The information content of interest rates and their derivatives for monetary policy

The term structure of interest rates and prices of interest rate derivatives provide central banks with a rich source of information on market expectations concerning a number of fundamental macroeconomic variables. This article describes how financial asset prices based on interest-bearing securities can be used to extract information about market expectations for future economic activity and inflation, as well as future changes in short-term interest rates. In addition to providing information on market expectations concerning these factors, the prices of such assets also provide valuable information on the degree of uncertainty which the market attaches to future developments. While such financial indicators are not a substitute for the central bank's own independent assessments and forecasts, the information conveyed by these indicators is important for monetary policy since it provides a means of cross-checking the central bank's own evaluation of risks to price stability and thereby contributes to determining the appropriate monetary policy reactions to counteract such risks.

1 Introduction

Information embedded in the market prices of various financial assets provides central banks with timely forward-looking information on market expectations regarding a number of fundamental factors, such as future economic activity, inflation and the path of short-term interest rates. The analysis of such expectations is important for the conduct of a forward-looking monetary policy that focuses on maintaining price stability in the medium term. In particular, in the context of the two-pillar monetary policy strategy pursued by the Eurosystem in order to maintain its primary objective of price stability, financial asset prices play an important role as indicators in the second pillar (see the article entitled "The stability-oriented monetary policy strategy of the Eurosystem" in the January 1999 issue of the ECB Monthly Bulletin).

An essential characteristic of the monetary policy strategy of the Eurosystem is that it does not foresee mechanistic monetary policy reactions to any indicators or forecasts. This also applies to market expectations extracted from financial asset prices. Moreover, such market expectations can never be a substitute for the central bank's own independent assessment of the economic situation and of future economic developments. Rather, these market indicators should be viewed as providing separate and complementary information which can be used to cross-check the central bank's own internal assessment and forecasts. Although market expectations can be extracted, in principle, from a wide range of financial asset prices, this article focuses solely on those asset prices which are based on fixed income securities, such as bonds, money market instruments and associated derivatives.

Financial asset prices reflect market expectations because they are inherently forward-looking in nature. Specifically, the current price of an asset is determined by the discounted expected value of its stream of future pay-offs. In general, the discount rates used to price financial assets are driven by two factors: the compensation for postponing consumption to a future date, and the compensation for bearing the risk associated with the uncertainty linked to the future stream of pay-offs. Hence, generally speaking, in order to price a financial asset, investors need to form expectations of future pay-offs from the asset and determine which discount rates – including risk premia – they should apply.

In a liquid and efficient market the price of an asset should therefore reflect both the market view of the expected future cash flows and the discount rates that determine this price. For a bond which is free of default risk and has known maturity and coupon payments, the problem of pricing the bond is merely one of determining the interest rates, including risk premia, that are needed to discount back each of the remaining coupon payments and the principal. These interest rates, in turn, are determined by expectations of underlying fundamental variables, such as future inflation and real interest rates, as well as compensation for the risk associated with the uncertainty surrounding these expectations. Hence, by studying variations in prices of financial assets such as bonds, it should be possible to extract information on how market participants' expectations change over time.

In addition to traditional financial assets, derivatives prices incorporate information on a number of other characteristics associated with market expectations (see Box 1). For example, derivative instruments such as options contracts make it possible to estimate the expected future volatility of an asset's return, which provides a measure of the uncertainty that the market attaches to future developments. Furthermore, options can be used to infer whether the uncertainty is perceived by the market to be symmetric or concentrated mainly in a specific direction. In fact, given a sufficient number of options prices, a measure of the market's perceived probability distribution for the future price of an asset can be obtained.

Before turning to the interpretation of indicators based on financial asset prices, it is important to emphasise certain caveats. While it is generally accepted that asset prices reflect the market view regarding future developments in the economy, the practical implications and, in particular, the methods of extracting expectations have not been conclusively established. As a consequence, the information contained in financial prices must be interpreted by using a variety of

Box 1

An overview of common derivatives contracts

Forwards, futures and options

Derivatives contracts are instruments with a pay-off which depends on the future price of an underlying asset, e.g. a bond. The two main types of derivatives contracts that are actively traded on exchanges around the world are futures and options, although there are a variety of other derivative instruments that are mainly traded over the counter, such as forwards and swaps. This box briefly describes the main features of the most common derivative instruments and the models used to price them.

A *forward* contract is an agreement to buy or sell a specific underlying asset at a predetermined price (the delivery price) at a certain future date (the delivery or maturity date). The buyer of the forward contract agrees to buy the underlying asset, while the seller of the forward agrees to sell the underlying asset at the maturity date for the delivery price. The delivery price is set so that the value of the forward contract is zero at inception. This delivery price is referred to as the forward price.

A similar instrument is the *futures* contract. By contrast with forwards, futures are standardised in terms of maturity, notional amounts, etc. and are traded on exchanges. Furthermore, in the case of futures contracts, payment into a margin account is required, against which gains and losses are settled on a daily basis (so-called "marking to market"), while forward contracts are settled only at delivery. As in the case of forwards, the initially agreed delivery price is set such that the initial value of the futures contract is zero, and the corresponding delivery price is known as the futures price.

An *option* is an instrument that gives the owner the right, but not the obligation, to buy or sell the underlying asset at a predetermined price (the strike price or exercise price) at a certain future date (the exercise or maturity date). A call option gives the holder the right to acquire the underlying asset, whereas a put option gives the holder the right to sell it. The seller of the option has therefore agreed to sell the underlying asset (in the case of a call option) or to buy it (in the case of a put option) at the strike price if the owner of the option decides to exercise it. There are two main types of options: "American" options, which the owner can decide to exercise at any time up to and including the maturity date, and "European" options, which may only be exercised at expiration. An option is said to be "at-the-money" if the current forward price of the underlying asset is equal to the exercise price of the option. If the exercise price of a call (put) option is higher (lower) than the forward price, the option is "out-of-the-money", whereas it is said to be "in-the-money" when the reverse is true.

Another important type of derivative instrument is the *swap* contract, in which two parties agree to exchange periodic payments for a predefined period of time. Interest rate swaps are discussed further in Box 2.

Derivatives pricing

Before discussing the indicators extracted from derivatives prices, a brief overview of how derivatives are priced may be useful. Starting with forwards, since the initial price is zero, the interesting aspect is the determination of the forward price. Assuming that the underlying asset is a traded financial security which does not make pay-offs during the period to maturity, the forward price is given by the current value of the underlying asset plus the interest rate earned on this value during the period to the maturity of the contract. The rationale behind this is that the cash flow of a forward contract settled at maturity can be completely replicated by a two-step strategy that involves (1) buying the underlying asset today and financing this purchase by borrowing at the available interest rate and (2) selling the underlying asset on the delivery date at the prevailing market price and repaying the loan. The amount that has to be repaid is the current value of the underlying asset plus the interest on this amount until maturity, which must also correspond to the forward price in order to exclude arbitrage opportunities. The futures price is generally similar to the forward price, and under some circumstances they may be identical.

Turning to options, the most commonly used formula for pricing European options was developed by Black and Scholes (1973).[1] According to their model, the value of an option is determined by five factors: the current price of the underlying asset, the strike price, the time to expiration of the option, the risk-free interest rate during the life of the option, and the volatility of the return on the underlying asset. The main assumption behind this result is that the price of the underlying asset follows a process which implies that returns are normally distributed with constant mean and volatility. All factors except for volatility are directly observable, which means that the latter must be estimated to allow the price of an option to be calculated.

This calculation can also be reversed, in the sense that given an observed option price, a value for volatility can be found that, by means of an option pricing model like the Black-Scholes formula, produces an option price which corresponds to the observed market price. This value for the volatility is referred to as the implied volatility. Given appropriate assumptions, the implied volatility can be interpreted as the market's best estimate of the expected volatility of the underlying asset's price during the remaining life of the option and therefore provides a measure of the uncertainty surrounding the evolution of the price of the underlying asset over the life of the option.

