ECB-Council Meetings and Money Market Uncertainty - Evidence from Option Markets *

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Abstract

In this paper we apply one of the new techniques to extract information on market expectations from option prices to investigate the effects of ECB-council meetings on uncertainty in market expectations. We construct risk-neutral probability density functions from LIFFE-Euribor futures options for ten episodes containing ECB-council meetings in 2000 and 2001. We then compute statistics derived from the risk-neutral density functions that capture the uncertainty of market participant's expectations and investigate changes in these statistics related to ECB-council meetings.

Keywords: implied probability density functions, risk-neutral expectations, option prices, monetary policy

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1 Introduction

The operating procedures implemented by most central banks of industrialized nations are focused on the money market and entail the manipulation of a very short-term interest rate that can be more or less directly controlled by the central bank.[1] Monetary policy, however, exerts its influence on real economic activity through changes in long-run real interest rates, which in turn are affected by changes in long-run nominal interest rates and changes in inflation expectations. But long-term nominal interest rates themselves are the result of the interaction of central bank operations on the short-end of the maturity spectrum with portfolio decisions of investors (Borio (1997)), so that the direct influence of central bank policy on long-term interest rates is quite weak. To enhance their ability to influence longer-term interest rates central banks have developed complex signaling strategies to convey information about the future course of monetary policy to the market and to shape market expectations appropriately. Because of these important interrelations between monetary policy, the monetary transmission process, and market expectations it is of great interest to examine empirically the reaction of market expectations to monetary policy decisions, particularly the effects on uncertainty in market expectations. Investigating the relationship between central bank policy and changes in the uncertainty in market expectations is important because it contains information first, on how strong uncertainty with respect to oberved monetary policy decisions is and second, on how capable the central bank is in conveying information about its intended future course for monetary policy to market participants.

In this paper we extract information on uncertainty in market participants' expectations from prices of interest-rate options. This is an application of one of a range of new techniques that have been developed over the last years to unlock the information on market expectations contained in derivatives prices. These techniques mark a further stage in studies of the information content of prices of financial derivatives. First, there is the vast literature on the information content of futures and forward prices, that represent the price of the underlying that a risk-neutral investor expects to prevail at expiration of the contract. This theoretical relationship has formed the basis of a

[1] For a detailed survey of central bank operating procedures, see Borio (1997).

large number of papers investigating the forecasting ability of future/forward prices for future spot prices.[2] On the next level researchers have investigated the information in implied volatilities that are obtained from observed option prices by inverting an appropriate option pricing formula. Many authors have interpreted implied volatility as the (average) volatility of the underlying's price market participants expect to prevail until the option expires and tested the forecasting ability of implied volatility with respect to future observed volatility.[3]

The new techniques, however, provide for the extraction of much more information than just expected value or expected standard deviation of the underlying asset's price. They make possible the construction of implied probability density functions (PDF) from cross-sections of option prices. These implied density functions also called risk-neutral density functions contain information on the market participants' expectations concerning the underlying asset's price at the options' expiration. Observing their behaviour over time provides an insight into changes in market expectations.[4] Central banks themselves have taken considerable interest in the development and application of these techniques.[5]

In this paper we will use one of these techniques to construct from observed option prices from 2000 and 2001 daily risk-neutral PDFs for future outcomes of an interbank interest rate. In ten event studies, we investigate changes in these risk-neutral PDFs related to meetings of the governing council of the European Central Bank (ECB), where we focus on a set of statistics that summarize uncertainty with respect to future

[2] See Cuthbertson (1996) for a survey.

[3] See, for example, Bank of Japan (1995), Campa and Chang (1995), Canina and Figlewski (1993), Day and Lewis (1992), Dumas, Fleming and Whaley (1998), Fleming (1998), Jorion (1995), Lamoureux and Lastrapes (1993), Neuhaus (1995), and Scott (1992).

[4] These techniques have been applied to various problems ranging from exchange rate expectations (Campa, Chang, and Reider (1997), Cooper and Talbot (1999)) over the credibility of exchange rate regimes (e.g. Campa and Chang (1996, 1998), Campa, Chang, and Reider (1998), Malz (1996)), to commodity markets (e.g. Melick and Thomas (1997)) and interest rate expectations (e.g. Abken, Madan, and Ramamurtie (1996), Coutant, Jondeau, and Rockinger (1998), Söderlind (2000)).

[5] See for example Bahra (1997), Butler and Davies (1998), Cooper and Talbot (1999), Coutant, Jondeau and Rockinger (1998), Fornari and Violi (1998), Galati and Melick (1999), Levin, McManus and Watt (1998), Malz (1996), McManus (1999), Melick and Thomas (1997), Nakamura and Shiratsuka (1999), Neuhaus (1995), and Bank for International Settlements (1999).

interest rates as represented by the risk-neutral density function. We propose a regression approach in order to deal with an important problem common in applied work with risk-neutral PDFs: It is known, that even with the most robust estimation techniques statistics computed from implied density functions are subject to substantial day-to-day variations (Bliss and Panigirtzoglou (1999), Cooper (1999), Melick (1999)). Consequently, we require a methodology to separate changes in the statistics resulting from important "news" from fluctuations purely caused by "noise".[6] Therefore we compare the statistics from the risk-neutral PDFs for a small number of business days after an ECB-council meeting with those for a corresponding number of business days before by means of a dummy variable in order to smooth out the random fluctuations and to highlight important changes in the risk-neutral PDFs after the council meeting.

