THE INFORMATION CONTENT OF OPTION PRICES DURING THE FINANCIAL CRISIS

Financial asset prices have experienced significant volatility in reaction to the financial and economic crisis. In the context of such market volatility, investors' expectations and the level of market uncertainty as regards the future course of financial asset prices provide valuable information for analytical purposes. This article presents a technique recently adopted by ECB staff for the purposes of quantifying market participants' expectations regarding future asset prices in the form of probability distributions drawing on option prices. It shows how these techniques can be applied to money and stock markets, and the information content of measures of market expectations is discussed, with a particular focus on the behaviour of such measures during the financial crisis. These measures of market expectations allow the central bank to better understand market sentiment and behaviour. They also extend the central bank's information set and have shown themselves to be particularly relevant during periods of financial market tension.

1 INTRODUCTION

Episodes of intense financial market volatility have been common since August 2007. Indeed, since the financial market turbulence and the financial and economic crisis began, most financial asset prices have experienced significant changes, and market uncertainty about future asset prices has also increased substantially. As a reflection of investors' reactions to the unfolding news and events of the time, fluctuations in financial asset prices and in perceived risks provide an additional source of information with relevance for economic and financial analysis.

This article discusses the estimation of the probabilities attached by market participants to possible future outcomes for a specific asset price. The set of likely future outcomes and the attached probabilities define a density function, such as those shown in Chart 1. More specifically, this article shows how such density extractions from option prices can be applied to short-term interest rates and stock prices and discusses the relevance of their information content for analytical purposes at the ECB. In brief, this relevance stems from several factors. First, as the ECB aims to steer short-term money market interest rates, it has a key interest in monitoring the evolution of short-term interest rates and associated expectations.[1] Second, stock prices reflect expected corporate earnings and can thereby provide useful information for assessing investors' expectations for economic activity. Finally, stock prices may – among other things – influence consumer spending via financial wealth and confidence effects. Ultimately, expectations as regards future stock market developments provide useful information about the risks and level of confidence in the market, as well as information about the outlook for both the economy and the financial market.[2]

Overall, this article makes clear that the regular monitoring of developments in expectations may provide useful information for economic and financial analysis. The structure of the article is as follows: Section 2 briefly explains the methodology behind the extraction of information from option prices; and Sections 3 and 4 present the application of these methods to both money and stock markets, with a focus on their information content.

2 EXTRACTING INFORMATION FROM OPTIONS

This section explains the extraction of information from options and the interpretation of the resulting probability density function. The box briefly describes the financial and statistical methodology behind the extraction.

1 For a related exposition on extracting information from interest rates, see the article entitled "The information content of interest rates and their derivatives for monetary policy", *Monthly Bulletin*, ECB, May 2000.

2 For a more detailed exposition, see the article entitled "Extracting information from financial asset prices", *Monthly Bulletin*, ECB, November 2004.

Box

AN OVERVIEW OF FINANCIAL AND STATISTICAL TERMINOLOGY

Futures and options on futures

Derivative instruments – and in particular the options on futures selected for this article – are appropriate financial market instruments from which to extract measures of uncertainty and their distribution around central market expectations. This box briefly describes the main features of both futures contracts and options on futures contracts. In addition, this box defines the statistical indicators that are used in the article to extract measures of uncertainty.

A futures contract is a standardised contract between two parties who agree, respectively, to buy and sell a fixed quantity of a specified asset of standardised quality on a predetermined date and at a pre-agreed price (known as the "futures price"). Such contracts are traded on futures exchanges. In the case of the three-month EURIBOR and the Dow Jones EURO STOXX 50, these contracts are traded on Euronext and Eurex respectively.[1] The pre-agreed delivery price is set in such a way that the initial value of the futures contract is zero and the corresponding delivery price is the futures price.

An option on a futures contract is an instrument that entitles – but does not oblige – its owner to buy or sell a particular futures contract at a specific price on or before a certain expiry date. There are two types of option on futures contracts: a "call option" gives the holder the right to acquire a given futures contract, whereas a "put option" grants the holder the right to sell it. The seller of the option therefore agrees to either sell a certain futures contract (in the case of a call option) or buy it (in the case of a put option), at a specific price, should the owner of the option decide to exercise it.

Estimating implied densities

This paragraph briefly explains how implied densities can be estimated using observable market prices for options and futures contracts. While a number of different techniques exist for estimating implied densities, here we concentrate on the method used to obtain the implied densities presented in this article. Black and Scholes defined the price of a European call option at time t as:

$$C(F_t, K, \tau) = e^{-r\tau} \int_k^{\infty} f(F_T)(F_T - K)\, dF_T$$

where C is the call function, K is the option's strike price, r is the risk-free rate, F_t is the value of the underlying future at time t and $f(F_T)$ is the implied density which describes the possible outcomes for the underlying future at time T. The option's time to maturity τ is equal to $T - t$. In practice, the task of estimating an implied density amounts to the estimation of a twice-differentiable call price function, as explained by Breeden and Litzenberger (1978)[2]. However, this cannot be applied directly, because we only observe option prices for a discrete set of strike prices,

1 Euronext NV is a pan-European stock exchange with headquarters in Amsterdam and subsidiaries in Belgium, France, the Netherlands, Portugal and the United Kingdom. Eurex is a derivatives exchange and is jointly operated by Deutsche Börse AG and SIX Swiss Exchange. It is based in Frankfurt am Main and has representative offices around the world.