A notable feature of the Black-Scholes model, and of option pricing models in general (given a few assumptions), is that the expected return on the underlying asset is not relevant for pricing an option. Since the expected return, which should reflect investors' risk preferences by incorporating a risk premium, is not included in the calculation of option prices, it may be concluded that the price of an option does not depend on the risk preferences of investors. The rationale is, loosely speaking, that option pricing is based on an arbitrage argument, whereby the pay-off of an option can be perfectly replicated through a portfolio of other traded securities. The absence of arbitrage opportunities requires that the value of the option be equal to the value of the portfolio that replicates the pay-off from the option, a condition which holds irrespective of individual

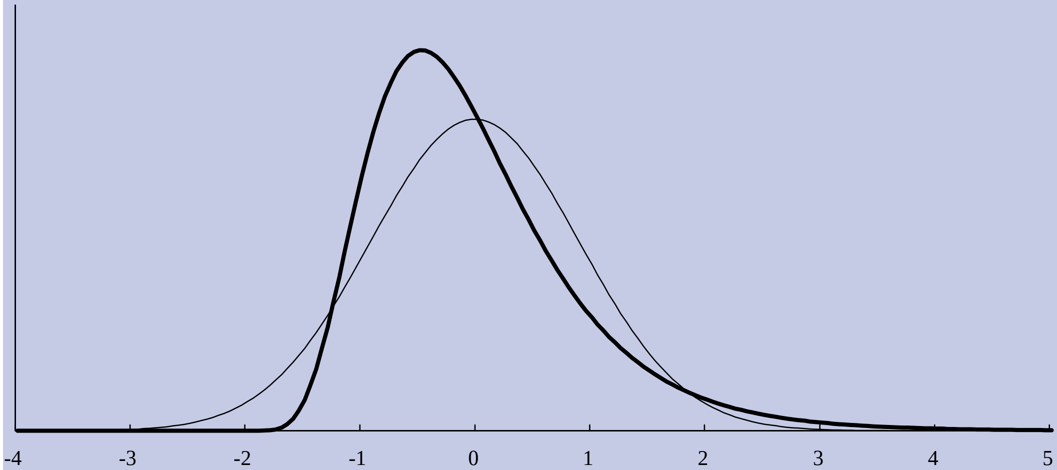
1 *Black, F. and Scholes, M. S. (1973), "The pricing of options and corporate liabilities,"* Journal of Political Economy, *81, 637-654.*

investors' preferences. Since preferences do not matter when pricing option contracts, it may be assumed, for example, that investors are risk neutral, which turns out to facilitate the pricing of options. This method is sometimes referred to as risk-neutral pricing.

Although the Black-Scholes model is widely used to price options and to calculate implied volatilities, it is commonly known that many of its underlying assumptions do not hold in the real world. In particular, the assumption that asset returns are normally distributed with constant volatility can be rejected for the vast majority of existing assets. In fact, volatility tends to vary over time and return distributions tend to have fatter tails than a normal distribution would imply (i.e. extreme price movements are more frequent than a normal distribution would predict). In many cases, the distribution is also skewed, implying that large price changes occur more frequently in one direction than in the other, as illustrated in the chart below. This chart shows two hypothetical return distributions with identical means and variances, but where one distribution is symmetric and the other is positively skewed. The positive skewness in this distribution is evident from the fact that the right-hand tail of the distribution is longer and wider than the left-hand tail, implying that outcomes far out in the right-hand tail (i.e. large positive outcomes) are more likely to occur than outcomes that are far out in the left-hand tail. For the symmetric distribution, however, the probabilities of positive and negative deviations of equal magnitude from the mean are identical.

Clearly, these departures from the assumptions do influence options prices, and it is therefore necessary to keep these caveats in mind when extracting information from observed option prices. In particular, by estimating the entire implied distribution of the underlying asset price at the time of expiration, rather than only the implied volatility, many of the aspects associated with departures from standard assumptions can be incorporated (see the appendix at the end of this article for further details).

Symmetric and positively skewed distribution



Note: The means and variances of the distributions are identical.

models, often in combination with a priori beliefs concerning the links between financial variables and economic developments. In addition, asset prices can be temporarily influenced by non-fundamental factors emanating from, for example, institutional features of the market or temporary imbalances between different types of agents in the market. For this reason, such factors must also always be taken into consideration in order to enable an appropriate assessment of market expectations to be conducted.

2 Indicators based on long-term fixed-income securities

The prices of long-term fixed-income securities such as government bonds can be used to infer market expectations regarding future economic activity and inflation. Furthermore, prices of derivatives on such securities can, to some extent, provide information on the degree of uncertainty associated with these expectations. The following sub-sections focus on these two aspects.

Inferring expectations concerning economic activity and inflation

In general, the nominal yield on a government bond can be decomposed into three elements: the expected real interest rate required by investors for holding the bond until it matures, compensation for the expected inflation rate during the life of the bond, and a component associated with various risk premia. The long-term real interest rate, in turn, is generally regarded as being linked to expectations of future economic growth. Variations in long-term bond yields over time could therefore, in principle, be interpreted in terms of changes in expected economic activity, expected inflation, risk premia, or a combination of these factors. Since bond prices are updated continuously, they can offer timely information on market expectations which reflect the latest information available to the market.

With regard to expectations of future economic activity, the slope of the yield curve is traditionally viewed as a useful indicator. A steepening of the yield curve is normally seen as signalling expectations of accelerating economic activity, whereas a flattening or even an inversion of the yield curve is taken as an indication of an expected slowdown in growth. There are a number of possible reasons why such a link may exist between the slope of the yield curve and expectations of future real growth. For example, if private agents believe there will be a weakening of real economic activity in the future, they will tend to increase their demand for long-term bonds with the expectation that the pay-offs from these bonds will compensate for losses in income when economic conditions have weakened. This will tend to drive up the price of long-term bonds relative to short-term bonds, which means that there would be a decline in long-term bond yields relative to short-term bond yields, resulting in a flatter yield curve. Similarly, when private agents expect economic conditions to improve in the future, they may consume more and save less, hence lowering their demand for long-term bonds such that the yield curve would tend to become steeper when economic growth is expected to pick up.

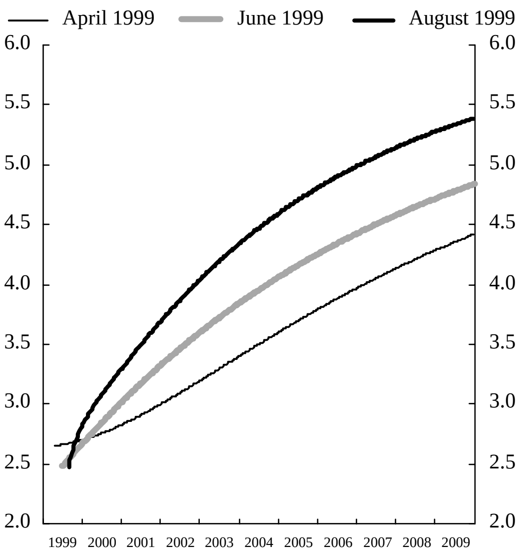
An alternative explanation is that when markets expect higher nominal growth, the central bank may be expected to react by increasing short-term interest rates in the future in order to contain inflationary tendencies. This would then be reflected in higher long-term interest rates today, since long-term rates can be viewed as averages of expected future short-term rates plus risk premia. As a result, the slope of the yield curve would tend to be positively related to expected future changes in real output.

In order to illustrate how the slope of the yield curve can change relatively rapidly as expectations regarding future economic activity are revised, Chart 1 displays the estimated euro area zero-coupon yield curves at three evenly spaced points in time during the spring and summer of 1999. The relative flatness of the yield curve in April, particularly at shorter maturities, reflected the then prevailing expectations that the recovery from the economic slowdown which had begun in late 1998 could take a relatively long time to materialise. However, this perception was subsequently quickly revised in the direction of a stronger and more rapid pickup in euro area economic activity, as indicated by the significant steepening of the yield curve in the following months.

Chart 1

Zero-coupon euro area yield curve

(percentages per annum)



Sources: Reuters and ECB estimation.
Note: The zero-coupon interest rates are estimated using Svensson's (1994) extension of the Nelson and Siegel (1987) method, applied to euro area money market and swap data. See Nelson, C. R. and Siegel, A. F. (1987), "Parsimonious modeling of yield curves," Journal of Business, 60, 473-489, and Svensson, L. E. O. (1994), "Estimating and interpreting forward interest rates: Sweden 1992-94," IMF WP/94/114, Washington D.C.