The next section gives a brief overview of the theoretical relationships between option prices and risk-neutral probability density functions that form the basis of our application. It also contains a short discussion of issues related to the interpretation of risk-neutral PDFs. The third section provides some information on the estimation technique used to extract risk-neutral probabilities from option prices. After that, section four presents the data set covered by our application and explains the methodology used to investigate the effect of ECB-council meetings on market expectations. In section five we discuss the results of our application and section six summarizes and provides some concluding remarks.

[6] One example is measurement error in option prices due to the minimum-tick size.

2 Option prices and risk-neutral probability density functions

As shown by Cox and Ross (1976), the price of an European option on the underlying asset S can be written as the discounted expected value of its payoff at expiration:[7]

$$v_t(S_t, K) = e^{-r(T-t)}\mathbf{E}_t^Q[h(S_T)|S_t], \tag{1}$$

where K is the exercise price, T is the expiration date, r is the risk-free rate of interest and $h(S_T)$ is the option's payoff function. For an European call option we have $h_c(S_T) = \max[S_T - K, 0]$ and for the put $h_p(S_T) = \max[K - S_T, 0]$. Therefore the call value is,

$$\begin{aligned} c_t(S_t, K) &= e^{-r(T-t)}\mathbf{E}^Q[\max[S_T - K, 0]|S_t] \qquad (2) \\ &= e^{-r(T-t)}\int_K^{\infty}(S_T - K)q(S_T|S_t)dS_T, \end{aligned}$$

and the put value,

$$\begin{aligned} p_t(S_t, K) &= e^{-r(T-t)}\mathbf{E}^Q[\max[K - S_T, 0]|S_t] \qquad (3) \\ &= e^{-r(T-t)}\int_0^{K}(K - S_T)q(S_T|S_t)dS_T. \end{aligned}$$

The expectation is taken with respect to the probability density function $q(S_T|S_t)$. This density is called the *risk-neutral* probability density function and corresponds (in complete markets) to the equivalent martingale measure of Harrison and Kreps (1979) from the asset-pricing literature.

Differentiating equation (2) with respect to the exercise price K yields,

$$\begin{aligned} \frac{\partial c_t(S_t, K)}{\partial K} &= -e^{-r(T-t)}\int_K^{\infty} q(S_T|S_t)dS_T \qquad (4) \\ &= -e^{-r(T-t)}[1 - Q(K|S_t)], \end{aligned}$$

[7] The owner of an European call option has the right but not the obligation to buy the underlying asset at a prespecified price (strike price or exercise price) on a given date (expiration date), whereas a European put option provides him with the right but not the obligation to sell the underlying asset at a prespecified price on the expiration date.

where $Q(\bullet|S_t)$ is the cumulative distribution function of S_T conditional on S_t. Therefore the first derivative of the European call option value with respect to the strike price equals the negative of the discounted risk-neutral probability of the option being in-the-money at the expiration date.[8]

The intuition behind this result is that if the option is sufficiently deep in-the-money it will almost surely finish in-the-money at expiration. Since it will be exercised with probability one, an increase in the exercise price by one unit will make the owner of the option pay one additional unit of currency for the underlying, thus reducing the call's value by the present value of one unit of currency. If, on the other hand, the option is far out-of-the-money and will almost surely expire worthless, a small increase in the exercise price should have no effect on the option value because the owner will not exercise it anyway. Finally, if an option will neither almost surely finish in-the-money nor almost surely out-of-the-money, an increase in the strike price by one unit should reduce the call option value by the present value of an amount between one and zero depending on the likelihood of the option being in-the-money at the expiration date.

Differentiating equation (4) once again yields the result of Breeden and Litzenberger (1978),

$$\frac{\partial^2 c_t(S_t, K)}{\partial K^2} = e^{-r(T-t)} q(S_T|S_t) \Big|_{S_T=K}. \tag{5}$$

That implies that the second derivative of the European call option value with respect to the strike price is equal to the discounted risk-neutral probability density of S_T.[9]

The risk-neutral PDF embodies information about the market participants' expectations for the price level of the underlying asset at T. However, the risk-neutral PDF cannot be interpreted straightforwardly as a representation of the market participants' expectations because this equivalence only holds for risk-neutral individuals. The risk-neutral PDF is the result of the interaction of market participants' "true" expectations and their risk-preferences which cannot be disentangled without further assumptions (e.g. Chang and Melick (1999)). For example, a high risk-neutral probability for a certain state of the world might be the result of a high "true" probability but can

[8] A call option is "in-the-money" if the underlying's price exceeds the exercise price, i.e. $S_t > K$, "at-the-money" if $S_t = K$ and "out-of the-money" if $S_t < K$.