2 Breeden, D. and Litzenberger, R., "Prices of state-contingent claims implicit in option prices", *Journal of Business*, Vol. 51, No 4, 1978, pp. 621-651.

rather than a twice-differentiable continuum. In fact, taking the second derivative of a call price function estimated directly, interpolating through the discrete set of data on option premia and strike prices can sometimes lead to unstable or inaccurate implied densities. Instead, Bliss and Panigirtzoglou[3] have suggested that smoother results might be obtained if the data on option premia and strike prices are transformed into implied volatility delta values prior to interpolation. The implied volatility is calculated by reversing the Black-Scholes formula in the sense that, given an observed option price, a value for volatility can be found that produces an option price which corresponds to the market price. The delta of an option measures the rate of change in the option price relative to changes in the underlying asset price. For example, with call options, a delta of 0.4 means that for every increase of one unit in the underlying asset, the call option will increase by 0.4 unit. For call options, the delta is always defined in the [0, 1] interval, whereas for put options, it is defined in the [-1, 0] interval.

Statistical moments and percentiles

The mean and variance of the implied density are known as the first two statistical moments. They provide information on both the central tendency and the width of a probability density function. The square root of the variance is the standard deviation. Skewness and kurtosis are the third and fourth moments and also provide information on the shape of the density.

Skewness is a measure of the asymmetry in the shape of a given probability density function. Skewness can be positive or negative. A negative skew occurs when the tail to the left of the implied density is longer than that to the right, reflecting the fact that more market participants expect interest rate values to be above the mean than below it. A positive skew, with a longer tail to the right of the probability density function, means the opposite. A zero value indicates that the values are evenly distributed on both sides of the mean, typically (although not necessarily) implying a symmetrical density.

Kurtosis is a measure of the "peakedness" of a probability density function. Higher kurtosis means that much of the variance is the result of infrequent but extreme changes, as opposed to frequent but modest changes. Economically speaking, kurtosis quantifies the likelihood that market participants attach to more extreme outcomes, compared with outcomes at the centre of the density.

A percentile is the value of a variable below which a certain percentage of the observations fall. So, the tenth percentile is the value below which 10% of the observations may be found. The fiftieth percentile divides the probability density function into two halves of equal mass and is equivalent to the median of the distribution.

The option's implied density function offers greater insight into the changes expected by market participants in the value of an underlying asset than commonly used measures (such as futures) that capture only the market consensus as regards expectations. For example, the width of an implied density function around its central value designates the range of expected prices to which some non-zero probability has been attached, thereby providing an indication as to the level of uncertainty surrounding the expected central value at a given point in time.

3 Bliss, R. and Panigirtzoglou, N., "Testing the stability of implied probability density functions", *Journal of Banking and Finance*, Vol. 26, 2002, pp. 381-422.

In statistical terms, this uncertainty is captured by the standard deviation of the implied density. In addition, it is often the case that a probability density function is asymmetric; that is to say, different probability masses are assigned to outcomes above and below the central expectation. In statistical terms, this asymmetry is captured by the skewness of the density. A positive skew points to a perception that outcomes are more likely to be below the central expectation than above it. A negative skew, on the other hand, indicates the opposite. Furthermore, in periods of financial stress, market participants may consider more extreme outcomes to be more likely than outcomes in the centre of the density. The kurtosis of the density quantifies this tendency.

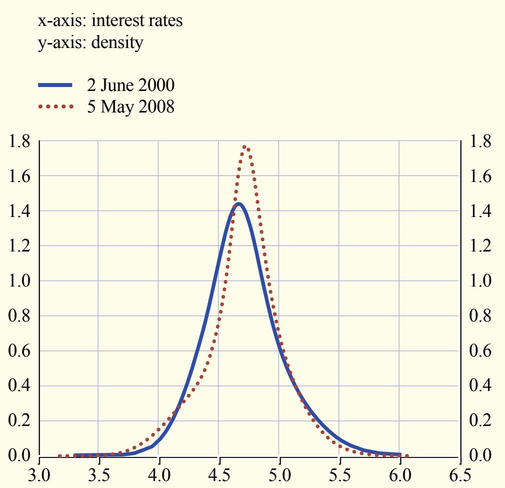
The techniques presented in the next few sections concern measures of uncertainty used for assessing market expectations as regards future developments in a short-term interest rate (the three-month EURIBOR) and a euro area stock price index (the EURO STOXX 50 index). These indicators have been selected because the higher levels of liquidity in these markets allow the extraction of signals from a large number of individual trades on a daily basis.

The forward-looking nature of option prices makes them suitable for the extraction of expectations and the quantification of uncertainty. Using all the available data relating to the prices of all appropriate options (see below), such as interest rate futures, from a given day, it is possible to summarise this wealth of information within a probability distribution representing the full range of expectations for an interest rate for a given period in the future.