Besides possibly signalling expectations of accelerating economic activity, an increase in the steepness of the yield curve may also be consistent with market expectations of upward price pressures. It is therefore conceivable that part of the yield curve steepening observed in Chart 1 could have been associated with market expectations of somewhat higher inflation. In fact, this does not appear unreasonable, as inflation expectations embodied in the yield curve in early 1999 may have been overly depressed owing to an overreaction to the financial turbulence that had been triggered by the emerging markets crises in the second half of 1998. This overreaction may have temporarily depressed the level of long-term bond yields.

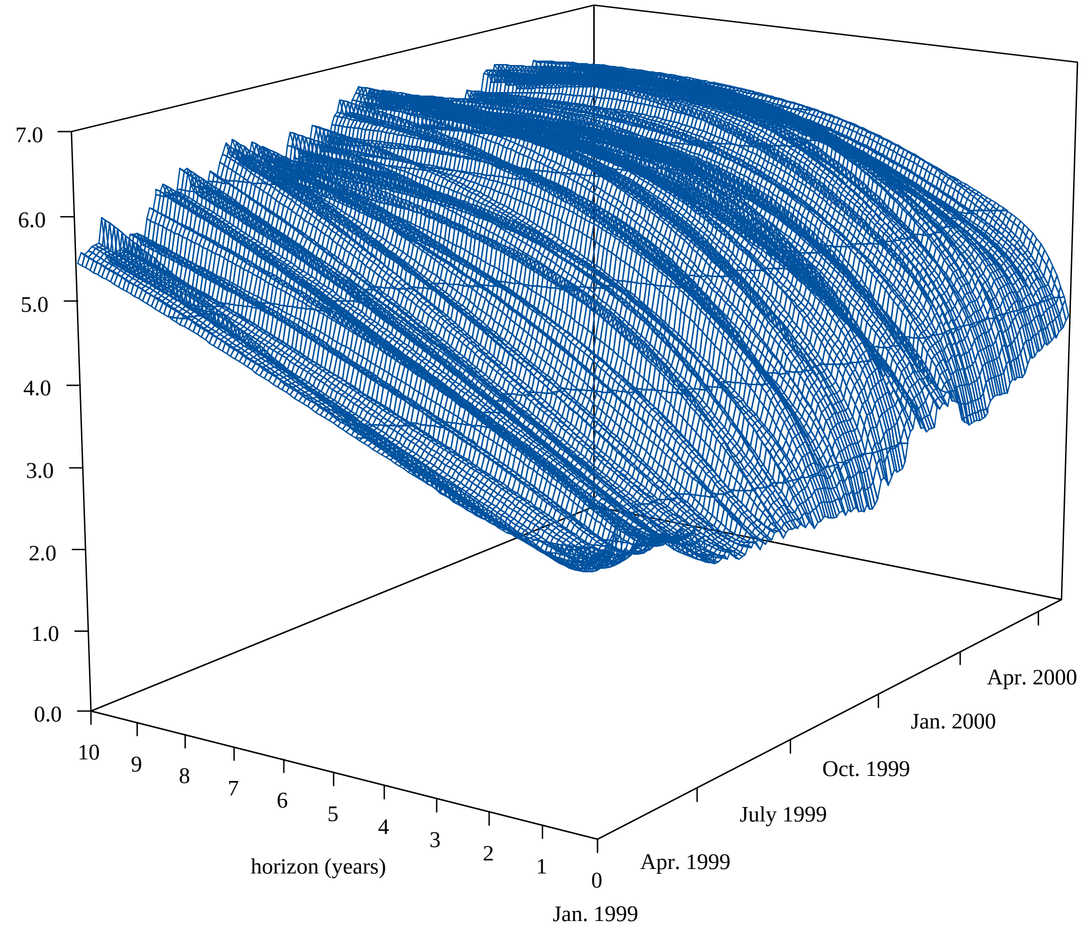
The relative influence of growth expectations and inflation expectations on the yield curve can be disentangled to some extent by employing additional indicators. A frequently used indicator is the implied instantaneous forward interest rate curve, which is sometimes referred to as the "implied forward overnight interest rate curve". This displays very short-term (i.e. approximately overnight) interest rates at various future horizons implied by the observed term structure of interest rates (see Box 4 in the January 1999 issue of the ECB Monthly Bulletin). Implied forward overnight rates can be interpreted as indicating the market's expectations regarding short-term interest rates at different future points in time, although it should be borne in mind that implied forward interest rates would be equal to expected future interest rates only in the absence of term premia. In other words, whereas the zero-coupon yield curve could be viewed as measuring expected averages of future short-term interest rates, the implied forward overnight interest rate curve can be seen as measuring the path of expected future short-term interest rates over time.

Chart 2 displays the estimated daily implied forward overnight interest rate curves from the beginning of 1999 until end-April 2000 for the euro area. In the chart, the estimation date together with the horizon of the forward rate and the level of the implied forward overnight rate are shown on three separate axes. It is evident that the shape of the forward yield curve has undergone significant changes since the beginning of 1999. In particular, the chart shows that the steepness of the implied forward overnight curve tended to increase at short and medium maturities, while at the long end of the curve the implied forward rates remained stable. These changes indicate that market expectations concerning the evolution of future short-term interest rates in the euro area over both short and medium horizons have been significantly revised during this period. From this perspective, it seems that the significant increase in long-term bond yields that occurred after the early months of 1999 (see Chart 3) to a large extent could be explained by expectations of higher short-term interest rates in the short to medium term.

Chart 2

Implied forward overnight interest rates for the euro area since the start of 1999

(percentages per annum; daily data)



Sources: Reuters and ECB estimation. The implied forward interest rates are estimated using Svensson's extension of the Nelson and Siegel (1987) method, applied to euro area money market and swap data.

Implied forward rates over short horizons are useful primarily for examining market expectations of short-term interest rate changes, and thereby provide information on expectations regarding monetary policy (see Section 3). Long-horizon implied overnight forward rates, by contrast, convey information about long-term expectations for real interest rates and expected inflation at distant future dates. Under the assumption that expected real interest rates and risk premia far ahead in the future are broadly stable, long-horizon implied forward rates can be seen as mainly reflecting expectations for inflation several years from now, i.e. after short-term shocks to inflation have abated. For this reason, implied forward overnight rates for very long horizons are often seen as an indicator of a central bank's credibility, as perceived by the market, in terms of maintaining price stability in the long run. In this respect, it is notable that in the case of the euro area the estimated implied forward overnight interest rate for the ten-year horizon has remained relatively stable since early 1999 (see Chart 3). This would seem to suggest that market confidence concerning the maintenance of price stability in the euro area over the medium to long term has remained quite stable since the launch of the single currency.

Another useful indicator that can assist in disentangling long-term expectations of real activity and inflation can be obtained by comparing nominal bond yields with yields on bonds that are linked to a price index. In particular, the yield differential between an index-linked bond and a nominal bond of the same maturity is referred to as the "break-even" inflation rate (see Box 2 on pages 12 and 13 of the February 1999 issue of the Monthly Bulletin). In the absence of risk premia, the break-even inflation rate is equal to the expected average inflation rate during the life of the bonds from which it is constructed. However, since it is likely that the bond yields include various premia, notably liquidity premia and risk premia related to inflation uncertainty, some caution should be exercised when interpreting the level of the break-even inflation rate. For this reason, it may be more sensible to focus on changes in the break-even inflation rate rather than on the level itself, although it should be borne in mind that this presupposes that premia are constant over time.