[9] The same result can be derived using European put options.

also be associated with a low "true" probability in combination with high risk aversion that makes the individual highly value payouts if this event occurs (e.g. Chang and Melick (1999), Galati and Melick (1999)). Without using an economic model specifying marginal utilities under different states of the world the approach most commonly used is to assume that risk-preferences are constant through the observation period and to focus on *changes* in the risk-neutral PDF which are interpreted as providing information on changes in the "true" density (e.g. Bahra (1997), Galati and Melick (1999), and Melick and Thomas (1998)).

3 Estimation Procedure

Because of the relationships stated in (2) and (3) it is possible to infer the risk-neutral PDF from observed prices of European options. Many different techniques have been applied to option prices in order to extract the implied risk-neutral PDF. Along broad lines, these techniques can be divided into two categories. One group directly utilizes equations (2) and (3) by making assumptions about the functional form of the PDF and fitting the resulting theoretical option prices to observed option prices in order to estimate the free parameters of the distribution. The other techniques use equation (5) as a starting point.
Using equation (5) to calculate the risk-neutral PDF requires call prices being available for continuous strike prices. However, in reality we are usually limited to just a few discretely spaced observations. Therefore these techniques rely on interpolation methods to construct a continuous option pricing function that can be differentiated numerically to obtain the risk-neutral PDF. Existing comparisons indicate that the interpolation approach might be more robust with respect to errors in option prices than methods based on the first group of techniques (Cooper (1999), Melick (1999) and Bliss and Panigirtzoglou (1999)).[10]

The most straightforward solution would be to interpolate (and extrapolate) or smooth the observed option prices directly. However, the curvature of the option pricing func-

[10]Studies of robustness of the various techniques focus on pricing errors in exchange traded options due to the minimum-tick-size requirement.

tion is difficult to approximate with commonly used methods and small fitted price errors will have a large effect on the risk-neutral PDF, especially in the tails (Bliss and Panigirtzoglou (1999), Cooper (1999), Cooper and Talbot (1999)). Therefore, the approach presented by Shimko (1993) is used who suggests to convert option prices into implied volatilities using the Black-Scholes option valuation formula and then to interpolate or smooth the implied volatilities which are finally converted back into option prices. This procedure does not assume the Black-Scholes formula to be correct but treats it as a convenient mapping from price space into volatility space and back (e.g. Bliss and Panigirtzoglou (1999), Malz (1998), Shimko (1993)). In Shimko (1993) a quadratic polynomial in strike prices is fitted to implied volatilities. Campa, Chang and Reider (1997) suggest using cubic spline functions in order to allow for more flexibility in the shape of the volatility smile. Malz (1998), again, uses a quadratic polynomial but fits implied volatility versus delta, the derivative of the Black-Scholes price with respect to S_t, instead of exercise prices. Bliss and Panigirtzoglou (1999) combine these approaches and estimate natural spline functions in delta/volatility space. Switching from strike prices to delta has the effect of grouping more densely options farer out-of-the-money or in-the money than options at-the-money, thus allowing for a more flexible shape near the center of the implied density function.

In this paper we follow the approach in Bliss and Panigirtzoglou (1999) in using a spline interpolation approach in delta/volatility space. First, we estimate implied volatilities from daily cross sections of observed option prices. Then, the implied volatility smile is constructed from piecewise cubic polynomials which are separated by the N observed option deltas (the knot points). The polynomials are constrained to be continuous at the knot points and to have continuous first and second derivatives. However, the spline function is not required to fit the observed implied volatilities exactly but to minimize the sum of squared deviations from approximated to actual implied volatilities. The objective function is,

$$\min_{\Theta} \sum_{i=1}^{N} \big(\sigma_i - f_i(\delta_i, \Theta)\big)^2 + \lambda \int_{\infty}^{+\infty} f''(\delta, \Theta)^2 d\delta, \qquad (6)$$

where Θ is the matrix of free polynomial parameters, f_i is the spline function in segment i and δ_i, σ_i are the knot points. λ is a smoothness penalty multiplying a measure of the degree of curvature in the function represented by the integral of its squared second derivative as in Bliss and Panigirtzoglou (1999).[11] Since the spacing of knot points is more dense the farer the observed strike prices are away from-the-money operating in delta space with a constant smoothness penalty allows for greater flexibility in the shape of the approximating function for strike prices at-the-money. The cubic spline is restricted to become linear outside the range of observed option prices.[12] The free parameters are estimated via nonlinear optimization.[13]

After estimation of the free polynomial parameters implied volatilities at a large number of equally spaced strike prices are computed including some extrapolation beyond the outer knot points.[14] In order to calculate the implied volatility for a specific strike price we first need to convert strike prices into option deltas. Unfortunately, delta itself is a function of the implied volatility, so delta and implied volatility have to be calculated simultaneously (Malz (1998)). The interpolated implied volatilities are then transformed back into call option prices by applying the Black-Scholes-formula (or the appropriate variant). Finally, we arrive at the implied PDF by differentiating numerically the call price function twice with respect to the exercise price and multiplying with $e^{r(T-t)}$.

[11] Bliss and Panigirtzoglou (1999) use vega, the derivative of the Black-Scholes-price with respect to volatility, as weight for the squared deviations in (6). This amounts to the assumption of homoscedastic errors in option prices. However, they show that the choice of a weighting scheme does not significantly affect the resulting risk-neutral density functions.

