change in the policy. Correspondingly, implied skewness seems to increase on the week before monetary policy tightening, and to decrease afterwards. The estimated coefficients for the monetary policy loosening dummies are statistically highly significant. However, the coefficients for the policy tightening dummies are statistically indistinguishable from zero. The model diagnostics reported in Table 2 show that the estimated model is well specified. The Breusch-Godfrey LM test and Engle's LM test indicate that there is no serial correlation left in the residuals, neither in the squared residuals. Moreover, the model diagnostics show that the residuals are homoskedastic and normally distributed.

As Figure 1 together with the estimation results in Table 2 indicate that the market expectations tend to become more asymmetric before monetary policy actions, it is of interest to examine whether asymmetries in bond market expectations can be utilised in predicting policy changes. To investigate whether changes in option-implied skewness have explanatory power for future changes in the monetary policy stance, limited dependent variable modelling is applied. It is expected here that market participants anticipate the forthcoming change in the monetary policy stance, and that this anticipation is shown in market expectations as increased asymmetry. This increased asymmetry in bond market expectations, in turn, is expected to provide a signal of the forthcoming monetary policy action.[12]

[12] However, it should be noted that in addition to monetary policy actions, asymmetries in bond market expectations may also be significantly affected by macroeconomic fundamentals (see Beber and Brandt, 2003), and hence, the forecasting exercise should be taken with some caution.

Table 2. Parameter estimates of the dummy regression.

The table reports the parameter estimates of the following regression specification:

$$\Delta SKEW_t = \alpha + \beta_1 DEC_t^- + \beta_2 DEC_t^+ + \beta_3 INC_t^- + \beta_4 INC_t^+ + \varepsilon_t$$

where $SKEW_t$ denotes option-implied skewness at time t, and DEC^-, DEC^+, INC^-, and INC^+ are dummy variables identifying the weeks before and after the monetary policy stance is loosened and tightened, respectively, and Δ is the first difference operator. The reported model diagnostics are the Breusch-Godfrey LM test for residual serial correlation, Engle's LM test for ARCH in residuals, White's heteroskedasticity test, and the Jarque-Bera statistic for normality of residuals.

	Estimate		S.E.	*t*-stat.
α	0.000		0.004	-0.131
β_1	-0.057	†	0.026	-2.189
β_2	0.065	†	0.026	2.494
β_3	0.005		0.026	0.180
β_4	-0.005		0.026	-0.207
AR(1)	-0.307	‡	0.070	-4.384
AR(2)	-0.146	†	0.069	-2.096
LM Test	1.913			
ARCH LM Test	2.058			
White's Test	0.987			
JB-stat.	0.542			
F-stat.	5.097	‡		
R^2	0.131			
Adjusted R^2	0.105			

‡ significant at the 0.01 level
† significant at the 0.05 level

Let MPA_t denote monetary policy action at time t and define MPA_t to take the value 1 if the monetary policy stance is changed at time t and 0 otherwise. Assume that the probability of a monetary policy action conditional on the lagged change in absolute implied skewness and a set of model parameters, $\theta=\{\alpha, \beta\}$, is given by the following probit model[13]

$$\Pr\left(MPA_t = 1 \mid \Delta ABSSKEW_{t-1}, \theta\right) = \Phi\left(\alpha + \beta \Delta ABSSKEW_{t-1}\right) \quad (11)$$

[13] It should be noted that this specification ignores the possibility of the ECB signalling a bias towards a policy change, for instance, two weeks before a Governing Council meeting.

where $\Phi(\cdot)$ denotes the cumulative standard normal distribution function, $ABSSKEW_t$ denotes absolute option-implied skewness at time t, and Δ is the first difference operator. Estimates of the unobserved parameters, $\theta=\{\alpha, \beta\}$, in Equation (11) can be obtained via maximum likelihood.

Table 3. Maximum likelihood estimates of the probit model.

The table reports the maximum likelihood estimates of the parameters, $\theta=\{\alpha, \beta\}$, in the following probit model:

$$\Pr\left(MPA_t = 1 \middle| \Delta ABSSKEW_{t-1}, \theta\right) = \Phi\left(\alpha + \beta \Delta ABSSKEW_{t-1}\right)$$