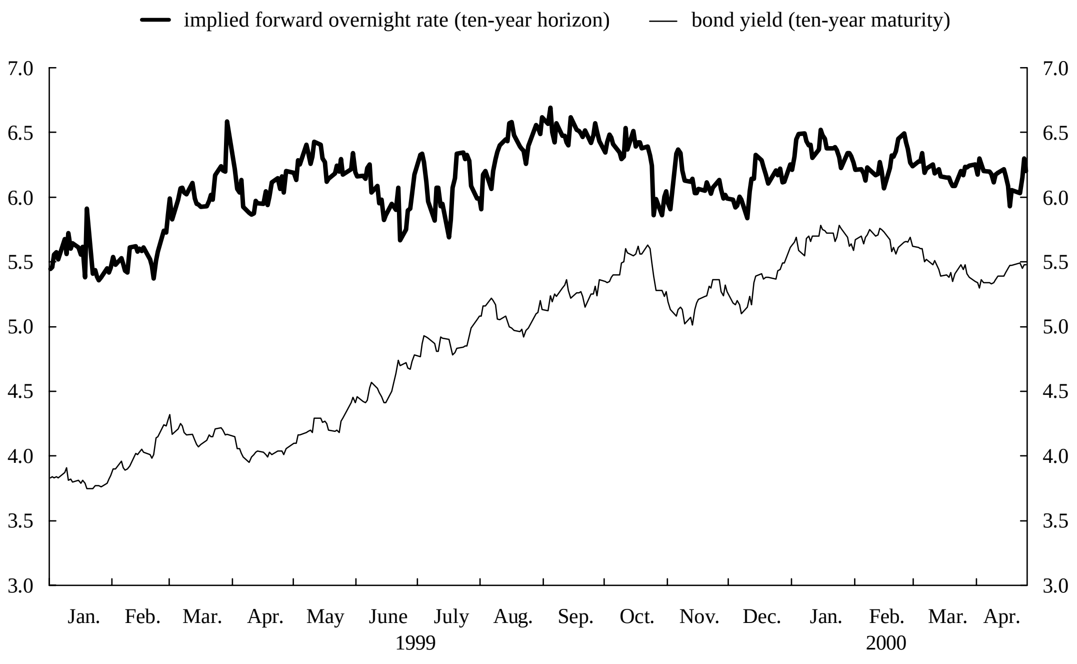
Within the euro area, only the French Treasury has issued index-linked government bonds with maturities of 10 and 30 years. The break-even inflation rate of these bonds refers to a specific measure of the French CPI (namely the Consumer Price Index excluding tobacco), and does not refer to the euro area Harmonised Index of Consumer Prices (HICP), which is used by the Eurosystem when defining price stability. Nonetheless, in the absence of similar instruments based on the entire euro area HICP, developments in the break-even inflation rate obtained from French index-linked and nominal bonds are frequently used as a proxy for changes in long-term inflation expectations of financial markets for the euro area as a whole. As such, the break-even inflation rate provides a useful indicator of market expectations, in particular as a complement to information coming from other measures of expected inflation.

The increase in nominal yields that took place in the euro area during much of the spring of 1999 coincided with an increase in the French

Chart 3

Implied forward overnight interest rate at the 10-year horizon, and 10-year government bond yield for the euro area

(percentages per annum; daily data)

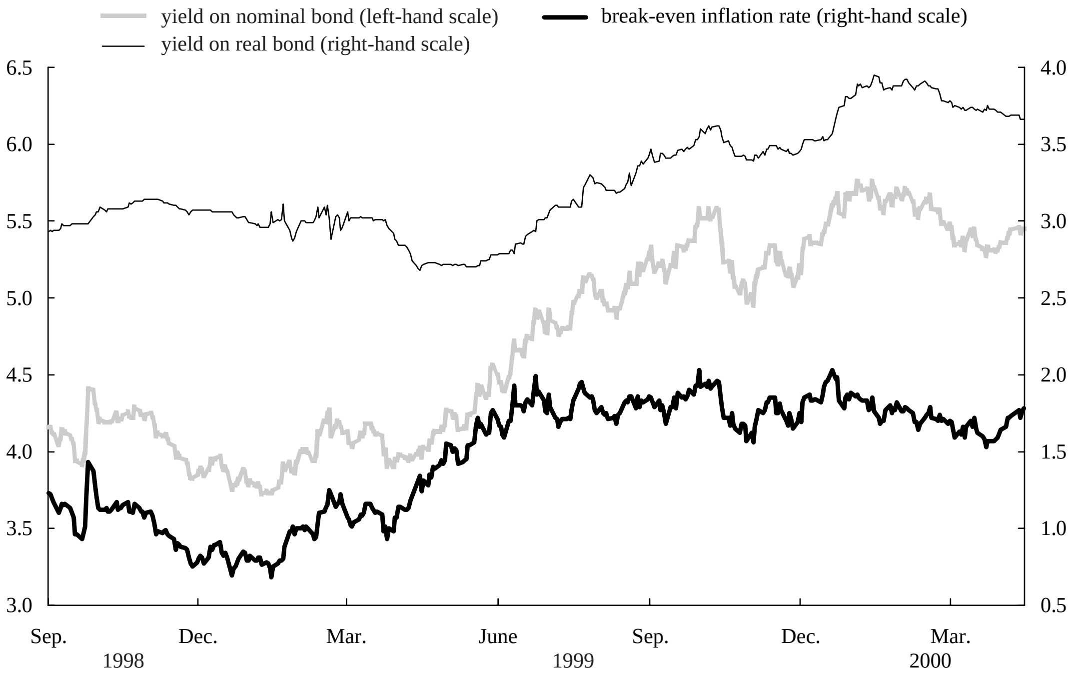


Sources: Reuters and ECB estimation. The implied forward interest rates are estimated using Svensson's extension of the Nelson and Siegel (1987) method, applied to euro area money market and swap data.

Chart 4

Break-even inflation rate calculated from the French CPI

(percentages per annum; daily data)



Sources: French Treasury, ISMA and Reuters.
Note: The real bond yields are derived from the market prices of French bonds which are indexed to the French CPI (excluding tobacco prices) and which mature in 2009. The nominal bond yields are derived from the market prices of French fixed income bonds which also mature in 2009.

break-even inflation rate (see Chart 4). This may have been the result of an increase in inflation expectations from the very low levels observed in early 1999, owing to the aforementioned possible overreaction to the financial turbulence associated with the emerging markets crises in 1998. It is notable that from around mid-1999, the break-even inflation rate remained confined to a relatively narrow range. Instead, the increase in nominal bond yields during this period was apparently the result of a substantial increase in the real yield. This suggests that after the first half of 1999 the observed increases in nominal bond yields were caused by improvements in market expectations regarding future economic activity, rather than increasing long-term inflation expectations. In this sense, developments in the break-even inflation rate are consistent with those of long-horizon implied instantaneous forward interest rates, suggesting that the ECB's credibility with regard to maintaining price stability in the long run has remained firm and stable.

Extracting and interpreting indicators of uncertainty

The indicators that have been discussed thus far in the preceding sub-section provide information on the average market expectations regarding economic activity and inflation or changes in these expectations over time. They do not, however, provide indications of the degree of uncertainty the market attaches to these expectations. Given that economic conditions change over time, it seems likely that the perceived uncertainty surrounding the market's assessment of future inflation and economic activity also varies. Furthermore, it is conceivable that other aspects of uncertainty can change, such as whether market participants perceive uncertainty to be evenly balanced or skewed in any particular direction.

As discussed in Box 1, derivative instruments contain information relating to various aspects of uncertainty. Swap spreads, for

Box 2

Swap spreads as indicators

A swap is a contract in which two parties agree to exchange periodic payments for a predefined period of time. An ordinary interest rate swap, for example, involves exchanging a series of payments corresponding to a certain fixed (long-term) interest rate on a notional principal against a series of payments corresponding to a short-term floating rate on the same notional principal. The principal itself, however, is not exchanged, which means that the principal is not lost if the counterpart to the swap agreement defaults. Swaps are non-standardised contracts and are generally traded over the counter, normally through a bank or through other financial institutions which act as dealers.

The “swap spread” is an indicator which has the potential to convey useful information on, among other things, the likelihood of default. The swap spread is defined as the differential between the fixed rate on an interest rate swap contract (henceforth referred to as the “swap rate”) and the yield on a government bond with a comparable time to maturity. Assuming that financial market agents entering into a swap contract are risk neutral and have the same degree of creditworthiness, the fixed swap rate is determined as the rate that equates the present value of the expected series of floating-rate payments with the present value of the future fixed-rate payments. As a result, it can be shown that factors such as the steepness of the yield curve and expected changes in the future differential between the short-term reference money market rate used in the swap agreement and the corresponding default-free interest rate will influence the swap rate and hence the swap spread.