[12] As Bliss and Panigirtzoglou (1999) point out this restriction can lead to negative tail probabilities if the slope of the polynomial is negative at the extreme knot points. However, this problem does not arise in this study.

[13] After some experimentation we set the smoothness penalty parameter λ equal to 0.01.

[14] Bliss and Panigirtzoglou (1999) compute implied volatilities for equally delta-spaced points. This leads to a more densely grid of implied volatilities at-the-money than away-from-the-money and reduces the accuracy in the tails of the numerically computed implied PDF. Furthermore the very densely spaced strike prices at-the-money can cause problems with the numerical differentiation of the call price function because the effect of small errors in the transformation of delta into price space will be aggravated by the numerical differentiation.

4 Data

In this study we use a set of prices of options written on a three month Euribor futures contract, i.e. a futures contract on a short-term inter-bank interest rate. Both options and futures prices were obtained from London International Financial Futures and Options Exchange (LIFFE). The options are American style and can be exercised at any time up to the expiration date. However, the futures-style margining procedure applied to short-term interest rate options at LIFFE leads to the result that the options are actually priced like European type options. Early exercise, i.e. exercise before the expiration date will not take place because there is no opportunity cost of holding a long position in the option.[15]

We use settlement prices of the options and the underlying futures contract which are each day determined by the exchange at the close of trading in the respective contract. One advantage of using settlement prices instead of trading prices is that during trading time transactions based on liquidity considerations might move prices temporarily away from their equilibrium values. This problem is mitigated by using settlement prices (Melick and Thomas (1998)). Since the members of the exchange also act as brokers or hold positions in options themselves there are sufficient incentives for them to determine settlement prices close to their equilibrium values (Söderlind (2000)).

The options and the underlying futures contract expire simultaneously on the third Wednesday of March, June, September, and December.[16] Therefore our results refer to the expectations of market participants with respect to the Euribor rate at expiry although the underlying asset is the respective futures contract. Exercise prices are spaced by intervals of 0.125, i.e. 12.5 basis points. Since the futures contract is quoted as 100.0 minus the interest rate, our results can be converted into interest rate space by subtracting the respective futures price from 100. The minimum tick size, i.e. the

[15] The option price is not paid upon purchase but option positions are marked-to-market daily giving rise to positive or negative variation margin flows. See LIFFE (2000) for details. Chen and Scott (1993) show that this leads to American options being priced as European Options.

[16] This is the regular expiration cycle. There also exist options and futures expiring on the other two of the three nearest calendar months which are, however, not as liquid as the options on the regular cycle. For further details see LIFFE (2000).

minimum price movement recorded is 0.005.[17]

Our approach consists of a set of event studies in which we track the changes in implied PDFs around ECB-council meetings. By means of a regression analysis we compare statistics computed from the risk-neutral PDFs on five business days immediately after the council meetings (including the day of the meeting) to those on the five business days immediately before by using a dummy variable for the days after the council meeting. This approach highlights significant and somewhat persistent changes in the risk-neutral density after the ECB-council meeting. An implicit assumption there is that the consequences of important news resulting from the council meeting on the risk-neutral PDF should persist for a few days. Looking only for these persistent effects makes the random fluctuations in the statistics to be smoothed out by the additional observations. In deciding on how many additional trading days to include we face a trade-off: If we add too few observations, we will not be able to "average away" the "noise" in the risk-neutral PDFs. On the other hand, if we add too many trading days to the sample, the effects caused by the central bank council meeting will be blurred by the additional information the market participants learn during that extended period. Choosing to compare five day periods before and after the events to be considered has another benefit as well. Since both subsamples compared share an identical day-of-the-week composition we effectively avoid problems related to day-of-the-week effects on the implied PDFs.

As events to be investigated we select among the meetings of the ECB-council between January 2000 and August 2001. The selection was based on the following criteria: First, we wanted any of the potential combinations between market expectations and the result of the council meeting to be represented in our sample. These combinations are: correctly anticipated interest rate increase, correctly anticipated interest rate decrease, no change in official rates that was anticipated correctly, an unexpected interest rate increase, an unexpected interest rate decrease and a situation in which the market expects a change in offical rates which however, does not manifest after the meeting.

[17] However the data on the CD-ROM "Financial Products: End of Day Data" distributed by LIFFE and used for the council meetings in 2000 is only recorded with an accuracy of 0.01. For 2001 we used option prices obtained from the LIFFE website with an accuracy of 0.005.

Second, for all business days within the ten day period centered on the day of the council meeting there had to be available option prices, e.g. there should be no bank holidays etc. in this time period. Finally, we also based our selection on the requirement of having a clear picture of what market participants expected from the ECB-council meeting. This information enables us, to place each event into the appropriate category with respect to the combinations between market expectations and result of the meeting explained above and facilitates the interpretation of the results.[18]

By applying these criteria we selected ten ECB-council meetings. Among these were two anticipated interest rate increases, one anticipated interest rate decrease, three council meetings where official interest rates were left unchanged as anticipated, one unanticipated interest rate increase, two cases where an interest rate step was expected but the council decided to leave official rates unchanged and one unexpected interest rate decrease.