Chart 1 illustrates two stylised examples of such implied densities, using expectations for the three-month EURIBOR three months ahead calculated on two different dates. Although these two implied densities have the same mean and the same standard deviation three months ahead, the uncertainty around the mean differs starkly. The implied density function mapped in blue is positively skewed, meaning that more market participants expect interest rate outcomes to be below the mean than above it. By contrast, the red implied density function is negatively skewed, meaning that the mass of the density is more concentrated around the higher interest rates, thus reflecting the fact that more market participants expect interest rate outcomes to be above the mean than below it. This difference in shape is explained by the variation in market expectations and levels of uncertainty on the two given dates.

As this implied density function presents the risk-neutral probability (i.e. the probability independent of whether investors are risk-averse or risk-seeking) that the market ascribes to all possible outcomes, it provides a quantitative measure of the market's assessment of the risks surrounding the futures rate, in terms of both magnitude and directional bias. The implied density is, however, only an approximation of real expectations, because risk aversion is not observed and hence not taken into account.

Chart 1 Implied density functions for two selected dates



Sources: NYSE Liffe and ECB calculations.

This implied density function can be derived by using a variety of different methods. Empirical evidence has shown that although these methods might differ as regards the tails of the densities, there is generally no major difference when comparing the central sections of the estimated implied probability density functions. Owing to its robustness and stability, the technique that was selected from all of those available in order to derive the implied densities for this article was a non-parametric technique.[3]

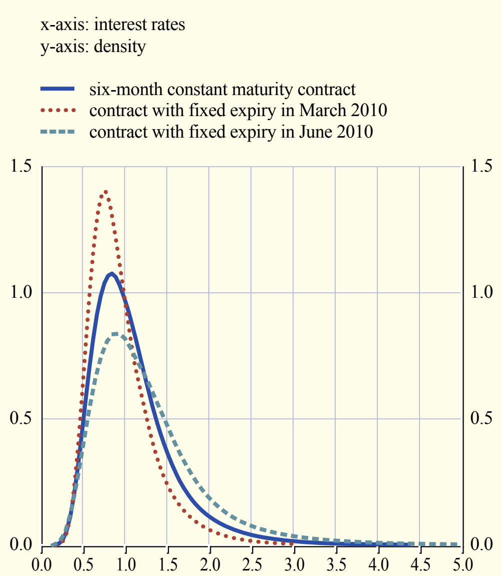
HOW TO MAKE MEASURES OF UNCERTAINTY COMPARABLE OVER TIME

Various types of options on futures contracts with a fixed expiry date are traded on a daily basis for the three-month EURIBOR and the Dow Jones EURO STOXX 50. In 2009 around 100,000 options on futures were traded on Euronext, producing an average daily trading volume of around 500 contracts. Each of these contracts expires on the same day as the underlying futures contract. In general, the closer the expiry date of the option contract – i.e. the closer the "future" is to the present – the lower the degree of uncertainty about the possible outcome of the underlying future. Thus, the level of uncertainty embodied in the implied probability density also tends to decline as the expiry date approaches. Consequently, very little trading, if any, takes place on the days immediately prior to the expiry date. More importantly, the resulting time pattern of a decreasing density width makes it misleading to compare implied densities relating to the same fixed expiry contract over time. A solution generally applied to allow the comparison of implied densities over time is to estimate "constant maturity implied probability density functions". By means of interpolation, one constructs an artificial measure that provides a signal on a daily basis for a period in the future, which is typically fixed at a horizon of three, six or nine months, one year, or one and a half years. These interpolations allow the analysis of a meaningful economic signal by correcting the general pattern that uncertainty typically declines the closer the expiry date gets to the present. This interpolation is performed across the implied volatilities of contracts with the same delta (i.e. the same rate of change in the option price relative to changes in the underlying asset price) but different maturities (see the box). The final schematic principle of this interpolation is shown in Chart 2, which shows an interpolation of a six-month constant maturity implied density on 27 October 2009. The discussion in the remainder of this article is based on interpolated constant maturity densities.

By plotting together all the daily three-month constant maturity implied density functions from the initial trading day on 13 January 1999 to the present day in a three-dimensional space

3 For a detailed description of the underlying methodology used to construct the implied probability density functions, see de Vincent, R. and Puigvert Gutiérrez, J.M., "A quantitative mirror on the EURIBOR market using implied probability density functions", *Working Paper Series*, No 1281, ECB, 2010.

Chart 2 Interpolation to obtain a six-month constant maturity probability density function on 27 October 2009

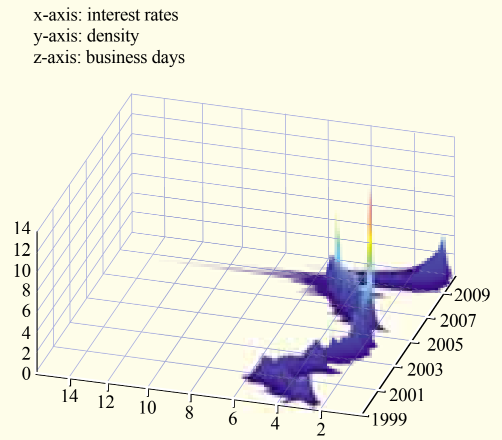


Sources: NYSE Liffe and ECB calculations.