Factors associated with the default risk of the agents in the swap market are likely to affect the swap rate, and thereby the swap spread, once the assumptions of risk neutrality and identical creditworthiness are dropped. In principle, the observed swap spread can be expected to vary according to, inter alia, changes in the aggregate likelihood of default, as perceived by the market. In other words, when the probability that any given firm will default is seen by the market as having increased, the swap spread will tend to widen, other things being equal. Since the likelihood of default typically increases in anticipation of or during a recession, the swap spread may also convey information with regard to changes in expectations of future economic activity. In addition, it is possible that perceived changes in liquidity risk may influence the swap spread from time to time, while

Ten-year euro area swap spread

(basis points; daily data)

Source: Bloomberg.
Note: The swap spread is defined as the differential between the fixed rate of a ten-year interest rate swap contract and the yield on a government bond with a comparable time to maturity.

variations in supply and demand of corporate and government bonds may induce temporary changes in the swap spread as well.

The effect of the emerging markets crises in the summer of 1998 and the ensuing financial turbulence is clearly displayed by a sharp increase in the euro area swap spread, which subsequently gradually dissipated towards the end of the year and in early 1999 (see the chart above). During the second half of 1999 the swap spread again tended to increase, as concerns related to the century date change began to influence the market. This was, nevertheless, only a short-lived phenomenon.

example, are considered to be informative indicators in this respect (see Box 2). Furthermore, options on long-term bonds may be useful in obtaining an indication of the degree of uncertainty associated with future developments in bond yields. Since bond yields can be decomposed into an ex ante real interest rate, a long-term inflation expectation and a component related to various premia, any measure of uncertainty extracted from bond options should also reflect uncertainty regarding all these components. However, no consensus exists on how to disentangle uncertainty linked to inflation expectations from uncertainty associated with changes in the real interest rate or with variations in risk premia. The fact that expectations regarding all these components affect the pricing of derivatives on long-term bonds makes it particularly challenging to extract and interpret the relevant forward-looking information from long-term bond options.

For the euro area the most liquid (and hence presumably the most informative) derivatives contracts on long-term bonds are the ten-year German Bund futures and the options associated with these contracts. A valuable measure of the overall uncertainty associated with future price movements in the ten-year Bund is the implied volatility which, given appropriate assumptions, provides a measure of the expected volatility in the underlying Bund contract during the life of the option (see Box 1). Chart 5 shows developments in the implied volatility derived from options on ten-year Bund futures, together with the volatility implied by options on the ten-year US Treasury note for comparison.

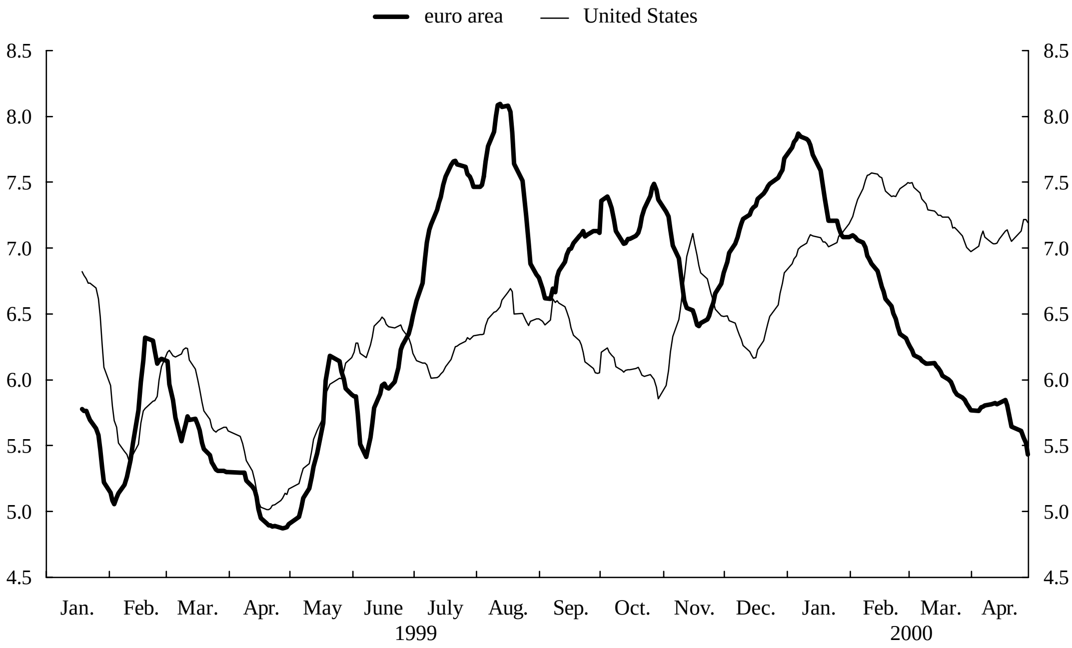
The implied volatility derived from options on German Bund futures contracts has tended to vary substantially since the start of 1999. While it mirrored developments in the corresponding measure of US implied volatility during the first few months of 1999, the volatility implied by options on the Bund futures contract decoupled from its US counterpart and began edging upwards in the early part of the summer. This heightening of uncertainty coincided with rising nominal bond yields in the euro area, which, as mentioned above, appeared to be linked to rising long-term real interest rates as a result of improving economic prospects. It therefore seems plausible that a substantial part of the increase in uncertainty surrounding future bond yield developments observed at this time was attributable to heightened uncertainty with regard to future real yields, as the strength and sustainability of the economic recovery may have been particularly uncertain around the turning point. However, part of the increase in implied volatility may also have been linked to somewhat higher uncertainty regarding future inflation and/or risk premia, as market participants may have become more uncertain about the impact of increasing economic activity on price pressures.

A notable decline in expected volatility occurred around the time of the increase in ECB interest rates on 4 November 1999. This decline in implied volatility may be seen as an indication of a reduction in uncertainty surrounding both future price pressures as well as inflation risk premia, as a consequence of the monetary policy tightening. However, as can be seen in Chart 5, the decline in expected volatility proved to be relatively short-lived as implied volatility derived

Chart 5

Implied volatility derived from options on futures contracts on the ten-year German Bund and the ten-year US Treasury note

(percentages per annum; ten-day moving average of daily data)



Source: Bloomberg.

Note: The implied volatility series in the above chart represent the nearby implied volatility derived from options on the near contract generic future, rolled over 20 days prior to expiry, as defined by Bloomberg. This means that 20 days prior to expiry of the contracts a change in the choice of contract used to obtain the implied volatility is made, from the contract closest to maturity to the next contract.

from options on Bund futures again started to increase in mid-November. This trend persisted until the end of 1999, at which time implied volatility set out on a declining path. Among the factors that appeared to contribute to the decline in implied volatility in early 2000 were the disappearance of the uncertainty related to the century date change and, more importantly, heightened expectations of a further interest rate increase by the ECB, and the actual decisions to raise rates on 3 February, 16 March and 27 April 2000.

As mentioned in Box 1, the information extracted from options prices can be enhanced by estimating the entire probability distribution of financial prices. In particular, observed prices for options on the same underlying asset, and with identical expiration dates, but over a range of strike prices can be used to obtain a measure of the "implied risk-neutral density". This reflects what the market would perceive as the probability distribution of the price of the underlying security at the future date when the option expires, if market participants were risk neutral. In fact, since the implied density is risk neutral, the mean of the distribution corresponds to the forward price for the relevant horizon. Given that investors are generally risk averse, the implied risk-neutral density is, however, likely to differ somewhat from the market's "true" perception of the probability distribution.