For each business day considered we use settlement prices for the option and futures contract on the regular cycle with the shortest maturity provided it is not below one month.[19] Since options far out-of-the-money or far in-the-money are not traded very actively und will therefore contain few reliable information on market participants' expectations we only use options with a time adjusted moneyness between +1.35 and −1.35 percent. Time-adjusted moneyness is here defined as $(\frac{K}{F_t} - 1)\frac{1}{\sqrt{T-t}}$, where F_t is the current futures price (compare Dumas, Fleming, and Whaley (2000)). This leads to a decline in the number of eligible options as their maturity shortens and reflects the fact that with a shorter maturity large changes in the underlying's price become less and less likely and therefore trade concentrates in fewer and fewer exercise prices around the current level of the futures price.

[18] For the information on market sentiment we draw on reports in the Financial Markets section of the *Frankfurter Allgemeine Zeitung*. It should be emphasized that we require information about market expectations about the upcoming council meeting for our classification, not about expectations with respect to monetary policy further away in the future.

[19] Options of very short maturity often are not traded very actively and thus might not provide much information on market participants' expectations. For one subperiod in January 2000 we used options with expiration in June and not in March because for the latter ones we encountered a considerable number of violations of the monotonicity of our computed delta with respect to strike price (see below).

Implied volatilities are then computed from the options selected by using Black's (1976) formula for pricing futures options.[20] Since European Put-Call-Parity holds for the options in our sample there is no difference in using put or call options. Therefore we decided to construct the volatility smile from in-the-money call and in-the money put options as in Aït-Sahalia, Wang und Yared (2001).[21]

In some cases inspection of the resulting delta/volatility pairs showed delta to be non-monotonous in strike price. In these cases we eliminated all delta/volatility combinations on the outer edge of our considered strike price spectrum beginning with the nonmonotonous observation. Finally, we dropped all observations with delta below 0.025 or above 0.975 because when approaching zero or one, delta becomes quite insensitive to changes in strike price and the volatility smile with respect to delta becomes so steep that it is no longer possible to fit the spline polynomials to the volatility smile.

5 Results

The results for the individual event studies are presented in tables 1-6. Each table shows the regression results for seven statistics computed from the risk-neutral PDF for each day in the time period considered. These statistics are the standard deviation of the logarithm of the Euribor rate, volatility, i.e. standard deviation scaled by the square root of time to maturity, a measure for skewness in the risk-neutral density, [22]

$$sp2 = \frac{\left(\mathbf{E}^Q[(\log(S_T) - \mu)^3]\right)}{stddev^{\frac{3}{2}}}, \tag{7}$$

[20] Calculating implied volatilities requires apart from the exercise price and the current value of the underlying asset a risk-free interest rate with the same maturity as the option as an input factor. We proxy for this interest rate by using linear interpolations from Euribor rates with maturity of one to five months.

[21] This avoids problems with using out-of-the money options for which the ratio of minimum tick size to price is relatively large. Since the maximum error introduced by discrete price quotation is equal to half the minimum tick size these options are suspect to carry large measurement errors (e.g. Bliss and Panigirtzoglou (1999)).

[22] Theoretically, the expected value of each of the implied distributions should equal the current futures price. All estimated mean values turned out to be very close to their theoretical values.

where,

$$\mu = \mathbf{E}^Q[\log(S_T)] \tag{8}$$

$$stddev = \mathbf{E}^Q[(\log(S_T) - \mu)^2], \tag{9}$$

and a measure for excess kurtosis,

$$wp3 = \frac{\left(\mathbf{E}^Q[(\log(S_T) - \mu)^4]\right)}{stddev^2} - 3. \tag{10}$$

These statistics are all computed with respect to the logarithm of the underlying's price, as suggested by Levin, McManus and Watt (1998) and McManus (1999), to facilitate comparison with a lognormal benchmark, i.e. Black's (1976) model for pricing futures options.[23]

An alternative skewness measure suggested by Campa, Chang and Reider (1998) is relative intensity which is defined as the difference between the expectations of the underlying's price conditional on being outside symmetric thresholds $\underline{S}, \bar{S}$ around the futures price.

$$rel.int = int_{\bar{S},+} - int_{\underline{S},-}, \tag{11}$$

where,

$$int_{\bar{S},+} = \int_{\bar{S}}^{+\infty} (S_T - \bar{S}) q(S_T) dS_T, \tag{12}$$

$$int_{\underline{S},+} = \int_0^{\underline{S}} (\underline{S} - S_T) q(S_T) dS_T. \tag{13}$$

$$\tag{14}$$

Apart from standard deviation, volatility and excess kurtosis we use scaled interpercentile ranges as suggested in Melick and Thomas (1998) to represent uncertainty in market expectations, i.e. the dispersion of expectations.[24] We construct scaled interpercentile ranges (sipr) by dividing the difference of the 90 and 10 percent percentiles of the risk-neutral PDF, and the difference between the 75 and 25 percent percentiles, respectively, by the futures price on that day.[25] Typically, the percentiles converge

[23] For Black's (1976) model, i.e. a single lognormal PDF, $sp2 = 0$, and $wp3 = 0$.

[24] For the use of percentiles computed from the risk-neutral PDF, see also Bahra (1997).