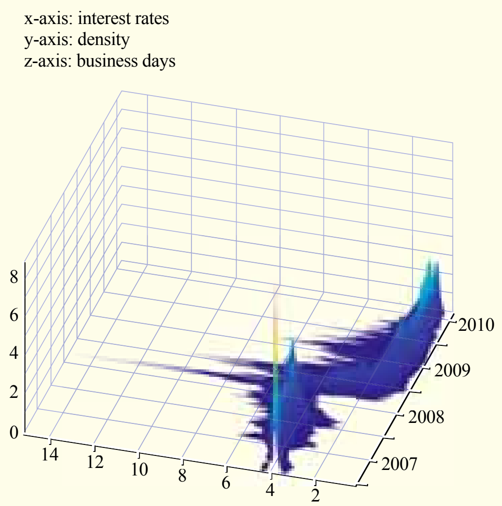
(see the first part of Chart 3), it is possible to demonstrate the evolution of the three-month constant maturity implied density function over time, showing interest rate expectations on one dimension, density on another and time on the third. Not only do the densities vary in terms of their central expectations, but their width and skewness also change significantly over time, indicating periods of varying uncertainty and asymmetry in expectations. In particular, the way these densities changed during the financial crisis can be observed in the second part of Chart 3.

Chart 3 Three-month constant maturity implied densities

(daily readings; 1999-2010)



(daily readings; 2007-2010)



Sources: NYSE Liffe and ECB calculations.

WHICH OPTIONS SHOULD BE USED FOR THE DERIVATION OF IMPLIED DENSITIES?

The trading of options most commonly involves call and put options with a strike price higher and lower respectively than the current underlying futures price; these are known as "out-of-the-money" calls and puts. These options tend to be more liquid than puts and calls respectively with the same strike price (i.e. "in-the-money" puts and calls) and are therefore more representative. Hence, the implied densities are best constructed by using only those option prices which are either "out of the money" or "at the money" (the latter being options for which the current forward price of the underlying asset is equal to the strike price of the option).

In addition, three other types of data quality check are performed on the price data. First, as a basic plausibility check, any option prices that are either equal to zero or negative in value are excluded. Second, according to option pricing theory, a call price function should be both monotonic and convex in order to yield non-negative probability estimates. Thus, any option prices that do not allow these requirements to be met are also excluded. Third, if after the application of the preceding two filters, there are fewer than three "out-of-the-money" option prices for a particular expiry date (that is to say, too few observations are available), no implied probability density function will be estimated for that expiry date. Although it very much depends on the fixed expiry contract and the trading day, around 40% of the options initially chosen are ultimately excluded.

Finally, a considerable caveat needs to be added for the interpretation of signals extracted from contracts dependent on interest rate forecasts or expected economic developments. Indeed, asset prices and the relevant option contracts might temporarily be influenced by non-fundamental factors, which include technical features of the specific markets or temporary imbalances between different types of agent. Crucially, such “distortions” need to be taken into account for the purposes of the economic interpretation of the signal. (See Section 3 for some examples taken from the financial crisis.)

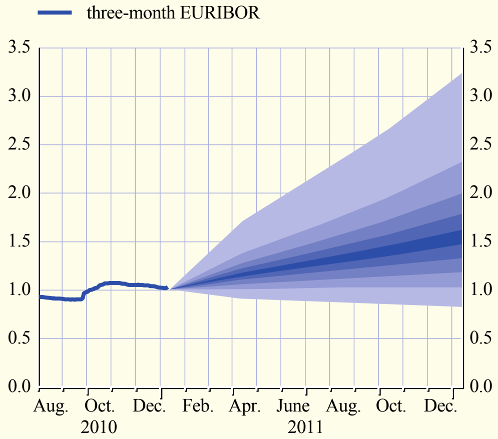
3 MONEY MARKET EXPECTATIONS AND UNCERTAINTY DURING THE FINANCIAL CRISIS

This section applies the density estimator to the three-month EURIBOR – i.e. an interest rate on unsecured funds. It discusses developments in market expectations during the crisis as regards the future path of this interest rate and highlights their information content. This short-term interest rate serves as an example, while a more comprehensive picture is obtained when interest rate expectations are monitored for a number of instruments and maturities.

Implied densities calculated for several horizons in the future provide a quick overview of market expectations at a certain point in time and may provide additional information for the central bank. Chart 4 depicts the probability of various outcomes for the three-month EURIBOR over the coming year. The solid line shows the actual path of the three-month EURIBOR in recent months. The fan chart shows expectations as regards the future outcome, as derived from the implied densities for the coming year. Each band of the fan chart represents 10% of the expectations. The central band predicts a gradual increase in the three-month EURIBOR over time. The width of a band increases with the expectation horizon owing to the greater degree of uncertainty surrounding outcomes at more distant points in time. The bands above and below the central band may also differ in terms of their width. Indeed, in Chart 4, bands are clearly wider above the central expectation, indicating that the risk of greater changes in the interest rate is currently considered to be tilted more to the upside than the downside. This is directly related to the skewness of the underlying implied densities, as can be seen from the implied density in Chart 5 which reflects the expectation three months ahead recorded on 14 January 2011 (see the dashed green line in the second part of the chart).