Nevertheless, assuming that risk premia mainly influence the mean of the distribution, the risk-neutral density should provide useful indications of other aspects of the distribution, such as the dispersion of uncertainty, and any asymmetries in the shape of the distribution. As previously mentioned, it is quite conceivable that market participants may from time to time view uncertainty as

Box 3

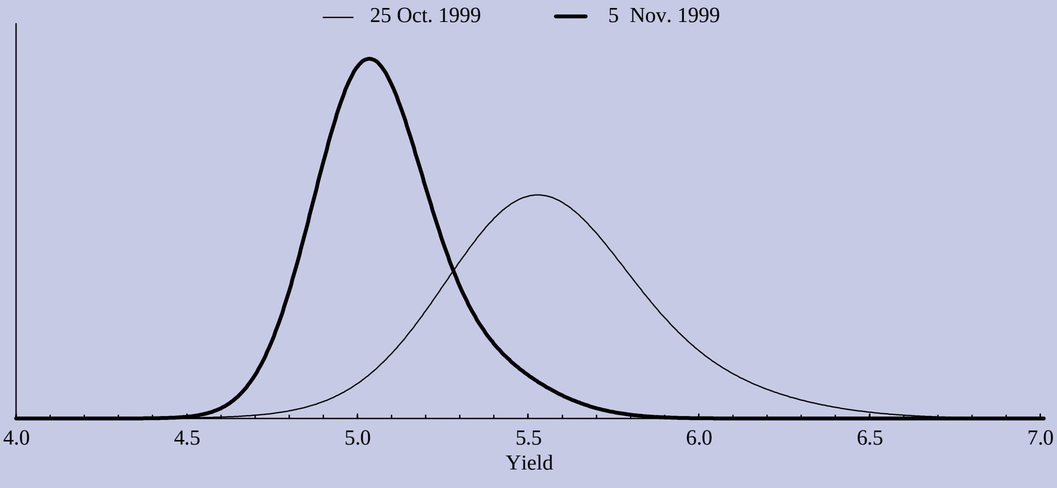
Risk-neutral densities implied by options on Bund futures around the time of the ECB interest rate increase in November 1999

An interesting episode of rapidly changing market perceptions took place in the period surrounding the ECB interest rate increase in early November 1999. As can be seen in Chart 3, long-term bond yields had been on a rising trend from the spring of 1999 until the end of October. The implied risk-neutral densities of the December 1999 ten-year Bund futures contract, according to options prices that prevailed on 25 October 1999, i.e. one and a half weeks before the interest rate decision was announced, exhibited a relatively high degree of dispersion (see the chart below), indicating that uncertainty was perceived to be high at that time.

On 4 November 1999 the Governing Council of the ECB announced the decision to increase interest rates by 50 basis points. As demonstrated by the implied risk-neutral density for 5 November, market uncertainty regarding future bond price developments was considerably reduced thereafter, while bond yields had fallen significantly. The decline in bond yields may have reflected lower inflation expectations and a reduction in inflation risk premia as a result of the monetary policy tightening. Furthermore, the reduced uncertainty regarding the future course of long-term bond yields may have pointed towards lower uncertainty with regard to future changes in inflation expectations, if the decision by the Governing Council of the ECB was seen as stabilising these expectations. In this case, the likelihood of large variations in inflation risk premia in the period ahead should also have been reduced, hence further contributing to the decline in uncertainty regarding future bond yields.

Another interesting aspect of the implied risk-neutral density for 5 November is that it was considerably more skewed to the right than the distribution for 25 October, implying that the perceived likelihood of large bond yield increases was higher than that of yield decreases of the same magnitude. One explanation for this could be that following the substantial declines in long-term bond yields over a few days, the potential for further large declines in long-term bond yields may have been perceived as being relatively limited. In other words, the more pronounced positive skewness of the implied distribution suggests that market participants saw it as more probable that they would be surprised by higher than expected bond yields in the future, than by lower than expected yields.

Implied risk-neutral densities for ten-year Bund futures (December 1999 contracts)



Sources: Bloomberg and ECB calculations.
Note: The implied risk-neutral densities are originally estimated for the Bund futures prices rather than the yields. These results are subsequently transformed into risk-neutral densities for the Bund yield to maturity, using an approximation which accounts for the duration and the convexity of the bond that is cheapest to deliver on the day of estimation (i.e. when the option prices are observed).

being skewed in one direction or the other, rather than being evenly balanced. In the case of the bond markets, estimates of implied risk-neutral densities extracted from options on Bund futures can be used to investigate these aspects of the perceived market uncertainty. As an illustration, Box 3 demonstrates how the implied risk-neutral density of the Bund futures contract changed around the time of the ECB interest rate increase in November 1999.

3 Indicators based on short-term money market rates

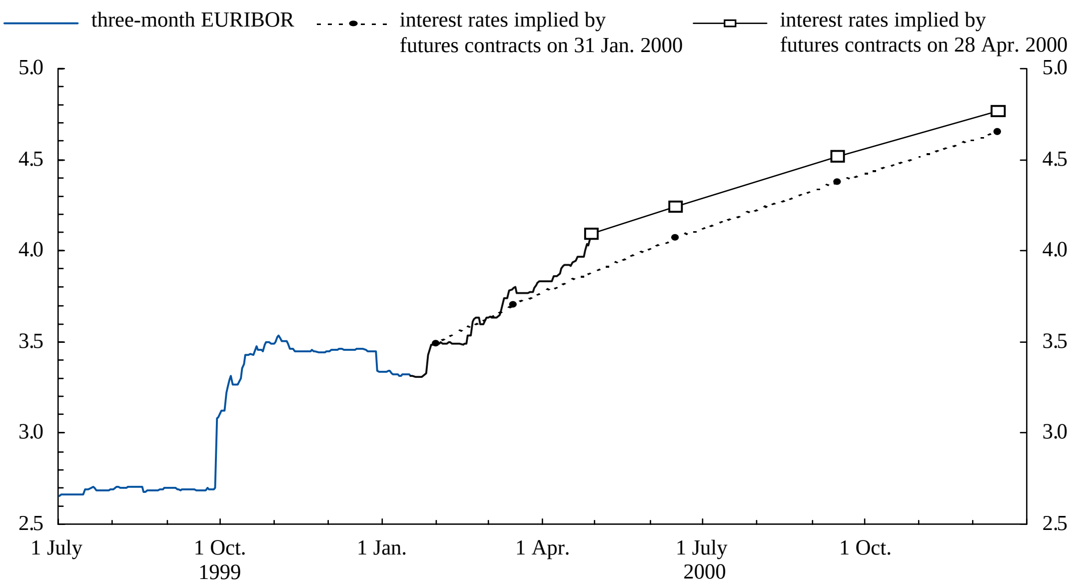
As mentioned above, financial market prices can also provide useful information regarding market expectations of short-term interest rates in the future, and the uncertainty surrounding these expectations. Since the central bank to a large extent influences interest rates over very short horizons, financial market prices also indirectly provide indications regarding the market's perception of future policy changes by the central bank.

Market expectations of future short-term interest rates

Information on market expectations regarding the evolution of short-term interest rates may be extracted from the money market yield curve or from futures contracts on short-term interest rates. For the euro area, measures of the EURIBOR (Euro Interbank Offered Rate) provide good indicators of developments in short-term interest rates. These rates are computed daily, for maturities ranging from one week to twelve months, as the average of the offer rates of a panel of banks actively engaged in the euro interbank market. The term structure of EURIBOR interest rates can be used to extract information regarding market expectations of the future evolution of short-term interest rates. Similar indications can be gauged from futures contracts on three-month EURIBOR rates, which are traded on several exchanges for a wide range of maturities. The high liquidity of some of these markets means that the prices of these instruments should reflect reasonably accurately the information available to financial markets. In Chart 6 the line depicting

Chart 6

Three-month EURIBOR interest rates and interest rates implied by futures contracts



Source: Bloomberg.

the evolution of the three-month EURIBOR interest rate since mid-1999 has been joined up with the interest rates that were implied in futures contracts with maturities at the end of March, June, September and December 2000, as at market closing on 31 January and 28 April 2000.

As always, some caution needs to be exercised when interpreting such indicators, since expectations derived from interest rates implied in futures contracts are likely to be biased by interest rate risk premia prevailing in financial markets. In particular, the effects of risk premia could be relatively large in the case of expectations over longer horizons. For this reason, interest rates implied by long-horizon futures are likely to overestimate future spot interest rates to a larger extent than short-maturity futures.