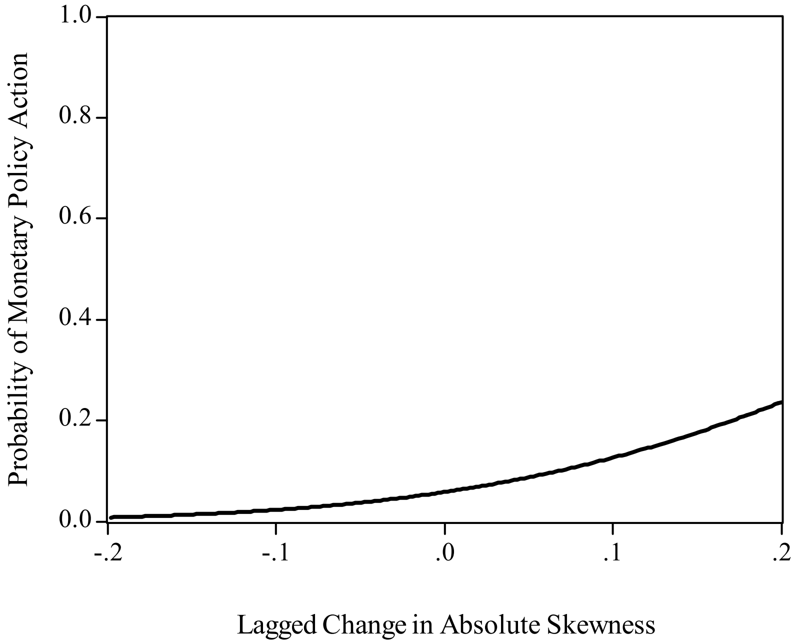
where $\Phi(\cdot)$ denotes the cumulative standard normal distribution function, MPA_t and $ABSSKEW_t$ denote monetary policy action and absolute option-implied skewness at time t, respectively, and Δ is the first difference operator. MPA_t is defined to take the value 1 if the monetary policy stance was changed at time t and 0 otherwise. The reported z-statistics are based on Huber-White standard errors.

	Estimate	S.E.	z-stat.
α	-1.562 ‡	0.139	-11.210
β	4.260 †	1.743	2.444
Log likelihood	-49.375		
LR-stat.	4.258 †		
Pseudo R^2	0.041		

‡ significant at the 0.01 level
† significant at the 0.05 level

Table 3 reports the maximum likelihood estimates of the probit specification given in Equation (11). The reported z-statistics as well as the LR-statistic indicate that the estimated model is statistically significant. The positive coefficient for the lagged change in absolute implied skewness suggests that increasing asymmetries in bond market expectations at time t-1 significantly increase the probability of a monetary policy action at time t. The probability response curve based on the estimated probit model is plotted in Figure 3. It is apparent from Figure 3 that the probability of a monetary policy action increases with increasing asymmetries in bond market expectations. This implies that when skewness is negative and becomes more negative or is positive and becomes more positive in a given week, the probability of monetary policy action in the following week increases.

Figure 3. Probability response curve.



The preceding analysis has assumed that the probability of a monetary policy action is only related to the lagged change in absolute skewness. However, it is well known that short-term money market rates tend to anticipate policy changes. In order to examine whether option-implied skewness has additional explanatory power over money market rates for predicting monetary policy actions, the analysis is extended by considering lagged changes in 1-month Euribor as an additional explanatory variable. Furthermore, a possible deficiency in the probit specification given by Equation (11) is that the central bank actually has a three-choice action set, as the reference interest rates may be either increased, decreased, or kept unchanged.[14] This three-choice action set can be modelled using a trinomial dummy variable. Let MPA_t denote monetary policy action at time t and define MPA_t to take values -1, 0, and 1 depending on whether the stance of monetary policy is loosened, unchanged, or tightened at time t, respectively.

[14] In fact, the ECB has altered the mimimum bid rate by both 25 and 50 basis points, and hence, the central bank action set could be modelled to include even five states. However, given the short sample period, three-choice action set is considered adequate.

Assume MPA_t to be related to the lagged changes in implied skewness and 1-month Euribor according to the following ordered probit specification

$$\Pr\left(MPA_t = j \mid \Delta SKEW_{t-1}, \Delta r_{t-1}, \theta\right) = \begin{cases} \Phi\left(\gamma_1 - \beta_1 \Delta SKEW_{t-1} - \beta_2 \Delta r_{t-1}\right) & \text{if } j = -1 \\ \Phi\left(\gamma_2 - \beta_1 \Delta SKEW_{t-1} - \beta_2 \Delta r_{t-1}\right) - \Phi\left(\gamma_1 - \beta_1 \Delta SKEW_{t-1} - \beta_2 \Delta r_{t-1}\right) & \text{if } j = 0 \\ 1 - \Phi\left(\gamma_2 - \beta_1 \Delta SKEW_{t-1} - \beta_2 \Delta r_{t-1}\right) & \text{if } j = 1 \end{cases} \quad (12)$$

where $\Phi(\cdot)$ denotes the cumulative standard normal distribution function, $SKEW_t$ is option-implied skewness at time t, r_t is 1-month Euribor at time t, and Δ is the first difference operator. The parameters, $\theta = \{\gamma_1, \gamma_2, \beta_1, \beta_2\}$, for the ordered probit model can be estimated by maximum likelihood.