[25] On all days in our sample these percentiles fall well within the range of prices covered by our option data.

towards the mean (i.e. the futures price) of the implied PDF as the option's maturity shortens so that the scaled interpercentile ranges decline with time until we switch to a contract with longer maturity. The intuition behind this observation is that, all other things equal, as the time to maturity decreases the market becomes more certain about the future price of the underlying while extreme outcomes become less likely (Bahra (1997)). To account for this maturity effect, we include a linear time trend in our regressions. Since the other calculated statistics from the implied PDFs might depend on maturity, too, we apply to them the same correction procedure. The regressions were done applying the Cochrane-Orcutt method in order to account for serial correlation in the OLS-residuals. We used F-tests to check for heteroskedasticity and used the consistent covariance matrix allowing for heteroskedasticity as in White (1980) when necessary.

Table 1 shows the regression results for the two cases of anticipated interest rate increases considered (03. Feb. 2000 and 31. Aug. 2000). For both episodes we find significantly negative coefficients of the dummy variable in the equations for the scaled interpercentile ranges, for standard deviation and for volatility. Clearly, uncertainty among market participants declined after the ECB-council meetings in these episodes.

Next, table 2 looks at the ECB-council meeting on August, 30, 2001 on which official interest rates were decreased by 25 basis points as anticipated by market participants in the light of the deteriorating business cycle conditions. The dummy variable coefficients are negative but not statistically significant in the equations for standard deviation, volatility and the wider scaled interpercentile range (sipr9010). Following the interpretation suggested by Nakamura and Shiratsuka (1999) the significant decline in excess kurtosis in conjunction with the negative signs on the respective coefficients in the equations for standard deviation and volatility indicates that uncertainty among market participants declined with respect to extreme future realizations of the Euribor. However, in the equation for the narrow scaled interpercentile range (sipr7525) the coefficient of the council meeting dummy is significantly positive. That shows that uncertainty as far as moderate changes in interest rates were concerned increased. These results have to be interpreted in the light of additional information: In the press conference after the council meeting the President of ECB Duisenberg made some surprisingly pessimistic remarks about expected growth rates in the European Monetary Union that might have aggravated uncertainty among market participants about future interest rates.

Table 3 shows the three cases where market participants correctly expected interest rates to be kept unchanged by the ECB-council (20 July 2000, 18. Jan. 2001, 07. June 2001). For the first event we find significant reductions in uncertainty as shown by both scaled interpercentile ranges, along with a significant increase in skewness, relative intensity, and excess kurtosis. However, the corrected coefficient of determination is very low for the equations of the latter three statistics.

In January 2001 we find positive coefficients on the dummy variable in the equations for the scaled interpercentile ranges, and negative coefficients in the equations on standard deviation and volatility. Of these only the positive coefficient on sipr7525 is significantly different from zero indicating an increase in uncertainty for moderate interest rate changes. The significantly negative effect of the council meeting dummy on excess kurtosis together with the negative coefficients in the equations for standard deviation and volatility shows that uncertainty with respect to more extreme interest rate changes declined.

In the third case we again notice significantly negative changes in uncertainty in expectations after the council meeting as shown by the equations for sipr9010 and sipr7525. The significant coefficients in the relative intensity and wp3 equations come together with very small $\bar{R}^2$.

Alltogether, we find in four out of six cases in which the results of the council meetings have been correctly anticipated evidence for a significant decline in uncertainty in market expectations. Particularly pronounced is this effect for the two council meetings for which the increase in official rates was correctly anticipated.

Next, in tables 4-6 the results for events where the market failed correctly to predict the results of the council meeting are presented. In table 4, that shows the result for the time period around March, 2, 2000, where the market expected an interest rate increase, and for March, 29, 2001, where market participants expected the ECB-council to lower official interest rates. For the first episode, we find a significantly negative effect on sipr7525. The coefficient of the council meeting dummy in the sipr9010 equation is negative but insignificant and of only small size. The respective coefficients for standard deviation and volatility are positive. The excess kurtosis equation exhibits a significantly postive effect of the council meeting and provides along with the results for the first two equations some evidence for increasing uncertainty with respect to extreme interest rate deviations in the future. For the second episode there are no significant effects of the dummy variable on any statistic.

Concerning the only episode of an unanticipated interest rate increase (08. June 2000), we find evidence for increasing uncertainty after the ECB-council meeting. The relevant coefficients are positive in the equations for standard deviation, volatility and both scaled interpercentile ranges and are significantly different from zero in the latter two.[26]

Finally, we consider the unexpected decrease in official interest rates decided upon by the ECB-council meeting on May, 10, 2001. The ECB-council explained this surprising decision by referring to a modified concept for computing M3 that yielded a growth rate for that monetary aggregate substantially below that of the conventional M3 measure.[27] The regression results indicate significant reductions in uncertainty after the council meeting as measured by standard deviation, volatility, and both scaled interpercentile ranges. Skewness increased but the equations for both skewness measures exhibit low values for $\bar{R}^2$. Excess kurtosis increased significantly, too. Nakamura and Shiratsuka (1999) suggest to interprete increasing excess kurtosis paired with decreasing standard deviation as indicating growing confidence in the current level of the underlying, i.e. declining uncertainty with respect to moderate changes in interest rates.
Possible interpretations for these strong results are, that the surprising decision of the ECB was explained well to the market so that uncertainty declined or that market participants were becoming increasingly nervous because of the lack of reaction of the ECB to the deteriorating perspectives for the European economies and that this decision by the ECB-council restored confidence that monetary policy would not be completely ignorant to the business cycle problems in the real economic sector.