Indicators of market uncertainty

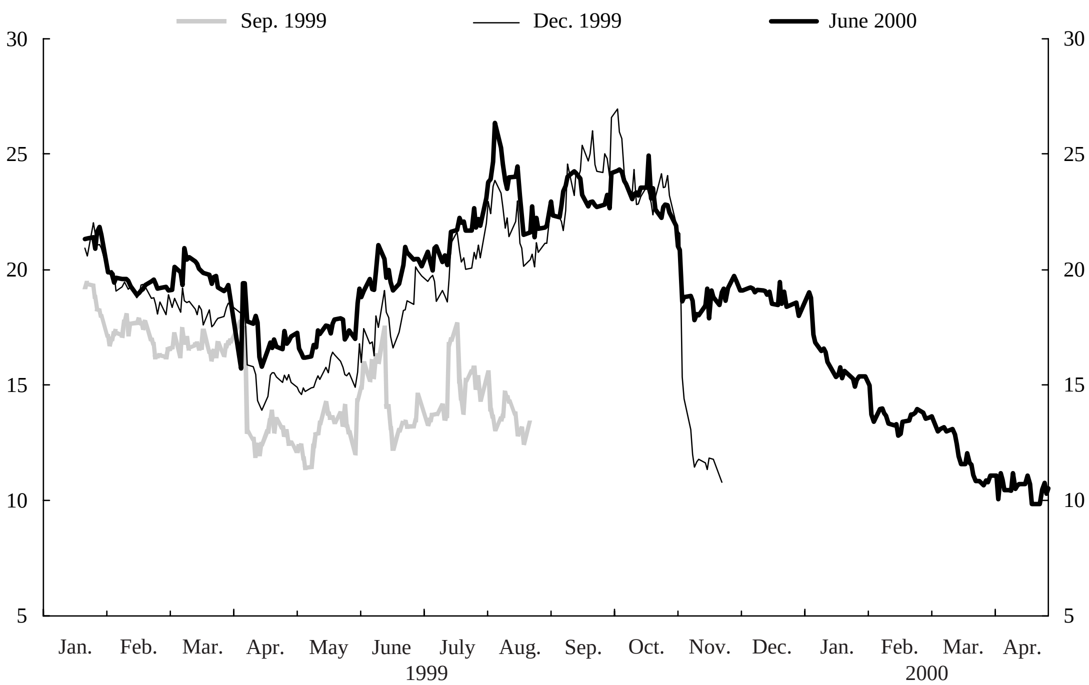
Measures of the expected volatility of future short-term and long-term interest rates can provide a central bank with valuable information about the dispersion of market expectations or uncertainty regarding future interest rate developments. A useful measure of expected volatility is implied volatility, which, as previously discussed, can be extracted from observed options prices. In the case of options on short-term interest rates, the most liquid market for interest rates in the euro area is that for options on three-month EURIBOR futures, where contracts for several maturities are actively traded and daily prices are available.

Chart 7 illustrates the evolution of expected volatility as measured by the implied volatility of futures contracts maturing in September 1999, December 1999 and June 2000 over the period from January 1999 to end-April 2000. As can be seen, implied volatility displayed a declining trend in early 1999 and then fell significantly following the announcement of the decision to lower ECB interest rates in April 1999. While uncertainty concerning short-term interest rates began to increase as from the summer of 1999, it

Chart 7

Implied volatility from options on three-month EURIBOR futures

(traded on LIFFE)



Source: Bloomberg.

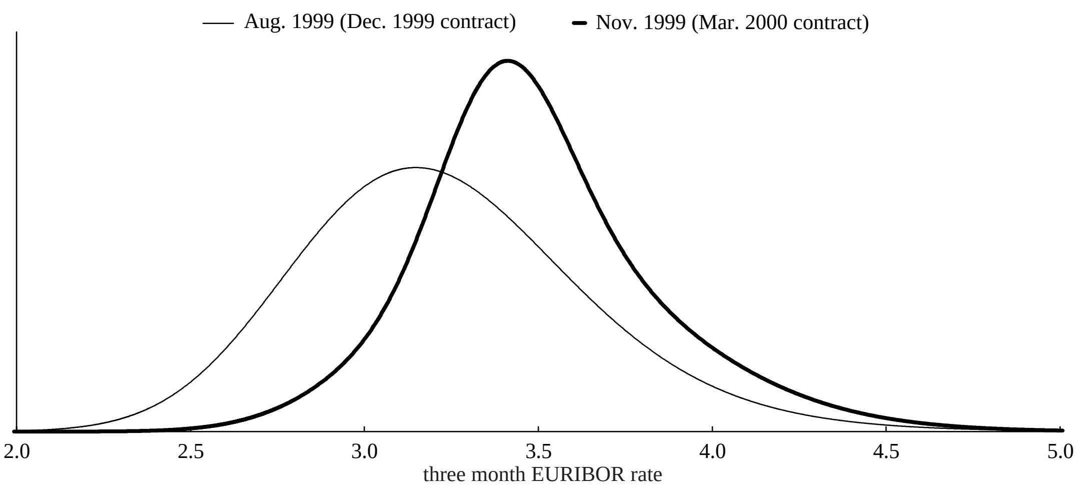
was again significantly reduced following the November 1999 decision to raise ECB interest rates. Since then, implied volatility has been on a declining path, indicating gradually reduced uncertainty regarding the course of future short-term interest rates.

As previously noted, implied volatilities are generally not constant across contracts with different expiration dates. In particular, the volatility implied by options on short-term interest rates in the euro area generally tends to be higher the longer the time to maturity of the option. However, while the volatility implied in contracts expiring in June 2000 remained above that of the December 1999 contract for most of last year, at the end of the third quarter of 1999 the December 1999 implied volatility increased above the volatility implied in options expiring in June 2000. This was probably a result of heightened market concerns over the transition to the year 2000 and the fact that the December 1999 maturity was that most affected by the uncertainty regarding the timing of a change in the monetary policy stance of the ECB. The increase in ECB interest rates on 4 November 1999 led to a pronounced fall in the volatility implied in the December 1999 contracts, which dropped well below the level of volatility implied in options expiring in June 2000.

As in the case of bond markets, implied risk-neutral densities can enhance the information which comes from financial markets, by allowing several aspects of the market's perceived uncertainty to be examined. As an illustration, Chart 8 compares two implied risk-neutral densities obtained using options on futures on the three-month EURIBOR rate with similar times to expiration. One density was estimated using options prices for the December 1999 contract observed around mid-August 1999, and the second density corresponds to March 2000 options prices traded a few days after the decision to raise ECB interest rates on 4 November 1999. The chart shows that the degree of uncertainty surrounding financial market expectations was less dispersed after the interest rate increase, while the mean of the distribution had moved to the right compared with three months earlier. These changes in the estimated risk-neutral density suggest that following the interest rate decision market uncertainty regarding the course of future short-term interest rates declined, while the expected level of the three-month EURIBOR rate around four months ahead, as measured by the forward rate, had increased. However, the somewhat less pronounced positive skew in November compared with August 1999 indicated that the perceived likelihood of higher than expected interest rates by the

Chart 8

Implied risk-neutral densities for the three-month EURIBOR interest rate



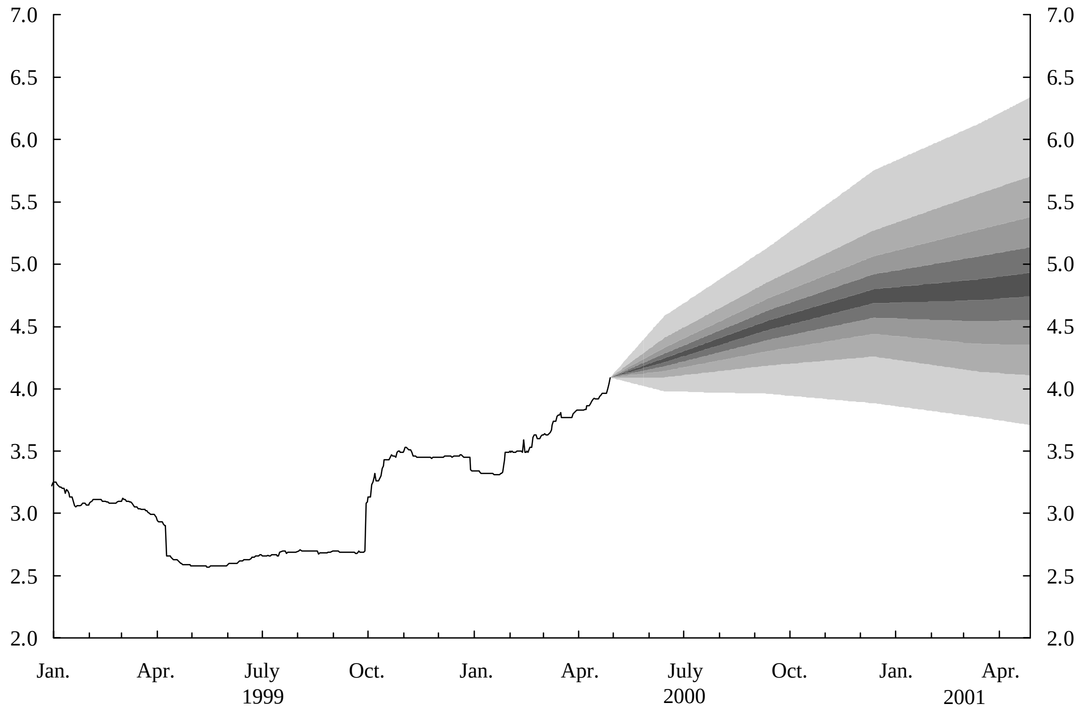
Sources: Reuters and ECB estimation.