Chart 4 Three-month EURIBOR and expectations thereof over the coming year

(percentages per annum)

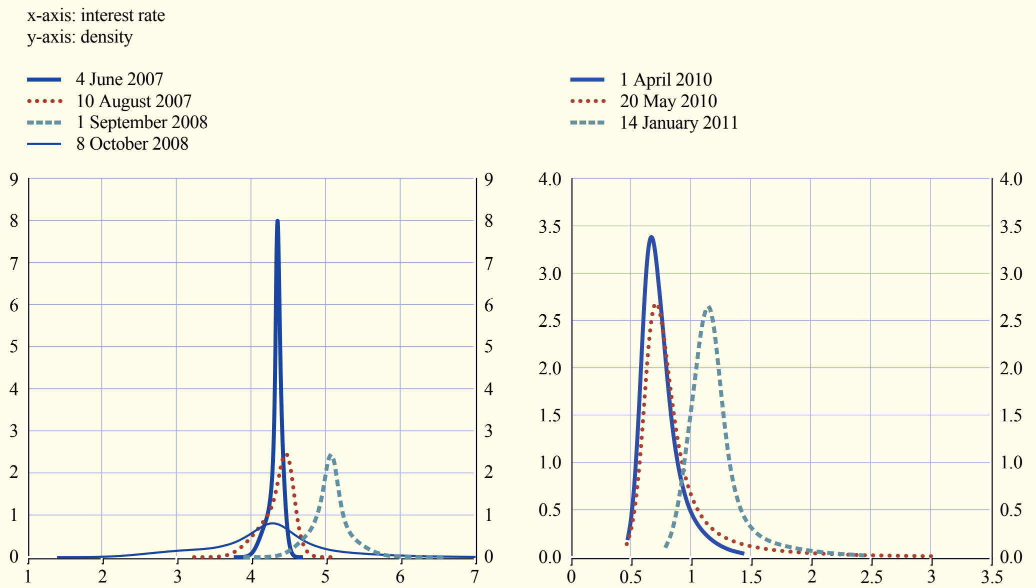


Sources: NYSE Liffe and ECB calculations.
Notes: The solid line shows the three-month EURIBOR up until 14 January 2011. The fan chart represents expectations and uncertainty as regards the evolution of the three-month EURIBOR in the coming year, based on option prices observed on 14 January 2011.

In normal times, this type of measure provides information on the range of expectations formulated by market participants with regard to future policy rate decisions. However, the financial crisis has biased the information that can be extracted from EURIBOR rates for two reasons. First, there were times during the crisis when interest rates on unsecured funding carried a considerable risk premium (i.e. the minimum compensation market participants require to take on the risk of providing such funding), thereby affecting the level of the EURIBOR. Second, uncertainty surrounding future developments in this risk premium led to heightened concerns about future EURIBOR levels. Overall, although the implied densities are derived using a risk-neutral approach, they capture risk by reflecting the presence of heightened risk aversion and the risk premium contained in the EURIBOR. This implies, therefore, that such implied densities contain valuable information about money market tensions.

Chart 5 presents implied densities for the three-month EURIBOR three months ahead on different days during the financial crisis.

Chart 5 Implied densities for the three-month EURIBOR three months ahead



Sources: NYSE Liffe and ECB calculations.

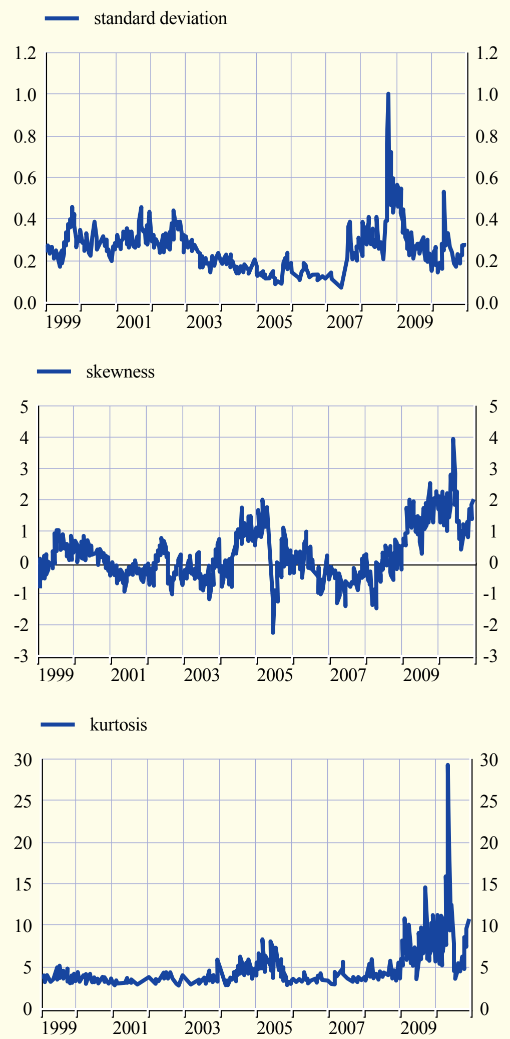
The densities show considerable differences over time, driven by changing expectations about both future policy rate decisions and the risk premium contained in the EURIBOR. The density in June 2007 (see the thick blue line) shows that, before the crisis, expectations were more highly concentrated around a small set of likely outcomes. At the start of the crisis in August 2007 (dotted red line), uncertainty, as observed from the width of the density, increased substantially. The mean and width increased owing to the heightened risk premia and related uncertainty respectively. Later, the mean increased further with the policy rate increase of July 2008. At the time of the first policy rate cut in October 2008 (thin blue line), following on from Lehman Brothers' collapse, uncertainty about future EURIBOR rates reached a very high level. The market consensus view, as measured by the mean, had already decreased by that point compared with one month earlier (dashed green line), thereby reflecting expectations of policy rate cuts. Market conditions gradually improved from then on as a reaction to the non-standard measures implemented by the Eurosystem in response to the elevated pressures in funding markets and sequential policy rate cuts. This tendency continued up until the sovereign debt crisis of spring 2010. In April 2010 (thick blue line) the density was asymmetric with a long tail to the right, implying that market participants considered substantial increases in the three-month EURIBOR to be likely over the coming months, and more so than decreases of an equal size. In the context of the crisis, this increasing likelihood attached by market participants to higher EURIBOR rates was most likely driven by an expectation that an increase in the risk premium was more likely. This asymmetry became significant at the height of the sovereign debt crisis (dotted red line), with more participants expecting strong upward movements in the rate – in other words, adverse money market outcomes and high risk premia. By comparison, the density in January 2011 (dashed green line) showed less asymmetry, reflecting a decrease in the uncertainty surrounding the risk premium, and had shifted towards somewhat higher interest rates, following developments in money market rates, but uncertainty remained elevated overall.