The results in tables 4-6 show much less evidence for decreasing uncertainty after ECB-

[26] Actually, for the council meeting considered, market participants expected an interest rate increase but only by 25 basis points as opposed to the actual increase by 50 basis points.
[27] See ECB (2001b) for details.

council meetings than those in tables 1-3. Among this group of events we even find the only case of a significantly positive effect of the council meeting on both scaled interpercentile ranges. We also note, that the implicit assumption in our approach, that the results of the ECB-council meeting is the dominant information in the time periods considered is not always valid. For two episodes we have clear reports that the market was confronted with additional and important information apart from the council meeting: Over the days around the council meeting on Jan., 18, 2001 new releases of US data showed the slowdown in the US economy to be more severe than expected and on August, 30, 2001 the expected decrease in interest rates coincided with a negative surprise of market participants by increasingly gloomy forecasts for economic performance of the Euro-zone.

Apart from these special cases the results for correctly anticipated decisions of the ECB-council show a clear tendency for uncertainty in expectations to decline after the council meeting. This tendency is particularly strong in the cases where the market succeeded in correctly predicting interest rate increases. This suggests that it might be more important for the confidence of market participants in their predictions of the future course of monetary policy to correctly anticipate changes in official rates than to correctly forecast rates to be left untouched. This tendency, that interest rate changes are more important to market expectations than constant interest rates, is also visible in the cases of unanticipated council decisions. Again, we find stronger significant results for unanticipated interest rate increases or decreases than for unantipated unchanged interest rates. The results for June 2000 also indicate that there is the potential for unanticipated interest rate changes to substantially increase uncertainty among market participants but that central bank efforts to thoroughly explain such unanticipated decisions can counter increasing uncertainty and may even let uncertainty decline as can be seen in table 6.

As far as skewness is concerned there are no clear results linking changes in asymmetry in expectations to specific scenarios.

6 Summary and conclusions

In this paper we applied the spline-interpolation technique suggested by Bliss and Panigirtzoglou (1999) to LIFFE Euribor Futures options in order to extract risk-neutral probability density functions. In order to investigate the effects of ECB-council meetings on uncertainty in market participants' expectations we constructed risk-neutral PDFs for ten ten-day time periods around council meetings that took place between January 2000 and August 2001. From these densities a set of statistics were computed to summarize uncertainty represented in the risk-neutral PDFs. By utilizing a regression approach we examined each of the time periods in consideration for significant effects of the council meeting on uncertainty in market expectations.
Our regression results showed some evidence that uncertainty declines after a council meeting if the market was able to correctly predict its result. This effects was especially important in cases where market participants correctly predicted increases in official interest rates. For council meetings with unanticipated results this tendency was much weaker. Another result of this study is that it appears to be important to take the background of the individual episodes into account. Special circumstances, particularly the arrival of important economic news apart from the announcement of the council's decision with respect to interest rates can cause substantial deviations in the results and have to be taken into consideration when interpreting the results.

Another limitation of our approach is the requirement that sufficiently precise information about the state of market expectations with respect to each of the council meetings to be considered is available and thereby limiting the number of eligible events. Since we intend to produce "stylized facts" we need this information in order to place each episode in question into the appropriate category with respect to what market participants expected from the council meeting and what eventually was decided.

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27. Jan. - 09. Feb. 2000 (June contract)				
statistic	constant	dummy	expiration	$\bar{R}^2$
stddev(log)	-0.01198	-0.00625**	0.00113**	0.905
volatility	0.05401	-0.00991**	0.00107	0.848
*sp*2	4.32869	-0.16053	-0.04413	-0.275
*wp*3	-7.00032	0.61850	0.07783	0.013
rel. intensity	0.11049	-0.00528	-0.00100	-0.273
sipr9010	0.00378	-0.00103*	0.00007*	0.976
sipr7525	0.00703*	-0.00079*	-0.00002	0.749
24. Aug. - 06. Sep. 2000 (December contract)				
statistic	constant	dummy	expiration	$\bar{R}^2$
stddev(log)	0.03624	-0.00889*	0.00045	0.813
volatility	0.12529**	-0.01598*	-0.00004	0.731
*sp*2	-1.06429	0.17399	0.00965	-0.275
*wp*3	2.79100	-0.32433	-0.01969	-0.160
rel. intensity	-0.04441	0.00408	0.00056	-0.445
sipr9010	0.00383	-0.00118*	0.00008	0.899
sipr7525	0.00193	-0.00039*	0.00003	0.574
* und ** denote significance at the 5- and 10%-level, respectively.				

Table 1: Regression results for anticipated interest rate increases.