The maximum likelihood estimates of the ordered probit model are reported in Table 4. The estimated partition boundaries as well as the coefficients for the lagged changes in implied skewness and 1-month Euribor are statistically highly significant. The estimated coefficients for the lagged changes in both implied skewness and 1-month Euribor are positive, indicating that increasing skewness and Euribor at time t-1 significantly increase the probability of monetary policy tightening at time t while decreasing skewness and Euribor at time t-1 significantly increase the probability of monetary policy loosening at time t. Hence, the estimation results suggest that asymmetries in bond market expectations do have additional explanatory power over money market rates for predicting policy changes.

In summary, both the probit and ordered probit estimation results show that lagged changes in option-implied skewness have some explanatory power for monetary policy actions. Together with the statistics reported in Table 1, the estimated probit and ordered probit models suggest that if skewness is negative and becomes more negative in a given week, the probability of monetary policy loosening in the following week increases. Similarly, the results suggest that if skewness is positive and becomes more positive in a given week, the probability of monetary policy tightening in the following week increases. These estimation results imply that asymmetries in market expectations anticipate monetary policy decisions of the ECB, at least to some extent.

Table 4. Maximum likelihood estimates of the ordered probit model.

The table reports the maximum likelihood estimates of the parameters, $\theta=\{\gamma_1, \gamma_2, \beta_1, \beta_2\}$, in the following ordered probit model:

$$\Pr\left(MPA_t = j \,\middle|\, \Delta SKEW_{t-1}, \Delta r_{t-1}, \theta\right) =$$
$$\begin{cases} \Phi\left(\gamma_1 - \beta_1 \Delta SKEW_{t-1} - \beta_2 \Delta r_{t-1}\right) & \text{if } j=-1 \\ \Phi\left(\gamma_2 - \beta_1 \Delta SKEW_{t-1} - \beta_2 \Delta r_{t-1}\right) - \Phi\left(\gamma_1 - \beta_1 \Delta SKEW_{t-1} - \beta_2 \Delta r_{t-1}\right) & \text{if } j=0 \\ 1 - \Phi\left(\gamma_2 - \beta_1 \Delta SKEW_{t-1} - \beta_2 \Delta r_{t-1}\right) & \text{if } j=1 \end{cases}$$

where $\Phi(\cdot)$ denotes the cumulative standard normal distribution function, MPA_t, $SKEW_t$, and r_t denote monetary policy action, option-implied skewness, and 1-month Euribor at time t, respectively, and Δ is the first difference operator. MPA_t is defined to take values –1, 0, and 1 depending on whether the monetary policy stance was loosened, unchanged or tightened at time t, respectively. The reported z-statistics are based on Huber-White standard errors.

	Estimate	S.E.	z-stat.
γ_1	-2.020‡	0.167	-12.105
γ_2	1.971‡	0.185	10.662
β_1	3.523†	1.442	2.443
β_2	4.415‡	1.384	3.189
Log likelihood	-55.414		
LR-stat.	11.588‡		
Pseudo R^2	0.095		

‡ significant at the 0.01 level
† significant at the 0.05 level

5. CONCLUSIONS

This paper contributes to the literature on the impact of monetary policy actions on financial markets by focusing on the asymmetries in bond market expectations around monetary policy actions of the European Central Bank. The asymmetries in market expectations are measured by the skewness of option-implied probability distributions of future bond yields. In order to assess the asymmetries in market expectations, implied probability distributions are extracted from German government bond futures options under the assumption that the distribution of the underlying asset price is a mixture of lognormal distributions. This approach allows for arbitrary skewness in the option-implied distribution, and therefore, provides a suitable framework for assessing possible asymmetries in market expectations.

The results of this analysis show that market expectations are systematically asymmetric around monetary policy actions of the ECB. Around monetary policy tightening, option-implied yield distributions are positively skewed, indicating that market participants attach higher probabilities for sharp yield increases than for sharp decreases. Correspondingly, around loosening of the policy, implied yield distributions are negatively skewed, suggesting that markets assign higher probabilities for sharp yield decreases than for increases. These results are reasonable, given the essentially asymmetric action set of the central bank during expansive and restrictive monetary policy periods.

Furthermore, the results of this paper indicate that market expectations are significantly altered around monetary policy actions of the ECB. The analysis shows that the asymmetries in market expectations tend to increase before changes in the monetary policy stance, and to decrease afterwards. This suggests that market participants are inclined to anticipate monetary policy shifts. Finally, the results indicate that asymmetries in bond market expectations may be utilised in predicting monetary policy actions of the ECB.

In general, the results of this paper show that option-implied asymmetries can provide useful insight into market expectations. These results may be of interest, for instance, to central banks, as the assessment of possible asymmetries in market expectations may provide useful complementary information for the purposes of formulating monetary policy and, additionally, for assessing the timing of monetary policy actions.

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