As explained in Section 2, the degrees of uncertainty and asymmetry are captured respectively by the standard deviation and the skewness of a density function. A third indicator, kurtosis, reflects the likelihood attached by market participants to extreme outcomes. Chart 6 presents the entire history of these descriptive statistics, which quantify developments in individual implied densities (such as those in Chart 5) and facilitate their comparison over time. If we focus once again on the period of the financial crisis, developments in the implied densities at this time clearly stand out.

The statistics provide valuable information about the money market situation and the impact of policy measures. Standard deviation, as a measure of uncertainty, captures well the critical moments of the crisis. Standard deviation increased with the onset of market tensions in the summer of 2007, after reaching a historically low level in early 2007. At the time of Lehman Brothers' collapse, it jumped to an extremely high level. Following a series of policy rate cuts and non-standard measures implemented by the Eurosystem, and also following similar actions at the global level, standard deviation gradually began to normalise.[4] This shows how these indicators could also be used to assess the impact of non-standard measures and related announcements. At the time of the sovereign debt crisis in May 2010, standard deviation showed another sharp rise.

Skewness also increased during the financial crisis, becoming particularly pronounced after 2009, and reached extreme levels during the sovereign debt crisis. This implies that market participants considered strong upward movements in the three-month EURIBOR to be both more likely than downward movements of an equal size and more likely than before, reflecting adverse expectations as regards future money market developments. The related higher probability attached to extreme outcomes also drove the high kurtosis observed. Furthermore, these statistics show that as policy rates approached their trough, skewness (and kurtosis) mirrored market tensions more closely than did standard deviation. The events of early May 2010 also triggered swift policy responses by euro area fiscal and monetary

Chart 6 Standard deviation, skewness and kurtosis of the implied densities for the three-month EURIBOR three months ahead



Sources: NYSE Liffe and ECB calculations.

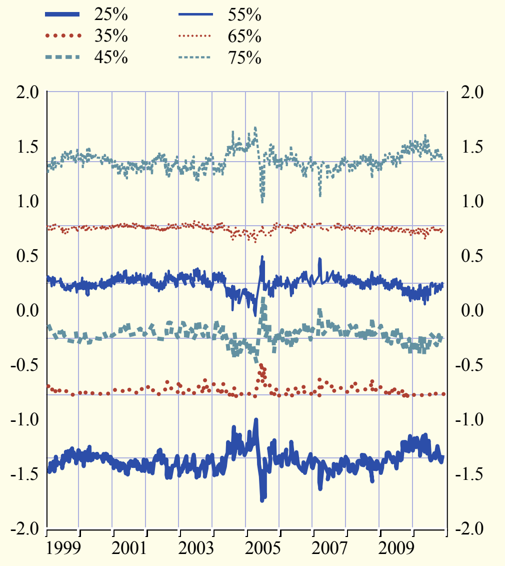
4 During the period from 8 October 2008 to 7 May 2009 ECB policy rates were cut by 2.25 percentage points. A series of non-standard measures were introduced, which included a move to a fixed rate tender procedure with full allotment in weekly refinancing operations, measures to improve liquidity in certain short-term foreign exchange markets, the expansion of the collateral framework, the enhancement of the provision of longer-term refinancing and a purchase programme for covered bonds.

policy authorities, leading to the normalisation of both skewness and kurtosis.[5]