23. Aug. - 05. Sep. 2001 (December contract)				
statistic	constant	dummy	expiration	$\bar{R}^2$
stddev(log)	-0.05538*	-0.00034	0.00187	0.958
volatility	-0.01813	-0.00067	0.00231*	0.917
*sp*2	-0.32808	-0.00534	-0.00408	-0.132
*wp*3	5.60633*	-0.44266*	-0.05027*	0.498
rel. intensity	0.00307	-0.00090	-0.00012	-0.387
sipr9010	-0.00356	-0.00014	0.00016*	0.932
sipr7525	-0.00437*	0.00025*	0.00010*	0.852
* und ** denote significance at the 5- and 10%-level, respectively.				

Table 2: Regression results for anticipated interest rate decrease.

13. July - 26. July 2000 (September contract)				
statistic	constant	dummy	expiration	$\bar{R}^2$
stddev(log)	0.05272*	-0.00387	-0.00004	0.376
volatility	0.18917*	-0.00964	-0.00152	-0.026
*sp*2	-5.20488*	0.60838*	0.11733*	0.073
*wp*3	-2.08238	0.37039**	0.06811	-0.203
rel. intensity	-0.09186*	0.01061*	0.00215*	0.134
sipr9010	0.00607*	-0.00049**	0.00001	0.632
sipr7525	0.00475*	-0.00042**	-0.00005	0.272
11. Jan. - 24. Jan. 2001 (March contract)				
statistic	constant	dummy	expiration	$\bar{R}^2$
stddev(log)	0.02238	-0.00115	0.00069	0.584
volatility	0.11731**	-0.00284	0.00019	-0.121
*sp*2	1.27161	-0.11430	-0.04130	-0.271
*wp*3	4.10805*	-1.03002*	-0.05840	0.660
rel. intensity	0.02629	-0.00409	-0.00072	-0.142
sipr9010	0.00099	0.00017	0.00012*	0.608
sipr7525	-0.00071	0.00051*	0.00007*	0.697
31. May - 13. June 2001 (September contract)				
statistic	constant	dummy	expiration	$\bar{R}^2$
stddev(log)	0.05171	-0.00206	0.00044	0.742
volatility	0.17367*	-0.00383	-0.00025	0.156
*sp*2	-0.04021	0.02830	-0.00968	-0.147
*wp*3	-4.66458*	0.30475*	0.08609*	0.117
rel. intensity	-0.02179	0.00258*	0.00016	-0.165
sipr9010	0.00826*	-0.00028*	0.00001	0.409
sipr7525	0.00705*	-0.00037*	0.00005*	0.576
* und ** denote significance at the 5- and 10%-level, respectively.				

Table 3: Regression results for anticipated constant interest rates

24. Feb. - 08. Mar 2000 (June contract)				
statistic	constant	dummy	expiration	$\bar{R}^2$
stddev(log)	0.00798	0.00052	0.00099	0.401
volatility	0.08755	0.00105	0.00084	-0.080
*sp*2	1.06802	-0.00554	-0.01601	-0.202
*wp*3	-2.85953	0.61860**	0.04861	0.218
rel. intensity	0.11028	-0.00469	-0.00139	0.106
sipr9010	0.00382	-0.00009	0.00006*	0.317
sipr7525	0.00689*	-0.00058*	-0.00041	0.558

22. Mar. - 04. Apr 2001 (June contract)				
statistic	constant	dummy	expiration	$\bar{R}^2$
stddev(log)	-0.02276	-0.00167	0.00175*	0.927
volatility	0.03075	-0.00362	0.00228*	0.854
*sp*2	-1.79572	0.18107	0.02062	0.249
*wp*3	4.93515	-0.13990	-0.06734	0.062
rel. intensity	-0.02620	0.00228	-0.00064	0.386
sipr9010	-0.00280	-0.00012	0.00019*	0.934
sipr7525	-0.00370**	-0.00008	0.00013*	0.901

* und ** denote significance at the 5- and 10%-level, respectively.

Table 4: Regression results for unanticipated constant interest rates

01. June - 14. June 2000 (September contract)				
statistic	constant	dummy	expiration	$\bar{R}^2$
stddev(log)	-0.05168	0.00116	0.00172*	0.652
volatility	-0.02977	0.00222	0.00229	0.395
*sp*2	1.04946	-0.00923	-0.01239	-0.324
*wp*3	3.93808	-0.04711	-0.04523	-0.060
rel. intensity	0.00928	0.00151	0.00001	-0.317
sipr9010	-0.01529*	0.00088*	0.00033*	0.852
sipr7525	-0.00669*	0.00035*	0.00015*	0.847

* und ** denote significance at the 5- and 10%-level, respectively.

Table 5: Regression results for unanticipated interest rate increase

03. May - 16. May 2001 (June contract)				
statistic	constant	dummy	expiration	$\bar{R}^2$
stddev(log)	0.07379	-0.00749*	0.00035	0.803
volatility	0.20841*	-0.01261*	-0.00037	0.658
$sp2$	-0.11390	0.15720**	0.00773	0.060
$wp3$	-8.25700*	0.41774**	0.10588*	0.419
rel. intensity	-0.04670*	0.009582*	0.00033	0.197
sipr9010	0.00901*	-0.00143*	0.00003	0.963
sipr7525	0.01287*	-0.00111*	-0.00008**	0.781

* und ** denote significance at the 5- and 10%-level, respectively.

Table 6: Regression results for unanticipated interes rate decrease