expiration of the options, relative to the likelihood of lower than expected rates, was seen as having declined following the interest rate decision.

The information conveyed by implied risk-neutral densities for contracts with different maturities can be illustrated in a simple and intuitive way by plotting the historical three-month EURIBOR rate and a "fan chart", which indicates different percentiles of the future EURIBOR rate. This is illustrated in Chart 9, which shows a time-series of the three-month EURIBOR rate from early 1999 to end-April 2000, and confidence bands corresponding to the 10, 30, 50, 70, and 90 per cent implied probabilities estimated using options prices observed on 28 April. The widest band includes a total of 90% of the implied risk-neutral probability mass for the future EURIBOR rate. In other words, according to the prevailing option prices, the market attached a 90% probability to the future three-month EURIBOR rate ending up within this confidence band at various future points in time. The chart displays an upward trend in expected EURIBOR interest rates, corresponding to the market's pricing of futures contracts on 28 April. In addition, the confidence bands become wider as the horizon increases, indicating greater uncertainty about future rates at more distant points in time. Furthermore, the fact that the implied risk-neutral densities are slightly positively skewed can be seen from the confidence bands above the central band, which are somewhat wider than the bands below it.

Chart 9

Three-month EURIBOR interest rate and confidence bands of the implied risk-neutral densities on 28 April 2000



Sources: Reuters and ECB estimation.
Note: The solid line shows the development of the three-month EURIBOR rate from the start of 1999 until 28 April 2000, while the confidence bands represent percentiles of the future three-month EURIBOR rate, based on risk-neutral densities implied by options and futures prices on 28 April 2000. The darkest central band corresponds to 10% of the implied risk-neutral probability mass. Each successive band covers an additional 20 percentage points, so that the widest band includes 90% of the implied probability mass.

4 Concluding remarks

Financial market indicators have the potential to provide central banks with timely forward-looking information in the form of market expectations regarding a number of fundamental factors such as future inflation and economic growth that are important for the conduct of monetary policy. In this respect, it is important to note that financial markets anticipate and "price in" expected changes in official interest rates when determining prices of financial assets. It is therefore always useful for monetary policy-makers to analyse these market expectations of changes in short-term interest rates as well, in order to assess which monetary policy expectations underlie financial market expectations for economic growth and inflation.

The monetary policy strategy of the Eurosystem ensures that the information from financial market variables is appropriately taken into account in the conduct of monetary policy. Specifically, the Eurosystem has chosen a two-pillar monetary policy strategy, in which the analysis of the information content of monetary aggregates is given a prominent role, and a broad range of other indicators are taken into account in the evaluation of risks to price stability. Financial asset prices play an important role, as timely forward-looking indicators of market expectations and perceived uncertainties in the second pillar of the monetary policy strategy.

Market expectations of economic activity and inflation extracted from financial asset prices cannot, however, be a substitute for a central bank's own assessment of future economic developments. Rather, these indicators can only be considered as providing complementary information that can be used to cross-check the central bank's assessment.

Appendix

Estimating implied risk-neutral densities

This annex explains briefly how implied risk-neutral densities (RNDs) can be estimated using observable market prices of options and futures contracts. While a number of different techniques exist for estimating RNDs, this annex concentrates on the method used to obtain the densities presented in this article.[1] As mentioned in Box 1, options can be priced using the principle of risk-neutral valuation. According to this method, the price of a "European" option can be expressed as the present value of the option's expected future pay-offs, where expectations are taken with regard to the "risk-neutral probability measure", and where the discount rate is the risk-free interest rate prevailing during the life of the option.

Consider a European call option with price c at time t, written on an underlying asset with price S. Let the exercise price of the option be X, and the expiration date of the option be the future time T. The price of the call option at time t can then be written as

$$c = e^{-r(T-t)} \int_X^{\infty} f^*(S_T)(S_T - X)\, dS_T,$$

where r is the risk-free interest rate, and $f^*(S_T)$ denotes the risk-neutral density function for the price of the underlying asset at the expiration date. European put options can be priced in a similar manner. Since the price of an option according to the formula given above is a function of the risk-neutral density function, option prices observable in the market should convey information regarding this density. In fact, provided that a

1 *For a discussion of other techniques for estimating implied RNDs, see for example Jackwerth, J. C. (1999), "Option-implied risk-neutral distributions and implied binomial trees: A literature review", Journal of Derivatives, Vol. 7, No. 2, pages 66-82.*

sufficiently large number of simultaneously quoted options with different strike prices are available, an estimate of the RND $f^*(S_T)$ can be obtained.

One way of proceeding to obtain an estimate of the RND is to assume some specific structural form for the density and then estimate the particular shape of the density that produces option prices which are as close as possible to the observed market prices. Following Melick and Thomas (1997)[2], assuming that a mixture of two lognormal distributions is flexible enough to describe the underlying distribution for the future price of the underlying asset, S_T, the following result is obtained:

$$f^*(S_T) = \theta g_1(\alpha_1, \beta_1, S_T) + (1-\theta) g_2(\alpha_2, \beta_2, S_T),$$

where

$$g_i(\alpha_i, \beta_i, S_T) = \frac{1}{S_T \beta_i \sqrt{2\pi}} exp\left(-\frac{(ln S_T - \alpha_i)^2}{2\beta_i^2}\right), \qquad i = 1,2$$

and where α_i and β_i are location and dispersion parameters, respectively, for the lognormal distributions, which determine the mean and the variance of the distributions. The parameter θ is a weighting parameter, which determines the relative weights of the two lognormals in the terminal distribution.

Provided that a sufficiently large number of simultaneously observed call and put option prices exist with identical times to expiration but different exercise prices, the parameters of the distribution, $\Theta = \{\alpha_1, \alpha_2, \beta_1, \beta_2, \theta\}$, can be determined by choosing them in such a way that the differences between the observed and the theoretical option prices is minimised. Let c_j denote one of the *m* observable call prices, and p_j one of the *n* available put prices, and let $c_j^*(\Theta)$ and $p_j^*(\Theta)$ denote the corresponding option prices produced by the assumed RND, then the five parameters of the mixture of lognormals can be estimated by minimising the sum of squared deviations between observed prices and the equivalent theoretical prices:

$$\Theta = \underset{\Theta}{arg\,min} \sum_{j=1}^{m} \left(c_j - c_j^*(\Theta)\right)^2 + \sum_{j=1}^{n} \left(p_j - p_j^*(\Theta)\right)^2.$$

Additional information can be exploited by including the forward price and the corresponding theoretical forward price obtained from the assumed distribution as an additional input in the minimisation problem. In practice, the minimisation problem is substantially simplified, since closed-form expressions exist for options and forward prices when the distribution of the price of the underlying asset is assumed to be a mixture of lognormals.

2 *Melick, W. R. and Thomas, C. P. (1997), "Recovering an asset's implied PDF from option prices: An application to crude oil during the Gulf crisis", Journal of Financial and Quantitative Analysis, Vol. 32, pages 91-115.*