Classifying densities, and thus the expectations they represent, as either exceptional or revealing requires a benchmark that can be considered neutral. The normal density is a natural candidate for a neutral benchmark with which to compare implied densities. Statistically, with the normal density, expectations are symmetrical around the mean, reflecting the fact that there is no information available to participants that would lead them to believe that a change in one direction was any more likely than a change in the other, or that larger changes had become particularly likely (i.e. the skew is zero and the kurtosis equals three). Yet the empirical financial literature has shown that financial prices are often not distributed in line with the normal density. Chart 7 illustrates the history of six density percentiles as horizontal lines, along with the values expected for them according to the normal density. The percentiles, selected from the centre of the density, are expected to be close to the normal density values. Any substantial or persistent deviations would be an indicator of exceptional developments in expectations. For example, the persistent deviation by several of the percentiles away from their expected value – a phenomenon which was observed from mid-2009 and continued into 2010 – confirms the exceptional nature of the developments in expectations, as discussed above.

Chart 7 Selected percentiles of implied densities (centred and normalised)

(six percentiles of implied densities for the three-month EURIBOR three months ahead)



Sources: NYSE Liffe and ECB calculations.
Notes: Each daily observation equals the observed percentile subtracted from the mean of the six percentiles for that day and divided by the standard deviation of the six percentiles for that day. The horizontal lines represent their expected values, based on the standard normal distribution.

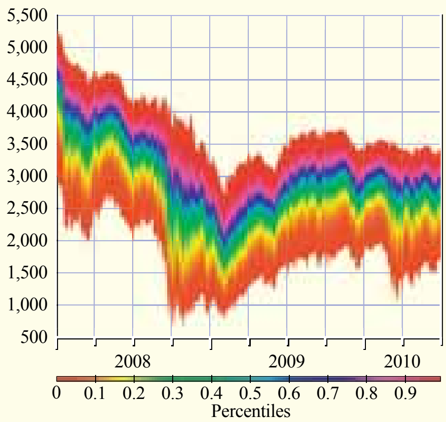
4 STOCK MARKET EXPECTATIONS AND RISKS DURING THE FINANCIAL CRISIS

Measures of the level of risk in the stock market, as perceived by investors, help with the assessment of stock market developments. By extracting implied densities from stock market index options, one can gauge market participants' perceptions of both stock market uncertainty and the balance of risks with regard to future stock market performance. In the context of the financial crisis, such measures were crucial, providing indications of the perceived fragility of overall stock market conditions and signalling potential risks to financial stability.

As an overview, Chart 8 shows the evolution of the euro area stock market index and the risks associated with it at the three-month horizon since the beginning of 2008, with the percentiles of the implied density reflected in different colour bands. As is evident from the chart, uncertainty remained high throughout

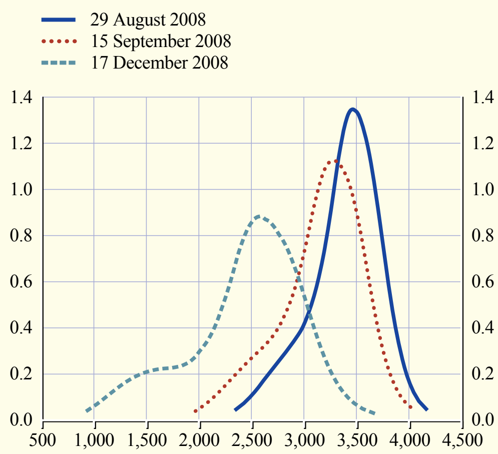
5 On 10 May 2010 the ECB – with a view to restoring the conditions necessary for the effective conduct of a monetary policy oriented towards price stability in the medium term and, in particular, with a view to supporting the transmission mechanism for monetary policy – announced the introduction of several measures, among them interventions in the euro area public and private debt securities markets (under the Securities Markets Programme), the reactivation of swap lines with the Federal Reserve and the introduction of additional liquidity-providing operations. For a more detailed exposition of the ECB's measures at the various stages of the crisis, see the article entitled "The ECB's response to the financial crisis", *Monthly Bulletin*, ECB, October 2010.

Chart 8 Evolution of expectations for the EURO STOXX 50 index three months ahead since the beginning of 2008



Sources: Bloomberg and ECB calculations.

Chart 9 Estimated probability density functions for the EURO STOXX 50 index in late 2008 (selected dates)



Sources: Bloomberg and ECB calculations.

the crisis and downside risks to the future stock market index were present for most of the period. To illustrate this in greater detail, the remainder of this section discusses the evolution of perceived risks during two specific episodes of financial distress: the intensification of the financial crisis in the autumn of 2008 and the euro area sovereign debt crisis in May 2010.

THE INTENSIFICATION OF THE FINANCIAL CRISIS IN AUTUMN 2008

During the summer of 2008 concerns mounted among investors regarding the health of the international financial system, and in particular that of major US financial institutions, culminating in the events of September of that year. Amid strong risk aversion, global financial markets experienced unprecedented volatility, with exceptionally large daily stock price movements becoming fairly frequent.[6]

To gauge the evolution of market sentiment, Chart 9 depicts implied densities for the EURO STOXX 50 index at three points in time: at the end of August 2008 (blue line); on 15 September 2008 (dotted red line), when the collapse of Lehman Brothers was first announced; and on 17 December 2008 (dashed green line), after the last step in the Federal Reserve's most recent easing cycle. Three main features can be inferred from Chart 9. As regards the central tendency, the expected value of the index, as projected three months ahead, fell by around 1,000 points between the first and last of the three dates in line with the process of stock market correction then under way.

Importantly, however, the estimation of implied densities also allows an assessment of the evolution of the perceived risks underpinning expectations revised in line with the market correction. For example, in addition to gradually moving to the left, the densities also became "wider" as the range of possible outcomes gradually expanded. This suggests that the downward correction in the actual and expected index level was also accompanied by

6 See the box entitled "Abnormal volatility in stock markets", *Monthly Bulletin*, ECB, November 2008.

an increase in uncertainty. More technically, the standard deviation of the density increased significantly as the financial and economic crisis intensified.

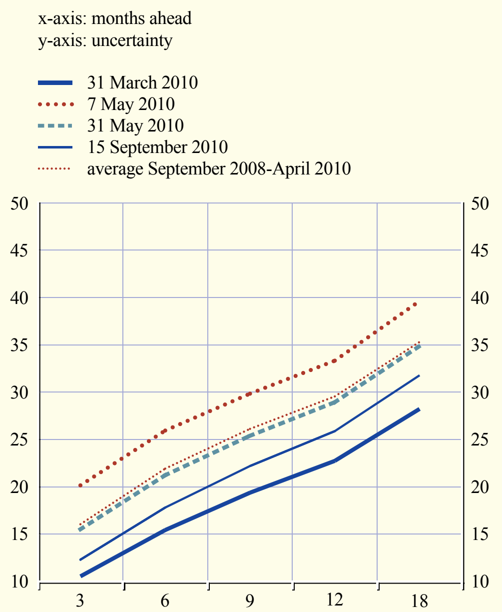
Furthermore, the densities in Chart 9 also show that in addition to the expected index level and the uncertainty surrounding it being revised as the crisis progressed, the asymmetry of the densities also increased. Specifically, it can be seen that the probability assigned to values lower than the central tendency clearly rose gradually over time relative to that assigned to values higher than the central tendency. In other words, downside risks tended to dominate these densities. More technically, the densities became more negatively skewed, which suggests that, in addition to the downward revision of the expected value of the EURO STOXX 50 index, investors considered it likely that the actual corrections would be stronger than the central expectation.

THE SOVEREIGN DEBT CRISIS IN THE EURO AREA IN THE SPRING OF 2010

Advances in major stock markets during March and most of April 2010, when stock price indices stood at record highs for the year, were reversed in late April and May 2010 as a result of the intensification of the euro area sovereign debt crisis (caused by the Greek crisis, the downgrading of the credit ratings of Portuguese and Spanish debt by some agencies, etc.).[7] Although euro area financial stock prices were the first to be affected, reflecting concerns about possible write-downs on banks' portfolio holdings of euro area government debt securities, the decline in stock prices spread to euro area non-financial stock prices as tensions intensified. It also spread beyond the euro area, particularly to the United States.

Although the market tensions that characterised the sovereign debt crisis had different origins to those observed in the autumn of 2008, the change in market sentiment and the surge in risk aversion among investors were once again fairly strong.

Chart 10 Term structure of uncertainty surrounding the EURO STOXX 50 index



Sources: Bloomberg and ECB calculations.
Note: Uncertainty in the y-axis is measured as percentage changes (annualised) in the EURO STOXX 50 index.

Chart 10 illustrates the changes in investors' uncertainty since late March 2010. First, an improvement in the outlook for global economic activity from the beginning of the year led to advances in major stock price indices, and so, in line with improved market sentiment, by late March 2010 (see thick blue line) stock market uncertainty at all horizons was significantly lower than the average level for the period from September 2008, when the crisis intensified, to April 2010 (see thin dotted red line). However, increasing concerns about the sustainability of public finances in some euro area countries changed that scenario. Stock market uncertainty rose gradually over the course of April and early May 2010, amid acute disruptions in some financial market segments, and surged well above average levels. The swift policy reactions of European institutions, as well as the additional

7 For additional details, see the box entitled "Developments in financial markets in early May", *Monthly Bulletin*, ECB, June 2010.

steps towards further fiscal consolidation taken by the countries most seriously affected, contributed to an easing of market tensions, and stock market uncertainty started to decline from its 7 May peak. This decline was, however, very gradual, with uncertainty only returning to average crisis levels by the end of May (see dashed green line) and remaining elevated, following the sovereign debt crisis, for most of the summer of 2010 (see thin blue line).

5 CONCLUSION

This article has shown that market participants' expectations and market uncertainty regarding the future course of financial asset prices represent a valuable source of information for economic and financial analysis. Moreover, their information content is of particular relevance in times of financial market tensions. The implied densities extracted from option prices help to reflect the uncertainty surrounding the market consensus view in a numerical manner, thereby allowing a more complete assessment of investors' expectations. While, for illustrative purposes, this article applies the extraction of implied densities to a short-term interest rate on unsecured funds (the EURIBOR) and to a stock market index (the EURO STOXX 50), this could obviously be extended to many other financial instruments.